Development of sectoral indicators for determining potential decarbonization opportunity

A joint study by IEEJ and Ecofys

– FINAL REPORT –

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FINAL REPORT

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Date: 23 March 2015

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Tables

Abbreviation

BAT	Best available technology
BF-BOF	Blast furnace-basic oxygen furnace
CHP	Combined heat and power
CHP	Combined heat and power plant
CO2	Carbon dioxide
DRI	Direct reduced iron
EAF	Electric arc furnace
EJ	Exajoules
EU	European Union
FTP	Federal test procedures in the United States
GJ	Gigajoules
kWh	Kilowatt hour
LDV	Light-duty vehicle
Lge	litre of gasoline equivalent
LHV	Lower heating value
MJ	Mega joule
Mt	Mega tonnes
MWh	Megawatt hour
NEDC	New European driving cycle
Nm3-O2	normal cubic metres oxygen
SEC	Specific energy consumption
t	Tonnes, for the pulp and paper sector t refers to air dry tonnes [Adt]
tcs	tone crude steel
TFEU	Total final energy use
TPEU	Total primary energy use

1 Introduction

The international climate negotiations acknowledge that ambition for reducing greenhouse gas emissions must be increased in the short term in order to keep climate change at safe levels.

The Ad-hoc group on the Durban platform (ADP) in its work stream 1 encouraged countries to submit national contributions to the global mitigation of greenhouse gas emissions within a 2015 international climate agreement. Under work stream 2 of the ADP countries identify options to increase ambition to reduce greenhouse gas emissions before 2020. The process aims at identifying thematic areas where further emission reduction potential is available, where measures have sustainable development benefits and where global actions have proven to be successful and can be scaled up.

This report provides a comparative analysis of the energy and carbon intensity indicators across seven major greenhouse gas emitting sectors namely steel, cement, pulp and paper, chemical, power, residential and commercial, and transport sectors, of major emitting countries Japan, USA, Russia, EU, UK, Germany, France, China, India, Indonesia and Brazil. While the analysis does not necessarily cover all countries mentioned given the lack of adequate and publicly accessible data, it provides valuable insight into the best practices across nations, and constitutes a benchmark for energy efficiency improvement and decarbonization.

This report is an output of the project "Development of Sectoral Indicators for Determining Potential Decarbonization Opportunity" by The Institute of Energy Economics Japan (IEEJ) and Ecofys. It builds upon an earlier project by IEEJ that aims at quantifying the existing global emission reduction potential through applying Best Available Technology (BAT).

2 Chemical and petrochemical industry

The chemical and petrochemical sector is by far the biggest energy user in the industrial sector, with about 10% of the global final energy demand and 30%, if feedstock is included. The sector accounts for around 7% of the global CO_2 emissions. The worldwide production is projected to at least double until 2050. The chemical and petrochemical sector started to improve their energy efficiency, beginning with the first global oil crisis; back then mainly driven by economical reason due to their high energy demand and costs. Until today good progress has been made, but still vast improvement are estimate to exist for this sector, about 10 EJ/y final energy, if applying best available technologies (BAT), using CHP or improve recycling (OECD/IEA, 2009; Saygin et al., 2011; Fleiter and Fraunhofer ISI, 2013).

2.1 Method

The chemical and petrochemical sector is a highly multifaceted sector with a large numbers of processes and multiple-product outcomes. On a global level, it is especially constraint by lacking data availability for each of these processes and products. Furthermore the definition of the system boundaries is critical, and countries have often chosen to take different approaches from each other. For instance some countries include processes / production steps while others exclude these entirely. In discussions with experts and based on a literature elaboration, we decided to illustrate the energy efficiency indicator as they are available in literature, rather than re-calculate these complex and sensitive data sets. Below we therefore describe the approach presented in (Saygin et al., 2011), who has approached the issue from a bottom up as well as a top-down perspective.

2.1.1 Data requirements and data sources

For the estimation of the Energy efficiency indicator (EEI) and the CO_2 indicator the following data were used:

- Energy consumption data from the IEA Energy Statistics (IEA, 2008a),
- Production data and Specific Energy consumption (SEC) for BAT and the average current situation (SRI Consulting, 2008).

The production data are based on several data sources, but most chemical processes are retrieved from (SRI Consulting, 2008). The data was used as reported in (Saygin et al., 2011). Within his calculations (Saygin et al., 2011) assume that most BAT use natural gas as fuel in the analysed countries, except for China and India where some BAT are running with coal or oil or in a combination with natural gas (Saygin et al., 2011). For the calculation of the CO_2 index the following datasets were used:

- fossil-fuel specific emissions factors as reported by the IEA (IEA, 2008b).
- carbon content of the key products were estimated to deduct the stored carbon from the CO_2 emissions based on (Saygin et al., 2009).

2.1.2 Energy consumption per tonne product

Table 1 contains the SEC for the production of the key chemicals, their production account for half of the sector's energy use per country. Note that it is not possible to aggregate these figures any further as the products differ too much. The figures are partly based on personal communications by the author with industry experts and on literature review (Saygin et al., 2011).

Table 1: Estimates for the average current SEC for the production of the key chemicals, 2006 (without electricity and excluding feedstock use; data in final energy terms, GJ/tonne of output) (Saygin et al., 2011).

Country	Steam cracking[1]	Ammonia[2]	Methanol[3]	Chlorine[4]	Soda ash[5]
Japan	12.6	14.3	-	1.9	10.6
Germany	15.7	16.6	12.4	2.3	11.6
USA	18.3	17.3	11.4	4.7	6.9
Brazil	17.1	15.3	10	4.4	11.7
China	16.7	28.9	15	2.7	13.8
France	15.4	16.5	-	2.3	11.6
India	16.7	19.5	10.9	0.6	13.6
Korea	12.6	21.3	-	1.9	10.6
World	16.9	20.9	10.9	2.9	10.9

Note: If any of these chemicals were not produced in these countries in year 2006, then we do not provide any SEC value for the production of that chemical in that country.

2.1.3 Energy efficiency index

The energy efficiency indicators (EEI) used here refers to a method applied in previous studies before (Saygin et al., 2011; Saygin and Patel, 2009; IEA, 2007; Neelis et al., 2007; Phylipsen et al., 1998). This method enables to take various products into account with specific process and energy requirements in a specific industrial sector. For the illustration we use the definition after (Blok, 2007) and data investigated by (Saygin et al., 2011)[6], briefly described in the following paragraphs.

Two approaches were applied, a *top-down* and a *bottom-up* approach. For this purpose 57[7] of the main chemical and petrochemical processes were taken into account, which cover about 95% of the

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[1] The output of steam cracking process is high value chemicals (HVC), see (Saygin et al., 2011) for the definition.
[2] The fuel use values account for the differences in process energy that are due to feedstock mix.
[3] Process fuel use for natural gas-based methanol production is 10 GJ/tonne of methanol (IEA, 2007). The SEC of the coal-fed methanol production process is 50% higher than the natural gas-based one (IEA, 2007).
[4] (Saygin et al., 2011) account for the differences in process shares across the countries and the SEC values are based on literature.
[5] (Saygin et al., 2011) account for the differences in process type across the countries and the SEC values are based on literature.
[6] The top-down approach is similar to the methodology applied in previous IEA publications (IEA, 2007),(OECD/IEA, 2009). However, Saygin et al. include more processes in the analysis (57 compared to originally 49) and chooses to determine the energy saving potentials using best practice technology (BPT) instead of best available techniques (BAT). BPT represents best practice technologies that are currently in use at industrial scale and they are therefore, by definition, economically viable, They also test feasibility of the bottom-up approach after (Neelis et al., 2007).
[7] The processes chosen is a selection of the key processes for key products (basic products) These 57 processes cover 66 most important chemical products in terms of physical production volumes.

total final energy use in the chemical and petrochemical sector worldwide. The data used refers to process heat only (fuel use including steam and feedstock); electricity is not included because detailed data were not available and only about one third of the electricity used would have been covered by the reported data (Kuramochi, 2006 and Saygin et al., 2011). To calculate the energy efficiency indicator the following formula were apply for the two approaches.

Top-down approach:

The *top-down* approach compares the current performance of the sector (for 2006) with the potential performance by applying best available technologies (BAT)[8]. EEI is the ratio of real energy use reported in the energy statistics and the energy use in the sector, when BAT would be applied to all processes and is calculated as followed:

Equation 1: EEI index in the chemical industry (top-down approach)

$$EEI_j = \frac{c \times TFEU_j}{\sum_{i=1}^{n} p_{j,i} \times SEC_{BAT,i}}$$

where:

EEI_j	= *energy efficiency indicator for country j;*
$P_{j,i}$	= *total physical production volume of a process i in the sector in country j;*
$SEC_{BAT,i}$	= *specific final energy consumption (SEC) under best available technology (BAT) for product i;*
$TFEU_j$	= *total final energy used (fuel and steam) in this sector in country j*
i	= *physical production level of process i;*
j	= *country;*
c	= *correction coefficient, a fixed value of 95%*[9]
n	= *number of products.*

Bottom-up approach:

In comparison to the *top-down* approach the *bottom-up* approach is not based on the energy statistic. Instead the *bottom-up* approach estimates the EEI as ratio of average current SEC of each process and the energy use on the basis of the difference between the average current SEC and the BAT of each process in the sector.

Equation 2: EEI index in the chemical industry (bottom-up approach)[10]

[8] BAT here defined as "best practice technologies that are currently in use at industrial and they are therefore, by definition , economically viable" (Saygin et al., 2011). (Saygin et al., 2011) uses the term best practice technology (BPT) instead of best available technologies (BAT).
[9] Fixed value is estimated based on the 57 process for several countries and for the world as a whole.
[10] The formula is a simplified demonstration according to the formula presented in (Saygin et al., 2009).

$$EEI_j = \frac{\sum_{i=1}^{n} SEC_{j,i} \times p_{j,i}}{\sum_{i=1}^{n} SEC_{BAT,i} \times p_{j,i}}$$

where:

EEI_j	*= energy efficiency indicator for country j;*
$P_{j,i}$	*= total physical production volume of a process i in the sector in country j;*
$SEC_{j,i}$	*= the average current specific energy consumption (SEC) for product i.*

2.1.4 CO_2 emissions index

The CO_2 emission index builds on the energy efficiency indicator, more particularly the bottom-up approach chosen. The CO_2 index only takes into account direct CO_2 emissions by application of BAT. Electricity use by sector, the related emissions (indirect emissions), emissions in the use phase and the waste treatment are not included. To calculate the CO_2 index the potential direct CO_2 emissions were estimated by multiplying the actual fossil fuel energy use and feedstock with the specific emission factor. The carbon captured in the different products is estimated by multiplying their production volume with the carbon content. This carbon storage is subtracted from the actual direct CO_2 emissions from the sector. This estimated for the current production and for the production using BAT. By comparison with the results the reduction potentials for direct CO_2 emissions can be estimated (Saygin et al., 2009)[11].

Equation 3: CO_2 index in the chemical industry

$$CO_2 Index_j = \frac{\sum_{i=1}^{n} (F_{SEC,j,i} \times e) - (C_{j,i} \times pv_{j,i})}{\sum_{i=1}^{n} (F_{BAT,j,i} \times e) - (C_{j,i} \times pv_{j,i})}$$

where:

F_{BAT}	*= fossil fuel and feedstock used for product i by applying BAT in country j;*
F_{SEC}	*= fossil fuel and feedstock used for product i by applying SEC in country j;*
e	*= fossil fuel specific CO_2 emissions factors;*
C	*= carbon capture in product i in county j;*
pv	*= production volume of product i in country j;*
j	*= country;*
i	*= produced product;*
n	*= number of products.*

[11] For the CO_2 index we inverse the calculation and switch nominator and numerator defined by (Höhne et al., 2006).

2.2 Results

2.2.1 EEI

Below the results of the EEI calculations are presented. The EEI was estimated for selected countries and regions, Table 2. These countries represent about 60% of the chemical and petrochemical sector's final energy use worldwide (Saygin et al., 2011). Unfortunately insufficient data was only available for Indonesia and Russia therefore no EEI could be calculated for these countries. For the EU as a Region the average of the member states for which data existed was calculated.

Table 2: Energy efficiency of the chemical and petro chemical sector for 2006 (incl. process energy and feedstock use, excl. electricity), modified after (Saygin et al., 2011).

Country	Top-down approach[12]		Bottom up approach		Difference in improvement potential (top-down - bottom-up
	EEI	Improvement potential	EEI	Improvement potential	
USA	1.32	24%	1.12	11%	13%
China	0.96	-4%	1.27	21%	-25%
Japan	1.18	15%	1.08	7%	8%
Korea	0.99	-1%	1.08	7%	-7%
Germany	1.02	2%	1.14	13%	-11%
India	0.98	-2%	1.23	19%	-20%
France	1.12	11%	1.11	10%	1%
Brazil[13]	1.14	12%	0.96	-4%	15%
UK[14]	1.06	6%	-	-	-
EU[15]	1.03	3%	1.12	11%	-9%
World	1.19	16%	1.18	15%	1%

[12] In IEA Energy Statistics total final energy use of the chemical and petrochemical sector is possibly under-reported for two components: (i) amounts of coal used as feedstock in the production of ammonia and methanol, particularly in China and (ii) refinery aromatics produced in petroleum refineries.
[13] The direct use of statistical data for Brazil leads to very high negative improvement potentials (43%) according to top-down approach. This may be because the energy use for bioethanol production is excluded from the system boundaries of the Brazilian chemical and petrochemical sector. It was checked whether this is the case by re-estimating the sector's coverage correction coefficient by the bottom-up approach. We estimate it as 153%, indicating that the energy use of bio-ethanol production is not reported as part of the chemical and petrochemical sector in the energy statistics of Brazil."
[14] *Figures come from a different report, (IEA, 2007)*
[15] *Estimated* out of 7 EU member states: Belgium, France, Germany, Italia, Luxemburg, Netherland, UK

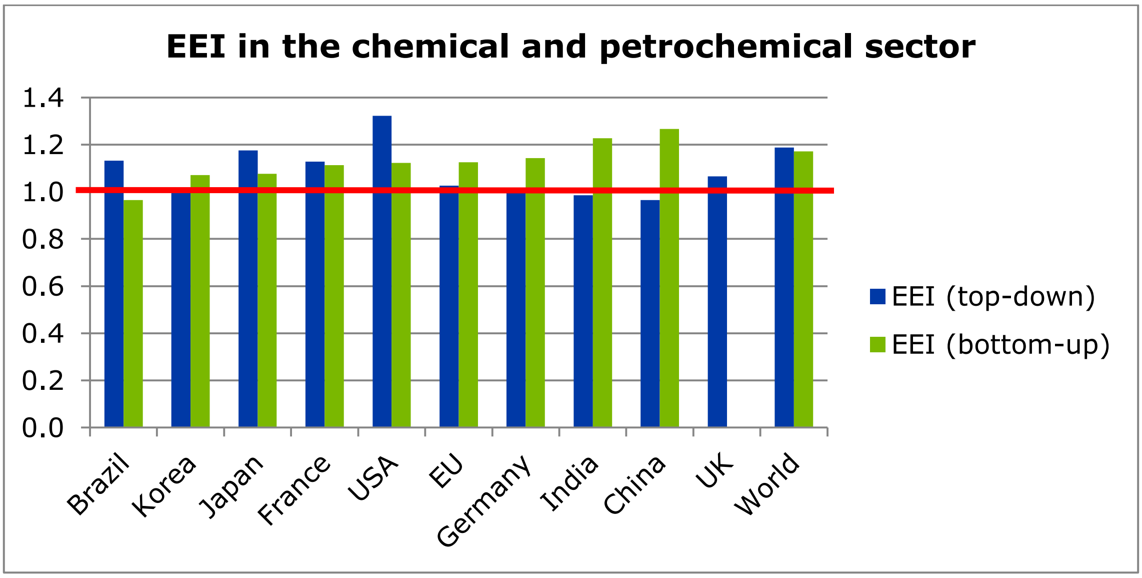

Figure 1: Energy Efficiency Indicator for 2006 for selected countries. Source: adapted after (Saygin et al., 2011).

According to (Saygin et al., 2011) a global final energy saving potential of about 5 EJ exists if BAT would be put in place. The EEI results of the two approaches (top-down and bottom-up) are thereby comparable for the global chemical and petrochemical sector (5 EJ and 4.6±1.1 EJ) as provided in Table 2. But on a country level the results of the two methods vary significantly. The difference between the two improvement potentials as reported in Table 2 illustrates this. An EEI below one indicates that a country has already a higher energy efficiency than BAT. Here this is the case for China (-3.7%), Korea (-0.6%), India (-1.5%) for the top-down approach. Furthermore Germany only has a low improvement potential of +1.5% according to this approach. The bottom-up approach presents a significantly different picture. Under this approach China has an improvement potential of 21%, Korea 7.1%, India 18.6%, and Germany 12.5%. According to the bottom-up approach USA (10.9%) have rather low improvement potential whereas the top-down approach estimated rather high improving potential. According to both approaches is the improvement potential is between 5-15% for Brazil, France and Italy.

2.2.2 CO_2 Index

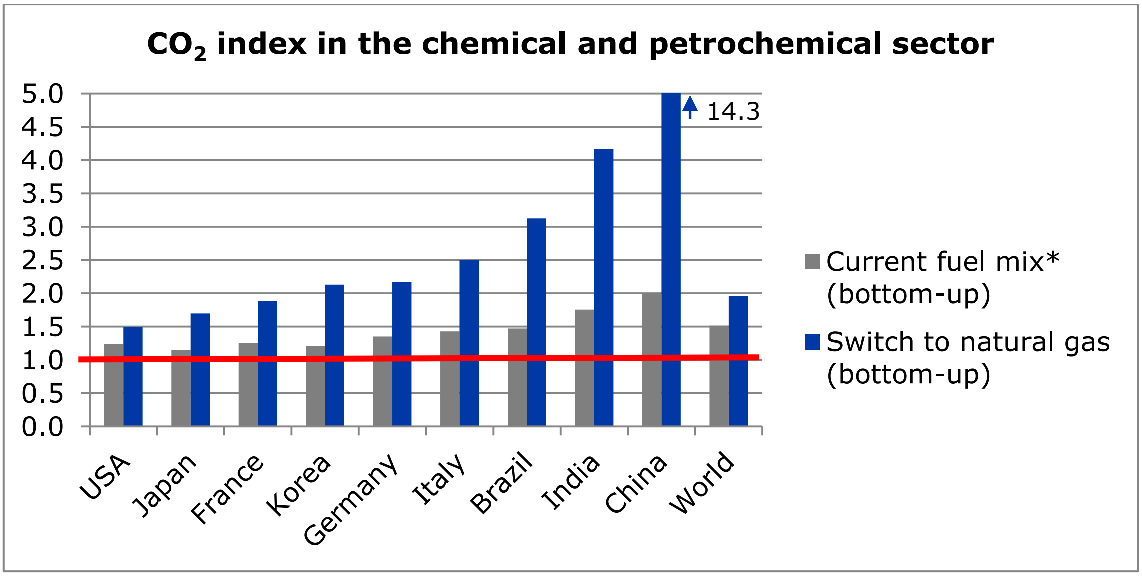

Figure 2: Current direct CO_2 Index (based on the BAT results from the bottom-up approach) calculated for fuel use scenarios, 2006. Source (Saygin et al., 2009).[16]

*This CO_2 index is calculated assuming that the current and future breakdown of fuel use and feedstock mix of the chemical and petrochemical sector of the selected countries are identical.

The CO_2 emissions index is presented in Figure 2 for the bottom-up approach. Two different figures are reported for each country, the first assuming the fuel mix as reported in 2006 and the second assuming a fuel switch to natural gas. Note that the CO_2 index is calculated assuming that the current and future breakdown by fuel use and the feedstock mix of the chemical and petrochemical sector for the selected countries are identical. The emission reduction potential is in the order of 20-35% with current fuel use and feedstock mix and about 25%-60% if a switch to natural gas would be considered (Saygin et al., 2009).

2.3 Discussion

Energy efficiency index:

The top-down approach overestimates the energy saving potential for some of the countries such as Japan, but mainly underestimates it for other such as Korea, China, or India. For these countries the EEI was below 1, indicating a potential beyond the BAT. This indicates the limitations of a top-down

[16] The extreme high figure in the *switch to gas scenario* for China can be explained by the switch from the carbon-intensive coal in China to less carbon-intensive natural gas (see also 2.1.1). There is not such a high change in other countries, because total energy use is a mix of coal, oil and natural gas whereas in China, it is mainly coal.

approach and highlights the benefits of using country specific data sources as done in the bottom up approach[17]. Reasons for this are after (Saygin et al., 2011):

- Complexity of the chemical and petrochemical sector; multi-products processes and complex material flows.
- Reliable input data like technology data, statistical data (energy, production data) reported by the different countries, which significant influence the outcome of the EEI.
- Missing out appropriate integration of heat cascading for the BAT and the SEC, thus the comparison calculated process heat and energy statistics not in totally line.
- BAT and many SEC estimation are based on European data sets and uniformed for whole world, since country specific or worldwide data were not available.
- Uncertainties fuzzy delimitation in accounting the energy statistic between chemical and petrochemical and the refinery sector.
- Estimation of one worldwide coverage correction coefficient (95%), which fits for global average estimations, but not for each country separately.

The top-down approach provides good insights energy efficiency ranges, but should be handled with care since it is not robust enough to give definite insights in country ranking concerning energy saving potentials. The bottom-up approach is an alternative, but is also limited by the provided input data.

Table 3 gives a brief overview of impacts on the calculation, due to setting certain assumption or data limitation.

The reason for the relative low saving potential in the chemical and petrochemical sector (compared to other sectors like iron and steel 29%, cement industry 23%) is the high share of feedstock use for which no savings are possible (Saygin et al., 2011). In order to improve this other energy efficiency improvements beside BAT could be taken into account such as like biomass feedstock use, higher recycling rates or a more intensive use of CHP.

CO_2 index:

There is a gap in the product scope for estimating the carbon storage and accounting for other uncertainties. For some products carbon storage is credited, but parts of this carbon are released later on, e.g. as a consequence of waste management activities or in case of urea fertilizer, where the CO_2 emissions are accounted to the agriculture use. CO_2 process emissions not related to the use of fossil fuels are not. They can be a significant share of the industrial CO_2 emissions. All the uncertainties highlighted and limitation on data availability and reliability highlighted for the EEI above are also valid for the CO_2 index.

[17] The availability of energy data is limited in the chemical and petrochemical sector. General reasons are: a) bad data quality and only limited available or accessible; b) the available data often don't match each other and are difficult to compare (different ascertainment approaches). The limitation effects both approached, top-down and bottom-up. The outcome has to be handled with care and conclusions have to be seen within this perspective.

Due to these limitations, the index can best be used as an indication of the emissions and reduction potential. It may not well suited for country specific emission reduction targets setting and neither for ranking the countries (Saygin et al., 2009).

Table 3: The impact of country-specific assumptions or data limitations on the calculations.

Country	Country- specific assumptions or data limitations	Impact on results
Brazil	Limitation of methodology and/or uncertainties in the input data[18]	Lower SEC, EEI and CO_2 index
	BAT figures represent situation in Europe	Lower/Higher SEC
China	Limitation of methodology and/or uncertainties in the input data[19]	Lower SEC, EEI and CO_2 index
	BAT figures represent situation in Europe	Lower/Higher SEC
Germany	85% of the feedstock and fuel use is natural gas	Lower CO_2 index
India	Limitation of the methodology and/or uncertainties in the input data	Lower SEC, EEI and CO_2 index
	BAT figures represent situation in Europe	Lower/Higher SEC
Japan	BAT figures represent situation in Europe	Lower/Higher SEC
South Korea	Limitation of in the methodology	Lower SEC, EEI and CO_2 index
	BAT figures represent situation in Europe	Lower SEC, EEI and CO_2 index
USA	In average twice as much energy is used compared to the most efficient plant in the world.	Higher SEC, EEI and CO_2 index
	BAT figures represent situation in Europe	Lower/Higher SEC

[18] The direct use of statistical data for Brazil leads to very high negative improvement potentials (43%) according to top-down approach. This may be because the energy use for bioethanol production is excluded from the system boundaries of the Brazilian chemical and petrochemical sector. We check whether this is the case by re-estimating the sector's coverage correction coefficient by the bottom-up approach. We estimate it as 153%, indicating that the energy use of bio-ethanol production is not reported as part of the chemical and petrochemical sector in the energy statistics of Brazil (Saygin et al., 2011).

[19] In IEA Energy Statistics total final energy use of the chemical and petrochemical sector is possibly under-reported for two components: (i) amounts of coal used as feedstock in the production of ammonia and methanol, particularly in China and (ii) refinery aromatics produced in petroleum refineries (Saygin et al., 2011).

References

Blok, K., 2007. Introduction to Energy Analysis. Techne Press, Amsterdam.
Fleiter, T., Fraunhofer ISI, 2013. Energieverbrauch und CO2-Emissionen industrieller Prozesstechnologien: Einsparpotenziale, Hemmnisse und Instrumente. Fraunhofer-Verl., Stuttgart.
Höhne, N., Moltmann, S., Lahme, E., Worrell, E., Graus, W., 2006. CO2 emission reduction potential under a sectoral approach post 2012. Köln.
IEA, 2008a. Energy balances for OECD and non-OECD countries - 2008. International Energy Agency, Paris, France.
IEA, 2008b. CO2 Emissions from Fuel Combustion 2008. Organisation for Economic Co-operation and Development, Paris.
IEA, 2007. Tracking Industrial Energy Efficiency and CO2 Emissions. Paris, France.
Kuramochi, T., 2006. Differentiation of greenhouse gas emissions reduction commitments based on a bottom-up approach: Focus on industrial energy efficiency benchmarking and future industrial activity indicators. Utrecht University Department of Science, Technology and Society.
Neelis, M., Patel, M., Blok, K., Haije, W., Bach, P., 2007. Approximation of theoretical energy-saving potentials for the petrochemical industry using energy balances for 68 key processes. Energy 32, 1104–1123. doi:10.1016/j.energy.2006.08.005
OECD/IEA, 2009. Energy Technology Transitions for Industry: Strategies for the Next Industrial Revolution. International Energy Agency (IEA), Paris, France.
Phylipsen, G.J.M., Blok, K., Worrell, E., 1998. Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry. Department of Science, Technology and Society, Utrecht University.
Saygin, D., Patel, D.M.K., 2009. Material and Energy Flows in the chemical sector in Germany.
Saygin, D., Patel, M.K., Tam, C., Gielen, D.J., 2009. Chemical and Petrochemical Sector - Potential of best practice technology and other measures for improving energy efficiency. International Energy Agency (IEA), Paris, France.
Saygin, D., Patel, M.K., Worrell, E., Tam, C., Gielen, D.J., 2011. Potential of best practice technology to improve energy efficiency in the global chemical and petrochemical sector. Energy 36, 5779–5790. doi:10.1016/j.energy.2011.05.019
SRI Consulting, 2008. Production, capacity and capacity average age data for selected chemical and for selected countries and for OECD regions.

3 Pulp and paper industry

In the pulp and paper industry a range of products are produced, ranging from low quality paper for wrapping and packaging to high quality printing paper. Each product has specific process and energy requirements that can vary largely. The pulp and paper industry processes fibrous raw material or recycling paper into paper. This includes several processes like raw materials preparation, pulping (chemical, semi-chemical, mechanical, or waste paper), bleaching, chemical recovery, pulp drying, and papermaking. The most energy consuming processes are pulping and drying (Worrell et al., 2008). The energy consumption of the pulp and paper processes in generally depends on the quality of the paper class to be produced. The large differences in the pulp characteristics and paper grades influence the energy consumption of the technologies used, i.e. also those of the best available technologies. The differences make it difficult to represent the whole range, because energy use depend on various specific properties like the raw material used, the grade and quality of the product or level of cascade energy use (Worrell et al., 2008). On a global level the IEA estimates potential savings by adopting BAT at approximately 1.4 EJ/year and 80Mt CO_2/year for the pulp and paper sector (OECD/IEA, 2009).

In comparison to the chemical industry the EEI had to be calculated separately as no up- to date study exists. We have therefore modified the approach already used in (Höhne et al., 2006, Phylipsen et al., 1998) and applied it here. In comparison to the approach described there, our calculations here assume however only one BAT value for the entire pulp and paper making process per paper product (see also below for a description of how this was implemented).

3.1 Method

3.1.1 Data requirements and data sources

For the estimation of the Energy efficiency indicator (EEI) and the CO_2 indicator the following data sets were used:

- Energy consumption per country, for the entire pulp and paper industry from the IEA Energy Statistics (IEA, 2013),
- Production data for both pulp and paper production per country and by different processes types from FAO (FAO, 2013)
- Specific energy consumption (SEC) for BAT for both integrated (i.e. one BAT value for the entire pulp and paper process) and separate (i.e. BAT values for each step, pulp and paper, separately) from Worrell et al., 2008.

For the estimation of the CO_2 index the following additional data sources were used:

- fossil fuel specific emissions factors from the IEA (IEA, 2012).

3.1.2 SEC and BAT

Below the current SEC per country as well as the achievable SEC per country based on BAT are depicted. The country specific energy consumption figures are derived from IEA energy statistics (IEA, 2013).

The BAT numbers are derived using the following approach: We assume for BAT[20] that the steam and electricity are generated in a cogeneration (CHP) installation and that 70% of the produced paper is made from recycled material[21]. The latter assumption is based on an expert judgement; in reality the maximum achievable recycling rate for the different paper types can vary largely. Furthermore we assume that the pulp and the papermaking process are performed on the same factory site, since the integrated approach is the most energy efficient approach[22]. The reason for this are the possibilities to supply heat energy, a smaller need for drying the pulp and minimized transportation (see also Equation 4) (Worrell et al., 2008).

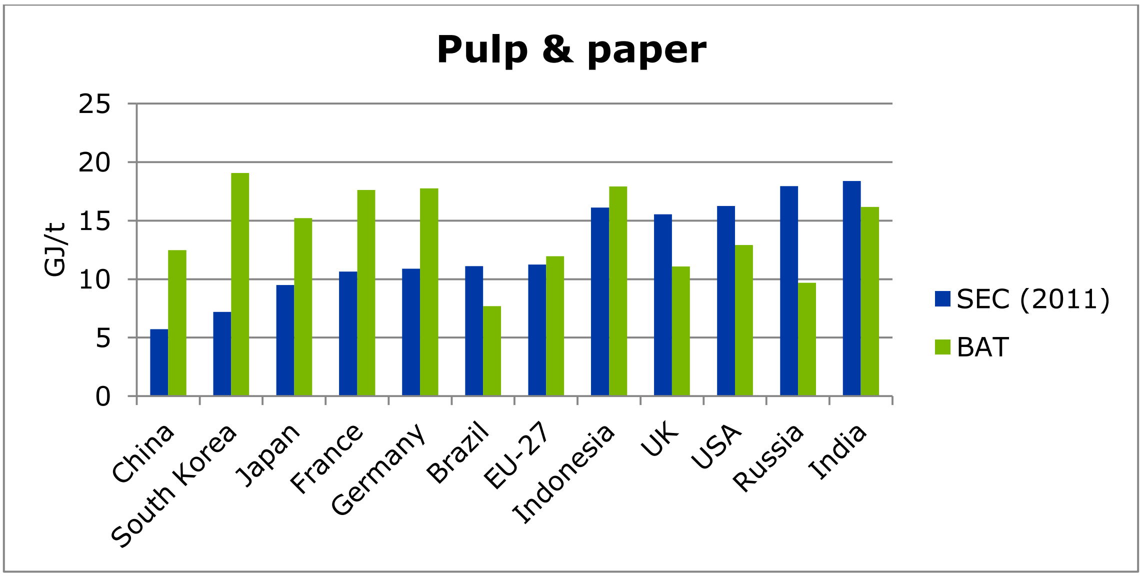

Figure 3: Specific energy consumption (SEC) and the specific energy use by applying best available technologies (BAT) in the pulp and paper sector for selected countries in 2011.

[20] International BAT energy use in pulp and papermaking technology is based on wood-based fibres. Hence, the identified best practice technologies may not be applicable to non-wood fibre based pulp mills. Even though there is increased interest in the use of non-wood fibres internationally, only a few best practice technologies are available (Worrell et al., 2008).
It is uncommon the SEC is lower than the BAT as is it presented here. The presented BAT values are the most up to date values available. Reason for that can be multifaceted, mainly due to insufficient data quality.

[21] The 70% recycling rate is based on expert's opinion and experiences in practice. Some pioneer's country like Korea or Germany already achieved 80-90%. We think the recycling rates can be higher, even though a 100% (global level) will not be reached due locked products or product losses during life cycle. Future-wise we don't see a technical limitation to make paper from recycling paper, even though today the literature quotes that some types/quality of paper can only be produced with wood-pulp.

[22] Currently the pulp- and the paper-making process are mainly separated geographically speaking.

3.1.3 Energy efficiency index

The EEI was calculated using a similar approach as the top-down approach described in chapter 2.1.3[23]. The calculation takes into account that different products have different energy needs[24]. For each product we defined a specific BAT energy consumption based on literature values from[25] (Worrell et al., 2008). We then calculated the BAT energy use per country by multiplying the BAT SEC by the country specific production per product. Finally, we divided the total final energy used by the sum of BAT values for the pulp and paper sector in that country.

Equation 4: EEI in the pulp and paper industry

$$EEI_j = \frac{TFEU_j}{\sum_{i=1}^{n} p_{j,i} \times SEC_{BAT,i}}$$

where:

EEI_j	= *energy efficiency indicator for country j;*
$P_{j,i}$	= *total production volume product i in the sector in country j;*
$TFEU_j$	= *total final energy used in this sector*[26] *in country j*
$SEC_{BAT,i}$	= *specific final energy consumption (SEC) under best available technology (BAT) for product i;*
i	= *physical production level of process i;*
j	= *country;*
n	= *number of products.*

A country using BAT would have an energy efficiency index of 1. An index of 1.2 would indicate that that country uses 20% more energy than BAT.

We use the final energy consumption when calculating the EEI, to show the energy efficiency of that sector excluding the efficiency of the electricity production. This gives the possibility to compare the energy efficiency of the pulp and paper sector in different countries with each other, while excluding the indirect influence from power generation efficiency. This gives a clear picture of the actual energy efficiency of the sector and is a measure for energy efficiency improvement opportunities.

Many countries import pulp to cover their paper production (e.g. China, EU), others produce more pulp than they need for their paper production and export them (Brazil, US, Indonesia). This influences the EEI, since the calculations are based on the paper production only. The BAT figures

[23] Please note that even though the bottom-up approach might be more accurate as shown for the chemical sector, we do not have the data necessary to replicate this approach for the paper industry

[24] The calculations differentiate between papers types like news prints, sanitary paper, wrapping paper, paper board etc. But do not differentiate between quality grades of the each paper types, e.g. different writing papers. Mainly due to missing data availability.

[25] BAT values were estimated for final energy use.

[26] The Pulp and paper sector include energy consumption of the printing and publication sector as well given in the IEA energy data (IEA, 2013).

assume an integrated approach, where pulp and paper is produced on the same site. With import of pulp the energy consumption for the production of the pulp is accounted for by the energy statistics of the exporting country. The opposite is the case for exporting countries. Therefore we introduced a *penalty* for importing countries and a *credit* for exporting countries in the calculations[27].

3.1.4 CO_2 emissions index

For the CO_2 index[28], the ratio of the actual CO_2 emissions to the amount of CO_2 emissions when applying BAT is calculated. It is calculated using the same approach as used for the EEI (top-down approach).

The CO_2 index considers indirect emissions from electricity generation. The BAT CO_2 emissions are based on BAT specific energy consumption figures as estimate for the EEI, multiplied by BAT CO_2 intensity for fuel consumption and the actual CO_2 intensity for power generation in the year and country considered. If GHG intensity for power generation decreases, BAT CO_2 emissions for pulp and paper production and real emissions of the sector decreases consequently.

Equation 5: CO_2 index in the pulp and paper industry

$$CO_2 Index_j = \frac{\sum_{i=1}^{n} E_{SEC,j,i}}{\sum_{i=1}^{n} E_{BAT,i,j}}$$

where:

E_{BAT}	= *CO_2 Emission for product i by applying BAT in country j*
E_{SEC}	= *CO_2 Emission for product i by applying current SEC in country j*[29]*;*
j	= *country*
i	= *produced product*
n	= *number of products*

$$E_{BAT} = BAT_{fuel\ use} \times BAT_{CO2\ emissions} + BAT_{el.use} \times GHG\ intesity_{el.sector}$$

$BAT_{fuel\ use}$	= *fuel used when applying best available technologies*
$BAT_{CO2\ emissions}$	= *emissions factor when applying best available technologies*
$BAT_{el.\ use}$	= *electricity used when applying best available technologies*
GHG intensity $_{el.\ sector}$	= *GHG emissions per produced electrical unit provided by the power sector*

[27] For the import/export penalty/credit we estimated the energy consumed for the exported/imported pulp based on average BAT SEC time the exported/imported pulp that are added/subtracted to the total final energy used.
[28] Currently, only CO2 emissions are considered.
[29] Including an import/export penalty/credit

Table 4 shows the best practice values for CO_2 emissions from fuel combustion for pulp and paper sector, based on IPCC report (IPCC, 1997) and expert judgement.

Table 4: Best practice values for CO_2 emissions (Ecofys et al., 2006), (IPCC, 1997).

	Product	Best practice CO_2 emissions factor for fuel consumption [kt CO_2/PJ $_{fuel}$]	Assumption
Wood Pulp	mechanical	56	100% natural gas
	chemical	56	100% natural gas
	other	56	100% natural gas
Fibre Pulp	other	56	100% natural gas
	recovered	56	100% natural gas
Paper	news print	56	100% natural gas
	printing and writing	50	25% biomass, 25% oil and 50% natural gas
	household and sanitary	50	25% biomass, 25% oil and 50% natural gas
	wrapping, packaging, board	56	100% natural gas
	other and board	56	100% natural gas

Alternatively to the above assumed use of largely natural gas as an energy source by BAT technology, we have also taken a second approach. Hereby we have determined the current specific emissions factor for a Brazil, a country that has been able to rely largely on biomass as an energy source.

3.2 Results

3.2.1 EEI

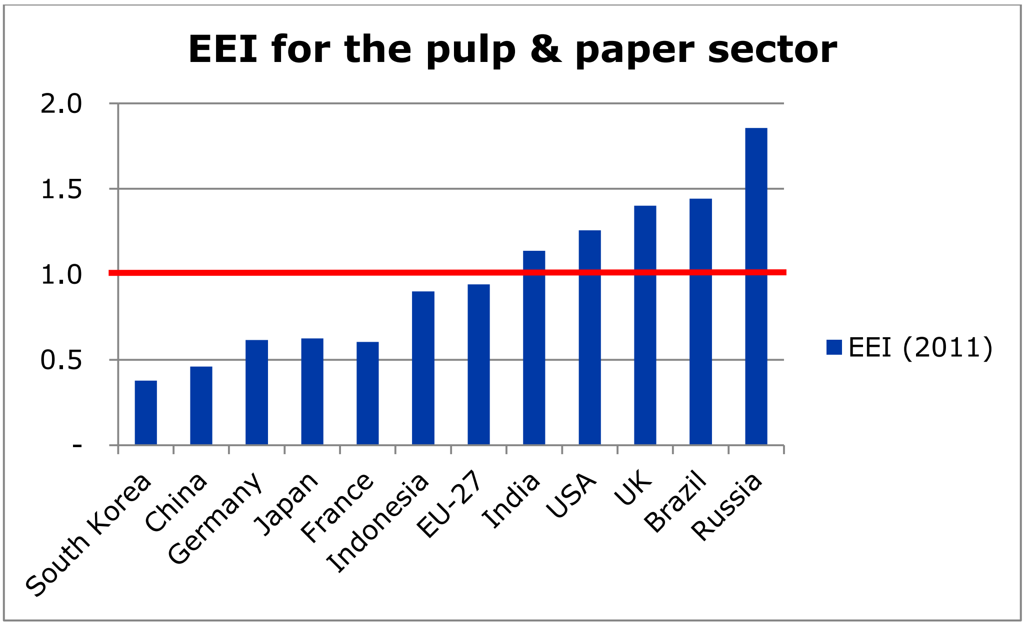

Figure 4: EEI in the pulp and paper sector of selected countries.

Figure 4 shows the results of our calculations of the EEI. Russia, Brazil, India, USA and the UK show the highest potential for energy savings (value well above 1). For South Korea, Japan, (China)[30] and Germany energy consumption is below our calculated BAT. The reasons for this are different from country to country and are further clarified below.

3.2.2 CO_2 index

About half of the global energy used by the pulp and paper industry comes from biomass; the rest comes from natural gas, coal or oil. Consequently CO_2 emissions are relatively low, even if energy efficiency is not very high. As laid out above (Section 3.1.4) we have undertaken calculations assuming two different fuel mixes for BAT (Figure 5 and Figure 6). We have kept both in here for comparison, however we believe that is a better representation of best practice.

In addition to the calculated CO_2 index the figures also show the *penalty / credit* that we have attributed to the countries as they import / export pulp and there have the energy consumption in

[30]The low energy saving potential for China is significant understated as a result of substantial underreporting in the energy statistics in the pulp and paper sector. The actual energy consumption could be 30-50% higher (OECD/IEA, 2009). In addition, China produces paper mainly from non-wood fibre based pulp. The international BAT energy use in pulp and papermaking technology is based on wood-based fibres. Hence, the identified best practice technologies may not be applicable to non-wood fibre based pulp mills (Worrell et al., 2008).

their country while not using the pulp in the paper process (export) or import the pulp whereby the energy consumption does not show up in the energy balances of the country and needs to be added.

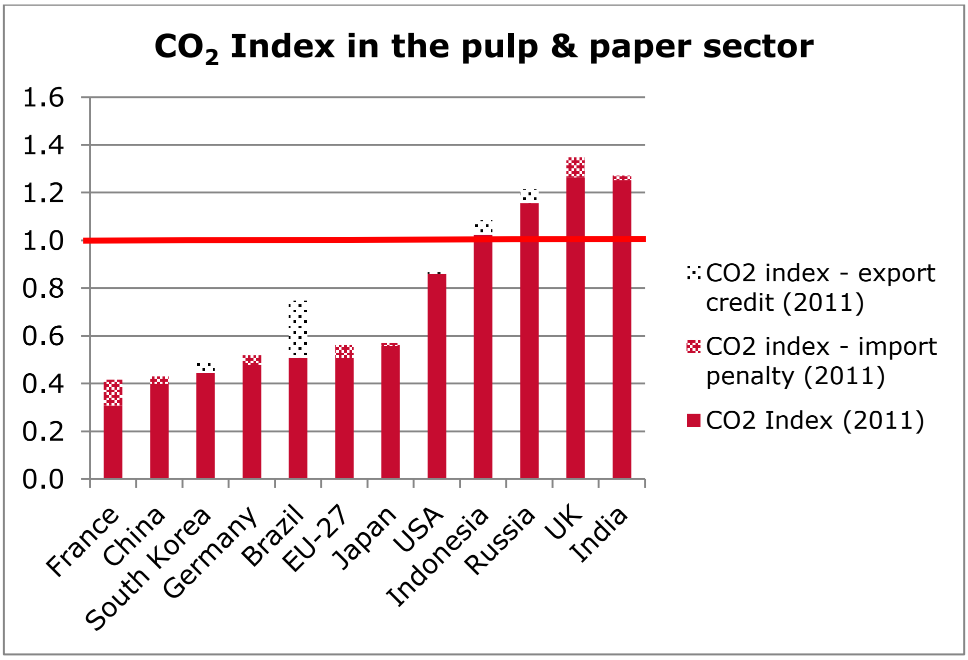

Figure 5: CO_2 index for the pulp and paper sector for selected countries assuming mainly a switch to natural gas.

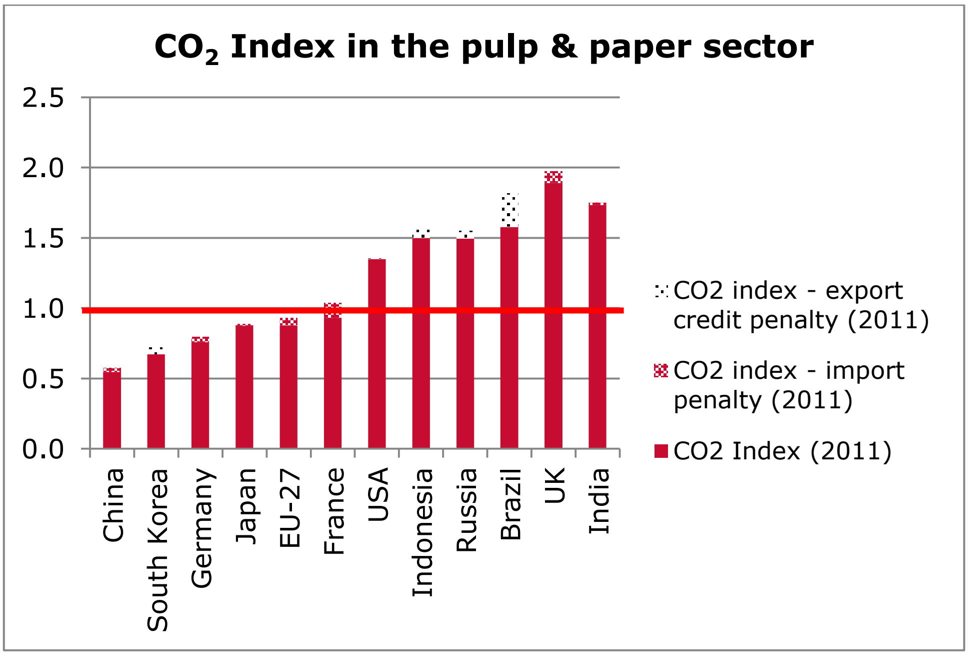

Figure 6: CO_2 index for the pulp and paper sector for selected countries assuming a fuel split as currently in Brazil (best practice).

Comparing the two assumptions, as expected, the CO_2 index is a lot higher for a number of countries if we assume that the fuel mix will mainly rely on natural gas. What can be observed is that some countries, namely China and South Korea, even under the ambitious scenario still have an EEI below 1. This fact could also be partially explained by the fact that there is a large share of autonomous production of energy in the sector, using residues from the process as input to produce electricity or heat. These do not necessarily show up in the energy balances. In Europe for instance, the sector itself produces about 46 % of the electricity it consumes (EC, 2012).

3.3 Discussion

Below is a summary by country of the most important data constraints / national circumstances that we have identified and how they influence the calculations above.

Table 5: The potential impact of country-specific assumptions or data limitations on the calculations.

Country	Country- specific assumptions or data limitations	Impact on results
Brazil	High share of pulp export	Higher SEC and CO_2 index or lower SEC[31]
	High share of newer pulping mills	Lower SEC, EEI and CO_2 index
China	Uncertainties in the reported energy data [32]	Lower SEC, EEI, CO_2 index
	Extreme high share of non-wood-fibre pulp mills.	
	CO_2 intensive fuel mix used for electricity in the production	Higher CO_2 index
France	High share of medium/old pulp mills	Higher SEC
Germany	High share of newer pulping mills	Lower SEC,EEI, CO_2 index
	High share of recycled material in the pulp production.	Lower SEC,EEI, CO_2 index
	Uncertainties in the reported energy data on biomass use[33]	Higher CO_2 Index
India	High share of small and medium pulp and paper plants (IEA, 2011)	Higher SEC, EEI
	Pulp production uses a high share of agricultural residues.	Higher SEC, EEI
	CO_2 intensive fuel mix used for electricity in the production	Higher CO_2 Index
Indonesia	High share of exported pulp	Higher SEC, CO_2 index or lower SEC, CO_2 index[34]
Japan	High share of recycled material in the pulp production.	Lower SEC,EEI, CO_2 index
South Korea	High share of newer pulping mills	Lower SEC,EEI, CO_2 index
	High share of recycled material in the pulp production.	Lower SEC,EEI, CO_2 index
Russia	High share on old pulp and paper mills (OECD/IEA, 2009)	Higher SEC, EEI, CO_2 index
	High share of CO_2 intensive fuel mix used for electricity in the production	High CO_2 Index
UK	High share of energy consumption by the publishing and printing subsector embedded into the total pulp and paper sector[35].	Higher SEC, EEI and CO_2 Index
USA	High share on old pulp and paper mills (OECD/IEA, 2009)	Higher SEC, EEI, CO_2 index

[31] Without the applied import penalty respectively export credit the SEC would be higher, with the applied import penalty respectively export credit the SEC could also be underestimated.
[32] (Kong, 2014) estimates a SEC from 13.2 GJ/tonne (2010) in national pulp and paper study. Compared to the here 7.4 GJ/tonne (2011).
[33] Many countries do not report the biomass energy used under the pulp and paper sector in the international energy statistics, but instead under other non-specific industries (UNIDO, 2010)
[34] Without the applied import penalty respectively export credit the SEC would be higher, with the applied import penalty respectively export credit the SEC could also be underestimated.
[35] UK has big printing sector that influence the IEA energy statistics, actually it is assumed that 30-50% of the reported total energy consumption in pulp and paper (and printing) sector is used by the printing and publishing sub-sector (Kuramochi, 2006).

Country	Country- specific assumptions or data limitations	Impact on results
	High share of exported pulp	Higher SEC, CO_2 index or lower SEC, CO_2 index
	High share of CO_2 intensive fuel mix used for electricity in the production electricity in the production	Higher CO_2 Index
	High share of energy consumption by the publishing and printing subsector embedded into the total pulp and paper sector	Higher SEC, EEI and CO_2 Index

There are a number of limitations with the data used:

- The IEA data on energy consumption for the pulp and paper sector also include the energy consumption of the printing and publishing sub-sector. E.g. in the Netherland about 15% of the energy consumption can be accounted for the printing and publishing sector (Worrell et al., 1994) we aspect them even higher for UK and US, among other due to their large English print market. This could not be distinctive in our approach. This can have a big influence on the SEC and EEI, depending on the share of energy consumption from the printing and publishing sector on the total pulp, paper and printing sector reported by the IEA statistics. So probably less energy is consumed by the pulp and paper sector as assumes in our data.
- High share of CHP makes it difficult to estimate reliable energy consumption data (Fleiter and Fraunhofer ISI, 2013). The integrated nature of processes in the pulp and paper sector make it difficult to account reliably for the sector's energy demand. For instance, only parts of the biomass energy used is reported under the pulp and paper sector in IEA data, but instead under other non-specific industries (OECD/IEA, 2009). This all effects EEI and CO_2 index.
- *"The United Nations Food and Agricultural Organization (FAO) provides comprehensive statistics on pulp and paper production, but categories for different paper grades do not match what is required for a more detailed indexed comparison of energy use by different paper grades. These indicators are not intended for benchmarking, which should be done on an individual mill or machine level"* (IEA, 2007).
- Integrated pulp and paper mills result in energy savings due to the reduced need to e.g. dry pulp and offers opportunities to provide a better heat integration (Worrell et al., 2008). To implement this integration approach on global market level might be difficult, especially if considering the large amounts of pulp that are imported/ exported.
- It is uncommon that the SEC is lower than the BAT. The presented SEC and BAT values are the most up to date values available. Reason for that can be multifaceted as mentioned above, but most probably due to data limitations.

In general, the outcome should be handled with care. Conclusions should be seen within the perspective of the limitation of data availability and method applied.

References

EC, 2012. Technology Information Sheet - Energy Efficiency and CO2 Reduction in the Pulp and Paper Industry.

Ecofys et al., 2006. Methodology for the free allocation of emission allowances in the EU ETS post 2012 - Sector report for the pulp and paper industry.

FAO, 2013. FAO database on forestry production and trade (Database).

Fleiter, T., Fraunhofer ISI, 2013. Energieverbrauch und CO2-Emissionen industrieller Prozesstechnologien: Einsparpotenziale, Hemmnisse und Instrumente. Fraunhofer-Verl., Stuttgart.

Höhne, N., Moltmann, S., Lahme, E., Worrell, E., Graus, W., 2006. CO2 emission reduction potential under a sectoral approach post 2012. Köln.

IEA, 2013. Energy balances for OECD and non-OECD countries - 2013. International Energy Agency, Paris, France.

IEA, 2012. CO2 Emissions from Fuel Combustion 2012. OECD Publishing; Éditions OCDE.

IEA, 2007. Tracking Industrial Energy Efficiency and CO2 Emissions. Paris, France.

IPCC, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Published by UK Meteorological Office for the IPCC/OECD/IEA, Bracknell, United Kingdom.

Kong, L., 2014. Analysis of Energy-Efficiency Opportunities for the Pulp and Paper Industry in China. eScholarship.

Kuramochi, T., 2006. Differentiation of greenhouse gas emissions reduction commitments based on a bottom-up approach: Focus on industrial energy efficiency benchmarking and future industrial activity indicators. Utrecht University Department of Science, Technology and Society.

OECD/IEA, 2009. Energy Technology Transitions for Industry: Strategies for the Next Industrial Revolution. International Energy Agency (IEA), Paris, France.

Phylipsen, G.J.M., Blok, K., Worrell, E., 1998. Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry. Department of Science, Technology and Society, Utrecht University.

UNIDO, 2010. Global Industrial Energy Efficiency Benchmarking - An energy policy tool.

Worrell, E., Cuelenaere, R.F.A., Blok, K., Turkenburg, W.C., 1994. Energy consumption by industrial processes in the European Union. Energy 19, 1113–1129. doi:10.1016/0360-5442(94)90068-X

Worrell, E., Neelis, M., Price, P., Zhou, N., 2008. World best practice energy intensity value for selected industrial sectors (No. LBNL-62806 Rev.2). Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

4 Steel

Energy indicator for steel sector refers to Oda et al. (2012), where it compares the energy efficiency for China, EU-27, France, Germany, India, Japan, Russia, South Korea, Ukraine, United Kingdom and the United States using their original estimation method.

Oda et al. (ibid.) analyzes two key steel production processes namely the blast furnace-basic oxygen furnace (BF-BOF) route and Electric Arc Furnace (EAF) route. As shown in Figure 7, 70% of worldwide crude steel is made from BF-BOF process using coke or coal before reduction in an Oxygen Blown Converter, whereas 29% of total production is produced via the EAF route. There are physical differences between this two process routes. Steel scrap based EAF has the advantage in terms of energy intensity. However, its production volume is limited by scrap availability on a global scale. Direct Reduced Iron (DRI) is also used in EAF route as an iron source in particular India, which uses mainly non- or slightly-caking coals in iron production. DRI accounts for 6% of total world iron production according to World Steel Association (2014).

This chapter focuses on the BF-BOF route which dominates worldwide crude steel production as the key activity of the iron and steel sector[36].

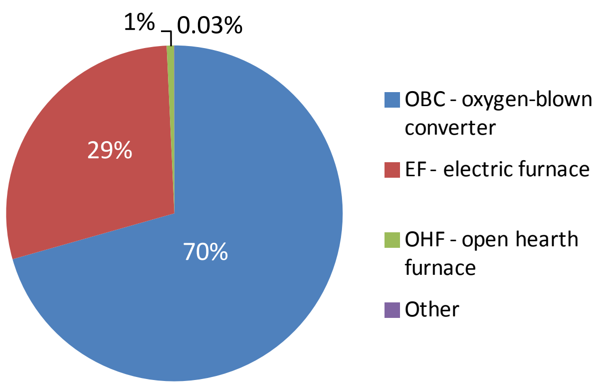

Figure 7: Share of worldwide crude steel production by process (2012) (World Steel Association, 2014).

4.1 Method

Oda et al. estimates the Specific Energy Consumption (SEC) for BF-BOF by region based on macro and micro approaches as described in Table 6. It sets "Model integrated steelwork" (Assumed system boundary as in Figure 8) to avoid incoherence for comparison by using common system boundary. For the process flow, processes from coke making to hot rolling are included within the boundary. For the energy flow, net energy consumption is defined as a summation of primary and secondary energy

[36] Please see supplementing information at the end of this chapter for details concerning EAF.

inputs minus energy output. Secondary energy carriers are measured in terms of primary energy base. Corrections for regional differences in hot metal ratio are made.

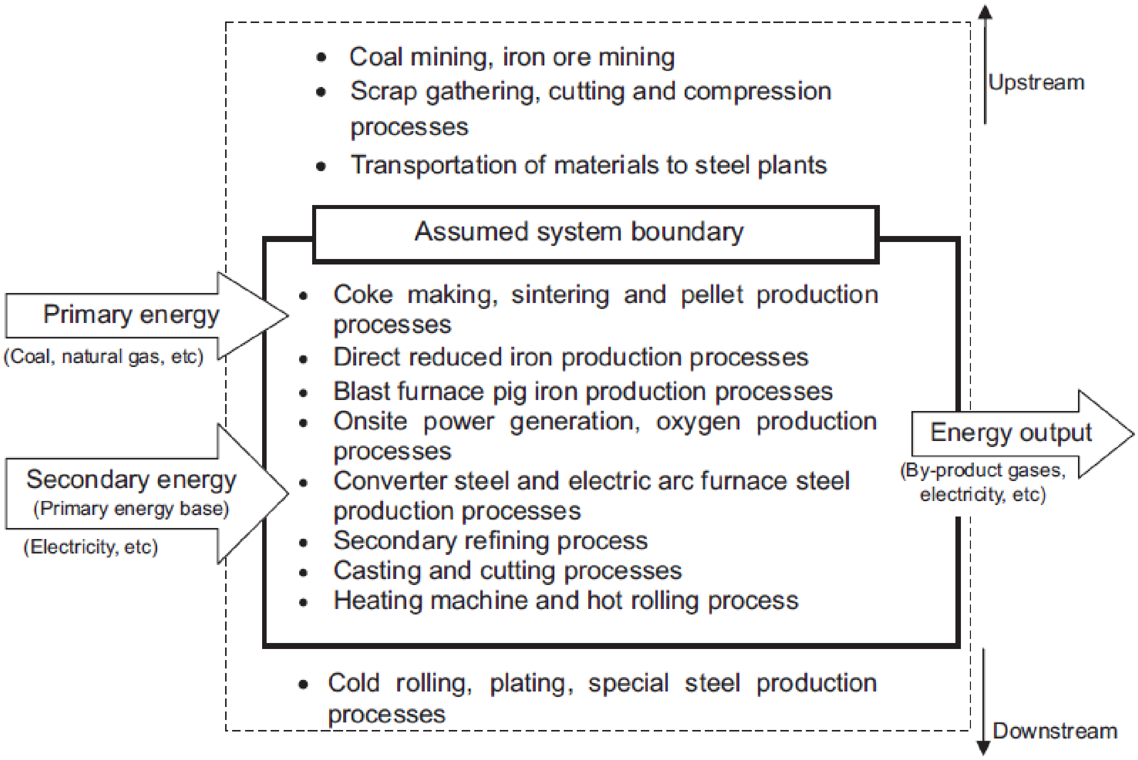

Figure 8: Assumed system boundary for iron and steel sector used in Oda et al. (ibid.).

SECs for BF–BOF by region estimated using the 'macro-statistics approach' is based on IEA Energy Balances and basically covers all countries, whereas the 'micro-data approach' gives solid and specific forms of information based on a wide variety of data, such as company reports.

Table 6: Approaches for estimation of BF-BOF SEC (Oda et al., 2012).

Macro-statistics approach	Micro-data approach
● IEA Energy Balances of OECD/Non-OECD countries	● SEC or CO_2 intensity reported by company or country (association) levels
● Crude steel production statistics published by World Steel Association	● Results of site survey by New Energy and Industrial Technology Development Organization (NEDO) Japan
	● Diffusion ratio for energy saving production equipment
	● Estimates based on the energy efficiency in 2000 in previous studies
	● Reducing agent consumption in blast furnace by region
	● IEA estimates of emission reduction potentials in 2005 by region

4.1.1 Macro-data approach

SECs in BF-BOF steel are estimated using primary energy consumption data from IEA statistics divided by total crude steel production.

The net energy consumption within the assumed boundary is estimated based on 'coke ovens' and 'blast furnaces' in energy transformation sector as well as 'iron and steel sector' in the energy demand sector of IEA's 'Extended Energy Balances'. 'Coke' and by-product gases are allocated between the iron and steel sector and other sectors. Regional share of the net energy consumption for three routes namely BF-BOF, Scrap-EAF and DRI-EAF is estimated using assumed representative SECs by route as given in Table 7.

Table 7: Assumed SEC by route for representative value (Oda et al., 2012).

GJ/ton of crude steel	Non-electricity	Electricity	Total
BOF steel	26.2	6.7	32.9
Scrap-EAF steel	2.9	7.3	10.2
DRI-EAF steel	18.1	8.6	26.7

Note: Oda et al. (op cit) estimations refer to a number of earlier studies including reports by the IEA. The value is measured with primary energy base (LHV). Assumed value of DRI-EAF steel is based on gas-based shaft furnace.

The amount of BF-BOF steel production is estimated using World Steel's statistics. Regional SECs estimates of BF-BOF steel using macro-statistics approach are given in Table 8.

Table 8: Estimated SEC in BF–BOF steel in 2005 based on macro-statistics approach (Oda et al., 2012).

GJ/ton of BOF crude steel	Estimate based on non-electricity consumption	Estimate based on total consumption
US	30.9	35.5
UK	29.3	26.9
France	26.4	30.6
Germany	24.0	26.4
EU27	25.5	28.8
Japan	23.5	25.7
Korea	28.9	34.2
China	28.6	30.5
India	40.9	30.0
Russia	47.8	65.0
Worldwide total	29.8	32.7

Note: The values are measured with primary energy base (LHV). The hot metal ratio was converted to 1.025. There was no correction for raw material quality.

4.1.2 Micro-data approach

The micro-data approach is based on a wide variety of data, such as company reports, association reports, and results of site survey, etc. For the estimation of SEC in China, a more detailed analysis was conducted based on the energy consumption data provided by large and medium–sized companies to the China Iron and Steel Association. The estimated SEC based on a micro-data approach is shown in Table 9.

Table 9: Estimated SEC in BF-BOF steel in 2005 based on micro-data approach (Oda et al., 2012).

GJ/ton of BOF crude steel	Estimated SEC
US	28.9
UK	27.6
France	24.4
Germany	23.6
Belgium, Netherlands	23.8
Japan	23.1
Korea	23.2
India	33.3
Russia	30.3

Note: Oda et al. (op cit) estimations are based on a large amount of literatures. The values are measured in terms of primary energy base (LHV). The hot metal ratio was converted to 1.025. There was no correction for raw material quality.

4.1.3 Correction for quality of raw materials

As a correction to the differences in the quality of raw materials used in producing countries, three percentage points are added to energy consumption in Europe, North America, and Brazil, where Brazilian iron ore which is low in silica and alumina content[37] is mainly used, and eight percentage points are withheld from energy consumption in India due to its high use of ash coal. Both corrections are made for the purpose of comparing process energy use within the same data boundary.

4.1.4 CO_2 emission indicators

Disaggregated energy consumption data by country and production route are required to estimate CO_2 emissions indicator. However, there is no publicly accessible data available currently. Therefore, the estimation of CO_2 emissions indicator for BF-BOF steel is excluded from this analysis.

[37] During our hearings with industry experts, it was known that high silica and alumina content has negative effects to oxidation-reduction reaction of ferrous oxide and thereby increases coke consumptions. Oda et al (ibid.) assumed that an increase of silica and alumina content leads to a difference of 3% in energy consumption.

4.2 Results

4.2.1 SEC for BOF steel in 2000 and 2005

Based on the interim estimates from the macro-statistics and micro-data approaches, SECs for BF-BOF steel in 2005 are estimated as shown in Figure 9, taking into account data reliability such as consistency and data coverage in terms of energy consumptions and productions.

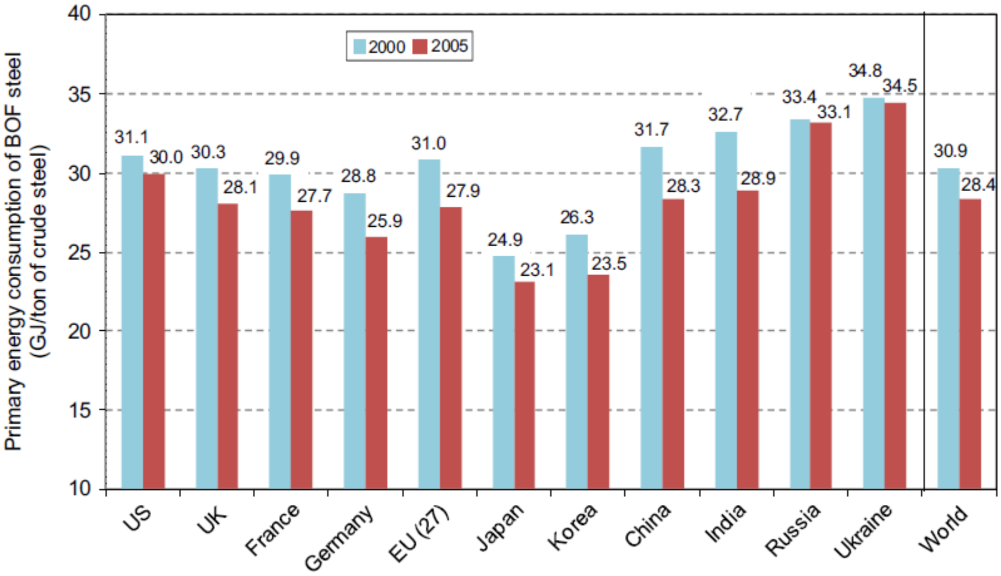

Figure 9: Final estimates of SEC for BOF steel in 2000 and 2005 (Oda et al., 2012).

Note: SEC is measured in terms of primary energy use (LHV). Corrections are done for both hot metal ratios and quality.

Figure 9 indicates that SEC in Japan, Korea, and Germany was relatively low and that in Russia and Ukraine it was relatively high for 2005.

The major factors behind regional differences are diffusion ratio for energy saving technology, production capacity, and vintage of facility. Operational practice and continual maintenance are also important.

References

Oda, J., Akimoto, K., Tomoda, T., Nagashima, M., Wada, K., Sano, F., 2012. International comparisons of energy efficiency in power, steel, and cement industries, Energy Policy 44, 118–129. doi:10.1016/j.enpol.2012.01.024

World Steel, 2014. Steel Statistical Yearbook 2014. http://www.worldsteel.org/dms/internetDocumentList/statistics-archive/yearbook-archive/Steel-Statistical-Yearbook-2014/document/Steel-Statistical-Yearbook-2014.pdf

Supplementing information: Electric arc furnace (EAF) in steel sector

EAF accounts for 29% of worldwide crude steel production in 2012 (World Steel, 2014).

Methodology

Oda et al. (ibid.) estimated SEC for Scrap-EAF by region based on the data for each EAF plant reported by AIST (2010) (Methodology [A]) and based on the improvement ratio of SECs in 2000-2005 (Methodology [B]).

Methodology [A]

The data of AIST (2010) includes company/location, tap-to-tap time, charged materials (percent of scrap), and power, oxygen and natural gas consumption of each EAF. In this analysis, oxygen consumption is converted into primary energy at the ratio of 6.48 MJ/Nm^3-O_2 in all regions based on actual electricity consumption using pressure swing adsorption. As AIST (2010) focuses only on EAF processes, energy consumption in other process, such as secondary refining, casting, and hot rolling processes, is added. Based on the assumed basic energy consumption by process and the reported SECs in EAF steelmaking route in the U.S., 3.23 GJ/tcs is assumed for additional energy consumption.

Methodology [B]

As AIST (2010) data is limited to seven countries, Oda et al. (ibid.) applied the improvement ratio for the period (2000–2005) to SECs for 2000 to derive the SEC for other steel producing countries. The SECs for 2000 are derived from Oda and Akimoto (2009), which are based on the vintage of EAFs and the IEA Extended Energy Balances.

To account for a high share of newly installed EAF capacity in total during the period 2000-2005 such as in India (70%), China (56%) and U.S (22%)[38], Oda et al. (ibid.) applied three levels of assumed SECs for new installation namely 8.0 GJ/tcs for OECD countries; 8.5 GJ/tcs for non-OECD countries except India; and 9.5 GJ/tcs for India (due to the high share of small-scale induction furnaces) to the SEC for 2000 to obtain the corresponding SECs for these countries. The outcomes are given as [B2] in Table Annex-1.

[38] Assuming a lifetime of 40-year.

Results

Table Annex-1 summarizes the results. The weight coefficients of method [A] are directly given along with regional share of production capacity of the EAF plants as reported by AIST (2010). The weight coefficients of method [B1] are based on regional Scrap-EAF route share. The rests are allocated to the weight coefficients of method [B2].

The final estimates shown in Table Annex-1 indicate that regional differences are relatively small. Compared to the worldwide average, the value for the most efficient region was 95% in 2005. The value for the least energy efficient region was 115%. This is partly because the Scrap-EAF route involves relatively similar technological processes compared to the BF-BOF route.

Table Annex 1: Summary of Scrap-EAF SEC estimates for 2005 (Oda et al., 2012).

	Interim estimates by approach (GJ/ton of EAF crude steel			Weight coefficients (%)			Final estimates (GJ/ton of EAF crude steel)
	[A]	[B1]	[B2]	[A]	[B1]	[B2]	
US	8.41	8.56	8.44	100	0	0	**8.41**
Canada	8.82	9.23	9.08	100	0	0	**8.82**
UK	-	8.19	9.39	-	10	90	**9.27**
France	-	9.12	9.12	-	25	75	**9.12**
Germany	-	8.77	8.66	-	19	81	**8.68**
Italy	-	8.58	9.03	-	45	55	**8.83**
Spain, Portugal	-	8.98	8.71	-	45	55	**8.83**
EU27	-	8.84	8.97	-	-	-	**8.93**
Japan	-	8.12	8.41	-	19	81	**8.36**
Australia, NZ	8.38	8.96	8.56	91	6	3	**8.42**
Korea	-	8.43	8.33	-	26	74	**8.36**
China	-	7.68	8.75	-	9	91	**8.66**
India	-	9.37	9.64	-	3	97	**9.64**
Turkey	-	9.03	9.01	-	49	51	**9.02**
Mexico	9.11	7.54	9.47	76	18	6	**8.85**
Brazil	9.16	9.00	8.91	30	13	57	**9.00**
Russia	-	10.21	10.13	-	2	98	**10.14**
World	8.51	8.56	8.83	-	-	-	**8.78**

Note: SEC is measured in terms of primary energy base (LHV).

References

Association for Iron and Steel Technology (AIST), 2010. AIST Industry Roundups, EAF Roundup, 2010.

Oda, J., Akimoto, K., 2009. An evaluation of energy efficiency in iron and steel sector. Journal of Japan Institute of Energy 88, 1009–1016 (in Japanese).

Oda, J., Akimoto, K., Tomoda, T., Nagashima, M., Wada, K., Sano, F., 2012. International comparisons of energy efficiency in power, steel, and cement industries, Energy Policy 44, 118–129. doi:10.1016/j.enpol.2012.01.024

5 Cement

5.1 Overview of the cement manufacturing process

The cement manufacturing process can be divided into the "raw material process", "calcination process" and "finishing process".

The "raw material process" is a process consisting of mixing the main raw materials, such as limestone, clay, silica, iron raw material, and other raw materials into a specific chemical composition and granulating them in raw material grinding mill. The resulting material is called "mixed raw material". Recently, many types of waste and by-products are widely used as alternative raw materials.

The "calcination process" is a process to produce clinker by burning the mixed raw materials at high temperature in rotary kiln. Clinker, an intermediate product is the main component for the manufacturing of cement. A major portion of energy used in the entire cement production is consumed during "calcinations process", which is, in the production of clinker[39].

Calcination of clinker takes place in a rotary kiln. Feeding the mixed raw materials to the preheater before entering the rotary kiln is commonly practiced nowadays to improve calcinations efficiency. The effective use of industrial and municipal waste as alternative fuel for the kiln is gaining popularity nowadays.

The "finishing process" is a process where gypsum is added to the clinker and grinded in the finishing mill. The resulting fine particles are known as the Portland cement. Mixed cement is produced by mixing the Portland cement and admixtures with a mixer.

5.2 Energy and CO_2 indicators in the cement manufacturing process

As mentioned in the previous section, the "calcinations" process is the most energy consuming process in cement production. Therefore, it is important to focus on the energy efficiency of the clinker production. In terms of CO_2 emissions, it is necessary to take into account the entire cement manufacturing process including the "calcinations process".

In addition, the use of an appropriate denominator to derive the energy and CO_2 efficiency indicators for cement industry depends on the types of the target.

[39] For example, the breakdown of energy consumption in each of the cement manufacturing process in Japan is as follows: raw material process (0% heat, 8% electricity); calcination process (72% heat, electricity 8%); and finishing process (0% heat, 12% electricity).

In terms of fuel energy reduction target, it is better to focus on fuel efficiency for energy intensive clinker process which constitutes the major portion of energy use in cement production. Improving energy efficiency of kiln is the most effective measure for energy efficiency improvement in the cement industry.

In terms of CO_2 emission reduction target, it is better to focus on not only fuel efficiency for clinker process but also the type of cement composition. Enhancing the use of alternative additives such as slag and fly ash contributes to lower CO_2 emissions from cement production process. The mixing rate for cement composition depends on quality regulation of cement and the needs or preferences of consumers which may differ among the regions.

Apart from the above, electricity consumption is also one of the important indicators for cement industry. Although electricity consumption is generally treated as indirect emission, cement manufacturing consumes a high level of electricity in particular for grinding, thereby suggesting the necessity of considering it as one of the performance indicators.

Based on the above discussions, indicators which are deemed suitable to appropriately measure the efficiency of cement manufacturing process are given in the following.

1. Thermal energy efficiency in clinker manufacturing process
   Weighted average thermal energy consumption (excluding heat consumption for alternative fuels) per tonne clinker in each kiln (MJ / tonne clinker)

This indicator compares the energy efficiency in clinker manufacturing process, the process which consumes the largest amount of energy in the entire cement manufacturing process. From the view point of achieving a sustainable society, it is necessary to consider the use of waste materials as neutral as it reduces the use of fossil fuels as discussed in chapter 5.1, therefore, thermal energy derived from waste should be excluded in the measurement.

2. CO_2 emissions intensity in cement manufacturing
   Weighted average net CO_2 emission (excluding CO_2 emission for alternative fuels) per tonne cement in each kiln (kg-CO_2/tonne cement)

This indicator measures CO_2 emissions intensity for the entire cement manufacturing process. Similar to indicator 1. in the above, the use of waste which would otherwise be incinerated or land filled as alternative fuel in cement kilns can contribute to the development of a sustainable society as it lowers overall CO_2 emissions by replacing fossil fuels. The net accounting method, which excludes CO_2 emissions from waste is desirable to appropriately account for the effective use of waste in cement manufacturing.

3. Electricity intensity in cement manufacturing
   Weighted average electrical power consumption (excluding electricity generated from waste heat) per tonne cement (kWh/tonne cement)

Electricity is one of the main forms of energy consumed in cement manufacturing, thereby suggesting the need to measure the efficiency of its consumption in production process. For cement plants which employ waste heat recovery power generation facility, electricity generated from such waste heat facility should be excluded in the measurement since it offsets a portion of electricity demand in cement manufacturing.

* Waste heat recovery power generation facility refers to a facility which recovers waste heat from the preheater exhausts and clinker coolers and uses it to provide low temperature heating needs in the plant, or in most cases to generate electricity to offset a portion of power purchased from the grid, or captive power generated by fuel consumption at the site.

The key challenge in developing the energy and CO_2 emission indicators for the cement industry is the poor availability of data. Therefore the approach taken here is to establish indicators using available data and resource.

5.3 Method

5.3.1 Selection of data

Energy and CO_2 indicators for cement industry analysis refers to publicly available "Getting the Numbers Right (GNR)" database developed by the Cement Sustainability Initiative (CSI) of World Business Council for Sustainable Development (WBCSD).The WBCSD CSI database is an independent database of energy and CO_2 performance information on the cement industry developed based on a uniformed system boundary and definitions and has the highest coverage of countries across world regions[40]. Consolidated data for country and region are published based on information submitted annually on plant basis by participating members. Despite the wide differences in coverage across regions, WBCSD CSI database is perhaps the best publicly available database on the cement industry.

The GNR Data is voluntarily collected by GNR participants for the database using the "CSI-developed CO_2 Accounting and Reporting Standard for the Cement Industry". The GNR system is intended to help the cement industry and policymakers alike to better assess the influence of kiln technology, fuel selection, plant location and other variables on global and regional plant performance and emissions management.

Countries or region covered are Africa, Asia (excluding China, India, CIS) + Oceania, Brazil, Central America, China, CIS, Europe, India, Middle East, North America, and South America excluding Brazil
Note that the performance indicators developed by the WBCSD CSI differ from the efficiency indicators suggested in chapter 5.2 in particular in terms of data boundary. Table 10 summarizes the key differences between the two:

[40] http://wbcsdcement.org/pdf/tf1_co2%20protocol%20v3.pdf

Table 10: Differences between the efficiency indicators suggested and WBCSD-CSI database.

	I. Efficiency indicator suggested	II.WBCSD-CSI data	Differences
Thermal energy efficiency in clinker manufacturing process	Weighted average thermal energy consumption (excluding heat consumption for alternative fuels) per tonne clinker in each kiln (MJ / tonne clinker)	329a Energy consumption (MJ/t) including energy for drying fuels and raw materials MJ / tonne clinker	II includes heat consumption for alternative fuels
CO_2 emissions intensity in cement manufacturing	Weighted average net CO_2 emission (excluding CO_2 emission for alternative fuels) per tonne cement (kg-CO_2/tonne cement)	326b Weighted average net CO_2 emission per tonne cement equivalent in each region over time (excluding CO_2 from electric power) (kg CO_2 / tonne cement equivalent calculated at company level)	The numerator of indicator II excludes CO_2 emission from on-site power generation while the denominator includes clinker bought from third parties for the production of cement
Electricity intensity in cement manufacturing	Weighted average electrical power consumption (excluding from waste heat power generation) per tonne cement (kWh/tonne cement)	3212b Weighted average power consumption for cement manufacturing per tonne of cement in each region over time (kWh / tonne cement)	II includes electricity generated from waste heat

5.3.2 GNR indicator

The following presents the indicators available in the GNR database and its calculation methods:

1. Weighted average thermal energy consumption (including energy for drying fuels and raw materials) per tonne clinker in each region (MJ / tonne clinker)

The indicator is calculated by total heat consumption of kilns (MJ, year) including heat consumption for drying fuels and raw materials in the region divided by production of clinker (tonne, year) in the region.

2. Weighted average net CO_2 emission per tonne cement equivalent in each region over time (kg CO_2 / tonne cement equivalent calculated at company level)

The indicator is calculated by total net CO_2 emission in the region (kgCO_2, year) divided by cement equivalent production (tonne, year) in the region.

*Net CO_2 emissions are calculated by the gross emissions minus the CO_2 emissions from alternative fossil fuels.

where, Gross CO_2 emissions include total fossil and direct CO_2 emissions from a cement plant or company. It excludes CO_2 emissions from on-site electricity production. Gross emissions also include CO_2 from alternative fossil fuels, but exclude CO_2 from biomass fuels and the biomass content of mixed fuels, since these emissions are regarded as climate-neutral.

Note that cement equivalent is the sum of all cements and clinker produced by a cement company, including clinker purchased from third parties and used to make cement.

3. Weighted average power consumption for cement manufacturing per tonne of cement (kWh / tonne cement)

The indicator is calculated by power consumption (kWh, year) for cement and clinker production divided by cement and cement substitute production (tonne, year).
Note that “cement and cement substitute production” excludes clinker sold but includes clinker bought.

5.4 Results

Figure 10 shows the weighted average thermal energy consumption (including energy for drying fuels and raw materials) per tonne clinker in each region for 2012. India is most energy efficient with 3080MJ/t-clinker, followed by China with 3300MJ/t-clinker and Asia with 3330MJ/t-clinker. The energy intensity of CIS is the highest among the region at 5080 MJ/t-clinker, followed by North America at 3870 MJ/t-clinker and Africa at 3760 MJ/t-clinker.

Regional differences in average thermal efficiency in general are the results from varying ages of installations and applied technologies, and different turnover and asset renewal times. The average thermal efficiencies of China, India, and Asia+Oceania are very close to the thermal efficiency of the most efficient preheater-precalciner kiln technology[41], while most kilns in the CIS region are old and less efficient wet kilns. The indicator nonetheless does not reflect the differences in the degree of alternative fuel usage in cement production between regions as it includes heat consumption from alternative fuel.

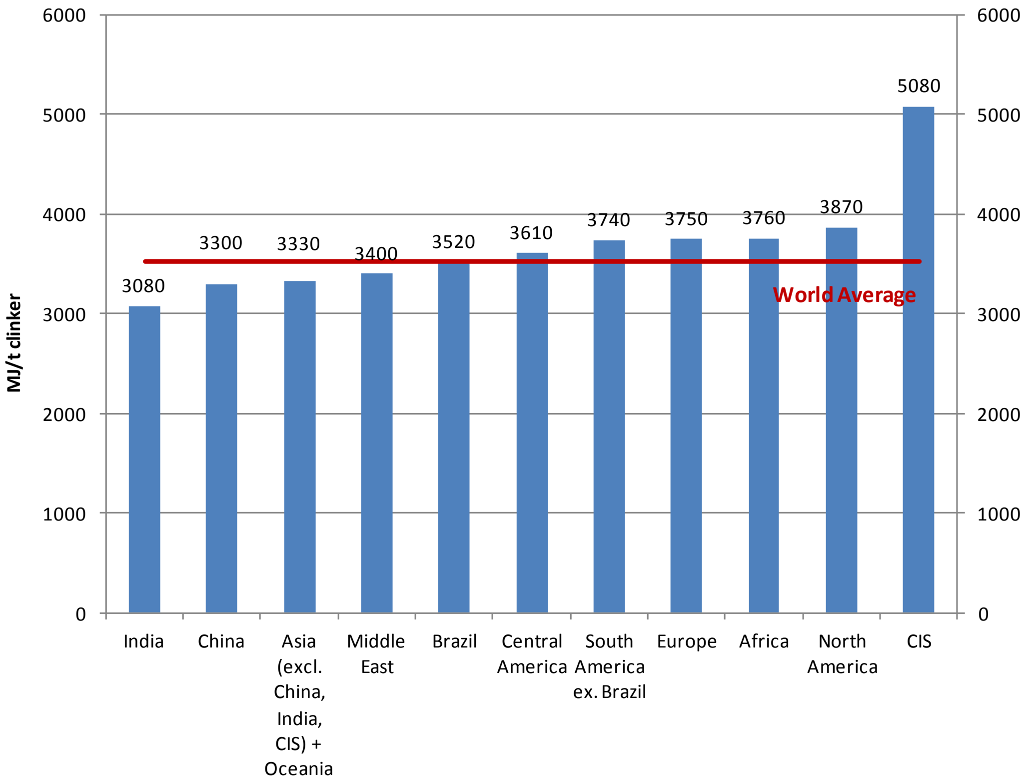

Figure 10: Weighted average thermal energy consumption including energy for drying fuels and raw materials (MJ / tonne clinker) 2012 (WBCSD GNR database).

[41] High thermal efficiency could be the result of low data coverage in these regions and data submitted are mostly limited to new capacities.

CO_2 emissions intensity per tonne cement is generally higher for countries which consume mostly Portland cement due to its high clinker-to-cement ratio. On the other hand, a lower intensity is observed in countries with a higher demand for blended cement which uses alternative blending materials such as fly ash, slag, etc as a substitute to clinker. It is therefore important to take into account differences in the types of cement available in the market when making comparisons. Additionally, the use of alternative fuel in cement industry influences energy and CO_2 emissions performances of cement manufacturing. Countries differ in their levels of alternative fuel usage on account of variations in regulatory background and waste availability. In general, countries with high alternative fuel use outperform in CO_2 emissions but less advantageous in terms of energy efficiency due to increased energy used if pre-treatment of waste is required.

Figure 11 shows weighted average net CO_2 emission per tonne cement equivalent in each region over time (excluding CO_2 from on-site power generation) for 2012. The net CO_2 emissions exclude emissions from alternative fuels. Brazil is most efficient with 561kgCO_2/t-cement equivalent, followed by Europe at 564kgCO_2/t-cement equivalent and South America at 573kgCO_2/t-cement equivalent. The CO_2 intensity of North America is the largest among the region at 764kgCO_2/t-cement equivalent.

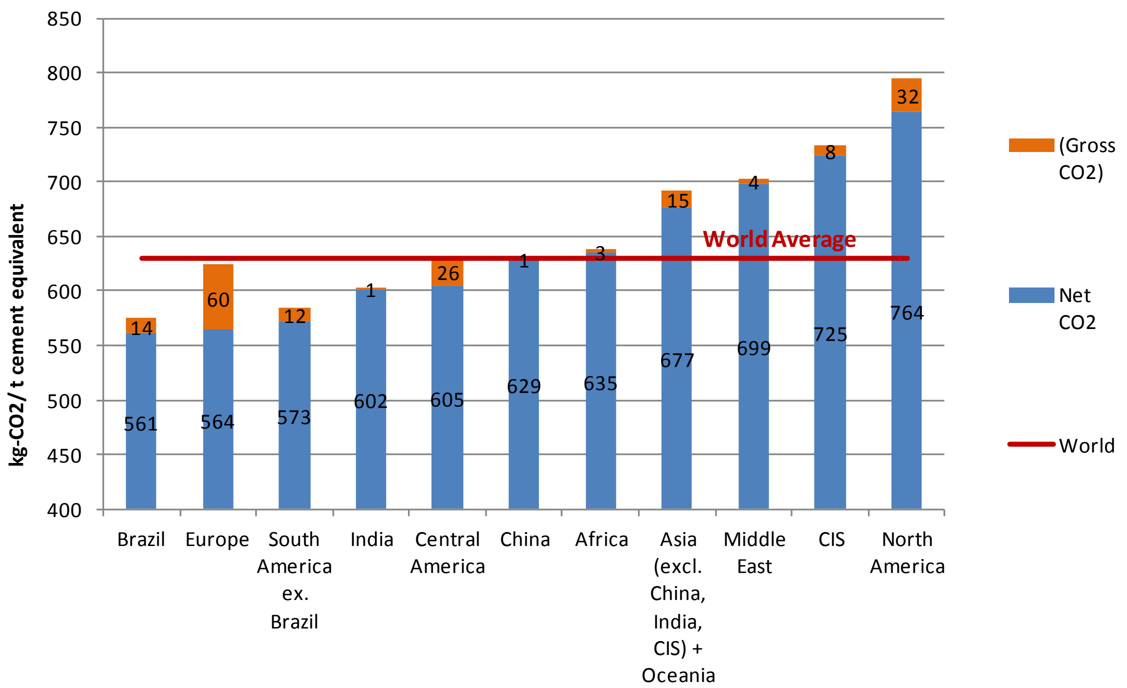

Figure 11: Weighted average net CO_2 emission per tonne cement equivalent (excluding CO_2 from on-site power generation) 2012 (kg CO_2 / tonne cement equivalent) (WBCSD GNR database).

The difference between the emission level of Gross CO_2 and Net CO_2 becomes greater in region which uses higher amount of waste as alternative fuels, while smaller in region with lower usage of waste. Table 11 gives the level of alternative fuel use in selected countries.

Table 11: The share of alternative fuel use in kiln of selected countries (CMA, 2013).

Country	Alternative fuel use (% of thermal energy consumption)
Netherlands	83
Switzerland	48
Austria	46
Norway	35
France	34
Belgium	30
Germany	42
Sweden	29
Luxemburg	25
Czech Republic	24
Japan	10
US	25
India	<1

Figure 12 shows weighted average electric energy consumption per tonne cement for 2012. India is most efficient with 69kWh/t-cement, followed by China at 89kWh/t-cement and Africa at 96kWh/t-cement. The power intensity of North America is the largest among the region at 125kWh/t-cement.

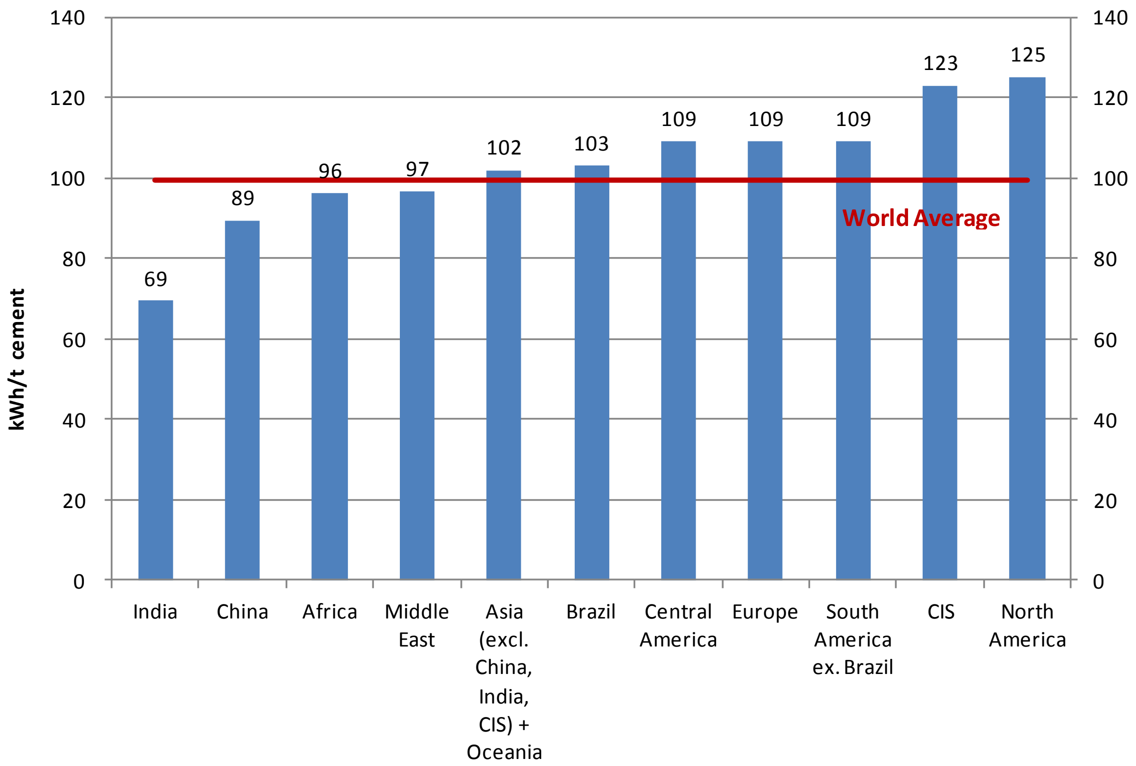

Figure 12: Weighted average power consumption for cement manufacturing per tonne of cement (kWh/t-cement) 2012 (WBCSD GNR database).

5.5 Discussion

The situation surrounding cement industry varies in each region and this lead to variation in results depending on the indicators measured. The outcomes suggest the need to compare not only one but several indicators for the following reasons. Careful consideration is also required in selecting the appropriate denominator and indicator for international comparison.

1. Data availability and boundary

Apart from European Cement Association (CEMBUREAU) and the Inter-American Cement Federation (FICEM) which share their database with GNR, worldwide database on cement industry is currently not publicly available. Further discussions are deemed necessary as significant uncertainty exists around the results presented in this analysis due to the absence of comprehensive data for countries like Japan, India, etc.

The compilation of energy and CO_2 indicators for cement industry are subject to the availability of various data including detailed energy consumption data for each process of clinker and cement production. Although the WBCSD CSI database is referred in this analysis, note that the coverage varies widely across regions. Additionally, it may be necessary to analyze changes in trends over a selected period of time to exclude annual irregularities.

The collection of national data for cement industry differs between countries and the quality of data is not always the same due to differences in definition and system boundary. The establishment of a reliable, comparable and highly transparent database for the cement industry requires close cooperation between respective organizations and authority in-charge among countries.

2. Definition used for cement products

The appropriate data to be used as the denominator differs depending on the operational characteristic of a cement plant. For example, in some countries clinker is produced in the same cement plant whereas in other countries, the production of clinker takes place at a facility separate to the cement plant. The "cement equivalent" denominator referred in this analysis is defined by the GNR database as the sum of all cements and clinker produced by a cement company including clinker purchased from third parties but excluding clinker sold. The definition suggests the tendency for a cement plant which purchases clinker from third parties to have lower energy intensity. On the other hand, "cementitious products" which is not referred in this analysis covers all alternative raw materials such as slag produced and sold to third parties but excludes clinker bought. In this case, cement plant with a large quantity of sales tends to have a smaller intensity. Caution must therefore be exercised in selecting the appropriate denominator considering its limitations from available data.

3. Energy efficiency in cement manufacturing process

The selection of appropriate indicators for cement industry is essentially the choice of indicators which could best measure the efficiency of a facility. Perhaps the most appropriate indicator from an energy efficiency point of view is the thermal energy efficiency in clinker manufacturing process since this is the most energy consuming process in entire cement production process. Ideally, energy from waste and biomass should be excluded in the evaluation on account of their contributions towards achieving a sustainable society.

4. Specific CO_2 emission

As explained above, Net CO_2 emission is calculated by Gross CO_2 emission subtracted with emission from alternative fuels such as waste oil, used tires, plastics, solvents, and bottom sludge. Therefore, the difference in number between Net CO_2 emission and Gross CO_2 emission is derived by the amount of waste used as an alternative energy source which varies widely across regions. Thus, the difference between the emission level of Gross CO_2 and Net CO_2 becomes greater in the region which uses larger amount of waste as alternative fuels, while smaller in the region with lower usage of waste.

It is noted that the amount of waste use in the region varies and is mainly influenced by the level of development of waste legislation, law enforcement, waste collection infrastructure, and local environmental awareness.

5. Specific power consumption

Although electricity consumption is treated as indirect emissions, the use of electricity in cement production is significant, thereby suggesting its importance as one of the performance indicators for cement industry. The efficiency of electricity consumption of cement plant is best measured by taking into account the entire cement manufacturing process and excluding electricity generated from waste heat recovery power generation facility since it offsets a portion of electricity demand in cement manufacturing. It is anticipated that more than 15% of electricity demand could be met by the efficient use of waste heat in cement kilns.

5.6 Glossary

- Perimeter of CO_2 emissions considered: only direct CO_2 emissions related to the production of cement and clinker, excluding on-site electricity production.
- Gross CO_2 emissions: direct CO_2 emissions (excluding on-site electricity production) minus emissions from biomass fuel sources.
- Net CO_2 emissions: gross CO_2 emissions minus emissions from alternative fossil fuels.
- Alternative fuels: fuels used for fossil fuel substitution in clinker production. Alternative fuels are derived from waste (excluding biomass waste).
- Clinker: intermediate product in cement manufacturing. Clinker is the result of calcination of raw materials in the kiln.
- Cement: finished product of the cement plant obtained by grinding the clinker and adding various components (gypsum, limestone).
- Cement equivalent is the sum of all cements and clinker produced by a cement company, including clinker purchased from third parties and used to make cement.
- Cementitious products are all clinker volumes produced by a company for cement making or direct clinker sale, plus gypsum, limestone, CKD, and all clinker substitutes consumed for blending, plus all cement substitutes produced. Clinker bought from third parties for the production of cement is excluded.

References

Cement Sustainability Initiative, WBCSD. "Getting the Numbers Right (GNR)". http://wbcsdcement.org/index.php/key-issues/climate-protection/gnr-database

WBCSD (2011). CO2 and Energy Accounting and Reporting Standard for the Cement Industry. http://wbcsdcement.org/pdf/tf1_co2%20protocol%20v3.pdf

Izumi Y (2014). Role of the Japanese Cement Industry in the Establishment of a Sustainable Society. Key Engineering Materials, vol. 617:50-58.

Cement Manufacturers' Association India, CMA (2013). Status of AFR in India.

6 Power

Energy and CO_2 indicators for power sector are calculated with reference to the methodology developed by Ecofys in its study - "International comparison of fossil power efficiency and CO_2 intensity – Update 2013" for selected countries/region namely US, Russian Federation, EU (as a group and separately United Kingdom, Germany, France), Japan, China, India, Indonesia and Brazil.

Below summarizes the methodology and results of this study.

6.1 Method

6.1.1 Energy efficiency of power generation

Energy efficiency of power generation is calculated as follows:

$$E = \frac{P + (H * S)}{INP}$$

Where:

E	Energy efficiency of power generation
P	Power production from public power plants and public CHP plants
H	Heat output from public CHP plants
S	Correction factor between heat and electricity, defined as the reduction in electricity production per unit of heat extracted. Assumed to be 0.175 in this study
INP	Fuel input for public power plants and public CHP plants

Energy efficiency of power generation is calculated for coal, oil and gas respectively taking into account production from public power plants and public CHP plants. Data for calculation is fundamentally based on data from IEA Energy Balances edition 2014 as showed in Table 12.

Table 12: Data and source.

Data	Source
Power production from public power plants and public CHP plants	IEA Energy Balances edition 2014
Heat output from public CHP plants	IEA Energy Balances edition 2014
Fuel input for public power plants and public CHP plants	IEA Energy Balances edition 2014
Correction factor between heat and electricity	Ecofys (2013). International comparison of fossil power efficiency and CO_2 intensity – Update 2013.

6.1.2 CO_2 intensity of power generation

CO_2 intensity for power generation is calculated for each country by fuel and for total fossil power generation. The calculation uses the same method as for calculating energy efficiency where heat generation is corrected by correction factor of 0.175. Table 13 summarizes the data used and its sources for the calculation of CO_2 intensity.

The formula for calculating CO2 intensity is as follows:

$$CO_{2i} = \sum C_i / \sum P_i$$

Where:

CO_{2i}	CO_2 intensity
i	Fuel source 1 … n
C_i	CO_2 emission per fuel source (tonCO_2)
P_i	Power production from public power and CHP plants per fuel source (MWh)

Table 13: Data and source.

Data	Source
CO_2 emission per fuel source	IEA CO_2 emissions from fuel combustion edition 2014
Power production from public power and CHP plants per fuel source	IEA Energy Balances edition 2014

6.2 Results

6.2.1 Average efficiency of power generation

Figure 13 shows average energy efficiency of fossil-fired power generation in 2012. Country wise differences in energy efficiency are large with Japan leading ahead at 44% followed by United Kingdom and Brazil, whereas country like India achieved a low 27.6% due to its high dependency on inefficient coal-fired power generation. China on the other hand recorded an average efficiency of 35.7%, up from 34.8% in 2009[42]. The improvements come mostly from its coal power plant which has increased steadily in the period 1990 to 2012 and accounted for close to 80% of total power generated in 2011. Japan leads amongst the countries covered for the analysis on account of the use of advanced combined cycle technology in newly built and replacement of aging gas-fired power plants in recent years.

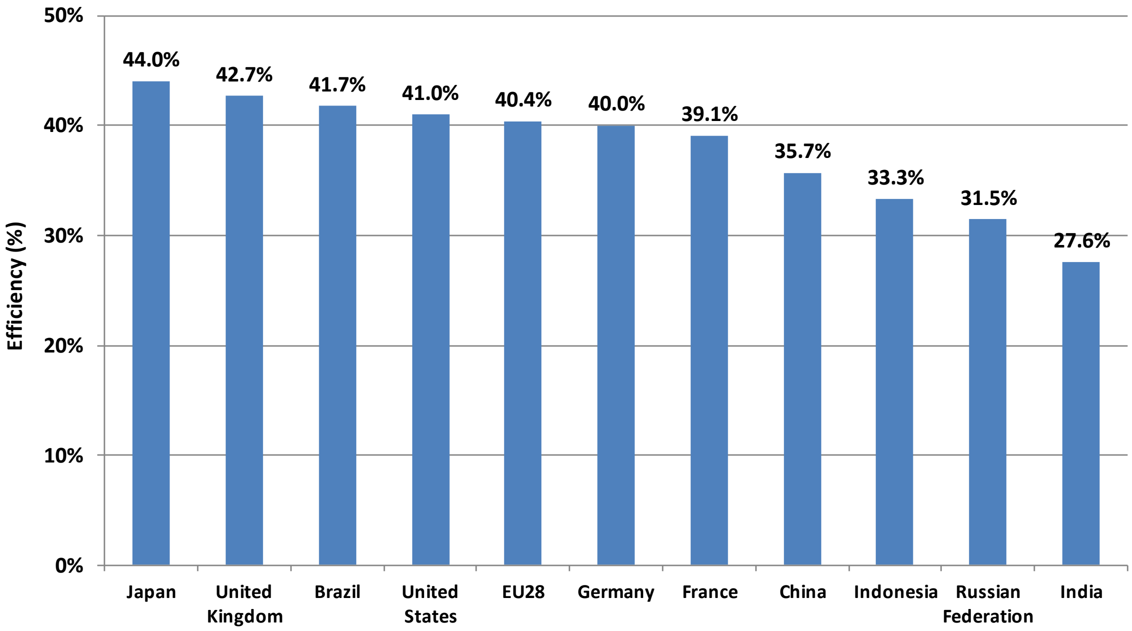

Figure 13: Average efficiency of fossil-fired power generation (2012) (compiled from IEA data).

Efficiency of coal-fired power generation ranged from 26.6% for India to 40.7% in the case of Japan in 2012 (Figure 14). Of all countries covered, China and Russia achieved a significant progress in efficiencies of its coal power plant facilities since 1990 while other countries have experienced limited improvement. Thermal efficiency for China has increased from 28.9% in 1990 to 35.7% at present. As for Russia, efficiency was 31.3% in 2012, up from 20.8% in 1990. Nonetheless, this is still substantially below industry benchmarks.

[42] Ecofys (2013). International comparison of fossil power efficiency and CO2 intensity – Update 2013.

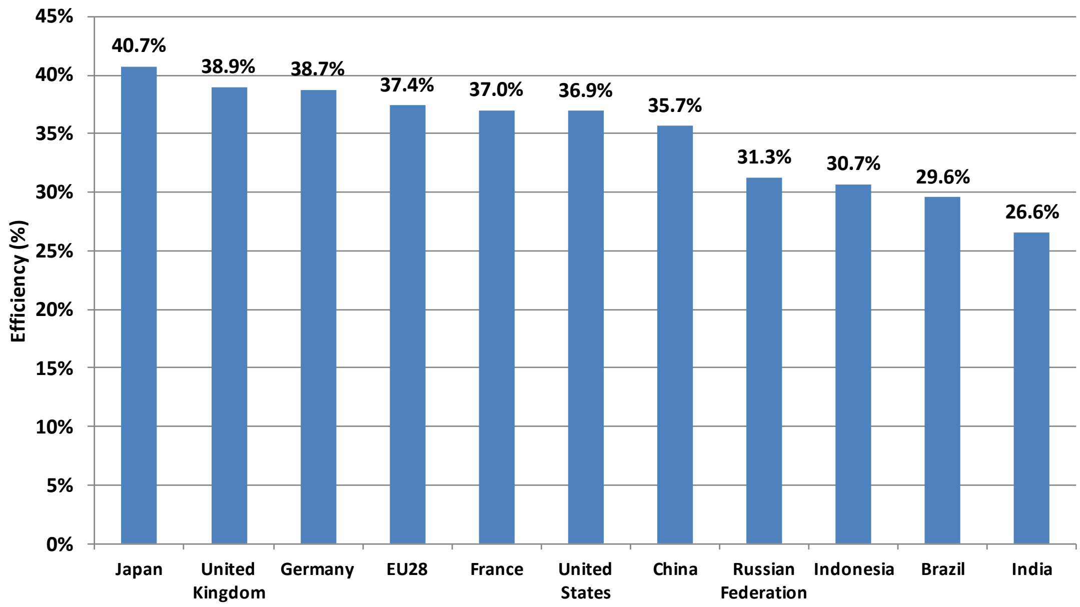

Figure 14: Efficiency of coal-fired power generation (2012) (compiled from IEA data).

For gas power plants, thermal efficiencies have generally improved in all countries except in China, on account of its relatively small share in generation mix[43] (Figure 15). The range of efficiency for countries is wide with 31.5% for Russia and 51.8% for United Kingdom. Russia obtains about 45% of its power needs from gas, mostly from combined heat and power plants, which is superior to a system that relies upon separate boilers and power plants. Average efficiency is well below sector average and far away from 59.3% for a modern combined cycle gas turbine plants. Its low efficiency is a result of limited investment in this sector since the collapse of the economy during the Soviet times, where 40% of its thermal power capacity is more than 40 years old.

[43] Please note that gas-fired power generation accounts for less than 2% of total electricity generated in 2012 and its thermal efficiency has remained constant since 1990.

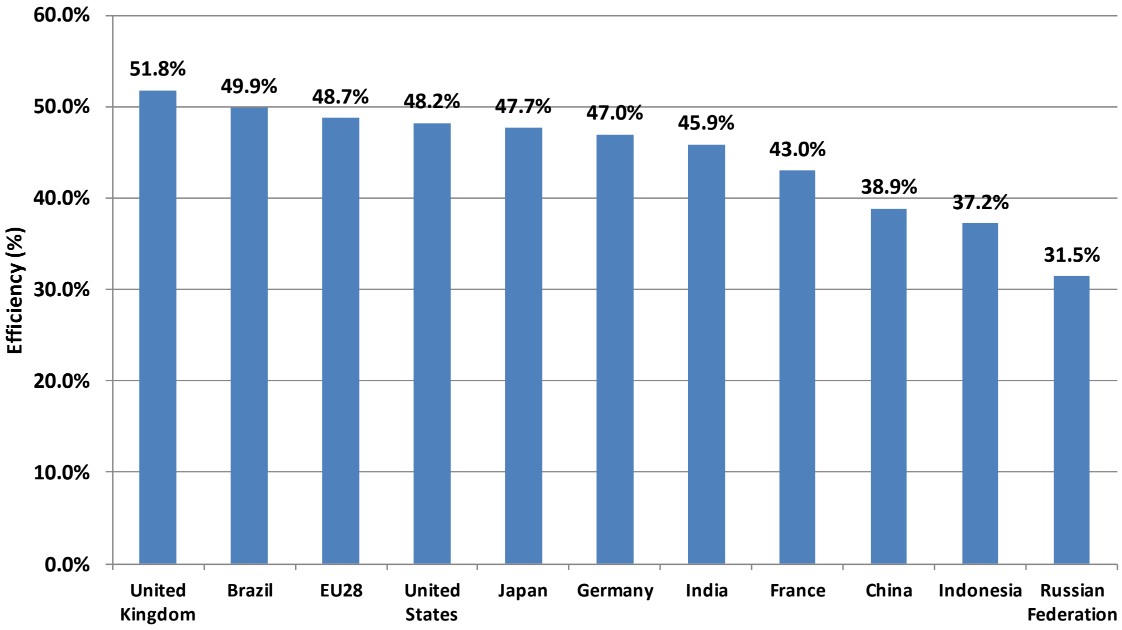

Figure 15: Efficiency of gas-fired power generation (2012) (compiled from IEA data).

6.2.2 CO_2 intensity of power generation

Figure 16 compares country wise CO_2 intensity for fossil fuel-fired power generation in 2012. CO_2 intensity for fossil fuel-fired power generation ranges from 590gCO_2/kWh for Brazil to 1181g CO_2/kWh for India. Japan comes at the second lowest at 615gCO_2/kWh for 2012. The share of coal, which has a larger CO_2 emission factor in power generation mix and generation efficiency influence the CO_2 intensity for fossil fuel-fired power generation. India emits 1181gCO_2 for every unit of electricity generated, almost double of that in Brazil. This is again due to the dominating role of coal-fired power generation in its energy mix. Compared to Japan, countries like China emit 50% more in emissions per unit of power generated from fossil fuel power plants.

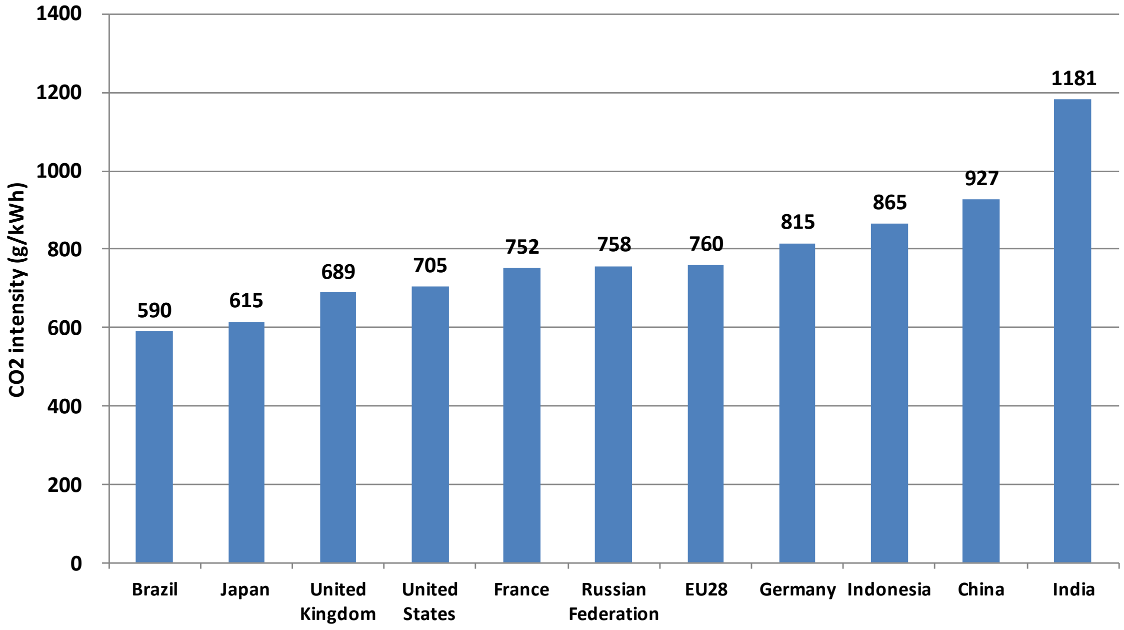

Figure 16: CO_2 intensity for fossil fuel-fired power generation (2012) (compiled from IEA data).

Figure 17 shows country wise CO_2 intensity for coal-fired power generation in 2012. CO_2 intensity for coal-fired power generation ranges from 857gCO_2/kWh for United Kingdom to 1256gCO_2/kWh for India, a difference of 47% in emissions per unit of electricity generated.

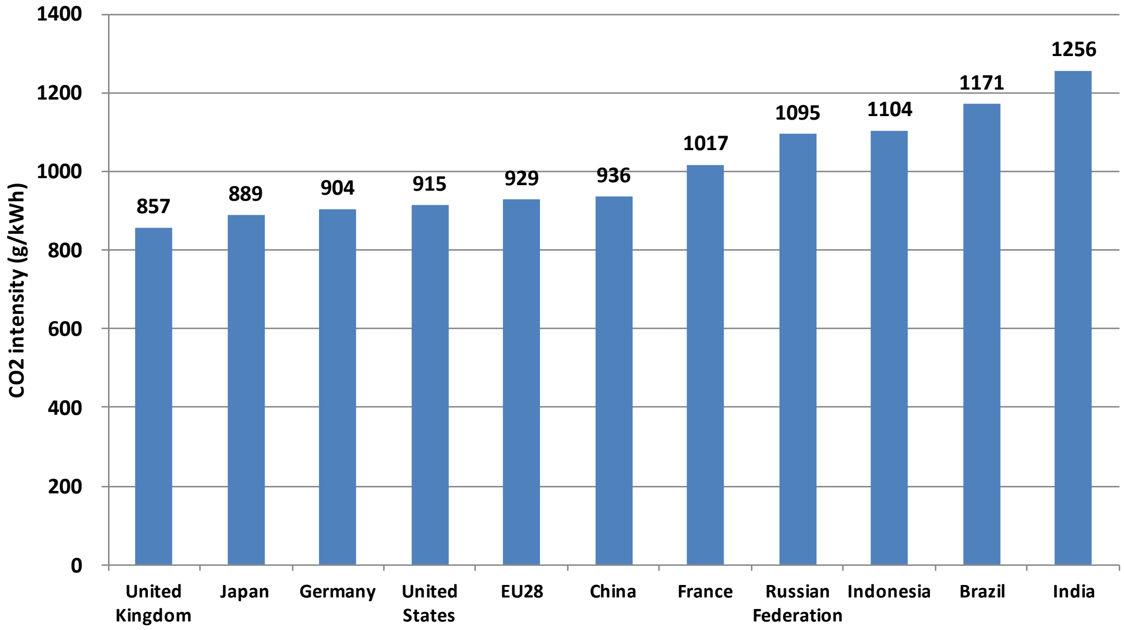

Figure 17: CO_2 intensity for coal-fired power generation (2012) (compiled from IEA data).

Figure 18 shows country wise CO_2 intensity for gas-fired power generation in 2012. CO_2 intensity for gas-fired power generation ranges from 388gCO_2/kWh for United Kingdom to 638gCO_2/kWh for Russia, a difference of 64% in emissions per unit of electricity generated.

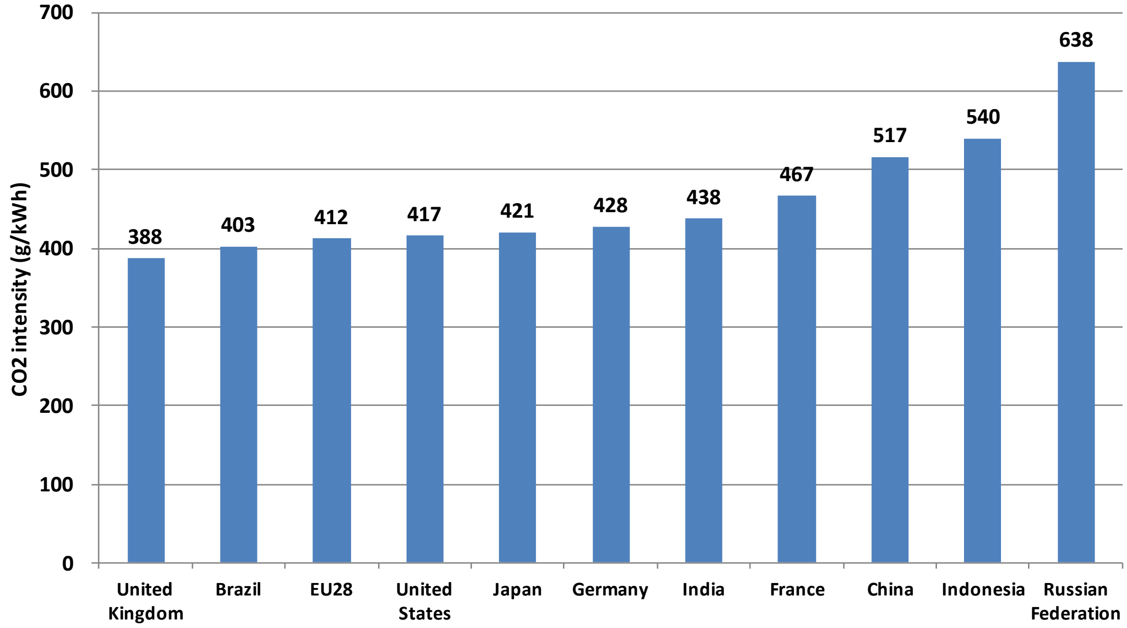

Figure 18: CO_2 intensity for gas-fired power generation (2012) (compiled from IEA data).

References

Ecofys, 2013. International comparison of fossil power efficiency and CO_2 intensity – Update 2013.
IEA, 2014. Energy Balances for OECD and non-OECD countries edition 2014.
IEA, 2014. CO_2 emissions from fuel combustion edition 2014.
The Federation of Electric Power Companies of Japan homepage.
http://www.fepc.or.jp/environment/warming/co2_taisaku/fire/index.html (in Japanese).

7 Transport

In this analysis, energy consumption efficiency for transport sector refers to Global Fuel Efficiency Initiative, GFEI's study in "International Comparison of Light-Duty Vehicle Fuel Economy and Related Characteristics" (GFEI, 2011), and the following updated paper of GFEI (2013) of "International comparison of light-duty vehicle fuel economy: An update using 2010 and 2011 new registration data", where fuel efficiency of LDV, mainly passenger vehicles, are compared for various countries, including Japan, EU27, United States, China, India, South Africa, Brazil, Indonesia, Russian, France, Germany and United Kingdom.

Due to data availability, this analysis focuses on light-duty vehicle (LDV). It does not cover the whole road sector and exclude other transport sectors such as aviation, railway, shipping and pipeline from the analysis. Considering the large energy consumption of LDV relative to total energy requirement of road sector and transport sector[44] as a whole, the analysis on LDV can be regarded as a good start in comparing the efficiency of transport sector.

Below summarizes the methodology and results of this study.

7.1 Method

GFEI's report estimates the fuel economy characteristics for recently registered vehicles (2005, 2008, 2010 and 2011) in countries with available data.

7.1.1 Data sources

Based on Polk Inc's database, which includes number of registrations and vehicle characteristics for various vehicle types at the manufacturer/model/configuration level of detail, IEA/GFEI added the database with fuel economy test data, using a range of sources containing official tested fuel economy for vehicle models sold in 2005, 2008, 2010 and 2011. Only the US and Japan have separate test cycle in the set of countries covered and all others report fuel economy using the European NEDC (New European Driving Cycle) test cycle (Table 14).

[44] Due to its large energy consumption relative to total fuel consumed by the transport sector, CO2 emission from road sector is anticipated to account for around 75% of total emissions from the transport sector. In addition, detailed CO2 emissions data covering only LDV is not available. Nonetheless, IEEJ estimated that passenger vehicle accounts for 57.8% of road's energy consumption in 2010, for the same regions covered in this analysis.

Table 14: New registrations of LDV covered by fuel economy information by country, 2005 and 2008 (GFEI, 2011).

Country/Region	2005	2008
China	74%	79%
France	73%	77%
Germany	65%	68%
India	71%	89%
Indonesia	63%	85%
Italy	65%	71%
Japan	97%	92%
Mexico	69%	78%
Russia	68%	76%
South Africa	67%	84%
United Kingdom	67%	71%
USA	65%	76%
Total	71%	78%
Worldwide	61%	62%

7.1.2 Average Fuel Efficiency

Average fuel efficiency is then calculated based on the weighted number of each year's new registered vehicles in each country (Table 15, Table 16, Figure 19).

7.2 Results

7.2.1 Fuel efficiency comparison for passenger vehicles (2005, 2008)

Table 15: Fuel Efficiency Comparison for Passenger Vehicles (2005, 2008) (Unit: Lge/100km) (GFEI, 2011).

Country/Region	2005	2008	Test cycle
Japan	6.7	6.2	10-15
EU27	7.0	6.6	NEDC
United States	9.7	9.1	FTP
China	7.8	8.1	NEDC
India	5.6	6.1	NEDC
South Africa	7.7	7.6	NEDC
Brazil	7.3	7.4	NEDC
Indonesia	7.2	7.3	NEDC
Russia	8.3	8.1	NEDC
France	6.6	6.0	NEDC
Germany	7.5	7.1	NEDC
UK	7.3	6.8	NEDC

Note 1: Lge is Liter of gasoline equivalent; 10-15 is the test mode used in Japan. NEDC is New European Driving Cycle commonly used in the Europe; FTP is the Federal Test Procedures in US.

Note 2: The above figures are so called fuel efficiency for different test mode, which is usually different from the on-road fuel efficiency.

Note 3: Though it is difficult to make direct comparisons among the figures derived using varying cycle modes, these results are still informative as they are designed to reflect the actual efficiency as much as possible.

7.2.2 Fuel efficiency comparison for passenger vehicles (2010, 2011)

Table 16: Fuel Efficiency Comparison for Passenger Vehicles (2010, 2011) (GFEI, 2013).

Country/Region	2010 (gCO_2/km)	2011 (gCO_2/km)	2010 (Lge/100 km)	2011 (Lge/100 km)
Japan	140.5	134.4	6.0	5.8
EU27	140.3	135.7	6.0	5.8
United States	194.7	192.8	8.3	8.2
China	-	-	-	-
India	-	-	-	-
South Africa	-	-	-	-
Brazil	-	-	-	-
Indonesia	-	-	-	-
Russia	-	-	-	-
France	130.5	127.7	5.6	5.5
Germany	151.2	145.6	6.5	6.2
UK	144.2	138.1	6.2	5.9

Note: Data in the first two columns are original data in GFEI (2013). Data in the last two columns are converted to Lge/100km by IEEJ based on ICCT's (2014) conversion methods. The conversion is intended to present vehicles' efficiency expressed in unit of fuel consumption, assuming that it is a gasoline vehicle.

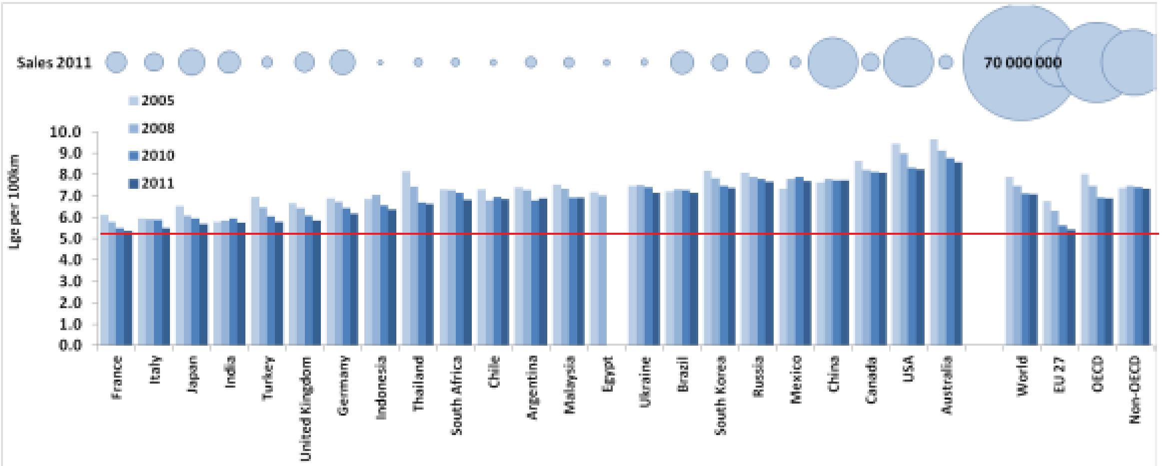

Figure 19: Fuel Efficiency Comparison for Passenger Vehicles (LDV) from 2005 to 2011 (GFEI, 2013).

As can be seen from the above tables and figures, several conclusions can be drawn.

- Although not all new registration vehicles have fuel economy information, but the database has a reasonable high coverage. As the result, for most countries, the difference between country's official figures and the above GFEI's results are within several percentages (GFEI, 2011).
- The fuel economy of all our concerned countries is improving from 2005 to 2011.
- For 2008, top three high efficient markets are India, Japan and EU27.
- For 2010 and 2011, both Japan and EU27 have improved their fuel efficiency, with EU27 catching up with Japan.
- The difficulties to compare energy efficiency in transport sector arise from the world-wide data availability, as well as different test modes.
- Comparing fuel efficiency based on vehicle stock or actual on-road efficiency is more challenging. It is therefore an important first step to compare fuel efficiency of new vehicles.

References

GFEI, 2011. International Comparison of Light-Duty Vehicle Fuel Economy and Related Characteristics, IEA, Paris. www.globalfueleconomy.org/Documents/Publications/wp5_iea_fuel_Economy_report.pdf

GFEI, 2013. International comparison of light-duty vehicle fuel economy: An update using 2010 and 2011 new registration data. http://www.globalfueleconomy.org/documents/publications/wp8_international_comparison.pdf

ICCT, 2014. Global passenger vehicle standards. http://www.theicct.org/info-tools/global-passenger-vehicle-standards

8 Buildings – heating, cooling and hot water

8.1 Method

8.1.1 Building stock size

In order to ensure consistent results for the eight covered countries / regions USA, Russian Federation, EU 28 (as a group), Japan, China, India, Indonesia and Brazil, the size of the building stocks have been calculated based on an approach using correlations between economic strength (measured in GDP/capita) and available floor space (Figure 20).

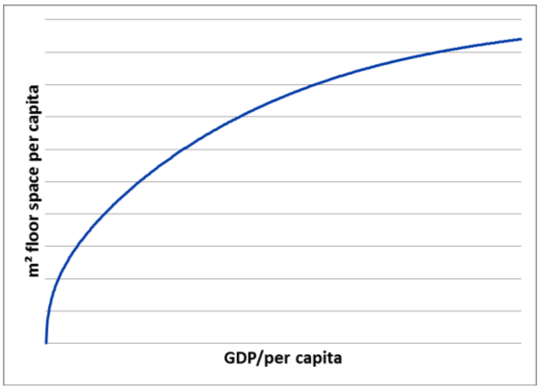

Figure 20: Qualitative illustration of correlation between GDP per capita and available floor space per capita.

Population growth data has been extracted from the "United States Census Bureau"[45], GDP growth assumptions from the IEA World Energy Outlook (WEO).

Our methodology allows the calculation of residential and non-residential floor space separately and is based on Ecofys` experiences in building stock research (most of them are confidential market research projects. On European scale some of them have been published, e.g. "renovation tracks Europe"[46], heat pump implementation scenarios[47] or Panorama of the European non-residential construction sector[48]). The model and its underlying formulas are based on building stock statistics from about 50 countries worldwide and has continuously improved over recent years (ongoing confidential PhD thesis work (Schimschar, 2008-present)). The model is based on Isaac & van Vuuren (2009) and uses average correlations between GDP per capita and residential living space (in this sense "average" means the average between different kinds of building categories such as detached

[45] http://www.census.gov/population/international/data/idb/informationGateway.php
[46] http://www.eurima.org/uploads/ModuleXtender/Publications/90/Renovation_tracks_for_Europe_08_06_2012_FINAL.pdf
[47] http://www.ehpa.org/media/studies-and-reports/?eID=dam_frontend_push&docID=1204
[48] http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/European%20non-residential%20building%20stock%20-%20Final%20Report_v7.pdf

and attached single and multi-family houses from different world regions). In a second step, typical correlations between the residential and non-residential floor space are used (we have found out that there are typical correlations between the residential and non-residential floor space per capita and GDP per capita. Such correlations are currently still investigated within the ongoing confidential PhD thesis work of Schimschar (Schimschar, 2008). For the project, the residential and non-residential floor space have been aggregated. The non-residential building sector comprises the following building categories:

- Offices
- Wholesale and retail trade
- Education
- Hotels and restaurants
- Health and social work
- Other

Not included are industrial floor spaces, warehouses and agricultural floor spaces.

8.1.2 Total energy consumption

Information on total energy consumption in the eight countries has been extracted from IEA energy balances for the year 2012. The IEA provides data for the residential sector as well as for the commercial and public services sector which is assumed to cover all non-residential services relevant for the purpose of this study (see covered building categories above). Based on this data and the calculated floor area it is possible to calculate the specific average energy consumption per square metre for all residential and non-residential buildings as well as the weighted average.

8.1.3 Total emissions

For the calculation of the CO_2 emissions in the building sector, the following emission factors have been used:

Table 17: CO_2 emission factors used for the calculation of the emissions in the building sector.

	Coal	Gas/ Diesel / fuel oil + Motor gasoline	Kero-sine	Natural Gas	LPG + Natural gas liquids	District heat	Geo-thermal, solar etc	Combustion renewable & waste	Electricity
Unit	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**	**Mt_{CO2} /TWh**
European Union 28	0.341	0.267	0.259	0.202	0.227	0.361	0	0	0.389
Brazil	0.341	0.267	0.259	0.202	0.227	0.068	0	0	0.068
China	0.341	0.267	0.259	0.202	0.227	0.711	0	0	0.764
India	0.341	0.267	0.259	0.202	0.227	0.856	0	0	0.856
Indonesia	0.341	0.267	0.259	0.202	0.227	0.755	0	0	0.755
Japan	0.341	0.267	0.259	0.202	0.227	0.495	0	0	0.497
Russian Federation	0.341	0.267	0.259	0.202	0.227	0.332	0	0	0.437
United States	0.341	0.267	0.259	0.202	0.227	0.495	0	0	0.503

The emission factors for coal, oil, kerosene, natural gas and LPG have been extracted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2: Energy - Chapter 2: Stationary Combustion, Table 2.5 (IPCC, 2006)). The district heat and electricity factors for each country are extracted from the IEA while for all kinds of renewable energies, an emission factor of zero has been used, as discussed with IEEJ.

8.1.4 Separation by space heating, hot water and space cooling

To allow separating the total residential energy consumption into the different energy uses, the following priority list of use types has been developed which reflects the importance for the residential occupants:

1) Cooking
2) Refrigeration
3) Lighting
4) Hot water
5) Washing machines
6) Space heating
7) Televisions
8) Space cooling
9) Other appliances

There exist a number of approaches and models for estimating the energy demand and consumption of different energy uses in the residential and non-residential building sector. Our model is mainly based on the same approach as the BUENAS model (McNeil et al., 2012). The energy demand for space heating and space cooling for example also depends on the amount of heating and cooling degree days while other energy uses much more depend on the economic strength of a country. The consumed energy in each country (as reported in the national IEA energy balances) was afterwards allocated to the different energy usages, taking into account that not all kinds of energy carriers are applicable for all types of energy use (e.g. that in developing countries kerosene is typically used for cooking or lighting while appliances use electricity). Considering the above described priorities, the calculated overall energy consumption has been calibrated with the total energy consumption as reported in the national energy balances (IEA). Thus it was possible to calculate the total energy consumption per type of energy use and per energy carrier.

A similar approach has been chosen for the commercial and public services sector. Also for this sector the energy demand for lighting, space heating, space cooling and hot water has been calculated with a similar approach like McNeil et al (2012) and calibrated with the official energy statistics.

8.1.5 Defining BAU and BAT technologies

In our analysis, we have defined the most relevant technologies used for space heating, hot water and space cooling supply. As especially for space cooling, the number of different systems is very large, we focussed on the four main groups of systems, namely

- Compact air conditioning units,
- Mono split systems,
- Multi split systems and
- Central chillers (including district chilled water).

For each of the technologies, average efficiencies have been defined. The BAU efficiencies have been used to calculate the energy demands in the building stock in 2012: By multiplying the before calculated energy consumptions with the respective efficiencies, the demand can be calculated. This 2012 energy demand is the basis for the two scenarios. Considering typical energy demands in new constructions, deep renovations and demolitions, the energy demand development has been calculated until 2030. Applying different efficiencies of the supply systems then allows calculating the energy consumption in each year. It should be noted that for the BAU scenario, we assumed a "frozen technology level" which means that the BAU efficiencies are not changing over the entire period until 2030. In contrast, the BAT scenarios consider two different efficiency levels: one efficient level until 2020 and another from 2021 to 2030.

For each of the technologies, "replacement specifications" have been defined. These specifications define, which systems are assumed to be replaced by which technology (see Table 18). For example it was assumed that coal boilers will be replaced by 50% with biomass condensing boilers and by 50% with water-water (respectively brine-water) heat pumps. This way we did not just consider the efficiencies of systems, but also their sustainability and emissions. All considered technologies, their BAU and BAT efficiencies as well as the replacement specifications are presented in Table 18 and Table 19.

Table 18: Considered BAU and BAT technologies, their efficiencies and replacement specifications.

Space heating

	Efficiencies BAU $\eta=P_{out}/P_{in}$	Efficiencies BAT 2012-2020 $\eta=P_{out}/P_{in}$	Efficiencies BAT 2021-2030 $\eta=P_{out}/P_{in}$	Exchanged by Share 1 / Technology 1		Exchanged by Share 2 / Technology 2	
Gas boiler	0.90	0.95	0.95	50%	Gas condensing boiler	50%	Water-w ater / Brine-Water hp
Gas condensing boiler	0.97	0.98	1.25	50%	Gas condensing boiler	50%	Water-w ater / Brine-Water hp
Gas heater (stove/oven)	0.65	0.65	0.65	100%	Air-air heat pump		
Oil boiler	0.90	0.95	0.96	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Oil condensing boiler	0.95	0.97	0.98	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Oil heater (stove/oven)	0.75	0.75	0.75	100%	Air-air heat pump		
Kerosene (paraffin) heater	0.90	0.94	0.94	100%	Air-air heat pump		
Biomass boiler	0.85	0.92	0.92	100%	Biomass condensing boiler		
Biomass condensing boiler	0.90	0.95	0.95	100%	Biomass condensing boiler		
Biomass stove	0.70	0.80	0.90	100%	Biomass stove		
Central district heating	0.97	0.98	0.99	100%	Central district heating		
Coal boiler, automatic	0.82	0.85	0.85	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Coal boiler, standard	0.60	0.65	0.65	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Solar thermal	0.40	0.40	0.40	100%	Solar thermal		
Direct electricity	1.00	1.00	1.00	100%	Water-w ater / Brine-Water hp		
Air-air heat pump	3.50	4.70	5.20	100%	Air-air heat pump		
Air-Water heat pump	3.20	3.90	4.80	100%	Water-w ater / Brine-Water hp		
Water-w ater / Brine-Water hp	4.75	5.35	5.85	100%	Water-w ater / Brine-Water hp		

Hot water

	Efficiencies BAU $\eta=P_{out}/P_{in}$	Efficiencies BAT 2012-2020 $\eta=P_{out}/P_{in}$	Efficiencies BAT 2021-2030 $\eta=P_{out}/P_{in}$	Exchanged by Share 1 / Technology 1		Exchanged by Share 2 / Technology 2	
Gas boiler	0.90	0.94	0.95	50%	Gas condensing boiler	50%	Water-w ater / Brine-Water hp
Gas condensing boiler	0.90	0.95	1.25	50%	Gas condensing boiler	50%	Water-w ater / Brine-Water hp
Oil boiler	0.90	0.94	0.94	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Oil condensing boiler	0.90	0.95	0.95	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Biomass boiler	0.80	0.90	0.90	100%	Biomass condensing boiler		
Biomass condensing boiler	0.85	0.90	0.90	100%	Biomass condensing boiler		
Biomass stove	0.60	0.70	0.80	100%	Biomass stove		
Central district heating	0.96	0.97	0.98	100%	Central district heating		
Coal boiler, automatic	0.75	0.78	0.80	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Coal boiler, standard	0.50	0.53	0.56	50%	Biomass condensing boiler	50%	Water-w ater / Brine-Water hp
Solar thermal	0.40	0.40	0.40	100%	Solar thermal		
Direct electricity	0.99	0.99	0.99	100%	Water-w ater / Brine-Water hp		
Air-Water heat pump	1.80	2.00	2.50	100%	Water-w ater / Brine-Water hp		
Water-w ater / Brine-Water hp	2.50	2.65	3.10	100%	Water-w ater / Brine-Water hp		

Space cooling

	Efficiencies BAU COP=Q/W	Efficiencies BAT 2012-2020	Efficiencies BAT 2021-2030	Exchanged by Share 1 / Technology 1	
Compact air conditioning unit	2.90	3.50	4.20	100%	Compact air conditioning unit
Mono split	3.20	3.80	4.50	100%	Mono split
Multi split	3.70	4.50	5.50	100%	Multi split
Central chillers (also district chilled w ater)	4.00	5.00	6.00	100%	Central chillers (also district chilled w ater)

Demand reduction through deep renovations

	Efficiencies BAU	Efficiencies BAT 2012-	Efficiencies BAT 2021-
Deep renovation (demand reduction compared to status Quo)	30%	70%	80%

Table 19: Assumed energy demands of newly constructed buildings in the BAU and the BAT scenario.

New constructions energy demand

Residential

	Unit	Status Quo (average)	Efficiencies BAU	Efficiencies BAT 2012-	Efficiencies BAT 2021-2030
European Union	kWh/m²a	108	80	30	20
Brazil	kWh/m²a	0	0	0	0
China	kWh/m²a	20	80	30	20
India	kWh/m²a	2	2	2	2
Indonesia	kWh/m²a	0	0	0	0
Japan	kWh/m²a	113	80	30	20
Russian Federation	kWh/m²a	224	150	35	25
United States	kWh/m²a	209	150	30	20

Commercial

		Status Quo (average)	Efficiencies BAU	Efficiencies BAT 2012-	Efficiencies BAT 2021-2030
European Union	kWh/m²a	114	80	30	20
Brazil	kWh/m²a	2	2	2	2
China	kWh/m²a	89	80	30	20
India	kWh/m²a	6	6	6	6
Indonesia	kWh/m²a	0	0	0	0
Japan	kWh/m²a	303	200	30	20
Russian Federation	kWh/m²a	226	150	35	25
United States	kWh/m²a	377	200	30	20

8.1.6 Formulas

As indicated in the chapters above, the entire approach is mainly based on Isaac & van Vuuren (2009) and the BUENAS model (McNeil et al., 2012). Main building stock formula is therefore Y=6.33Ln(x) – 28.95.

For the separation of energy carriers by energy use, not just one formula is necessary but a set of calculation steps and manual adjustments. Therefore it is not possible to just present one formula here. All formulas and a detailed description of the methodology can be extracted from McNeil et al. (2012).

8.2 Results

8.2.1 Building stock characteristics

The following table shows the building stock size of the covered countries in the years 2012, 2020 and 2030. The numbers represent the total sum of residential and commercial floor space.

Table 20: Building stock size 2012, 2020 and 2030.

Building stock						
	Total floor area 2012	Total floor area per capita 2012	Total floor area 2020	Total floor area per capita 2020	Total floor area 2030	Total floor area per capita 2030
Country	Mio m²	m²/cap	Mio m²	m²/cap	Mio m²	m²/cap
European Union	27,482	54	29,821	58	31,774	61
Brazil	5,977	30	7,386	35	8,927	40
China	34,182	25	50,096	36	64,154	46
India	20,515	17	28,974	22	41,319	28
Indonesia	4,636	19	5,918	22	7,238	25
Japan	7,223	57	7,680	61	7,771	64
Russian Federation	5,438	38	6,593	47	7,651	55
United States	19,899	63	22,106	66	24,722	68

As can be seen, the largest building sector currently exists in China (~42 billion m²), followed by the European Union (~29 billion m²), India (~25 billion m²) and the United States (~21 billion m²). Per capita this order changes as in the US, the average floor area per capita is 63 m², followed by Japan with 57 m², the EU with 54 m² and Russia with 38 m². It should be noted that these numbers are not statistically collected numbers but are model outcomes based on statistics. Therefore, these numbers can differ from that of national statistics.

As described in chapter 8.1.1, the stock size in 2020 and 2030 is a result of the population development and assumed average floor space per capita based on GDP. The result is a calculated annual stock increase for which a number of new constructions and demolitions are lying behind. Additionally, a number of deep renovations and system retrofits are taking place which are considered to be the same in the BAU and the BAT scenario. It was assumed that the annual deep renovation rate is 1.5% in the residential and 1% in the non-residential sector in each country, while the system retrofit rate is 5% (assuming a 20 year life time of systems). As systems are also retrofitted within a deep renovation, the real retrofit rate is 5% minus 1.5% (1% respectively) due to renovations = 3.5% (4% respectively). Additionally, it was assumed that the demolition rate in the residential sector is 10% of the annual growth rate and 20% in the non-residential sector (the non-residential sector usually is much more dynamic which means having more new constructions and demolitions than the residential sector). The results for each country can be found in the following tables.

Table 21: Building stock development 2012-2020.

Building stock development 2012-2020

Country	Total floor area 2012	Total number of newly constructed floor area 2013-2020	Total number of demolished floor area 2013-2020	Total number of renovated floor area (incl. System exchange) 2013-2020	Total number of retrofitted floor area (system exchange) 2013-2020	Total floor area 2020
	Mio m²	Mio m²	Mio m²	Mio m²	Mio m²	Mio m²
European Union	27,482	2,663	-324	3,125	8,286	29,821
Brazil	5,977	1,590	-181	746	1,882	7,386
China	34,182	17,981	-2,066	4,622	11,605	50,096
India	20,515	9,436	-977	2,777	6,806	28,974
Indonesia	4,636	1,431	-149	599	1,470	5,918
Japan	7,223	522	-65	813	2,163	7,680
Russian Federation	5,438	1,318	-163	662	1,711	6,593
United States	19,899	2,495	-288	2,270	6,074	22,106

Table 22: Building stock development 2020-2030.

Building stock development 2020-2030

Country	Total floor area 2020	Total number of newly constructed floor area 2021-2030	Total number of demolished floor area 2021-2030	Total number of renovated floor area (incl. System exchange) 2021-2030	Total number of retrofitted floor area (system exchange) 2021-2030	Total floor area 2030
	Mio m²	Mio m²	Mio m²	Mio m²	Mio m²	Mio m²
European Union	29,821	2,225	-272	4,196	11,179	31,774
Brazil	7,386	1,744	-203	1,134	2,897	8,927
China	50,096	16,015	-1,957	7,868	20,271	64,154
India	28,974	13,842	-1,497	4,906	12,161	41,319
Indonesia	5,918	1,477	-157	935	2,311	7,238
Japan	7,680	106	-15	1,054	2,815	7,771
Russian Federation	6,593	1,211	-153	976	2,566	7,651
United States	22,106	2,957	-340	3,164	8,475	24,722

8.2.2 Energy consumption / emissions (all energy uses) of the building stock

Table 23 shows the total and specific energy consumption as well as CO_2 emissions in the building sector of the eight covered countries in 2012. The numbers represent the entire energy consumption / emissions in the sector which means that all types of energy uses are included (not just space heating, hot water and space cooling).

Table 23: Total and specific energy consumption and emissions in the building sector of the eight covered countries in 2012.

Total energy consumption	Total energy consumption all buildings 2012	Total CO2 emissions all buildings 2012	Specific energy consumption all buildings (all purposes) 2012	Specific CO2 emissions all buildings (all purposes) 2012
Country	TWh	Mt CO2	kWh / m²	kg CO2 / m²
European Union	4,869	1,298	169	45
Brazil	397	35	55	5
China	5,021	1,217	118	29
India	2,280	304	91	12
Indonesia	718	99	106	15
Japan	1,307	471	175	63
Russian Federation	1,784	544	257	78
United States	5,454	1,925	262	92

Table 23 shows that in all categories, the USA is the largest energy consumer and emitter. Although in terms of building stock size, the USA just is on the 4th place (see Table 20), the specific energy consumption in the USA is so high that it results as the largest total energy consumer within the covered countries.

8.2.3 Space heating energy consumption and related emissions

Table 24 presents the energy consumption for space heating purposes in the eight covered countries in 2012. The table also distinguishes between energy carriers.

Table 24: Space heating energy consumption and emissions in the eight covered countries in 2012.

Space heating energy consumption 2012	Coal	Gas/ Diesel / fuel oil	Kerosine	Natural Gas	LPG + Natural gas liquids	Heat	Geothermal , solar etc	Combustion renewable & waste	Electricity	Total
Country	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh
European Union	127	457	0	1,448	85	298	0	444	151	3,010
Brazil	0	0	0	1	0	0	0	0	0	2
China	553	316	0	131	17	131	0	0	60	1,208
India	17	0	0	6	32	0	0	8	0	62
Indonesia	0	0	0	0	0	0	0	0	0	0
Japan	6	90	110	225	48	6	0	0	230	715
Russian Federation	46	43	0	411	49	790	0	22	26	1,388
United States	15	259	0	1,784	75	16	0	149	1,238	3,536

In order to allow a heating degree day specific country comparison, the following table also lists the heating degree days and adjusts the energy and emissions to 2500 heating degree days.

Table 25: Space heating energy consumption, related emissions and national heating degree days.

Space heating energy consumption 2012

	Heating degree days (HDD)	Total space heating energy consumption all buildings 2012	Total space heating related CO_2 emissions all buildings 2012	Specific space heating energy consumption all buildings 2012	Specific space heating related CO_2 emissions all buildings 2012	Adjusted to 2500 HDD	Adjusted to 2500 HDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	2,976	3,010	643	105	22	88	19
Brazil	69	2	0	0	0	10	2
China	2,283	1,208	442	27	10	29	11
India	111	62	14	1	0	25	5
Indonesia	0	0	0	0	0	0	0
Japan	2,389	715	228	96	31	100	32
Russian Federation	5,560	1,388	395	200	57	90	26
United States	2,406	3,536	1,082	169	52	176	54

As can be seen, the specific space heating consumption in the Russian Federation is the highest (200 kWh/m²a), followed by the USA (169 kWh/m²a), the European Union (105 kWh/m²a) and Japan (96 kWh/m²a). Adjusting these values to a fix amount of 2500 heating degree days however shows that the specific consumption per 2500 HDD is the highest in the USA and with some space followed by Japan, the Russian Federation and the EU.

The following two tables present the results of the BAU (Table 26) and BAT (Table 27) scenarios.

Table 26: Space heating energy consumption and related CO_2 emissions in 2030 - scenario BAU.

Space heating energy consumption 2030 - Scenario BAU

	Heating degree days (HDD)	Total space heating energy consumption all buildings 2030	Total space heating related CO2 emissions all buildings 2030	Specific space heating energy consumption all buildings 2030	Specific space heating related CO2 emissions all buildings 2030	Adjusted to 2500 HDD	Adjusted to 2500 HDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	2,976	2,498	472	79	15	66	12
Brazil	69	3	0	0	0	10	1
China	2,283	2,775	624	43	10	47	11
India	111	79	21	2	1	43	12
Indonesia	0	0	0	0	0	0	0
Japan	2,389	479	169	62	22	64	23
Russian Federation	5,560	1,223	325	160	42	72	19
United States	2,406	2,435	727	98	29	102	31

Table 27: Space heating energy consumption and related emissions in 2030 - scenario BAT.

Space heating energy consumption 2030 - Scenario BAT							
	Heating degree days (HDD)	Total space heating energy consumption all buildings 2030	Total space heating related CO2 emissions all buildings 2030	Specific space heating energy consumption all buildings 2030	Specific space heating related CO2 emissions all buildings 2030	Adjusted to 2500 HDD	Adjusted to 2500 HDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	2,976	2,015	415	63	13	53	11
Brazil	69	2	0	0	0	10	1
China	2,283	1,172	288	18	4	20	5
India	111	70	18	2	0	38	10
Indonesia	0	0	0	0	0	0	0
Japan	2,389	393	147	51	19	53	20
Russian Federation	5,560	896	262	117	34	53	15
United States	2,406	1,622	554	66	22	68	23

Table 26 shows that the largest energy consumer for space heating purposes in 2030 will be China in the BAU scenario which means in case that no significant system efficiency improvements will take place. However it is interesting to see that Table 27 shows that in a BAT scenario, the largest consumer will be the European Union. Main reason for this result is that in China the new construction sector is much more important than in the EU, the US or Japan. As has been described in chapter 8.1.5, for new constructions the energy demand can be reduced to a large extent, therefore China, currently also using much less efficient systems than e.g. the EU offers a very large potential for reducing future energy consumption if the right actions are taken soon.

Per square metre, the largest energy consumption in both scenarios has been calculated for Russia, in the BAU scenario followed by the EU and the USA, in BAT scenario followed by the USA and the EU. Adjusted to 2500 HDDs, the USA is largest consumer in both scenarios.

Figure 21 shows the scenario comparison for space heating energy consumption in all covered countries. The blue bar represents the status quo energy consumption in 2012, the green bar the 2030 energy consumption according to the BAU scenario and the grey bar the 2030 BAT consumption.

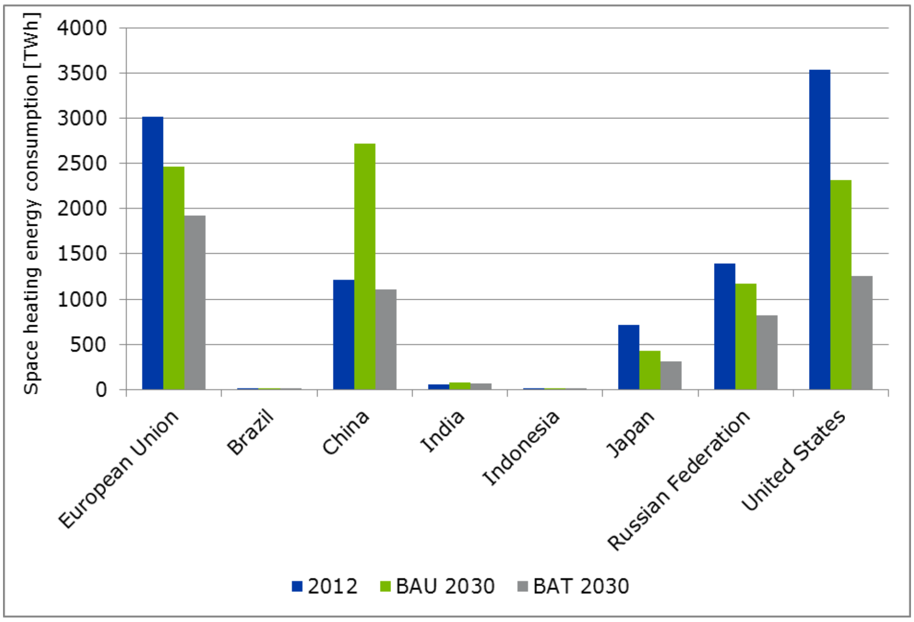

Figure 21: Scenario comparison for space heating energy consumption.

Figure 22 presents the resulting relative decreases and increases in space heating energy consumption in the covered countries. The blue bar represents the development between 2012 and 2030 BAU consumption, the green bar the development between 2012 and 2030 BAT and the grey bar reduction potential in the year 2030 between the BAU and the BAT scenario.

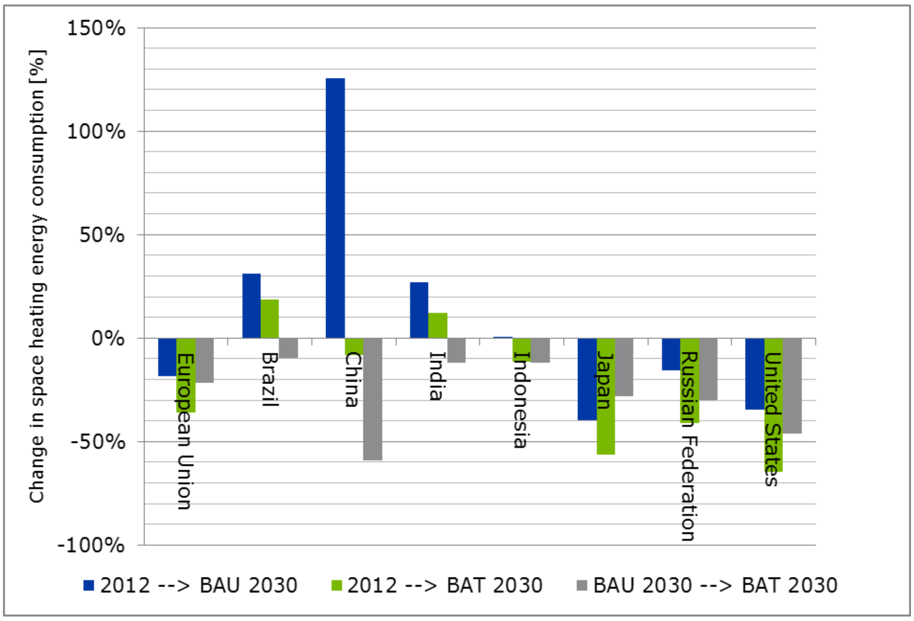

Figure 22: Resulting relative decreases and increases in space heating energy consumption in the covered countries.

The following Table 28 and Table 29 show the underlying numbers of the scenarios. Table 28 contains the final energy data, Table 29 CO_2 emission data.

Table 28: Scenario comparison of space heating energy consumption in the covered countries.

Space heating scenario comparison	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	TWh	TWh	TWh	%	%	%
European Union	3,010	2,459	1,927	-18%	-36%	-22%
Brazil	2	3	2	31%	19%	-10%
China	1,208	2,721	1,108	125%	-8%	-59%
India	62	78	69	27%	12%	-12%
Indonesia	0	0	0	1%	-12%	-12%
Japan	715	432	311	-40%	-57%	-28%
Russian Federation	1,388	1,169	821	-16%	-41%	-30%
United States	3,536	2,315	1,252	-35%	-65%	-46%

Table 29: Scenario comparison of space heating related CO_2 emissions in the covered countries.

Space heating scenario comparison	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	Mt CO2	Mt CO2	Mt CO2	%	%	%
European Union	643	438	365	-32%	-43%	-17%
Brazil	0	0	0	-50%	-57%	-15%
China	442	612	274	39%	-38%	-55%
India	14	21	17	48%	23%	-17%
Indonesia	0	0	0	27%	4%	-18%
Japan	228	157	125	-31%	-45%	-20%
Russian Federation	395	313	250	-21%	-37%	-20%
United States	1,082	700	479	-35%	-56%	-32%

8.2.4 Hot water energy consumption and related emissions

Energy for hot water generation is an important energy use responsible for a large amount of emissions in the covered countries. Table 30 shows the energy consumption for hot water generation in the eight covered countries in 2012. The table also distinguishes between energy carriers.

Table 30: Hot water energy consumption and emissions in the eight covered countries in 2012.

Hot w ater energy consumption 2012	Coal	Gas/ Diesel / fuel oil	Kerosine	Natural Gas	LPG + Natural gas liquids	Heat	Geothermal , solar etc	Combustion renewable & waste	Electricity	Total
Country	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh
European Union	0	50	0	171	10	36	29	0	130	426
Brazil	0	0	0	4	12	0	0	2	25	43
China	0	53	0	63	0	82	37	0	44	278
India	23	0	0	13	70	0	0	30	4	140
Indonesia	0	8	0	2	45	0	0	2	0	58
Japan	0	0	0	85	39	0	6	0	56	186
Russian Federation	0	1	0	29	3	48	0	0	0	81
United States	0	31	0	271	28	0	18	0	149	497

Table 31 additionally presents the specific energy consumption per square metre in 2012 and the related emissions from hot water generation in the covered countries.

Table 31: Hot water energy consumption and emissions in the eight covered countries in 2012.

Hot water energy consumption 2012	Total hot water energy consumption all buildings 2012	Total hot water related CO2 emissions all buildings 2012	Specific hot water energy consumption all buildings 2012	Total hot water related CO2 emissions all buildings 2012
Country	**TWh**	**Mt CO2**	**kWh / m²**	**kg CO2 / m²**
European Union	426	114	16	4
Brazil	43	5	7	1
China	278	119	8	3
India	140	30	7	1
Indonesia	58	13	13	3
Japan	186	54	26	7
Russian Federation	81	23	15	4
United States	497	144	25	7

According to our calculations, the highest specific energy consumption for hot water generation exists in Japan (26 kWh/m²a) slightly followed by the USA (25 kWh/m²a). The EU and Russian Federation can be classified as medium-range consumers (15/16 kWh/m²a), the other countries as low-range consumers (7-8 kWh/m²a).

For the BAU and the BAT scenario we did not consider any demand reductions but considered a stable specific energy demand for hot water generation between 2012 and 2030. The results of the BAU and the BAT scenario can be found in Table 32 and Table 33.

Table 32: Hot water energy consumption and emissions in the eight covered countries in 2030 - Scenario BAU.

Hot water energy consumption 2030 - Scenario BAU	Total hot water energy consumption all buildings 2030	Total hot water related CO2 emissions all buildings 2030	Total hot water energy consumption all buildings 2030	Total hot water related CO2 emissions all buildings 2030
Country	**TWh**	**Mt CO2**	**kWh / m²**	**kg CO2 / m²**
European Union	384	92	12	3
Brazil	50	5	6	1
China	505	157	8	2
India	239	79	6	2
Indonesia	74	22	10	3
Japan	144	42	19	5
Russian Federation	101	26	13	3
United States	441	118	18	5

Table 33: Hot water energy consumption and emissions in the eight covered countries in 2030 - Scenario BAT.

Hot water energy consumption 2030 - Scenario BAT				
	Total hot water energy consumption all buildings 2030	Total hot water related CO2 emissions all buildings 2030	Total hot water energy consumption all buildings 2030	Total hot water related CO2 emissions all buildings 2030
Country	**TWh**	**Mt CO2**	**kWh / m²**	**kg CO2 / m²**
European Union	371	88	12	3
Brazil	47	5	5	1
China	481	148	7	2
India	222	71	5	2
Indonesia	68	20	9	3
Japan	135	38	17	5
Russian Federation	96	24	13	3
United States	408	108	17	4

It can be seen that the highest specific energy consumption in both scenarios are in Japan, followed by the USA and the EU.

Figure 23 shows the scenario comparison for hot water energy consumption in all covered countries. The blue bar represents the status quo energy consumption in 2012, the green bar the 2030 energy consumption according to the BAU scenario and the grey bar the 2030 BAT consumption.

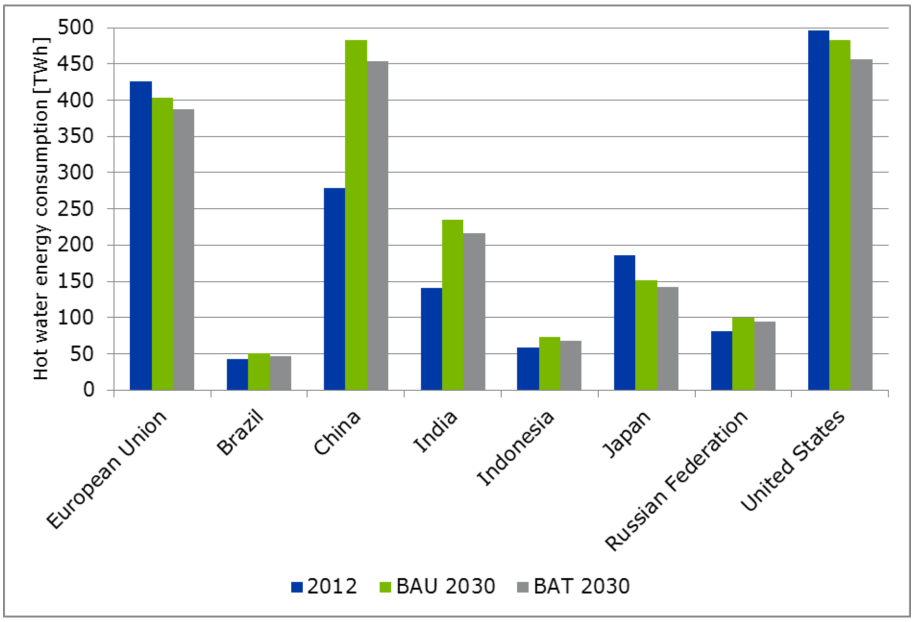

Figure 23: Scenario comparison for hot water energy consumption.

Figure 24 presents the resulting relative decreases and increases in hot water energy consumption in the covered countries. The blue bar represents the development between 2012 and 2030 BAU consumption, the green bar the development between 2012 and 2030 BAT and the grey bar reduction potential in the year 2030 between the BAU and the BAT scenario.

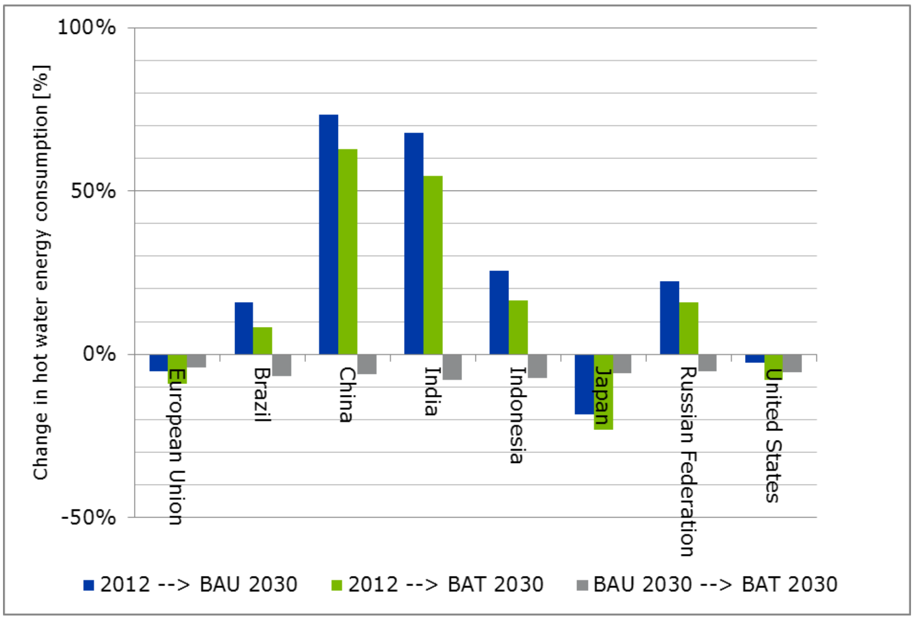

Figure 24: Resulting relative decreases and increases in hot water energy consumption in the covered countries.

The following Table 34 and Table 35 and show the underlying numbers of the scenarios. Table 34 contains the final energy data, Table 35 the CO_2 emission data.

Table 34: Scenario comparison of hot water energy consumption in the covered countries.

Hot water scenario comparison						
	2012	**BAU 2030**	**BAT 2030**	**2012 --> BAU 2030**	**2012 --> BAT 2030**	**BAU 2030 --> BAT 2030**
	TWh	**TWh**	**TWh**	**%**	**%**	**%**
European Union	426	404	387	-5%	-9%	-4%
Brazil	43	50	47	16%	8%	-7%
China	278	483	453	73%	63%	-6%
India	140	235	217	68%	55%	-8%
Indonesia	58	73	68	26%	16%	-7%
Japan	186	151	142	-19%	-23%	-6%
Russian Federation	81	99	94	22%	16%	-5%
United States	497	483	457	-3%	-8%	-5%

Table 35: Scenario comparison of hot water related CO_2 emissions in the covered countries.

Hot water scenario comparison						
	2012	**BAU 2030**	**BAT 2030**	**2012 --> BAU 2030**	**2012 --> BAT 2030**	**BAU 2030 --> BAT 2030**
	Mt CO2	**Mt CO2**	**Mt CO2**	**%**	**%**	**%**
European Union	114	93	89	-18%	-22%	-5%
Brazil	5	5	4	-6%	-15%	-9%
China	119	151	139	27%	17%	-8%
India	30	79	70	162%	133%	-11%
Indonesia	13	22	20	69%	52%	-10%
Japan	54	43	40	-20%	-25%	-7%
Russian Federation	23	25	24	11%	5%	-6%
United States	144	126	118	-12%	-18%	-6%

8.2.5 Space cooling energy consumption and related emissions

Space cooling energy consumption in the covered countries is completely supplied by electricity. Alternative technologies such as solar cooling still just take a negligible share. Table 36 presents the energy and related emissions in the eight covered countries that has been used in 2012 for space cooling purposes. In order to allow a cooling degree day specific country comparison, the cooling degree days are listed as well and the energy and emissions have been adjusted to 1000 cooling degree days in additional columns.

Table 36: Space cooling energy consumption and emissions in the eight covered countries in 2012.

Space cooling energy consumption 2012							
	Cooling degree days (HDD)	Total space cooling energy consumption all buildings 2012	Total space cooling related CO2 emissions all buildings 2012	Specific space cooling energy consumption all buildings 2012	Specific space cooling related CO2 emissions all buildings 2012	Adjusted to 1000 CDD	Adjusted to 1000 CDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	130	111	43	4	1	30	12
Brazil	1,938	35	2	5	0	2	0
China	902	76	58	2	1	2	2
India	2,958	14	12	1	0	0	0
Indonesia	3,029	10	7	1	1	0	0
Japan	565	77	38	10	5	18	9
Russian Federation	120	8	4	1	1	10	4
United States	662	272	137	13	7	20	10

As can be seen, the specific space cooling consumption in the USA is the highest (13 kWh/m²a), followed by Japan (10 kWh/m²a). Adjusting these values to a fix amount of 1000 cooling degree days however shows that the specific consumption per 1000 CDD is the highest in the EU and with some space followed by the USA, Japan and the Russian Federation.

The following two tables show the results of the BAU and the BAT scenarios for the year 2030.

Table 37: Space cooling energy consumption and emissions in the eight covered countries in 2030 - Scenario BAU.

Space cooling energy consumption 2030 - Scenario BAU							
	Cooling degree days (HDD)	Total space cooling energy consumption all buildings 2030	Total space cooling related CO2 emissions all buildings 2030	Specific space cooling energy consumption all buildings 2030	Specific space cooling related CO2 emissions all buildings 2030	Adjusted to 1000 CDD	Adjusted to 1000 CDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	130	118	42	4	1	29	10
Brazil	1,938	51	6	6	1	3	0
China	902	189	127	3	2	3	2
India	2,958	87	83	2	2	1	1
Indonesia	3,029	22	18	3	2	1	1
Japan	565	79	38	10	5	18	9
Russian Federation	120	11	5	1	1	12	5
United States	662	298	137	12	6	18	8

Table 38: Space cooling energy consumption and emissions in the eight covered countries in 2030 - Scenario BAT.

Space cooling energy consumption 2030 - Scenario BAT								
	Cooling degree days (HDD)	Total space cooling energy consumption all buildings 2030	Total space cooling related CO2 emissions all buildings 2030	Specific space cooling energy consumption all buildings 2030	Specific space cooling related CO2 emissions all buildings 2030	Adjusted to 1000 CDD	Adjusted to 1000 CDD
Country	Kd/a	TWh	Mt CO2	kWh / m²	kg CO2 / m²	kWh / m²	kg CO2 / m²
European Union	130	115	41	4	1	28	10
Brazil	1,938	45	5	5	1	3	0
China	902	153	103	2	2	3	2
India	2,958	67	64	2	2	1	1
Indonesia	3,029	19	15	3	2	1	1
Japan	565	78	37	10	5	18	9
Russian Federation	120	10	4	1	1	11	5
United States	662	288	132	12	5	18	8

It can be seen that the main outcomes keep the same. Largest total and specific energy consumer in both scenarios is the USA, adjusting the consumption to 1000 CDD shows that the EU will still be tha largest consumer in 2030.

Figure 25 shows the scenario comparison for space cooling energy consumption in all covered countries. The blue bar represents the status quo energy consumption in 2012, the green bar the 2030 energy consumption according to the BAU scenario and the grey bar the 2030 BAT consumption.

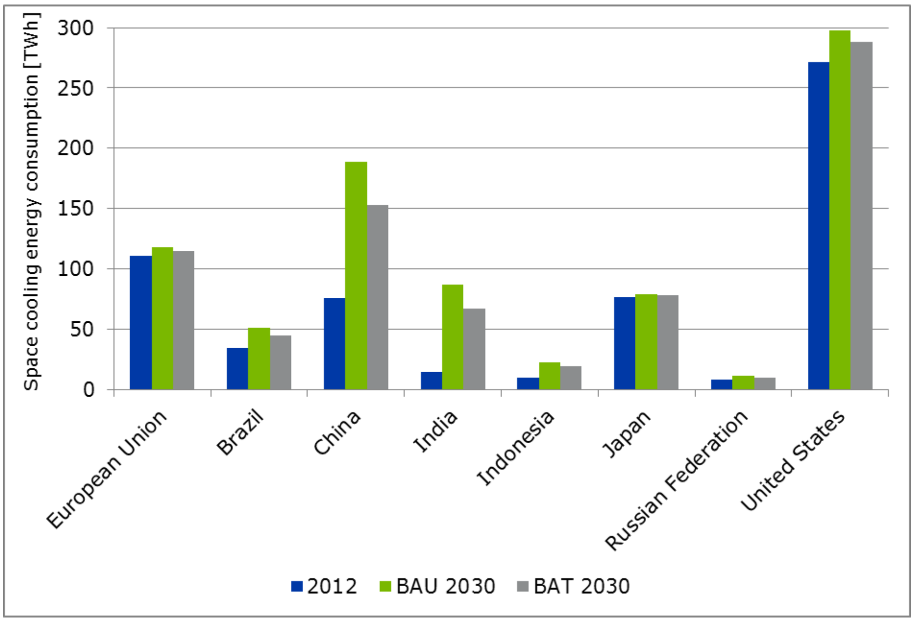

Figure 25: Scenario comparison for space cooling energy consumption.

Figure 26 presents the resulting relative decreases and increases in space cooling energy consumption in the covered countries. The blue bar represents the development between 2012 and 2030 BAU consumption, the green bar the development between 2012 and 2030 BAT and the grey bar reduction potential in the year 2030 between the BAU and the BAT scenario.

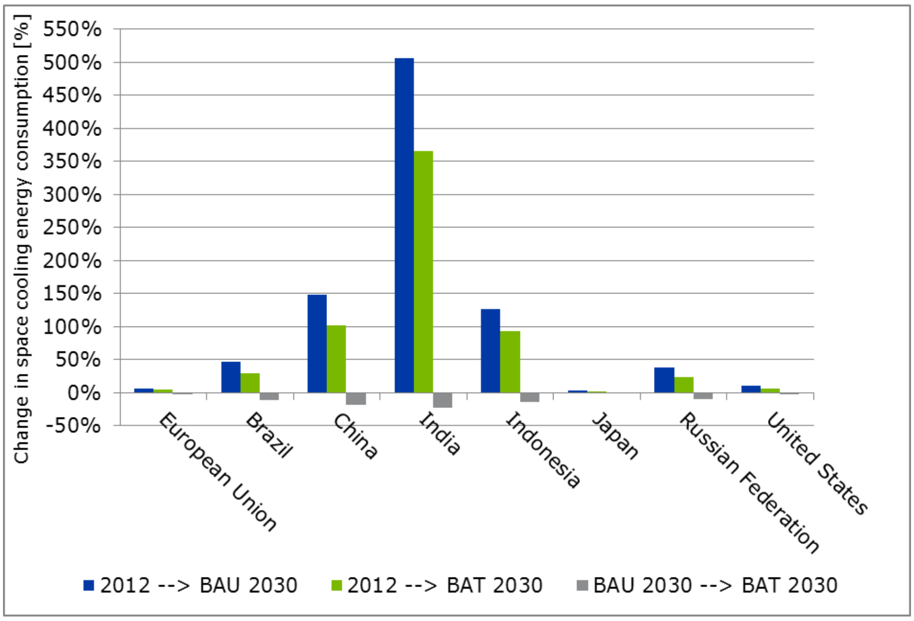

Figure 26: Resulting relative decreases and increases in space cooling energy consumption in the covered countries.

The following Table 39 and Table 40 and show the underlying numbers of the scenarios. Table 39 contains the final energy data, Table 40 the CO_2 emission data.

Table 39: Scenario comparison of space cooling energy consumption in the covered countries.

Space cooling scenario comparison						
	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	TWh	TWh	TWh	%	%	%
European Union	111	118	115	6%	4%	-2%
Brazil	35	51	45	46%	29%	-12%
China	76	189	153	148%	102%	-19%
India	14	87	67	506%	366%	-23%
Indonesia	10	22	19	126%	92%	-15%
Japan	77	79	78	3%	2%	-1%
Russian Federation	8	11	10	37%	24%	-10%
United States	272	298	288	10%	6%	-3%

Table 40: Scenario comparison of space cooling related CO_2 emssions in the covered countries.

Space cooling scenario comparison						
	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	Mt CO2	Mt CO2	Mt CO2	%	%	%
European Union	43	42	41	-2%	-4%	-2%
Brazil	2	6	5	143%	114%	-12%
China	58	127	103	118%	77%	-19%
India	12	83	64	578%	421%	-23%
Indonesia	7	18	15	136%	100%	-15%
Japan	38	38	37	-1%	-2%	-1%
Russian Federation	4	5	4	31%	18%	-10%
United States	137	137	132	0%	-3%	-3%

8.3 Conclusions and discussion

The used approach resulted in a good overview of the current and future building stock characteristics, energy consumption and related emissions from space heating, hot water generation and space cooling. Our scenarios have identified a large potential for energy and emission reductions, especially China turned out to promise a very large reduction potential of about 50% between a "Business As Usual" (BAU) path and a "Best Available Technology" (BAT) path.

The following Table 41 presents the summarised results for the sum of energy consumption for space heating, hot water and space cooling purposes of the two scenarios for all covered eight countries. Table 42 shows the related emissions.

Table 41: Scenario comparison of space heating, hot water and space cooling energy consumption in the covered countries.

Space heating + hot water + space cooling scenario comparison						
	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	TWh	TWh	TWh	%	%	%
European Union	3,547	2,980	2,429	-16%	-32%	-18%
Brazil	80	104	94	30%	17%	-9%
China	1,562	3,393	1,714	117%	10%	-49%
India	216	401	353	85%	63%	-12%
Indonesia	68	96	87	40%	27%	-9%
Japan	978	662	532	-32%	-46%	-20%
Russian Federation	1,477	1,280	926	-13%	-37%	-28%
United States	4,304	3,096	1,997	-28%	-54%	-35%

Table 42: Scenario comparison of space heating, hot water and space cooling related CO2-emssions in the covered countries.

Space heating + hot water + space cooling scenario comparison						
	2012	BAU 2030	BAT 2030	2012 --> BAU 2030	2012 --> BAT 2030	BAU 2030 --> BAT 2030
	Mt CO2	Mt CO2	Mt CO2	%	%	%
European Union	800	573	495	-28%	-38%	-14%
Brazil	8	11	10	36%	21%	-11%
China	618	890	516	44%	-17%	-42%
India	56	183	151	225%	169%	-17%
Indonesia	20	40	35	93%	70%	-12%
Japan	320	238	203	-26%	-37%	-15%
Russian Federation	422	343	278	-19%	-34%	-19%
United States	1,363	963	729	-29%	-46%	-24%

As can be seen in Table 42, all countries offer an emission reduction potential between the BAU and the BAT scenario of at least 10%. In China, the emission reduction potential even exceeds 40%, followed by the USA with 24%, Russia with 19% and India with 17%.

However, the results are also connected with some uncertainties that are described in the following.

IEA statistics are strongly discussed in the international community as they often seem to be fuzzy in some areas. However, advantage of IEA statistics is that they are available for almost all countries in the world, collected and prepared with the same methodology, therefore streamlined and promising the highest grade of accuracy. It should be noted that the total amount of consumed energy in a country as reported by the IEA has a significant impact on the specific energy consumption values that are calculated based on it.

The building stock data used for this analysis is based on general correlations and therefore definitely holds a specific risk for uncertainty. However this approach promises a good grade of consistency as in national statistics it is often unclear e.g. which kinds of buildings are included in a specific statistic and which not. Additionally the definitions for living area, useful area etc. normally vary from country to country. Using this approach assumes the same definitions and correlations and therefore is assumed to be appropriate for this kind of analysis. It should be noted that also the size of the building stock has a significant impact on the specific energy consumption values.

The entire methodology for splitting the total energy consumption in the countries into the different energy uses holds a large number of uncertainties. However we assume that the numbers give a good indication about the relative share of energy that is used for different energy uses within one country. And assuming that IEA data is reliable, also a cross country comparison should be relatively secure.

References

IEA, 2013. Energy balances for OECD and non-OECD countries - 2013. International Energy Agency, Paris, France.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy. Hayama, Japan.

McNeil, M.A., Letschert, V.E., Can, S. de la R. du, Ke, J., 2012. Bottom-Up Energy Analysis System – Methodology and Results. Online Publication.

Isaac, M., van Vuuren, D.P., 2009. Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy 37, 507–521.

Schimschar, S., 2008. PhD Thesis: Energy- und emission reductions in the global building stock. University of Utrecht, Netherlands.

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