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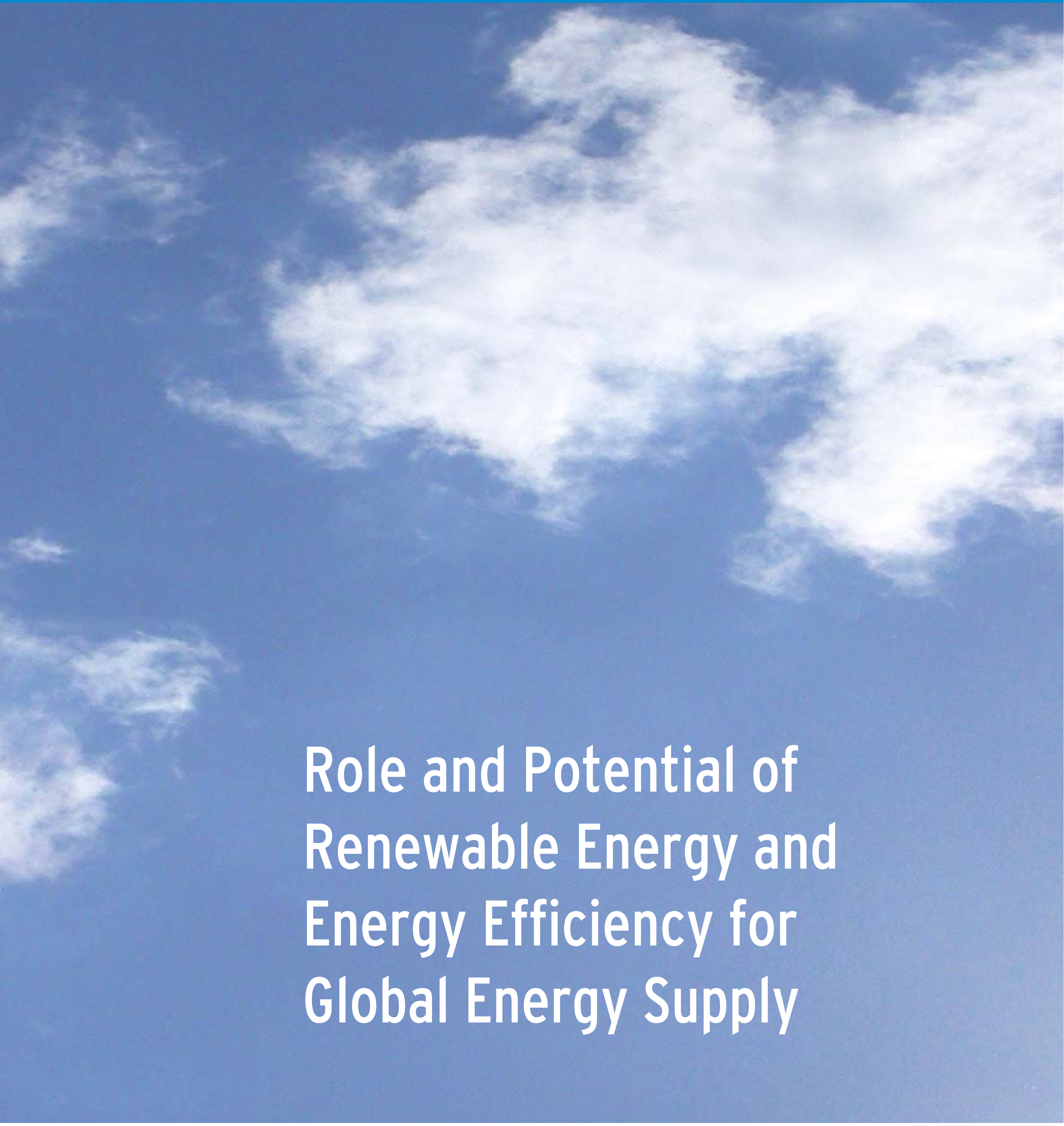

Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply

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Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply

by

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16. Kurzfassung

Die Analyse globaler Energieszenarien in Teil I des Berichts kommt zu dem Ergebnis, dass die Ausnutzung der Potenziale der Energieeffizienz sowie der erneuerbaren Energien jeweils eine Schlüsselrolle für die Einhaltung globaler CO_2-Emissionsreduktionsziele spielen.

Anhand einer breit angelegten Literaturanalyse wird in Teil II gezeigt, dass das technische Potenzial zur Nutzung erneuerbarer Energien den heutigen weltweiten Endenergiebedarf um ein Vielfaches übersteigt.

Die Analyse von verschiedenen Annahmen zur Kostenentwicklung für die Stromerzeugung aus erneuerbaren Energiequellen in Teil III kommt zu dem Ergebnis, dass die zentralen Studien auch in der langfristigen Betrachtung eine große Übereinstimmung aufweisen.

Teil IV untersucht die weltweiten Effizienzpotenziale und zeigt, dass bei einer Implementierung von Maßnahmen zur Verbesserung der angebots- und nachfrageseitigen Energieeffizienz der jährliche Primärenergieeinsatz des Jahres 2050 auf 48% des von der IEA im Baseline-Szenario ihrer Studie „Energy Technology Perspectives“ erwarteten Bedarfs reduziert werden kann. Dabei ist mit ca. 55% bis 60% der insgesamt betrachteten Effizienzmaßnahmen ein großer Anteil kostendeckender Maßnahmen identifiziert worden (Teil V).

Die Analyse der Berücksichtigung von Verhaltensdimensionen in Energieszenarien in Teil VI zeigt auf, dass soziale Aspekte nur unzureichend in bisherigen Studien abgebildet sind, und weist auf entsprechende Fragestellungen für die Forschung hin.

17. Schlagwörter

Erneuerbare Energien, Energieeffizienz, Potenziale, Kosten, Verhaltensänderungen, Energieszenarien, Energiepolitik, Zukunftstechnologien, Klimaschutz

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16. Abstract
The analysis of different global energy scenarios in part I of the report confirms that the exploitation of energy efficiency potentials and the use of renewable energies play a key role in reaching global CO2 reduction targets.
An assessment on the basis of a broad literature research in part II shows that the technical potentials of renewable energy technologies are a multiple of today’s global final energy consumption.
The analysis of cost estimates for renewable electricity generation technologies and even long term cost projections across the key studies in part III demonstrates that assumptions are in reasonable agreement.
In part IV it is shown that by implementing technical potentials for energy efficiency improvements in demand and supply sectors by 2050 can be limited to 48% of primary energy supply in IEA’s “Energy Technology Perspectives” baseline scenario. It was found that a large potential for cost-effective measures exists, equivalent to around 55-60% of energy savings of all included efficiency measures (part V).
The results of the analysis on behavioural changes in part VI show that behavioural dimensions are not sufficiently included in energy scenarios. Accordingly major research challenges are revealed.

17. Keywords
Renewable energy, energy efficiency, potentials, costs, behavioural changes, energy scenarios, energy policy, future technologies, climate protection

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Executive Summary

Role of renewable energy and energy efficiency in global energy scenarios

A broad range of different global energy scenarios confirms that the exploitation of energy efficiency potentials and the use of renewable energies play a key role in reaching global CO_2 reduction targets.

In scenarios aiming at the stabilisation of greenhouse gas concentration at 450 ppm equivalent, the contribution of renewables to global primary energy supply reaches between 31% (Greenpeace/EREC, Energy [R]evolution) and 23% (IEA World Energy Outlook 2008, 450 Policy Scenario) in 2030. By 2050, renewables are expected to contribute between 56% (Greenpeace/EREC, Energy [R]evolution) and 35% (IEA Energy Technology Perspectives, BLUE Map) to primary energy supply.

Differences in the share of renewables across scenarios are partly due to different assumptions on the potentials for increasing energy efficiency. Compared to other scenarios, the more ambitious reduction of energy demand in the Greenpeace/EREC Energy [R]evolution scenario facilitates higher shares of renewables in energy consumption. In the IEA scenarios, also nuclear and fossil technologies with carbon capture and storage (CCS) are considered to be essential elements for achieving the climate protection targets. In particular the use of CCS in the IEA WEO scenario leads to high CO_2 abatement costs, as CCS is not expected to gain economic competitiveness before 2030. It remains unclear what constraints the market uptake of more cost effective renewable options in the IEA scenarios.

While all scenario studies analysed provide a wealth of detailed information on various technical and economic issues, there is a general lack of reporting key assumptions in a comprehensive and transparent way, which sometimes makes comparison across studies difficult. All studies analysed are particularly weak in providing data on the heating sector, which in spite of its large contribution to fuel consumption and CO_2 emissions in general is treated as a second priority only. A more transparent documentation of basic assumptions and constraints is desirable for any future scenario work.

Global potentials of renewable energy sources

The largest electricity generation potential on a global scale is seen for the solar technologies concentrating solar thermal power plants (CSP) and PV, followed by wind onshore and ocean energy. The global potential for direct thermal use of solar and geothermal energy several times exceeds global low temperature demand.

The potential for CSP and PV electricity generation is particularly large in Africa.

Wind onshore potentials are high in North America, while Latin America has abundant biomass resources.

Current global final energy consumption is less than 5% of the overall projected technical renewable energy potential.

Costs of renewable energy technologies

In general the cost estimates for renewable electricity generation technologies and even long term cost projections across the key studies are in reasonable agreement. For well known technologies like PV or wind the differences in future cost assumptions are quite small. Differences are larger for technologies in an early development stage, for which there is not yet an established lead technology (like wave energy). Differences between cost estimates can be large when site specific conditions influence investment costs, like in the case of hydropower or geothermal energy. The variation in cost data is also large when a variety of different technical concepts and different applications exist, like in the case of biomass use.

For most renewable energy technologies costs of renewable energy technologies in IEA-ETP in general are towards the lower range of cost estimates, although the share of renewables in the IEA scenarios in general is smaller than in the other scenario studies. Costs for renewable energy technologies in the Greenpeace/EREC scenario, which is a dedicated ‘renewables’ scenario, are in most cases higher than the IEA estimates.

Results show that for all renewable technologies except hydro it is expected that a significant reduction in electricity generation costs can be realised over the next twenty years. Taking into account an expected increase in fossil fuel prices and CO_2 emission costs, it is most likely that by 2030 most of the renewable electricity generation technologies will be competitive against electricity generation from fossil fuels.

Cost data on renewable heating and cooling technologies are quite poor in all the scenario studies analysed. As far as data are available, and taking into account the large uncertainties which partly are due to differences in plant size and in the type of application, there is a reasonable agreement across scenarios on cost data for solar collectors and biomass heating systems. There is however a significant difference in assumptions on costs for heat pumps using shallow geothermal resources.

Global potentials of energy efficiency

On a business-as-usual trajectory, worldwide final energy demand is expected to grow by 95% from 290 EJ in 2005 to 570 EJ in 2050. By exploiting the technical potential for energy efficiency improvement in that period the increase can be limited to 8%. Respecting the technical energy efficiency potentials, worldwide final energy demand can be reduced to 317 EJ in 2050.

Primary energy supply can be limited to 392 EJ in 2050 by implementing technical potentials for energy efficiency improvements in demand and supply sectors. This is 10% below primary energy supply in 2005 (440 EJ) and 55% lower than the primary energy supply in 2050 in the case of business-as-usual development.

Costs and bounds of energy efficiency

Few global studies on energy efficiency costs and benefits are available. Some studies that calculate CO_2 mitigation costs for energy efficiency show large differences in costs estimates.

Cost estimates for efficiency measures are very sensitive to fuel price assumptions. They can change from positive to negative costs just by higher fuel price assumptions. Also the discount rate used influences costs significantly as well as assumptions regarding incremental investment costs of energy efficiency measures and estimated fuel savings. Further research is therefore needed to estimate global and regional costs of energy efficiency measures.

We estimate that to implement the global technical potential as calculated in the respective part of this report, annual costs equivalent to 0.5% of GDP in 2050 are needed.

It was found that there is a large potential for cost-effective measures, equivalent to around 55-60% of energy savings of all included efficiency measures. There are however a number of market failures and barriers that inhibit the uptake of energy efficiency measures. These are e.g. insufficient and inaccurate information, capital market barriers, low energy costs and low price elasticity. Policies aimed at removing market barriers are important to stimulate energy efficiency improvement.

Energy consumption and behavioural changes

The results of the analysis on behavioural changes show that behavioural dimensions are not sufficiently included in energy scenarios. Some scenarios completely omit this dimension, other scenarios indicate that explicit behavioural changes play a role, but the scenario modellers do not make explicit behaviour a guiding principle in their modelling. Two explanations for these approaches (or omittances) are possible: 1) explicit behavioural changes (of individual actors and groups) are not considered to play a role in future energy systems 2) explicit behaviour is considered to be too complex to be modelled in energy scenarios.

It has to be discussed whether behavioural dimensions can be explicitly integrated into the existing architecture and logic of scenarios at all, or the scenario structures themselves have to be changed. It is still an open question to what extent explicit behavioural dimensions can be quantified at all or to what extent they have to remain a parameter that can only be analysed qualitatively.

Revealed major research challenges are twofold: To find ways to integrate behavioural changes into current scenario structures as well as to to develop different scenario approaches to focus on behavioural changes as a major parameter.

The integration of behavioural changes into current scenario structures remains a great challenge that has not been addressed in a satisfactory way yet. As a first approximation of integrating some aspects into scenario modelling, the focus should be put on the following aspects: References to individual actors and consideration and integration of social and cultural relations (context of “Lebenswelt”). A stronger reflection of the normative orientations of the scenarios themselves should be combined with the development of means to methodically deal with norms.

Behavioural changes could be integrated better into more open and transparent scenario models that allow detailed modifications of assumptions. Typical bottom-up models could principally be used for this: they allow setting assumptions for each sector and each technology separately, which helps to make the modelling and its results as transparent as possible.

Resumé

The report’s results emphasise that there still is a considerable unexploited potential for renewable energy, energy efficiency as well as for behavioural changes to reduce future global energy-related CO_2 emissions. The overall technical and behavioural potentials for renewable energy technologies and energy efficiency improvements are significant. Further development is needed for their exploitation, in particular for overcoming economical, infrastructural and political constraints.

Zusammenfassung

Die Rolle von erneuerbaren Energien und Energieeffizienz in globalen Energieszenarien

Die Analyse globaler Energieszenarien zeigt, dass für die Einhaltung globaler CO_2-Emissionsreduktionsziele die Ausnutzung der Potenziale der Energieeffizienz sowie der Technologien zur Nutzung erneuerbarer Energien jeweils eine Schlüsselrolle spielen.

Szenarien, die eine Stabilisierung der Treibhausgaskonzentration auf einem Niveau von maximal 450 ppm CO_2-Äquivalenten anstreben, erreichen im Jahr 2030 einen Anteil erneuerbarer Energien zur Deckung des Primärenergiebedarfs zwischen 31% (Greenpeace/EREC, Energy [R]evolution) und 23% (IEA World Energy Outlook 2008, 450 Policy Scenario). Für das Jahr 2050 wird erwartet, dass der Beitrag erneuerbarer Energien auf 56% (Greenpeace/EREC, Energy [R]evolution) bzw. 35% (IEA Energy Technology Perspectives, BLUE Map) des Primärenergieeinsatzes gesteigert werden kann.

Die unterschiedlichen Einschätzungen des Beitrags erneuerbarer Energien sind unter anderem auf Differenzen in den Annahmen bezüglich des Potenzials von Effizienzsteigerungen zurückzuführen. So ermöglicht die deutlichere Reduktion der Energienachfrage im Greenpeace/EREC Energy [R]evolution Szenario einen im Vergleich zu anderen Szenarien höheren Anteil von erneuerbaren Energien am Primärenergieeinsatz. In den Szenarien der IEA spielen außerdem Kernenergie und fossile Energieträger in Verbindung mit CCS (Carbon Capture and Storage) eine bedeutende Rolle zur Erreichung der Klimaschutzziele. Allerdings führt insbesondere der Einsatz von CCS in den Szenarien der IEA zu hohen CO_2-Vermeidungskosten, da ein wirtschaftlicher Einsatz von CCS vor 2030 nicht erwartet wird. Es bleibt unklar, welchen Beschränkungen die breite Markteinführung kostengünstiger Technologien zur Nutzung erneuerbarer Energien in den IEA Szenarien unterliegt.

Während die betrachteten Szenarien detaillierte Informationen zu einzelnen technischen und ökonomischen Fragestellungen geben, ist ein grundsätzliches Defizit in Hinblick auf eine nachvollziehbare und transparente Darstellung zentraler technologischer und ökonomischer Grundannahmen vorhanden. Vergleiche zwischen den Szenarien werden dadurch erschwert. Insbesondere Daten zum Wärmesektor bleiben weitgehend unvollständig. Angesichts der Bedeutung des Wärmesektors bezüglich Energiebedarf und CO_2-Emissionen ist diese zweitrangige Behandlung nicht angemessen. In künftigen Szenarioanalysen sollte eine umfassendere und transparentere Dokumentation grundlegender Annahmen und ihrer Grenzen angestrebt werden.

Globale Potenziale erneuerbarer Energien

Das weltweit größte technische Potenzial zur Stromerzeugung besitzen solare Technologien wie konzentrierende solarthermische Kraftwerke (Concentrating Solar Thermal Power Plants, CSP) und Photovoltaik (PV). Es folgen onshore Windenergie und Meeresenergie. Das technische Potenzial für die thermische Verwendung von solarer und geothermischer Energie übertrifft um ein Vielfaches den weltweiten Niedertemperatur-Wärmebedarf.

In Afrika ist das Potenzial zur Stromerzeugung von CSP und PV besonders groß. Das technische Potenzial der Windenergie (onshore) ist besonders hoch in Nordamerika, während Lateinamerika über ein ergiebiges Biomassepotenzial verfügt.

Schließlich lässt sich feststellen, dass der heutige weltweite Endenergiebedarf weniger als 5% des projizierten technischen Potenzials zur Nutzung erneuerbarer Energien beträgt.

Kosten der Nutzung von erneuerbaren Technologien

Die Kosten für die Stromerzeugung aus erneuerbaren Energiequellen werden in den zentralen Studien auch in der langfristigen Betrachtung relativ übereinstimmend eingeschätzt. Für Technologien wie PV und Wind unterscheiden sich die Kostenprojektionen nur sehr geringfügig. Die Differenzen sind größer bei Technologien, die sich noch in einem frühen Stadium ihrer Entwicklung befinden, und für die daher noch keine anerkannte Leittechnologie verfügbar ist (z.B. Wellenenergie). Es treten aber zum Teil deutliche Unterschiede in der Einschätzung zukünftiger Kosten auf, wenn standortspezifische Bedingungen die Investitionskosten stark beeinflussen (z.B. Wasserkraftwerke, Geothermie).

Für den Großteil der Technologien zur Nutzung erneuerbarer Energien gilt, dass sich die in der IEA-Studie “Energy Technology Perspectives” aufgezeigten Kosten tendenziell eher im unteren Bereich der geschätzten Kostenentwicklungen befinden, obwohl der Anteil der Erneuerbaren in den IEA-Szenarien meist kleiner ist als in den anderen Szenarien. Die Kostenannahmen des Greenpeace/EREC Szenarios, eines ausgewiesenen “Erneuerbaren-Szenarios“, liegen eher über den Schätzungen der IEA.

Es wird erwartet, dass in den nächsten zwanzig Jahren für fast alle Technologien zur Nutzung erneuerbarer Energien (mit Ausnahme der Wasserkraft) eine deutliche Reduzierung der Stromerzeugungskosten realisiert werden kann. Unter Annahme steigender Kosten für fossile Energieträger und für CO_2-Emissionen ist zu erwarten, dass bis 2030 die meisten Technologien zur Erzeugung regenerativen Stroms wettbewerbsfähig sein werden.

Daten zur Kostenentwicklung von Technologien zur erneuerbaren Wärme- und Kältegewinnung werden in den untersuchten Studien nur unvollständig ausgewiesen. So weit vorhanden, stimmen sie - unter Berücksichtigung der Unsicherheiten infolge von Unterschieden in Kraftwerksgrößen und Arten der Anwendung - für Solarkollektoren und Biomasse-Wärmeanlagen weitgehend überein. Deutliche Unterschiede bestehen allerdings in den Annahmen zu Kosten für Wärmepumpen, die oberflächennahe Erdwärme nutzen.

Potenziale zur Steigerung der Energieeffizienz

Für den Fall einer “Business as usual”-Entwicklung wird erwartet, dass die weltweite Nachfrage nach Endenergie um 95% von 290 EJ im Jahr 2005 auf 570 EJ im Jahr 2050 steigt. Sollte in der gleichen Periode das vorhandene Potenzial zur Steigerung der Energieeffizienz genutzt werden, ließe sich die Zunahme auf 8% begrenzen. Der weltweite Bedarf an Endenergie könnte so auf jährlich 317 EJ im Jahr 2050 reduziert werden.

Der jährliche Primärenergieeinsatz kann bei der Implementierung von Maßnahmen zur Verbesserung der angebots- und nachfrageseitigen Energieeffizienz auf 392 EJ im Jahr 2050 reduziert werden. Das sind 10% weniger als der Primärenergieeinsatz des Jahres 2005 (440 EJ) und 55% weniger als für den Fall einer „Business as usual“-Entwicklung für das Jahr 2050 angenommen wird.

Kosten und Hemmnisse zur Umsetzung von Energieeffizienzmaßnahmen

Kosten und Nutzen von Maßnahmen zur Steigerung der Energieeffizienz werden nur in wenigen Studien behandelt. Analysen, die Kosten für eine Verminderung von CO_2-Emissionen im Bereich von Energieeffizienz berechnen, zeigen dabei große Differenzen auf.

Kostenabschätzungen für Energieeffizienzmaßnahmen hängen stark von den Annahmen zu fossilen Energieträgerpreisen ab. Sie können in Folge höherer Brennstoffkosten das Vorzeichen wechseln und negativ werden. Daneben beeinflussen die zugrunde gelegte Diskontierung sowie inkrementelle Investitionskosten von Effizienzmaßnahmen und erwartete Einsparungen an Ausgaben für Brennstoffe die Höhe der erwarteten Kosten signifikant. Weitere Forschungsanstrengungen zur Abschätzung globaler und regionaler Kosten der Durchführung von Effizienzmaßnahmen sind also erforderlich.

Für die Implementierung des in dieser Studie analysierten technischen Potenzials zur Steigerung der Energieeffizienz wird erwartet, dass die Höhe der Kosten 2050 jährlich ca. 0,5% des weltweiten Bruttoinlandsproduktes (der weltweiten Wirtschaftsleistung) betragen wird.

Es besteht ein großes Potenzial an kostendeckenden Effizienzmaßnahmen. Als solche wurden ca. 55% bis 60% der insgesamt betrachteten Effizienzmaßnahmen identifiziert. Eine erfolgreiche Markteinführung kann allerdings durch Marktversagen und andere Hemmnisse verhindert werden. Hierzu gehören beispielsweise unzureichende und falsche Informationen, Hürden im Kapitalmarkt, niedrige

Energiekosten und eine geringe Preiselastizität. Maßnahmen, die auf eine Beseitigung der Marktschranken zielen, sind insofern für eine Förderung der Energieeffizienzsteigerung sehr wichtig.

Energieverbrauch und Verhaltensänderungen

Die Ergebnisse unserer Analyse zeigen, dass Verhaltensdimensionen in Energieszenarien nur unzureichend abgebildet werden. In einigen Szenarien werden diese Dimensionen vollständig vernachlässigt. Andere deuten an, dass explizite Verhaltensänderungen eine Rolle spielen, erheben explizites Verhalten allerdings nicht zu einem leitenden Prinzip der Modellierung. Zwei Erklärungen sind dafür möglich: 1) expliziten Verhaltensänderungen (von Individuen und Gruppen) wird keine Rolle für zukünftige Energiesysteme zugedacht und 2) explizites Verhalten wird als zu komplex erachtet, um in Energieszenarien modelliert werden zu können.

Die Frage muss diskutiert werden, ob Verhaltensdimensionen überhaupt explizit in die bestehende Szenarioarchitektur und -logik integriert werden können, oder ob die Strukturen der Szenarien geändert werden müssen. Es ist noch offen, in welchem Umfang explizite Verhaltensdimensionen tatsächlich quantifiziert werden können bzw. zu welchem Maß sie ein Parameter bleiben, der lediglich qualitativ analysiert werden kann.

Die aufgezeigten Fragestellungen für die Forschung lassen sich also in zwei Gruppen klassifizieren: In die Integration von Verhaltensänderungen in bestehende Szenariostrukturen sowie in die Entwicklung unterschiedlicher Ansätze von Szenarien, um Verhaltensänderungen als bedeutenden Parameter fokussieren zu können.

Als erste Annäherung für die Berücksichtigung von Teilaspekten von Verhaltensänderungen in der Szenariomodellierung sollten folgende Aspekte im Mittelpunkt stehen: Bezugnahmen auf einzelne Akteure, die Integration sozialer und kultureller Beziehungen (Kontext der „Lebenswelt“) sowie eine deutlichere Reflexion der unterschiedlichen normativen Orientierungen der verschiedenen Szenarien und Entwicklung von Hilfsmitteln zum methodischen Umgang mit Normen.

In offenere und transparentere Szenariostrukturen, die detaillierte Anpassungen von Annahmen erlauben, könnten Verhaltensänderungen besser integriert werden. Hierfür können typische Bottom-up-Modelle verwendet werden: Sie ermöglichen es, unterschiedliche Annahmen für verschiedene Sektoren und Technologien festzulegen. Dies wiederum ermöglicht eine hohe Transparenz der Modellierung bzw. der Modellergebnisse.

Resumé

Die Ergebnisse dieses Berichtes unterstreichen, dass weltweit beachtliche, bisher nicht ausgeschöpfte Potenziale zur Nutzung erneuerbarer Energien und zur

Steigerung der Energieeffizienz vorhanden sind. Zusammen mit dem bisher nur unvollständig berücksichtigten Potenzial von Verhaltensänderungen zur Reduzierung des Energiebedarfs werden vielfältige Möglichkeiten aufgezeigt, um künftige CO_2-Emissionen des Energiesektors deutlich reduzieren zu können. Zur Ausschöpfung dieser Potenziale ist eine Weiterentwicklung von Technologien zur Nutzung erneuerbarer Energien und von Effizienzmaßnahmen notwendig, insbesondere aber müssen ökonomische, infrastrukturelle und politische Schwierigkeiten überwunden werden.

Part I:

Role of Renewable Energy and Energy Efficiency in Global Energy Scenarios

Kristina Nienhaus (DLR), Carolin Capone (Ecofys)

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1 Preface

Climate change as a consequence of an increasing anthropogenic GHG concentration (IPCC 2007) urges a reduction of emissions in order to limit global warming. As energy-related CO_2 emissions constitute one of the major sources, it is a crucial objective to develop climate protection strategies within the energy sector. Global energy scenarios are a necessary resource for guiding the development of energy policies and investment decisions.

This analysis' aim is to reveal the key targets for a selection of global energy scenarios. The respective trajectories are analysed, as they disclose different ways for the energy sector to respond to need for deep emissions cuts.

2 Role of renewable energy and energy efficiency in global energy scenarios

2.1 Introduction

Five studies and seven scenarios have been chosen to be analysed, with an emphasis on regarding the role of renewable energy and energy efficiency.

They all have a global scope and are released by established institutions. The choice for the scenarios has been made by looking for the most ambitious scenario in terms of CO_2 emissions' reduction within each study.

- *International Energy Agency - World Energy Outlook (2008):*
  550 Policy Scenario (WEO 08 550)
  450 Policy Scenario (WEO 08 450)
- *Greenpeace/EREC - Energy [R]evolution (2008):*
  Energy [R]evolution Scenario (E [R])
- *International Energy Agency - Energy Technology Perspectives (2008):*
  BLUE Map Scenario (BLUE Map)
- *European Commission - World Energy Technology Outlook (2006):*
  Carbon Constraint Case (WETO CCC)

This report provides comparison merely on an aggregated level. In order to disclose findings for the deployment of renewables and exploitation of energy efficiency potentials, the analysis precedes as follows:

Individual analyses for the scenarios are undertaken in chapter 2. The scenario frame is introduced followed by subchapters covering population and GDP projections as key determining factors for the development of energy demand. The subchapter about cost assumptions gives an insight into expected aggregated additional investment costs, fuel savings, carbon prices, specific technology investment costs and fuel prices. This is followed by the analysis of the energy sector's development, with a main focus on the role of renewable energy and energy efficiency (further subdivision: primary energy/renewable energy's share in primary energy supply, electricity generation, heat and transport; energy efficiency/end-use efficiency, energy supply efficiency, carbon intensity).

A synopsis is provided in chapter 3, comparing the key results of chapter 2. Data is disclosed for primary energy demand, final energy demand, electricity generation, new capacities, additional investment and savings and energy-related CO_2 emissions.

All prices and costs are given in $€_{2005}$. Conversion factors have been presumed as follows:

1 $\$_{1995}$ = 0.9861 $€_{2005}$

1 $\$_{2005}$ = 0.8038 $€_{2005}$

1 $\$_{2006}$ = 0.7792 $€_{2005}$

1 $\$_{2007}$ = 0.7589 $€_{2005}$

2.2 Scenario types

The analysed energy scenarios can be categorised into intervention and backcast scenarios. Intervention scenarios like the WEO 07 APS and EC WETO CCC develop a plausible future under the question of "What would happen if condition X were imposed on the future described by a reference scenario?" (Hamrin et al., 2007).

Backcast scenarios like the climate policy scenarios in WEO 2008 and the Energy [R]evolution pose the question of "What energy path would achieve a future condition X?" (Hamrin et al., 2007).

Comparing the scenarios' trajectories for the deployment of renewable energy and the exploitation of energy efficiency potentials, it is also vital to respect their respective aims for climate policy (maximum increase in temperature compared to pre-industrial levels and corresponding maximum concentration of GHG).

Another informative detail on the studies is the traceable participation of stakeholders. Information on this and the above described characteristics of the analysed scenarios can be found in table 2-1.

Table 2-1: Characteristics of considered scenarios

Study	Scenario	Abbreviation	Type of Scenario	Projection Period	Targets		Model	Stakeholder Participation
					Maximum increase in temperature	Maximum concentration of GHG (ppm)		
IEA WEO 2008	550 Policy Scenario	WEO 08 550	Backcast	2030	3 °C	550	WEM	Yes (science, administration, industry & NGOs)
	450 Policy Scenario	WEO 08 450	Backcast	2030	2 °C	450	WEM	
EREC/Greenpeace	Energy [R]evolution	E[R]	Backcast	2050	2 °C	450	MESAP PlaNet	Yes (science, industry & NGOs)
IEA ETP 2008	BLUE Map	BLUE Map	Backcast	2050	2 °C	450	ETP MARKAL	Yes (science, industry & administration)
IEA WEO 2007	Alternative Policy Scenario	WEO 07 APS	Intervention	2030	3 °C	550	WEM	Yes (science, industry & administration)
	450 Stabilisation Case	WEO 07 450	Backcast	2030	2 °C	450	WEM	
EC WETO 2006	Carbon Constraint Case	WETO CCC	Intervention	2050	3 °C	550	POLES	Yes (science, administration & industry)

2.3 International Energy Agency: World Energy Outlook 2008

Key scenarios

Reference Scenario:	The Reference Scenario is supposed to indicate a baseline picture - no new energy-policy interventions by governments are assumed beyond those already enacted or adopted by mid-2008. Any further development is not incorporated.
550 Policy Scenario:	The 550 Policy Scenario analyses implications for the energy sector of international and national policy action to limit greenhouse-gas concentration in the atmosphere to 550 parts per million of CO_2-eq. Energy-related CO_2 emissions are reduced by taking into account policy mechanisms that are currently under discussion.
450 Policy Scenario:	The 450 Policy Scenario aims to stabilise greenhouse-gas emissions at 450 parts per million of CO_2-eq.

World Energy Outlook: 550 Policy Scenario

Scenario frame

- Key drivers: Stabilisation of the GHG concentration level at 550 ppm with the aim of limiting a rise in temperature to 3 °C. Implications and results of a respective, plausible post-2012 international climate-policy framework, regarding policies and measures that are currently considered.
- Emissions are assumed to fall after 2020, amounting to 32.9 Gt in 2030.
- Following policy mechanisms are combined:
    - Cap-and trade systems (binding emissions caps for OECD+ countries - OECD and EU member countries - for the power generation and the heavy industry sector)
    - International sectoral agreements (for the iron/steel/cement/vehicle- and aircraft-manufacturing sector in OECD+ countries and the ‘other major economies’ group other major non-OECD+ economies, including China, Russia, India, Indonesia, Brazil and Middle East)
    - National policies and measures (for ‘other countries’ in all sectors, for major economies (excl. OECD+) in the power generation and iron/steel/cement industry sector and for the buildings sector across all countries).
- The group of ‘other countries’ implements only national policies, but can participate in the cap and trade systems by generating and selling emissions credits.

Population projections

- Population projections are based on UNDP 2007 projections.
- Average annual growth rate: 0.97% between 2006 and 2030. Growth is expected to slow progressively over the projection period.
- Global population 2006: 6.5 billion people, 2030 8.2 billion.
- Population in emerging economies is continuing to grow at fast rates. Non-OECD countries' average annual growth rate rate: 1.1%, OECD countries': 0.4%. For most of the growth in OECD countries the population in North America is accounted for. Population is expected to decline in OECD Pacific (mainly on account of Japan) and Eastern Europe/Eurasia (for the most part because of Russia).
- Increase will occur in urban areas. Rural population is considered to start to decline in about a decade.
- Rapid urbanisation in non-OECD countries.
- Major parts of the world, especially in Africa, stay widely rural.
- Ageing of the population in all regions. The proportion of people over 60 years old rises from 11% in 2006 to about 15% in 2030.

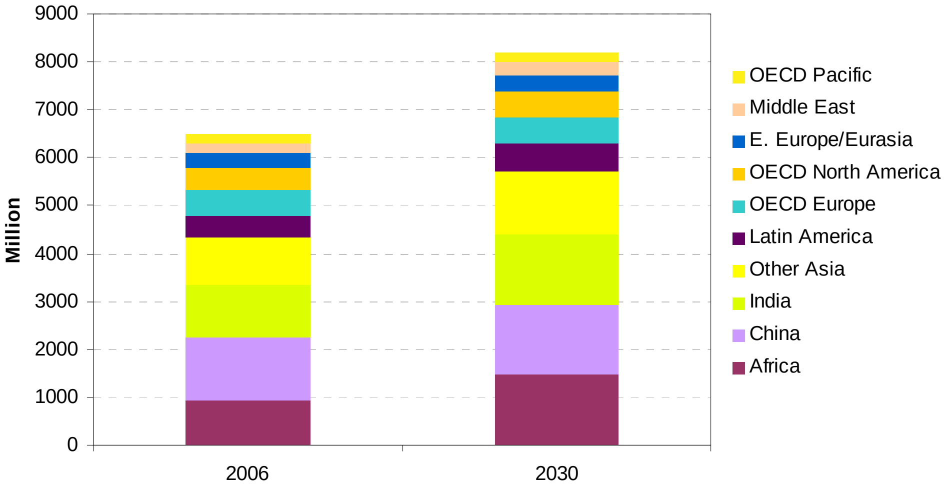


Figure 2-1: IEA WEO 2008, Population

GDP projections

- World average annual GDP growth rate (in PPP terms): 3.3% over the period 2006-2030. Stronger increase in the period 2006 to 2015: 4.2% per year; 2015-2030: 2.8% per year.
- Growth rates in non-OECD countries are higher than in OECD countries.
- Highest average growth rates in China and India at 6.1% resp. 6.4% per year (2006-2030). India's growth rates are accelerating due to population growth and its earlier stage in the development process.
- The emerging economies' growth rates are assumed to slow as they mature.

- All OECD regions have to face intense competition from emerging economies, ageing and stabilisation resp. decline of their population. Their economies' growth rates slow in consequence.
- Europe and the Pacific: average of 1.9% resp. 1.6% growth per year (2006-2030).
- North America remains the fastest growing OECD region (2.2% per year between 2006 and 2030), partly due to its relatively young and growing population.
- No absolute figures for GDP provided.

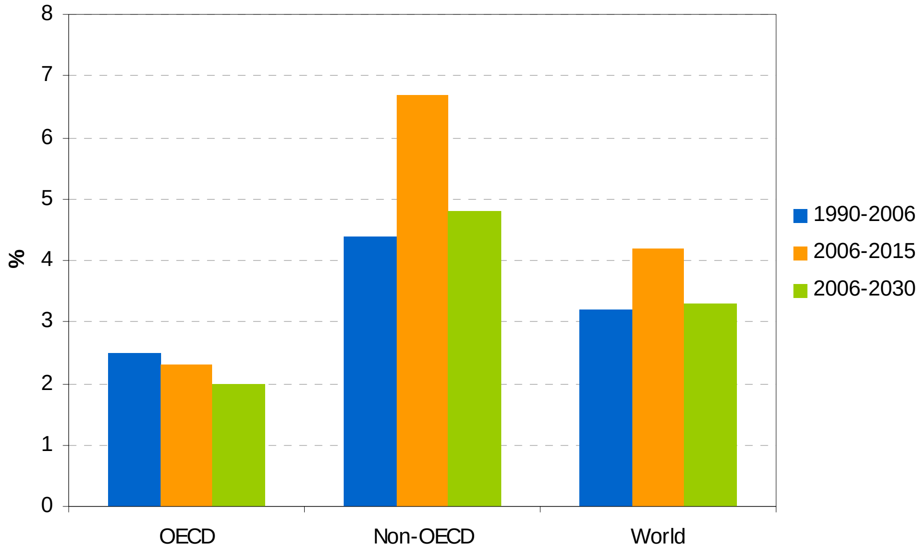


Figure 2-2: IEA WEO 2008, GDP growth rates (in PPP terms)

Cost assumptions and economic implications

Table 2-2: IEA WEO 2008, Investment costs for renewable energy

	2006	2015	2030
Wind Onshore (€/kW)	1380-1520	1250-1370	1140-1330
Wind Offshore (€/kW)	2220-2460	1820-2010	1860-2050
Geothermal (€/kW)	2670-3110	2500-2920	2390-2770
PV (€/kW)	4840-5650	2580-2960	1780-2240
CSP (€/kW)	2870-3340	2050-2430	1520-1820

Table 2-3: IEA WEO 2008, Fossil-fuel price assumptions

	2006	2015	2030
Crude Oil Imports (€/barrel)	n.a.	n.a.	75.9
Natural Gas Imports (€/MBtu)	n.a.	n.a.	n.a.
Steam Coal Imports (€/tonne)	49.3	91.1	64.5

- Lower oil prices in the 550 Policy Scenario than in the Reference Scenario due to lower demand.
- The carbon price in OECD+ countries is expected to reach €30.4/t CO_2 in 2020 and €68.3/t CO_2 in 2030.

- Additional energy investment in the energy sector (relative to the Reference Scenario) in the 550 Policy Scenario adds up to €3.2 trillion. This is the sum out of €0.9 trillion invested in power plants (renewables, nuclear and CCS; total investment in the power sector amounts to €5.5 trillion) and €2.3 trillion invested in energy efficiency.
- The additional costs equate to 0.24% of world GDP per year on average over the period 2010-2030. Additional annual expenditure by individuals is €13 per person (in the OECD+ region: €41).
- Fossil fuel savings between 2010 and 2030: over €5.3 trillion.

Primary energy

- Total primary energy demand in the 550 Policy Scenario is almost reaching 650,000 PJ per year in 2030. Its growth rate is supposed to decline from 1.45% (2006-2020) to 0.76% in the period from 2020 until 2030. The average annual increase is 1.2%.
- In 2030, the biggest share is contributed by oil at nearly 200,000 PJ, followed by coal and gas at about 150,000 PJ resp. 140,000 PJ per year.
- Plants fitted with CCS are expected to play a significant role: Over the period 2007-2030 new capacity of 161 GW is assumed to be built.
- Nuclear is estimated to provide an annual 45,500 PJ by 2030, its additional capacity is considered to amount to 251 GW.
- The highest growth rate is reported for the group of ‘other renewables’ (wind and solar are mainly mentioned): it grows at an average of 8.5% yearly from 2,800 PJ in 2006 to 19,600 PJ in 2030.

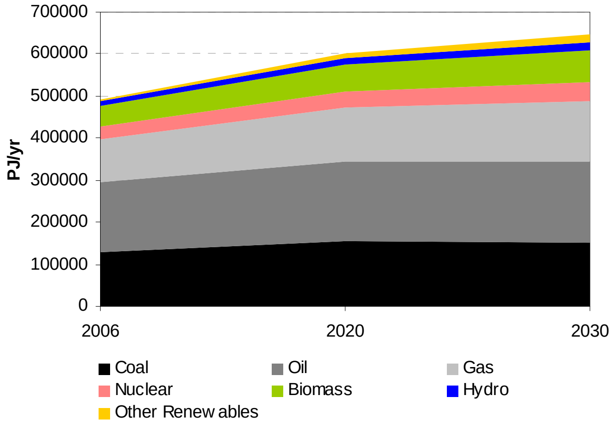


Figure 2-3: IEA WEO 2008 550, Total primary energy demand

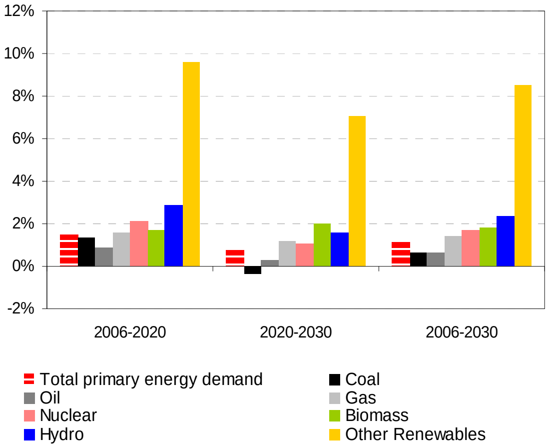


Figure 2-4: IEA WEO 2008 550, Average annual change rates of total primary energy demand

Renewable energy’s share in primary energy supply

- By 2030, renewable energy technologies are expected to contribute 115,000 PJ per year to primary energy supply.
- Most of the energy is assumed to be extracted from biomass, which will reach 76,500 PJ in 2030. Its yearly average growth rate is presumed at 1.8% per year, starting from 50,000 PJ in 2006.
- Hydro energy is growing at 2.9% per year until 2020, in the following decade its average growth rate falls to 1.6% per year.
- The group of ‘other renewables’ (solar and wind are the only explicitly mentioned technologies) is assumed to increase at an average of 9.6% in the period 2006-2020, from 2020 to 2030 this will slightly slow down to a yearly average of 7%.

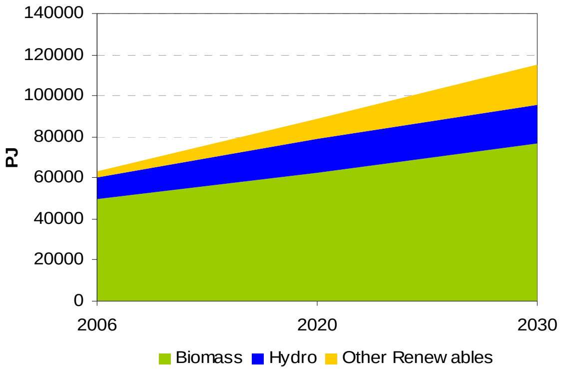


Figure 2-5: IEA WEO 2008 550, Total contribution of renewable energy to primary energy demand

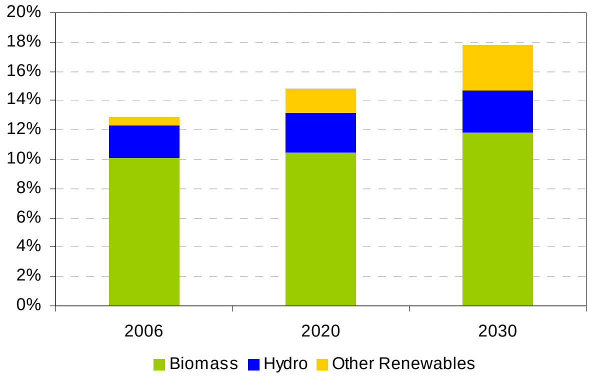


Figure 2-6: IEA WEO 2008 550, Share of renewable energy in primary energy demand

Renewable energy’s share in electricity generation

- Data for electricity generation from renewable energy technologies is dissolved in categories for hydro, biomass, wind onshore, wind offshore, tide and wave, concentrating solar, solar PV and geothermal.
- Renewables account for 9,160 TWh per year in 2030. This is 30.3% of total electricity generation, which amounts to 30,200 TWh per year in 2030.
- Hydro energy: reaching 5360 TWh per year in 2030, 17.8% of total electricity generation. Its deployment slows down from an average 2.9% per year until 2020 to 1.7% in the following decade.
- Biomass: amounts to 1200 TWh per year in 2030, 3.9% of total electricity generation. Average annual growth rate is 6.9% (2006-2030).
- Wind onshore: peaks at 1400 TWh per year in 2030, 4.6% of total electricity generation. Its average annual growth rate in the period 2006-2030 amounts to 10.4% (2006-2020: 14.4%/yr, 2020-2030: 5.1%/yr).
- Wind offshore: 2030 contributing 550 TWh per year (starting from zero in 2006).

- Solar PV: amounts to 350 TWh per year in 2030, 1.2% of total electricity generation. Average annual growth rate is 20.8% per year in the period 2006-2030 (2006-2020: 27.9%/yr, 2020-2030: 11.5%/yr).
- Concentrating solar power: contributes 125 TWh per year in 2030 (starting from zero in 2006), 0.4% of total electricity generation. Average annual growth rate from 2020 to 2030 is 20.1%.
- Geothermal: increases to 200 TWh per year in 2030, 0.7% of total electricity generation. The average annual growth rate is 5.2% for the period 2006-2030 (2006-2020: 5.5%/yr, 2020-2030: 4.8%/yr).
- Tide and wave: increases to 30 TWh per year in 2030, 0.1% of total electricity generation. For the period 2006-2030 the average annual growth rate is estimated at 15.2% (2006-2020: 17.9%/yr, 2020-2030: 11.6%/yr).

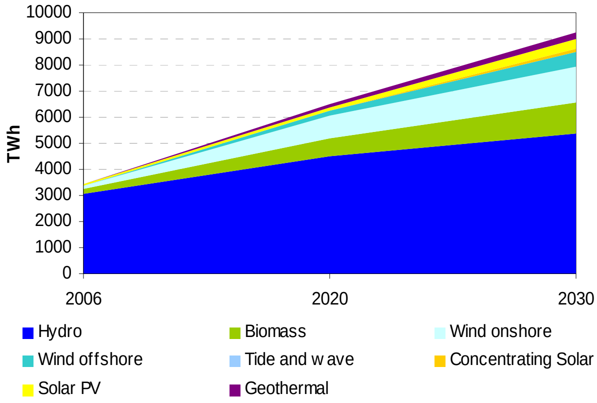


Figure 2-7: IEA WEO 2008 550, Total contribution of renewable energy to electricity generation

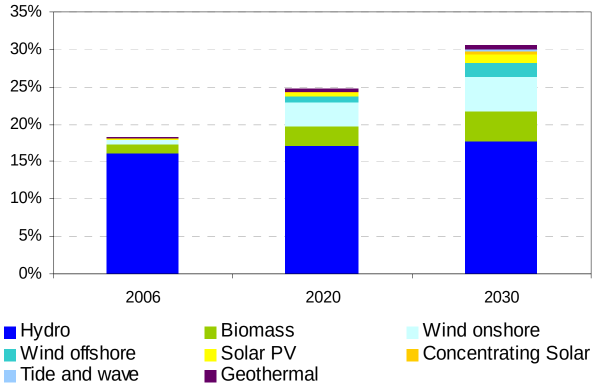


Figure 2-8: IEA WEO 2008 550, Share of renewable energy in electricity generation

Renewable energy for heat and transport

- In the residential sector by 2030 an additional 920 PJ per year for heating is assumed to be delivered by solar energy. For services this amounts to around 380 PJ.
- The consumption of traditional biomass for cooking and heating is expected to decrease.
- In the transport sector an increased penetration of biofuels and continued uptake of hybrid vehicles is assumed. Biofuels reach 7,180 PJ per year by 2030 (total world energy demand for transport: 124,680 PJ, 73% from road transport).

Energy efficiency

- Energy efficiency improvements are only implicated by changes in energy demand and CO_2 emissions, the scenario does not contain specific quantitative data on energy efficiency.
- In the transport sector, some quantitative data on energy efficiency on a sub-sector level is provided indirectly, reporting carbon intensity.

- Energy demand and CO_2 efficiency are considered in higher detail; results are reported for three regions sector-wise as well as per fuel.

End-use efficiency

- Increase in primary energy demand between 2006 and 2030 is highest for Other Major Economies (70%), followed by Other Countries (35%) and is limited to 4% in OECD+ countries.
- In comparison to the reference, decrease in coal demand is highest among the fossil energy sources. Annual average growth is 0.7% until 2030 as compared to 2% in the reference. Mainly responsible for this drop are more efficient coal firing plants, introduction of energy efficiency policies as well as capacity additions in nuclear and renewable technologies in Other Major Economies.
- Oil demand rises to 95mb/d in 2020 and to 98mb/d in 2030. More than half of the absolute savings in world oil demand occur in the transport sector in OECD+ countries and in the group Other Major Economies.
- Energy efficiency standards in the building sector reach today´s OECD level in Other Major Economies in 2030. As a result, residential energy consumption is reduced by 5,650 PJ compared to the reference.
- In 2030 energy intensities in the group of “Other Countries” are approximately twice as high as energy intensities in OECD+ and Other Major Economies. OECD+ countries and Other Major Economies in 2030 show comparable energy use per unit of GDP.
- Future GDP projections are based on IEA figures for 2006, and follow the growth projections provided in the WEO 08.

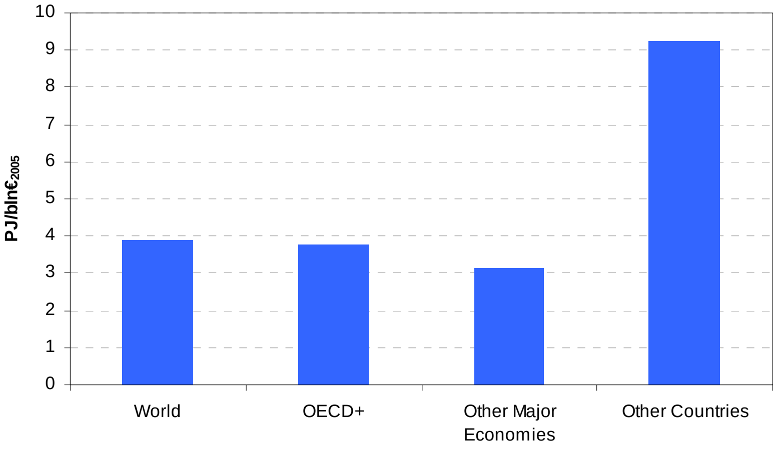


Figure 2-9: IEA WEO 2008 550, Energy intensity of economies 2030

Energy supply efficiency

- Conversion efficiencies of power plants on a global scale increase slightly between 2020 and 2030, resulting in a lower energy supply loss factor. A regional differentiation cannot be derived from the data provided in the scenario.

- Coal demand until 2030 decreases most significantly as compared to the reference. Two-thirds of these reductions are achieved due to more efficient power plants in Other Major Economies, mainly in China and India.

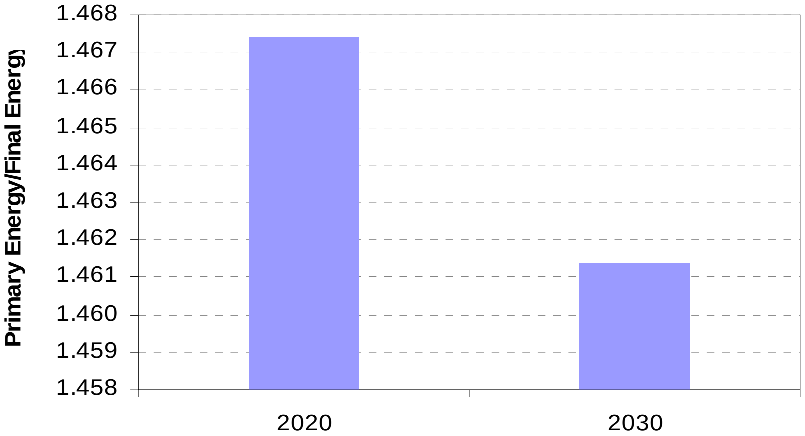


Figure 2-10: IEA WEO 2008 550, Global energy supply loss factor

Carbon intensity

- Carbon intensity declines by 2.6% per year between 2006 and 2030. The average quantity of CO_2 emitted per PJ of fossil energy used worldwide is projected to decrease from 70.22 Gt CO_2 in 2006 to 0.0507 Mt CO_2 in 2030.
- 63% of CO_2 emission reductions (compared to the reference) stem from efficiency improvements in the end-use sector and in power generation.
- CO_2 emissions from transport grow by 27%, reaching 8.3 Gt in 2030. Overall, transport accounts for one-third of the global increase in emissions from energy-related sources.
- Energy-related CO_2 emissions from OECD+ countries are one-fifth lower in 2030 than in 2006. Other Major Economies see an increase of 60% from 2006 to 2030.
- In the transport sector, more efficient OECD+ countries improve their fleet efficiency by 34% until 2030 (106g CO_2/km in 2030), less efficient OECD+ countries see an improvement of almost 40%, resulting in a fleet efficiency of 130g CO_2/km in 2030. Other Major Economies reach a level close to the average reached by OECD+ countries while Other Countries arrive at a less stringent standard of 135g CO_2/km in 2030.
- In the buildings sector, biggest reductions in emissions occur in OECD+ countries, while Other Major Economies are projected to have growing emissions throughout the projection period, and total emissions in Other Countries grow at a rate of 0.9% per year between 2006 and 2030.

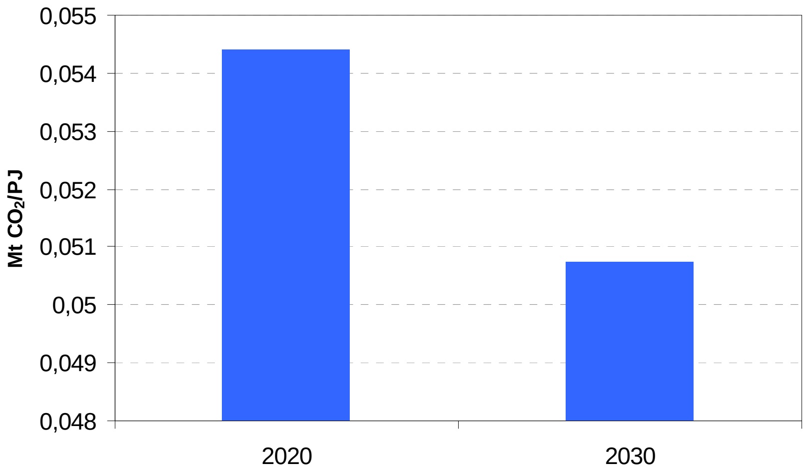


Figure 2-11: IEA WEO 2008 550, Carbon intensity of primary energy demand

World Energy Outlook: 450 Policy Scenario

Scenario frame

- Key drivers: Stabilisation of the GHG concentration level at 450 ppm with the aim of limiting a rise in temperature to 2 °C. Implications and results of a respective, plausible post-2012 international climate-policy framework, regarding policies and measures that are currently considered.
- Energy-related CO_2 emissions are presumed to fall sharply after 2020. Emissions peak at 32.5 Gt in 2020, then decline to 25.7 Gt in 2030. The overshooting of the target level is explained with slow rates of capital-stock turnover in the power sector.
- Following policy mechanisms are combined:
  - Cap-and trade systems (binding emissions caps for OECD+ countries for the power generation and the heavy industry sector)
  - International sectoral agreements (for the iron/steel/cement/vehicle- and aircraft-manufacturing sector in OECD+ countries and the group of 'other major economies')
  - National policies and measures (for 'other countries' in all sectors, for major economies (excl. OECD+) in the power generation and iron/steel/cement industry sector and for the buildings sector across all countries)

  (See "550 Policy Scenario", with one extension: the 'other major economies' group is presumed to participate in the cap-and-trade regime from 2020 with binding emission caps.)
- The group of 'other countries' implements only national policies, but can participate in the cap and trade systems by generating and selling emissions credits.

Population projections

- See "550 Policy Scenario".

GDP projections

- See "550 Policy Scenario".

Cost assumptions and economic implications

- Specific technology costs: see "550 Policy Scenario"
- The group of 'other major economies' is expected also to participate in the cap-and-trade system. The carbon price for these countries is assumed to converge the one for OECD+ countries, which is estimated to reach €136.6/t CO_2 in 2030.
- The high carbon prices are supposed to drive an investment of €508 billion for CCS technologies (including retrofitting).
- Additional investment (relative to the Reference Scenario) amounts to €7 trillion,

comprising additional €2.7 trillion for power plants and €4.3 trillion for efficiency measures over the period 2010-2030.

- The necessary investment at average equates to 0.55% of world GDP.
- In the period 2021-2030 investment is presumed to be much higher than in the first decade. This also applies to investment in energy efficiency, especially in buildings. Additional annual individual expenditure by individuals in OECD+ countries is €114 in the projection period's last decade.
- Fossil fuel savings: €4.4 trillion. Relative to the 550 Policy Scenario energy savings are larger, but electricity prices are assumed to be higher in consequence of increasing carbon prices.

Primary energy

- Primary energy in the 450 Policy Scenario is expected to grow at an average of 1.4% per year until 2020, reaching about 600,000 PJ in 2030, then growth levels offs to 0.1% per year between 2020 and 2030. On average, primary energy demand rises at annual 0.8% (2006-2030).
- Fossil fuels maintain their increasing path until 2020, then contributing around 468,000 PJ per year. In the following decade fossil fuels decline, at the end of the period they amount to annual 404,000 PJ. The input of coal decreases most at an average of 4.2% per year in that time. Oil as the fossil fuel contributing the largest share peaks at annual 190,500 PJ in 2020, in 2030 it provides 180,400 PJ per year.
- Over the period 2007-2030 new capacities of plants fitted with CCS in the amount of 348 GW are assumed to be built.
- Nuclear energy is increasing at 2.7% per year on average over the period 2006-2030, capacity additions reach 391 GW. Its total amount in primary energy demand peaks at 57,000 PJ in 2030.

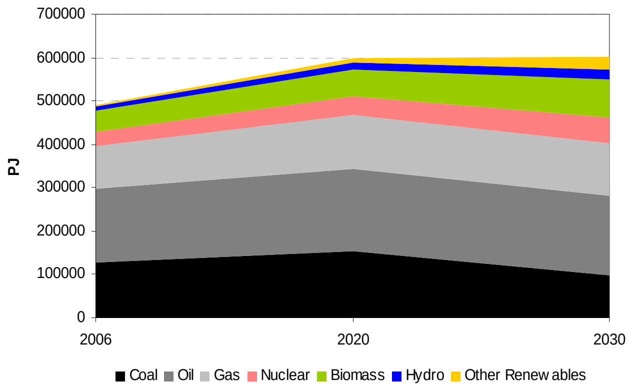


Figure 2-12: IEA WEO 2008 450, Primary energy demand

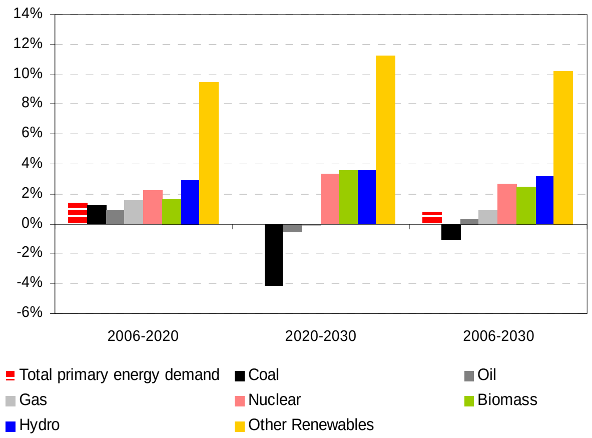


Figure 2-13: IEA WEO 2008 450, Average annual change rates of total primary energy demand

Renewable energy's share in primary energy supply

- The contribution of renewable energy is particularly expanding in the period 2020-2030. Starting from annual 52,400 PJ in 2006, they contribute 72,400 PJ in 2020 and peak at 117,300 PJ in 2030.
- Biomass is increasing at an average of 2.5%/yr (2006-2030). In 2030, it amounts to 88,700 PJ per year, 14.8% of total primary energy supply.
- The contribution of hydro energy is reaching 23,200 PJ/yr in 2030, its annual average growth rate is 3.2%.
- The group of "Other Renewables" has got the highest average annual growth rate of 10.2% per year. Their share reaches 4.8% of total primary energy supply.

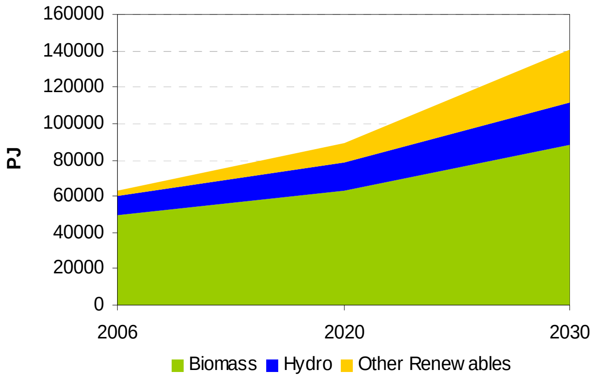


Figure 2-14: IEA WEO 2008 450, Total contribution of renewable energy to primary energy supply

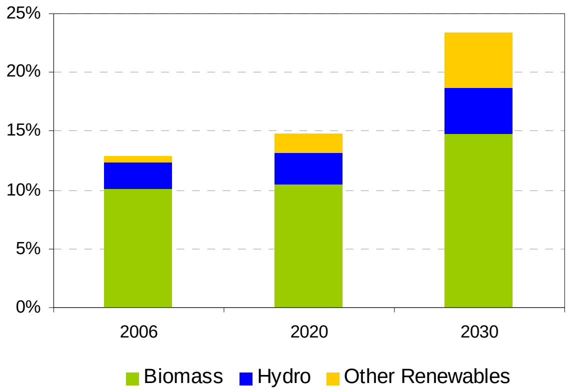
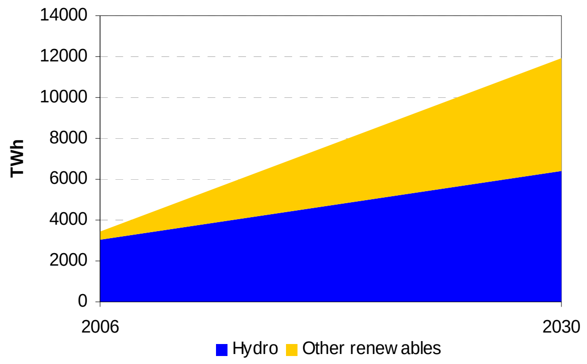


Figure 2-15: IEA WEO 2008 450, Share of renewable energy in primary energy supply

Renewable energy's share in electricity generation

- Total electricity production is assumed to increase from 19,000 TWh per year in 2006 to 29,000 TWh in 2030.
- Renewable energy's contribution is also considered to rise from around 3,500 TWh in 2006 to 12,000 TWh per year in 2030, which is 41.1% of total electricity generation.
- Hydro energy: peaks at 6,400 TWh per year in 2030, 22.2% of total electricity generation. Average annual growth rate is 3.2% per year in the period 2006-2030.
- Other renewables than hydro: reach 5,500 TWh per year in 2030, 18.9% of total electricity generation. Average annual growth: 11.2%.
- For Europe it is projected that in 2030 39% of electricity is generated from renewable sources.



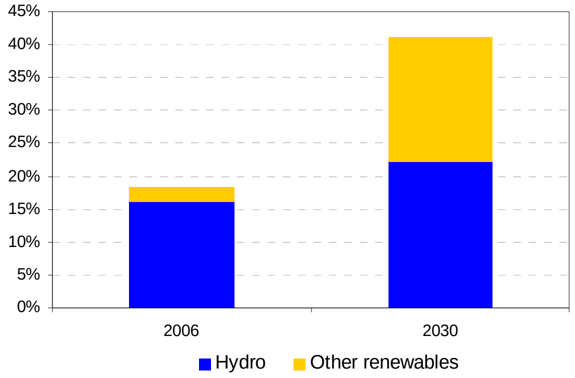


Figure 2-16: IEA WEO 2008 450, Total contribution of renewable energy to electricity generation

Figure 2-17: IEA WEO 2008 450, Share of renewable energy in electricity generation

Renewable energy for heat and transport

- For the group of OECD+ countries and the ‘other major economies’ an uptake of renewable heating installations (excluding biomass) is expected to reach 4190 PJ per year in 2030.
- In the transport sector biofuels are expected to contribute over 10,050 PJ per year in 2030. The majority is expected to be made up of second-generation biofuels.
- An off-take of electric vehicles and plug-in hybrids is assumed to result in an increased demand for electricity in the transport sector of 2100 PJ per year in 2030 compared to the 550 Policy Scenario (no absolute figures available for comparison).

Energy efficiency

- As well as the WEO 08 550 scenario the WEO 08 450 scenario represents only results in terms of carbon intensity. Energy efficiency is only indirectly implicated in terms of CO_2 emission reductions.
- While the scenario provides some data for end-use efficiency, the supply side is almost entirely neglected.
- In general, only few qualitative data is provided and figures are mostly reported relatively to the WEO 08 550 scenario.

End-use efficiency

- Energy efficiency improvements result in reduced energy demand across all sectors.
- The level of coal demand in 2030 is below current coal demand. 60% of the reductions in fossil fuel use (relative to the reference) are reductions in coal demand. Two-thirds of the reductions occur in Other Major Economies, mainly in the power sectors in China and India.
- World electricity generation in 2030 falls by around 4% relative to the 550 Policy Scenario due to efficiency gains.

- In the industry sector energy efficiency improvements in Other Major Economies lead to most of the reductions in CO_2 emissions (4.3 Gt in 2030). In OECD+ countries CCS is responsible for most savings.
- The building sector sees a wide range of energy efficiency improvements of appliances and machinery, including a worldwide shift to compact fluorescent lamps and other best available practices. Global electricity use is reduced by 1,850 TWh compared to the reference scenario in 2030, mainly because of rising electricity prices. About 90% of the absolute savings are generated in OECD+ countries and Other Major Economies.

Energy supply efficiency

- For Other Major Economies policies to improve efficiency of fossil fuel plants are assumed, leading to a greater number of high-efficient, ultrasupercritical and integrated gasification combined cycle coal plants, rather than conventional subcritical units.

Carbon intensity

- The indicator for carbon intensity of primary energy demand in 2030 is reduced to 42,743 t CO_2/PJ.
- Global energy-related CO_2 emissions peak in 2020 at 32.5 Gt and then decline to 25.7 Gt in 2030 as a result of strong and broad policy action. Other Major Economies are responsible for most savings.
- In Other Major Economies, CO_2 emissions peak in 2020 and then decline steeply as a result to the introduction of a carbon price to 12 Gt/yr in 2030. Emissions in OECD+ countries are in steep decline, resulting in 3 Gt/yr in 2030, or 30% less than in 1990.
- CO_2 emissions from the power sector in 2030 fall to 8.3 Gt, 27% lower than in 2006. Improved energy efficiency, employment of the CCS-technology, as well as addition of capacity in nuclear and renewable power generation are responsible.
- In the industry sector CO_2 intensity is one-third lower worldwide by 2030 in comparison to the reference scenario. With a 60% decrease in emissions, Other Major Economies are the main contributor to the reductions.
- In the building sector the reduction in electricity use leads to a decrease in CO_2 emissions by 4.5 Gt in 2030 compared to the reference. Additional 0.9 Gt are saved from fossil fuel consumption. Biggest savings occur in OECD+, where emissions will be 46% lower in 2030 than in 2006.
- The transport sector saves 1.1 Gt of CO_2 emissions until 2030 as compared to the reference. Average fleet efficiency in OECD+ in 2030 is 90 g CO_2/km, 110 g CO_2/km in Other Major Economies and 122 g CO_2/km in other countries.
- As for the 550 policy scenario, future GDP projections are based on IEA figures for 2006, and follow the growth projections provided in the WEO 08.

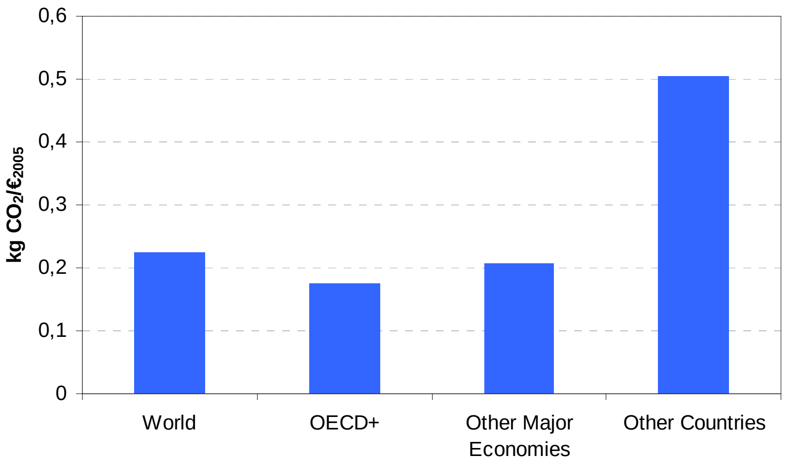


Figure 2-18: IEA WEO 2008 450, Carbon intensity of economies 2030

2.4 EREC/Greenpeace: Energy [R]evolution 2008

Key scenarios

Reference Scenario:	Based on the IEA's Reference Scenario from 'World Energy Outlook 2007'. Main characteristics are the consideration of already accepted policies and measures and the freezing of any further development. As the period 2030-2050 is not covered by the IEA's Reference Scenario, it has been extended by extrapolating its key macroeconomic indicators.
Energy [R]evolution Scenario:	Exploration of a sustainable, nuclear-free path to half CO_2 emissions and limit an increase in global temperature to 2°C. Economic growth is to be decoupled from the consumption of fossil fuels.

Energy [R]evolution

Scenario frame

- Key drivers: Reduction of energy-related CO_2 emissions to around 10.6 Gt per year by 2050 (21 Gt in 2030) to stabilise GHG concentration levels at 450 ppm and limit an increase in global temperature to 2°C. Phase out of nuclear energy until 2050.
- Three step approach,
  - Exploitation of the potential for energy efficiency
  - Use of all cost-effective renewable energy sources for heat and electricity generation and production of biofuels. Enhancing decentralised energy systems like cogeneration.
  - Energy-efficient transport: electric vehicles, alternative fuels, segment split, modal split
- Consideration of sustainability criteria: Greater equity in the use of sources and respect for natural limits of the environment

Population projections

- Population projections in the Energy [R]evolution Scenario are as the IEA's WEO 2007 based on UNDP projections from 2007.

Projections for 2005-2030:

- Population growth slows from 1.1% per year in 2005-2015 to 0.9% in 2015-2030.

- The developing countries are expected to account for almost all the increase in world population; as a consequence, the share of the world's population living in developing regions will increase from 76% (2007) to 80% (2030). China's population is thereby assumed to grow at a slower rate than India's, by 2030 it will be caught up.
- Population in the transition economies is considered to decline; population in OECD countries is expected to grow by an average of 0.4%, whereas most of the increase is due to net immigration in North America and Europe.
- The increase of world population is supposed to take place in urban areas, rural populations will decline.

Projections for 2030-2050:

- Between 2030 and 2050, population in China is expected to decline by annual 0.2%, reaching 1,420 million by 2050 (15% of world population). India's growth in population levels off to 0.5% per year. In 2050, 1,660 million people are assumed to live in India, that is 18% of world population.
- Africa's population is expected to grow by an annual 1.4% in the period 2030-2050. By 2050, 2,000 Million people will be living in Africa, that is 22% of projected world population.
- Population in OECD Pacific and Transition Economies is expected to decrease at annual 0.5%.
- During 2030 and 2050 world population growth slows to the annual rate of 0.5%. In 2050, 9,170 million people will be living in the world.

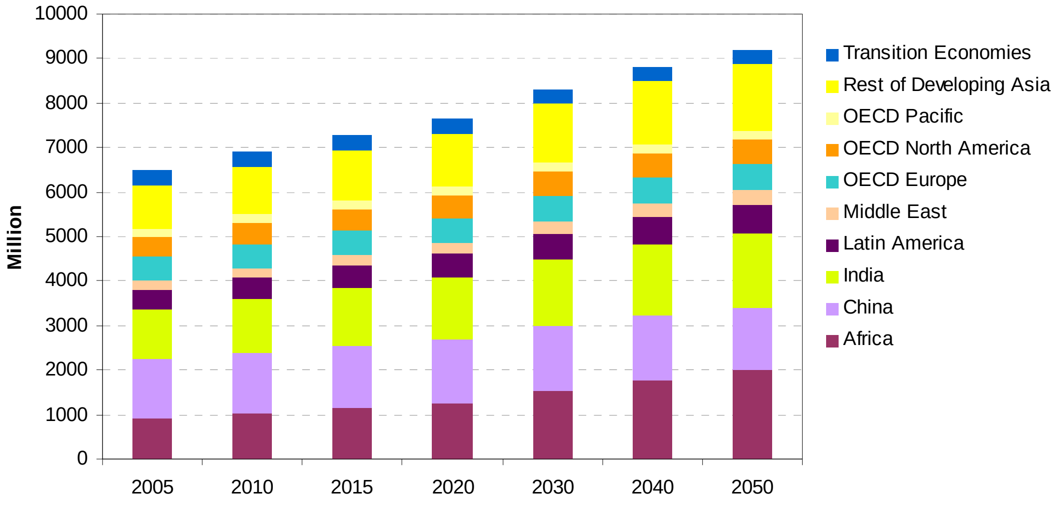


Figure 2-19: GP/EREC 2008 E[R], Population

GDP projections

- GDP Projections are based on IEA's calculation on GDP development in the World Energy Outlook 2007.
- The projection for the period 2030-2050 is based on own assumptions made by the Energy [R]evolution team.

- On average, GDP growth is 3.3% over the period 2005-2050. The growth rates decline from a yearly 4.6% (2005-2010) to 2.9% in the time from 2040-2050.
- China and India are expected to report the highest growth rates. However, as their economies mature, the GDP development eases over the projection period. Coming from a yearly increase of 9.3% in 2005-2010 China's GDP growth is assumed to fall to 5.7% per year in the following decade. India's economy is projected to have a more stable GDP growth: In the period 2005-2010 it is 8% per year, in the following decade slowing down to 6.2%, then overtaking China's economy. This trend continues in the following decades.
- The OECD region is assumed to grow at an average 1.8% per year over the whole projection period. OECD North America is growing fastet at 2.2% per year.
- No absolute figures for GDP provided.

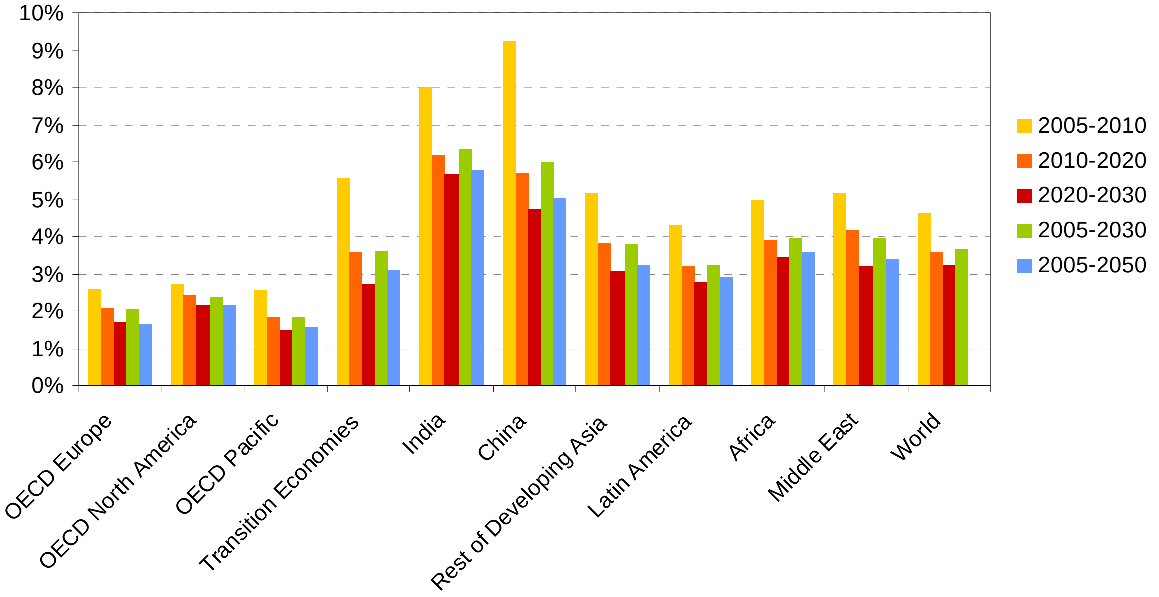


Figure 2-20: GP/EREC 2008 E[R], Annual GDP growth rates (PPP)

Cost assumptions and economic implications

Table 2-4: GP/EREC 2008 E[R], Carbon price assumptions

	2010	2020	2030	2040	2050
Carbon price (€/tCO_2), Kyoto Annex B	8.0	16.1	24.1	32.2	40.2
Carbon price (€/tCO_2), Kyoto Non-Annex B		16.1	24.1	32.2	40.2

Table 2-5: GP/EREC 2008 E[R], Investment costs for renewable energy

	2005	2010	2020	2030	2040	2050
Wind Onshore (€/kW)	1210	1100	950	890	880	880
Wind Offshore (€/kW)	3020	2800	2090	1770	1600	1520
Geothermal, CHP (€/kW)	14070	10490	7640	6390	5570	5070
Geothermal, electr. only (€/kW)	14020	12090	9290	8160	7630	7220
PV (€/kW)	5310	3020	1330	1030	920	870
CSP (€/kW)	6050	5100	4210	3560	3510	3470

Table 2-6: GP/EREC 2008 E[R], Fossil-fuel price assumptions

	2005	2010	2015	2020	2030	2040	2050
Crude Oil Imports (€/barrel)	42.2	80.4	84.4	88.4	96.5	104.5	112.5
Natural Gas Imports (€/GJ)							
US imports	4.6	9.2	10.2	11.8	14.8	17.6	19.8
European imports	4.7	8.0	9.2	10.7	13.8	16.6	18.5
Asia imports	4.5	9.2	10.1	11.8	14.7	17.6	19.8
Hard Coal Imports (€/tonne)		114.7	134.4	156.3	202.1	250.1	288.6

- Total investment volume for the period 2005-2030: €11.8 trillion. Compared with the investment costs in the reference scenario this is an additional €2.7 trillion.
- Annual average investment: under 1% of global GDP.
- Electricity sector: 80% of investment goes to renewable energy (€7.2 trillion, 2004-2030), the fossil fuel share is focused mainly on combined heat and power (CHP) and efficient gas-fired power plants.
- Annual average investment into the power sector: €470 billion (2005-2030).
- Fuel savings between 2005 and 2030: €15 trillion.
- Annual fuel savings: €600 billion.

Primary energy

- In the overall view, primary energy demand's growth in the Energy [R]evolution Scenario is marginal, at average 0.05% per year between 2005 and 2050. Starting from 475,000 PJ/yr in 2005, in 2015 demand peaks at 549,000 PJ/yr. By 2050, primary energy demand decreases to 481,000 PJ/yr due to improving energy efficiency.
- Fossil fuels decline after 2015 at an average 2.1% per year.
- In 2050, crude oil is assumed to provide 84,000 PJ per year, natural gas' contribution is expected at 74,600 PJ, and hard coal's contribution at 51,400 PJ per year. In total, fossil fuels provide 210,000 PJ per year.
- The use of CCS is not considered in the Energy [R]evolution Scenario.
- Nuclear power and lignite are phased out until 2050.
- Renewable energy is growing at an average of 3.4% per year from 2005 until 2050. It is assumed to contribute 270,900 PJ per year by the mid-century.

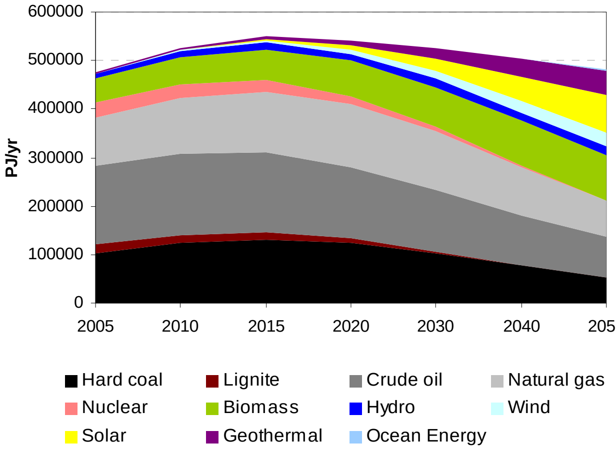


Figure 2-21: GP/EREC 2008 E[R], Primary energy demand

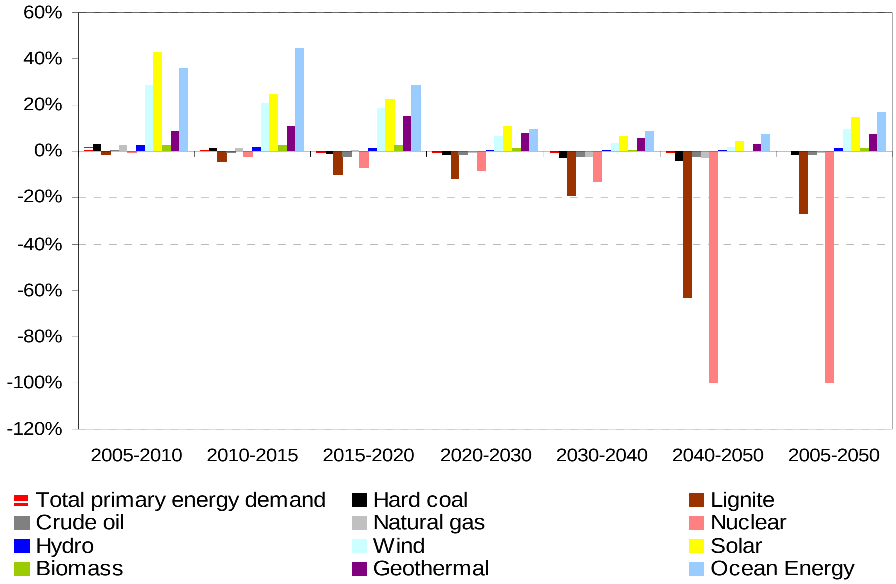


Figure 2-22: GP/EREC 2008 E[R], Average annual change rates in primary energy demand

Renewable energy’s share in primary energy supply

- Renewable energy plays a major role in the Energy [R]evolution Scenario. At the end of the projection period it contributes 270,900 PJ per year. That is 56.3% of total primary energy supply.
- Biomass in 2050: 94,800 PJ per year (19.7% of total primary supply)
- Solar energy in 2050: 76,400 PJ per year (15.9% of total primary supply)
- Geothermal in 2050: 50,100 PJ per year (10.4% of total primary supply)
- Annual change rates are highest at ocean energy. It grows with an average of 17.1% per year between 2005 and 2050. Solar energy has a rate of 14.5%, wind of 10.1% and geothermal of 7.5%.

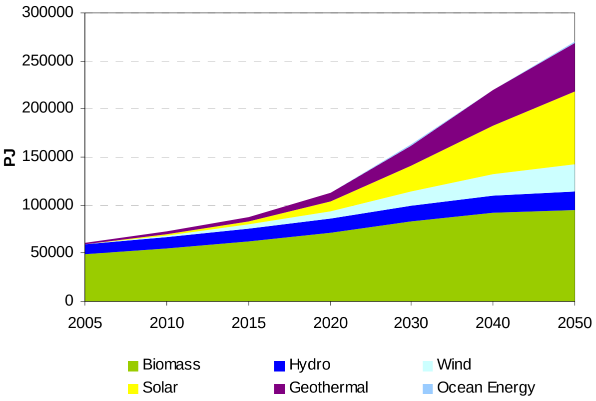


Figure 2-23: GP/EREC 2008 E[R], Total contribution of renewable energy to primary energy demand

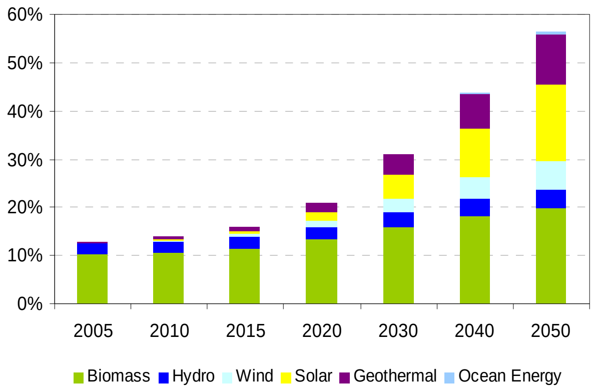


Figure 2-24: GP/EREC 2008 E[R], Share of renewable energy in primary energy demand

Renewable energy's share in electricity generation

- In 2050, renewable energy is generating 28,600 TWh per year. This is 77.1% of total electricity generation. Over the period 2005-2030 the average increase of total generation by renewables is 4.9% per year. (2030: 14,000 TWh/yr, 48.1% of total, 2005-2030: +5.9%/yr).
- Installed renewable capacity: 9,100 GW (2050) resp. 4,540 GW (2030).
- Until 2020, hydro and wind are major contributors, in the following decades complemented by biomass, PV and CSP.
- Hydro and CSP, combined with efficient heat storage, are important elements as non-fluctuating renewable energy sources.
- Hydro: only slightly increasing up to 5,350 TWh per year in 2050, 14.4% of total electricity generation (2030: 4,430 TWh/yr, 15.2% of total).
- Biomass: amounts to 3,530 TWh per year in 2050, 9.5% of total electricity generation. Its average annual growth rate declines from 8.6% (2005-2030) to 3.4% (2030-2050). By 2030: 1,830 TWh/yr, 6.3% of total.
- Wind: reaches 7,740 TWh per year in 2050, 20.9% of total electricity generation. Increases decline from 16.2% per year between 2005 and 2030 to 2.9%/yr for the following two decades. By 2030: 4,400 TWh/yr, 15.1% of total.
- Solar PV: amounts to 4,300 TWh per year in 2030, 11.7% of total electricity generation. Annual growth rate declines from 30.6% (2005-2030) to 6% (2030-2050). By 2030: 1,350 TWh/yr, 4.6% of total.
- CSP: contributes 5,260 TWh per year in 2050, 14.2% of total electricity generation. Its growth rate declines from 32.1%/yr over 2005-2030 to 7.8%/yr from 2030 to 2050. By 2030: 1,170 TWh/yr, 4% of total.
- Geothermal: reaches 1,700 TWh per year in 2050, 4.6% of total electricity generation. Annual increase: 10.4% for 2005-2030 resp. 4.7% for 2030-2050. By 2030: 680 TWh/yr, 2.3% of total.

- Ocean energy: contributes 680 TWh in 2050, 1.8% of total electricity generation. Its average growth rate per year is 25.1% (2005-2030) resp. 7.8% (2030-2050). By 2030: 150 TWh/yr, 0.5% of total.

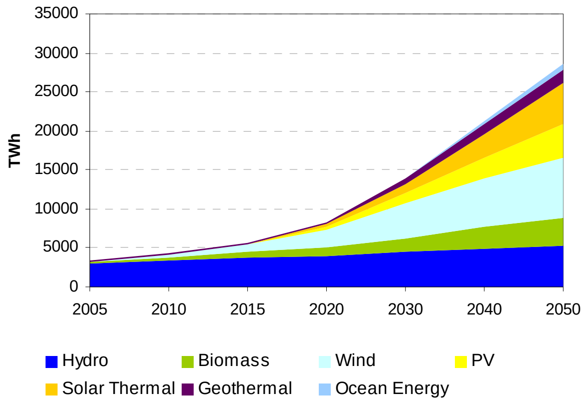


Figure 2-25: GP/EREC 2008 E[R], Total contribution of renewable energy to electrictiy generation

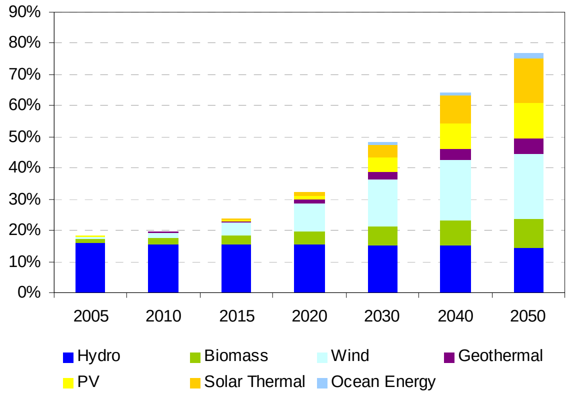


Figure 2-26: GP/EREC 2008 E[R], Share of renewable energy in electricity generation

Renewable energy for heat and transport

- Total heat supply rises to 162,400 PJ/yr in 2030 and 161,700 PJ/yr in 2050.
- The lack of district heating networks is considered to be a structural barrier to the large scale utilisation of geothermal and solar thermal energy.
- The contribution of renewable energy increases by 2.5% per year over the period 2010-2050. By 2050 it amounts to 114,500 PJ/yr, which is 71% of total heat supply (2030: 73,100 PJ/yr, 45% of total).
- In the period 2010-2050 solar collectors are growing fastest at 10% per year, contributing 41,900 PJ/yr in 2050 (25.9% of total). Geothermal energy is increasing at 8.4% per year, ending up at 25,000 PJ/yr in 2050. Biomass peaks at 47,800 PJ/yr by 2050, 29.5% of total heat supply. Growth rates level off.

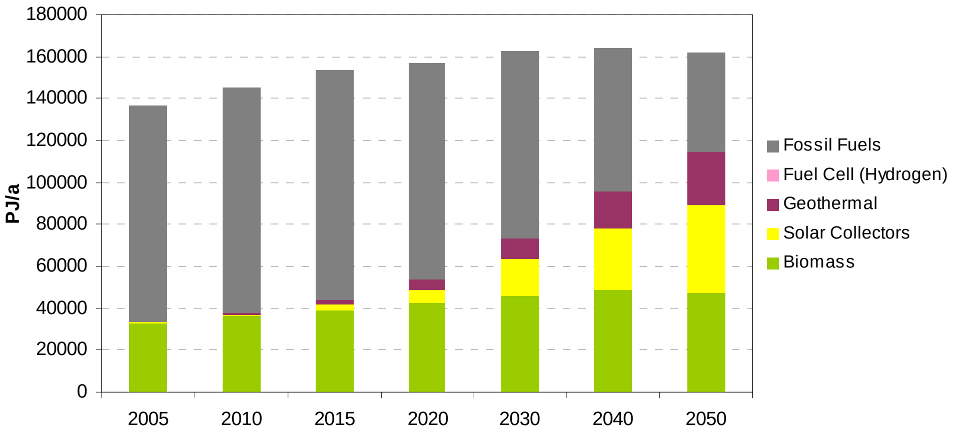


Figure 2-27: GP/EREC 2008 E[R], Total heat supply

- Starting from 83,900 PJ/yr in 2005 final energy demand for transport peaks at 93,900 PJ/yr in 2015 and goes back to 83,300 PJ/yr in 2050. Oil products are increasingly replaced, they remain contributing 57.3% in 2050.
- Electric vehicles powered by renewable sources are considered to play an increasingly important role from 2020 onwards.
- Biofuels, renewable electricity and hydrogen (which is assumed to be derived completely from renewable electricity for transport) provide 29,600 PJ/yr by 2050. This equates to 35.6% of total energy demand for transport and an average annual change rate of 7% between 2010 and 2050.
- By 2050, renewable electricity amounts to 15,600 PJ/yr (18.7% of total). Biofuels provide 12,800 PJ/yr (15.3% of total) and hydrogen is delivering 1,280 PJ/yr.
- By mid-century electricity (renewable and other) will provide 23.6% of the transport sector's total energy demand.

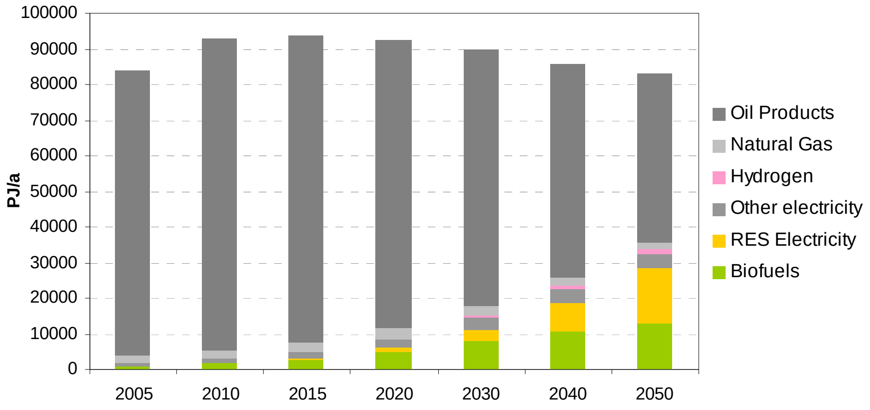


Figure 2-28: GP/EREC 2008 E[R], Total final energy demand for transport

Energy efficiency

- The [R]evolution scenario emphasises the role of energy efficiency and is characterised by significant efforts to fully exploit its large potential. Assumptions are based on current best practice and technologies which will become available in the future. While assuming continuous innovation, also implementation constraints in terms of costs and other barriers are taken into account.
- Energy efficiency improvements are reported qualitatively and quantitatively, region-wise as well as on a sector-basis. Some data is also provided for single specific measures.
- Next to consideration in the scenario, the Energy [R]evolution report comprises an entire chapter focusing on the technical potential for energy efficiency improvements, future technologies and implementation possibilities. Special attention is paid to energy efficiency in the transport sector.

End-use efficiency

- Active policy and technical support for energy efficiency measures will lead to a reduction in energy intensity of almost 73%. As a result, absolute primary energy demand increases only slightly – from currently 474,900 PJ/yr (2005) to 480,860 PJ/yr in 2050.
- Whilst taking into account implementation constraints for energy efficiency measures in terms of costs and other barriers growth in final energy demand can be limited to 28% between 2005 and 2050 compared to 95% in the reference.
- Current per capita demand for heat supply is reduced by 30% in spite of improving living standards.
- Final energy demand in the industry sector grows by 32% between 2005 and 2050. In the same time span energy demand grows by 11% in the transport sector and by 38% in the buildings and agriculture sector.
- Most important energy saving options are efficient passenger and freight transport as well as improved heat insulation and building design.
- The economies of India and China are expected to grow especially fast up to 2050. Consequently, the large potential for employment of energy efficient technology results in respectively low energy intensities.
- Future GDP projections are based on IEA 2006 statistics, and follow the growth projections provided in the [R]evolution scenario (until 2030 growth figures coincide with figures stated in the reference scenario of IEA's World Energy Outlook 2007, subsequently they are extrapolated).

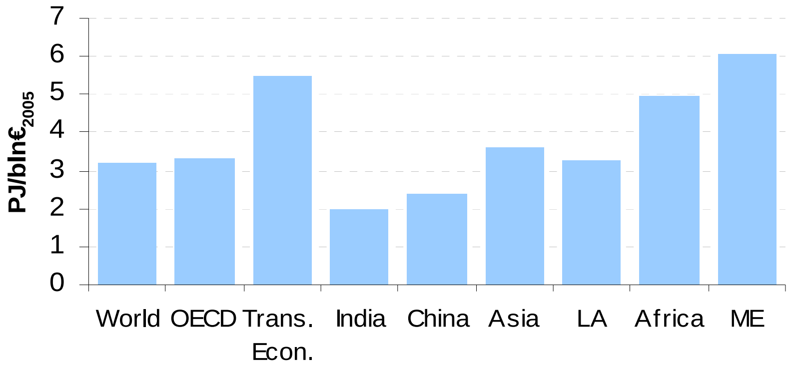


Figure 2-29: Greenpeace/EREC 2008 E[R], Energy intensity of economies 2030

Energy supply efficiency

- Efficiency in energy conversion improves gradually over the decades.
- The supply system´s energy conversion efficiency is improved to a large extent by growing use of CHP installations, which increasingly use natural gas and biomass. In the long term, further expansion of CHP is limited due to decreasing demand for heat and the large potential for producing heat directly from renewable energy sources.

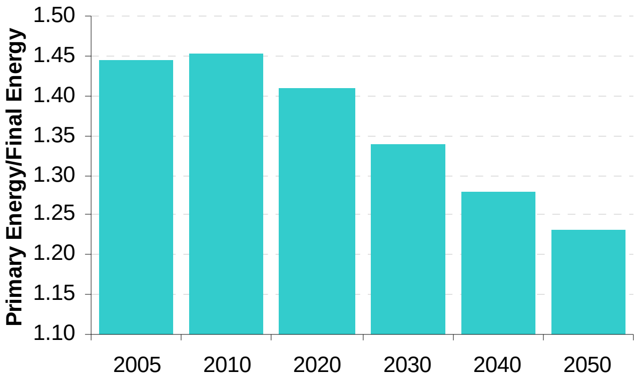


Figure 2-30: Greenpeace/EREC 2008 E[R], Energy supply loss factor

Carbon intensity

- Total CO_2 emissions decrease from 24,350 million tonnes in 2005 to 10,600 million tonnes in 2050.
- With a share of 35% of total CO_2 emissions in 2050, the power sector remains the largest source of emissions followed by the transport sector.
- Annual per capita emissions will drop from 3.7 tonnes to 1.15 tonnes. OECD countries will be able to reduce their CO_2 emissions by about 80%. The USA reduce their per capita CO_2 emissions from 19 tonnes now to 3 tonnes by 2050. For the EU-27 countries, per capita emissions will fall from 8 to under 2 tonnes per capita. Developing countries such as the Philippines manage to keep per capita emissions at their current level of about 1 tonne of CO_2 until 2050, while maintaining economic growth.
- In 2050, coal (followed by oil) is by far the largest source of CO_2, mainly from coal-fired power stations in China and India and other developing countries.
- Together, China and India are responsible for almost half of the CO_2 emissions in 2050, while all OECD countries together will have a share of about 22%.

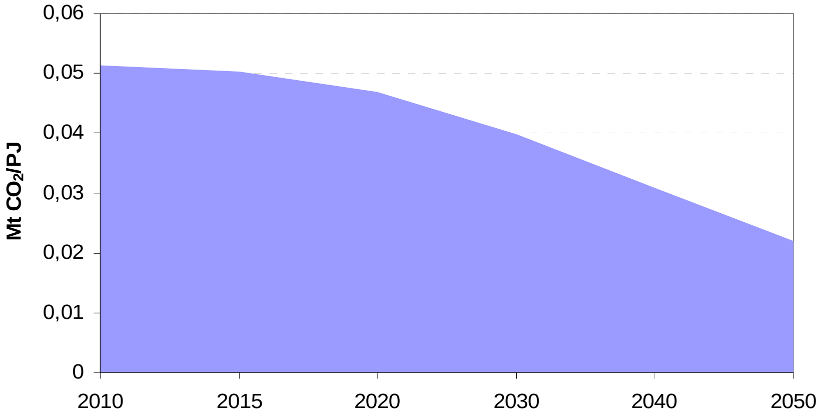


Figure 2-31: Greenpeace/EREC 2008 E[R], Carbon intensity of primary energy demand

2.5 International Energy Agency: Energy Technology Perspectives 2008

Key scenarios

Baseline Scenario:	Consistent with the World Energy Outlook 2007 Reference Scenario for the period 2005 to 2030. For the period 2030 to 2050 trends have been extended with the Energy Technology Perspectives model analysis.
ACT Scenarios:	Aim to reduce CO_2 emissions in 2050 back to 2005 levels.
BLUE Scenarios:	Target of a 50% reduction from current levels in CO_2 emissions by 2050.

For scenario groups ACT & BLUE five variants have been developed:

'Map' (contains relatively optimistic assumptions for all key technology areas)
'High nuclear'
'No CCS'
'Low renewables'
'Low end-use efficiency gains'

ETP BLUE Map Scenario

Scenario frame

- Key drivers: 50% reduction from current levels in CO_2 emissions by 2050; combined with deep cuts of other GHG emissions the scenario is supposed to be consistent with a global rise in temperatures of 2°C-3°C. CO_2 emissions in 2050 amount ot 14 Gt per year.
- Consistency with the World Energy Outlook 2007 450 Stabilisation Case for the period until 2030.
- Least-cost scenario analysis: Potential contributions that technologies in electricity generation, road transport, buildings and appliances, and industry can make to improve energy security and to reduce the environmental impacts of energy provision and use.
- Deployment of all technologies involving costs of up to €156 per tonne of CO_2 saved when fully commercialised in the case of optimistic assumptions about the progress of key technologies. If this fails to reach expectations, costs are expected to rise to €390 per tonne. The average cost of the technologies needed for BLUE Map is in the range of €30 to €91 per tonne of CO_2 saved.
- For the transportation sector BLUE has three additional variants besides the Map scenario: EV success with optimistic assumptions for electric vehicles, FCV success (optimistic for H_2 fuell cell vehicles) and a conservative scenario.

Population projections

- World population is estimated to grow at an average annual rate of 0.8% to 9,190 million in 2050.
- At that time India (1,660 million) with having an average increase of 0.9% per year is assumend to have more inhabitants than China (1,410 million), which has an annual average growth rate of 0.15% over the whole period and in total even registers a decline from 2030 to 2050.

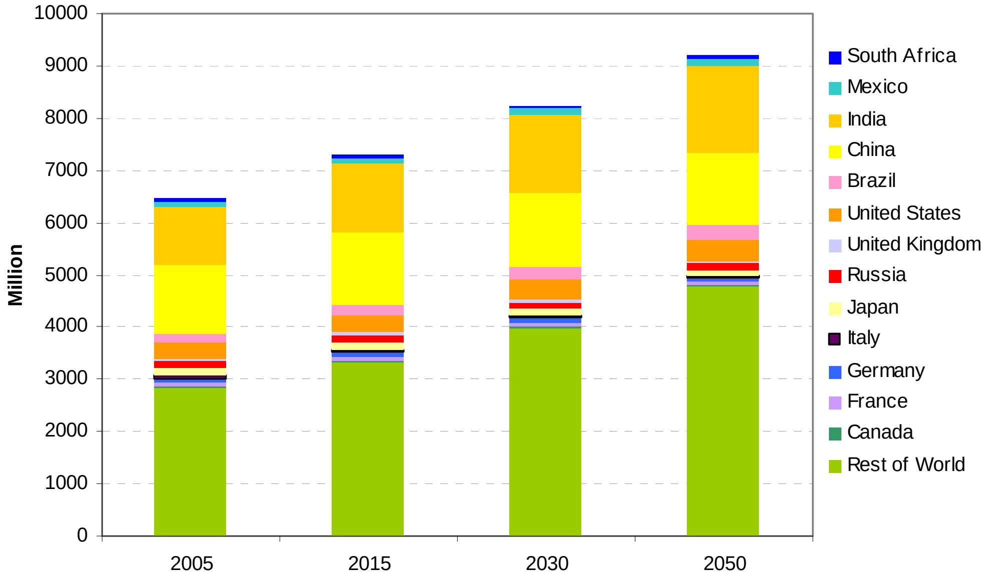


Figure 2-32: IEA ETP 2008, Population

GDP projections

- Average annual world economic growth rate: 3.3% between 2005 and 2050.
- The pattern of economic growth is considered to change after 2030 as population growth is estimated to slow down and the economies of developing countries are assumed to mature. The average annual growth rate is expected to decline from 4.2% per year in the period 2005-2015 to 2.6% per year between 2030 and 2050.
- No absolute figures for GDP provided.

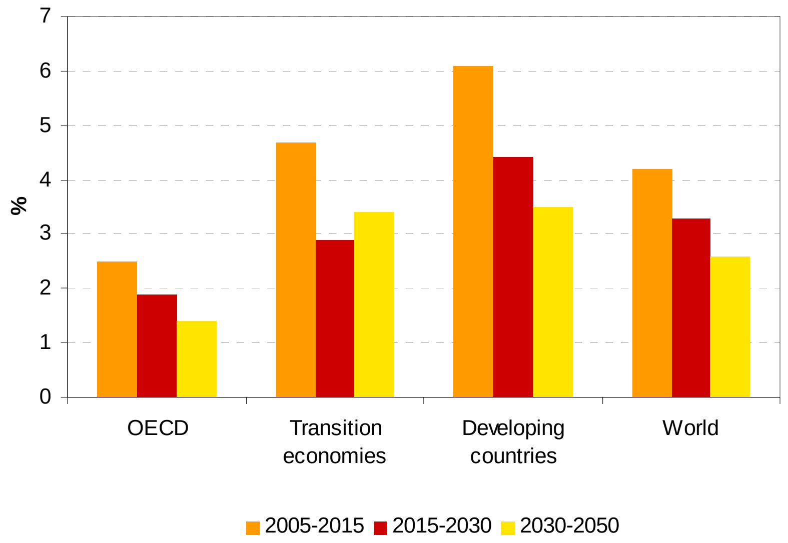


Figure 2-33: IEA ETP 2008, Annual GDP growth rates (PPP)

Cost assumptions and economic implications

Table 2-7: IEA ETP 2008 BLUE Map, Investment costs for renewable energy

	2006	2010	2015	2020	2030	2050
Wind Onshore (€/kW)	950-1330	n.a.	n.a.	n.a.	n.a.	n.a.
Wind Offshore (€/kW)	1790-2340	n.a.	1480-2030	1330-1790	1170-1560	1170-1480
Geothermal, hydrothermal (€/kW)	1320-4440	n.a.	n.a.	n.a.	1170-3900	1090-3820
Geothermal, hot dry rock (€/kW)	3900-11890	n.a.	n.a.	n.a.	3120-7790	2340-5840
PV (€/kW)	4870	2920-3440	n.a.	n.a.	1480	830
CSP (€/kW)	3120-7010	n.a.	n.a.	n.a.	n.a.	n.a.

Table 2-8: IEA ETP 2008 BLUE Map, Fossil-fuel price assumptions

	2006	2030	2050
IEA crude oil import (€/barrel)	48.3	48.3	50.6
Natural gas			
United States imports (€/MBtu)	5.6	6.1	6.2
European imports (€/MBtu)	5.7	5.7	5.8
Japanese LNG imports (€/MBtu)	5.5	6.1	6.2
OECD steam coal imorts (€/tonne)	49.1	47.5	47.5

- Carbon price: €2005 155.8/t CO_2
- Additional investment needs: €35.1 trillion over the period up to 2050 (€860 billion trillion per year). This equates to an average of around 1.1% of global GDP each year from now until 2050 and is considered to reflect a re-direction of economic activity and employment, and not necessarily a reduction of GDP.
- Total additional investment in the power sector (incl. CCS and nuclear power): €2.8 trillion.

- The estimated total undisclosed fuel cost savings for coal, oil and gas over the period to 2050 are expected to amount to €39.7 trillion.

Primary energy

- Entire data for primary energy demand in the BLUE Map scenario is not displayed. So data used in this report are read off ETP's figures.
- Primary energy demand in the BLUE Map scenario is thus expected to reach some 670,000 PJ by 2050 with an average increase per year for the period 2005-2050 of 0.75%.
- The total contribution of fossil fuels is assumed to decline to 346,000 PJ in 2050. Only gas is expected to increase with 0.5% per year to a total of around 126,000 PJ.
- CCS is playing a major role in the BLUE Map scenario. By 2050, plants with approximately 1,100 GW will be fitted with CCS technology.
- The scenario's change rates for energy sources rank from 4.2% for not disclosed "Other renewables", 2.6% for biomass to 2.5% for nuclear energy.

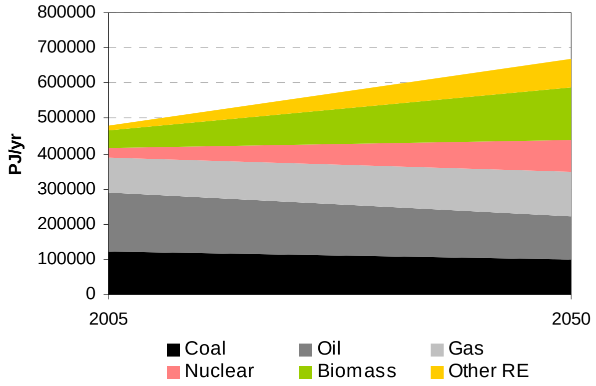


Figure 2-34: IEA ETP 2008 BLUE Map, Primary energy demand

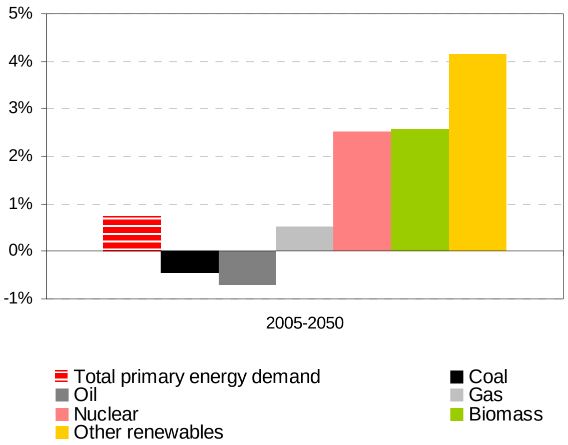


Figure 2-35: IEA ETP 2008 BLUE Map, Average annual change rates of total primary energy demand

Renewable energy's share in primary energy supply

- The contribution of renewable energy to primary energy demand is not reported in detail, except of biomass (despite the deep technological analysis). Data for other renewable energy sources are reported as a combined quantity.
- Biomass is expected to approach the level of oil consumption in 2005. About half of the primary bioenergy is assumed to be used for power generation, heating and industrial feedstocks. The other half is expected to be used for the production of liquid biofuels. It is used to reach the modes of transport that lack other options (especially trucks, ships and aircraft).

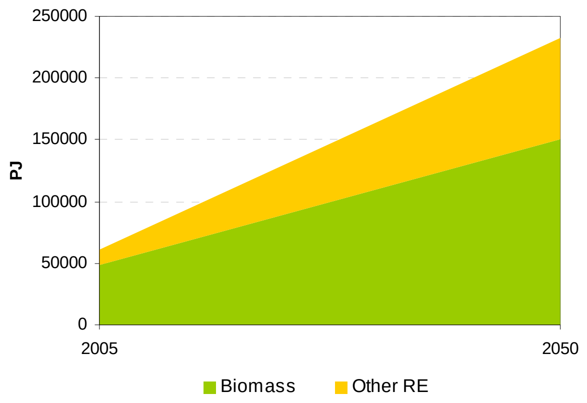


Figure 2-36: IEA ETP 2008 BLUE Map, Total contribution of renewable energy to primary energy demand

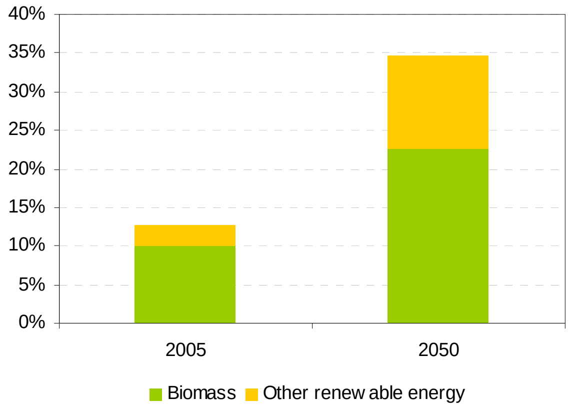


Figure 2-37: IEA ETP 2008 BLUE Map, Share of renewable energy in primary energy demand

Renewable energy’s share in electricity generation

- Total electricity production is considered to more than double between 2005 and 2050 and to reach 42340 TWh (3641 Moe) by 2050. This is due to an increasing demand-side electrification as as zero-emission solution for the long term.
- Significant electrification is considered for the buildings and transport sectors; in the buildings sector, heat pumps become to play an increasing role; in the transport sector, the scenarios assume an important role for plug-in hybrid and electric vehicles. These changes result in a rise in electricity demand of the order of 4000 TWh.
- The increasing share of renewables in power generation from 18% to 46% implies a more than four-fold extension of total power production from renewables. Most of the growth is assumed in emerging renewable technologies: wind, photovoltaics, concentrating solar power, biomass, and to a lesser extent geothermal; the use of hydropower, too, is expected to double from 2005 to 2050.
- Up to 2020 biomass and wind are assumed to constitute the bulk of new renewables capacity. After 2020, solar is considered to make a more significant contribution. The capacity factor for Concentrating Solar Power (CSP) is assumed to be higher than for photovoltaics (PV); it is therefore considered to generate about two thirds of total solar power generation by 2050. The growth of hydroenergy is expected to ease in the period 2030-2050 as the availability of suitable sites raises constraints. In 2050, hydro, wind and solar are assumed to make an equally important contribution to electricity generation.
- The share of intermittent renewable energy in electricity generation worldwide is around 20.6% in 2050 (about 3500 GW).
- Photovoltaic energy’s production profile matches well with the need for air conditioning; besides that variability can also be compensated for by additional electricity storage capacity. It is estimated to increase from 100 GW in 2005 to 500 GW in 2050. This storage consists of a combination of pumped hydro storage, underground compressed air energy storage systems, and other storage options to a lesser extent. About 1000 GW of gas-fired capacity also are considered to operate as reserve for these variable renewables.

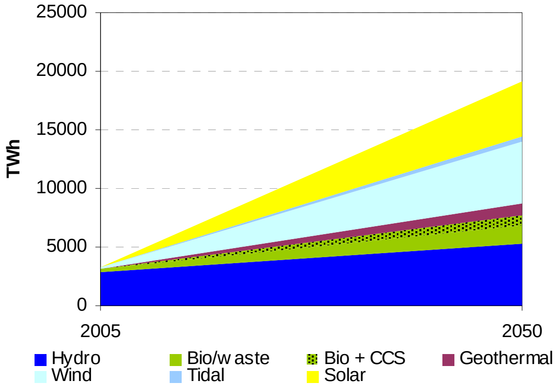


Figure 2-38: IEA ETP 2008 BLUE Map, Total contribution of renewable energy to electrictiy generation

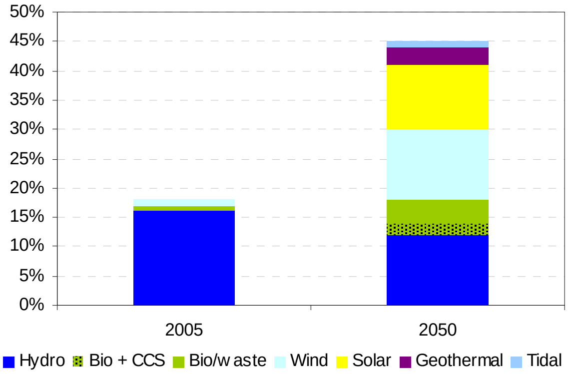


Figure 2-39: IEA ETP 2008 BLUE Map, Share of renewable energy in electricity generation

Renewable energy for heat and transport

- Solar hot water systems are expected to provide between 14% and 42% of hot water needs in the service sector in 2050.
- Biomass and solar heat is used in industry for delivering process heat.
- Geothermal for district heating and industrial processing.
- For 2050 it is assumed that 41,030 PJ/yr from biomass are used for direct heat in industry and buildings.
- In the transport sector, 29,300 PJ second-generation biofuels (mostly BtL to replace petroleum diesel) per year are assumed for 2050. They are designated mainly for trucks, ships and aircraft; emphasis on biodiesel, not on bioethanol (8,370 PJ).
- For cars and light trucks: electricity and hydrogen fuel.
- In 2050, 11,930 PJ low GHG electricity per year for plug-ins and pure electric vehicles.
- In 2050, 12,980 PJ low GHG hydrogen per year.
- Total demand in the transport sector ~ 108,900 PJ/yr (2005-2050).

Energy efficiency

- The BLUE Map scenario does not contain detailed numerical data tables, but offers some numerical information in a text-based form; it has a sectoral organization which makes it less comparable to the other scenarios.
- Energy efficiency is considered to great detail in this report, however, the supply side of energy efficiency is not inspected.
- Energy efficiency improvements are regarded to constitute the largest contributor to CO_2 emission reductions.

End-use efficiency

- Final energy demand is reduced by approx. 33% until 2050 in comparison to the reference.
- Overall energy efficiency improves by 1.7% per year and final energy intensity falls by 2.5% per year. Energy use per unit of GDP in 2050 is only about 30% of its level in 2005.
- Electricity demand in 2050 is only 15% below the reference scenario. It increases because of an assumed switch from fossil fuels to CO_2-free electricity in the building and transport sector.
- Largest reductions in energy use occur in the buildings sector, reflecting the significant technical potential to reduce space heating and cooling needs in existing and new buildings, as well as to improve the energy efficiency of lighting, electric appliances and equipment.
- Energy savings in transport are also very significant, whereas industry shows smaller savings, reflecting the high efficiencies already achieved in a number of energy-intensive sectors and the need for energy that is intrinsic in most industrial processes.
- Over 60% of the energy reduction occurs in developing countries and nearly 30% in OECD countries.
- Energy intensity of the transition economies declines (-2.9%/year) by more than that of the OECD countries, reflecting the significant energy efficiency with the modernization of their economies and structural changes (e.g. shifting from production of raw materials to less energy-intensive manufactured products).

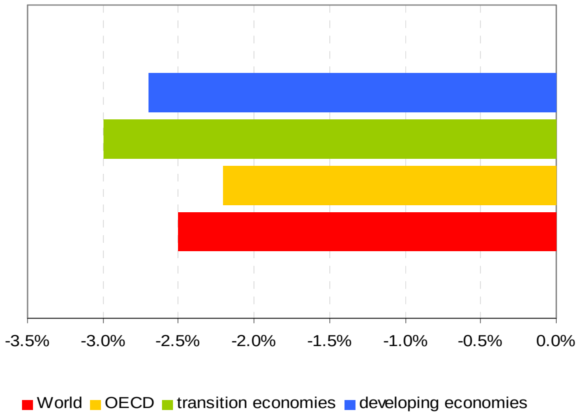


Figure 2-40: IEA ETP 2008 BLUE Map, Changes in energy intensity (final energy/GDP)

Carbon intensity

- In 2050, total CO_2 emissions are reduced by 85% below the reference scenario.
- Direct emissions from coal, oil and gas are 64% lower than the reference.
- OECD countries account for 30% of the total global emission reductions compared to the reference scenario. Emissions are reduced by more than 50% compared to 2005 levels, while non-OECD countries reduce their emissions by less 50%.
- CCS plays a key role in the BLUE Map scenario and accounts for 37% of total emission reduction.
- The shift towards electricity in buildings and in the transport sector (especially for heat pumps and plug-in hybrids) reduces CO_2 emissions as the electricity sector is virtually decarbonized.
- In the transport sector CO_2 emissions are about 20% below the level of 2005. Efficiency gains for all transportation modes provide about half the CO_2 emission reduction. The other half comes from the use of biofuels and the introduction of electric and fuel cell vehicles.
- The industrial sector shows total fuel and electricity savings of 41% of total emissions reduction in the BLUE Map scenario.
- The shift towards best available technology in the building sector leads to reduction in fossil fuel consumption, with reductions in oil and gas consumption accounting for 11% and 7% of the emission reductions, respectively.

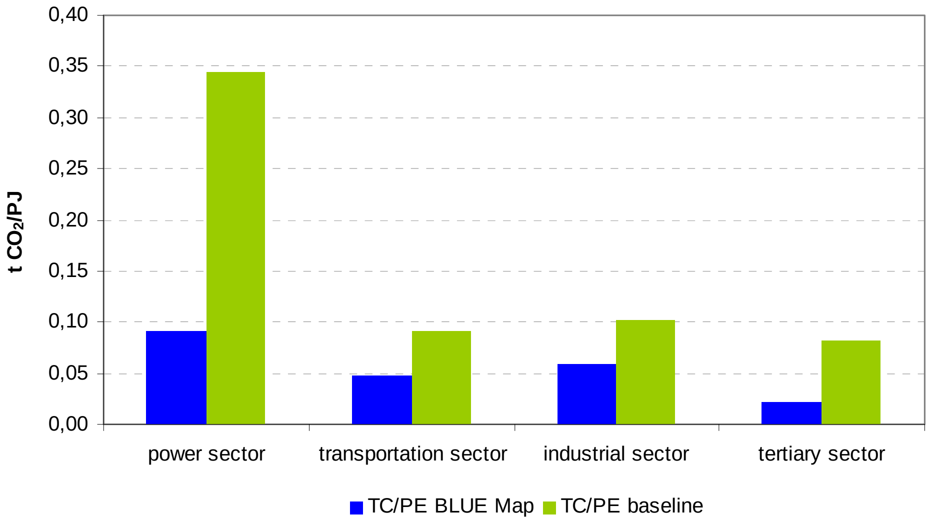


Figure 2-41: IEA ETP 2008 BLUE Map, Carbon intensity of energy supply

2.6 European Commission: World Energy Technology Outlook 2006

Key scenarios

Reference projection:	Assumes the continuation of existing economic and technological trends, including short-term constraints on the development of oil and gas production and moderate climate policies.
Carbon Constraint Case:	Explores consequences of more ambitios carbon policies, aiming at a stabilisation close to 500 ppmv.
H2 Case:	Pathways towards a so-called “hydrogen economy” derived from the Carbon Constraint Case.

WETO Carbon Constraint Case

Scenario frame

- In the Carbon Constraint Case (CCC) a state of the world with moderately ambitious climate targets, aiming at an emission profile that is compatible in the long-term with concentration levels below 500 ppmv for CO_2 is presumed.
- In 2030 CO_2 emissions amount to 29.5 Gt per year, in 2050 they amount to 25.5 Gt per year.
- The CCC is based on a set of carbon values that describe the expected intensity and timing of the emission reduction policies in the different regions of the world, with distinguishing between Annex B and non-Annex B countries. For Annex B countries, the carbon value starts from the value for Europe in the Reference case of 10 €/t CO_2 in 2010 and increases linearly to 200 €/t CO_2 in 2050. For Non-Annex B regions, the carbon value starts at 10 €/t CO_2 in 2020 and increases at a constant rate slightly above 10% per year, to catch up with the 200 €/t CO_2 in 2050. Only small purchases of emission credits from Non-Annex B countries are assumed.
- The scenario sets up two main consequences:
  - modification of demand determined by the relative price elasticities
  - modification of the penetration rates of technologies, corresponding to their associated carbon emissions.
- Early action is assumed in Annex B countries, while more time is allowed for emerging and developing countries.

Population projections

- Population in the WETO is expected to rise to 8,860 million in 2050. This corresponds to an average annual growth rate of almost 0.7% in the period 2010-2050.

- The population in Africa and the Middle-East is supposed to rise fastest with 1.5% per year.
- After 2030, the population in several regions of the world decreases (incl. Europe and China)

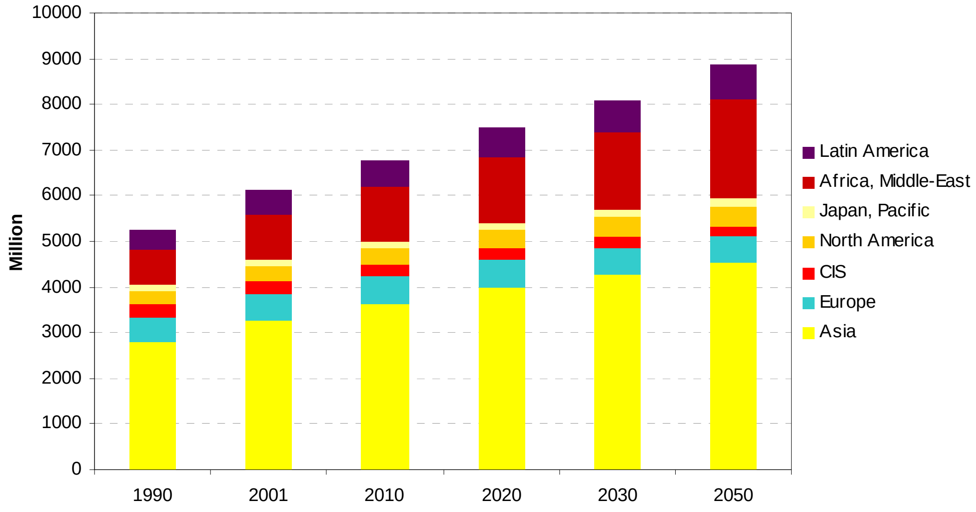


Figure 2-42: EC WETO, Population

GDP projections

- GDP is considered to grow in all regions, worldwide the average annual increase is estimated at 2.6% between 2010 and 2050.
- For a better comparison, only growth rates are disclosed. In absolute figures world GDP reaches USD (1995) 164 090 000 000 000 by 2050, i.e. EUR (2005) 161,814 trillion (2030: EUR 104,500 trillion).
- The economy in Africa and the Middle East is expected to develop fastest (3.6% per year, 2010-2050) together with Asia (3.3%) and Latin America (2.6%).

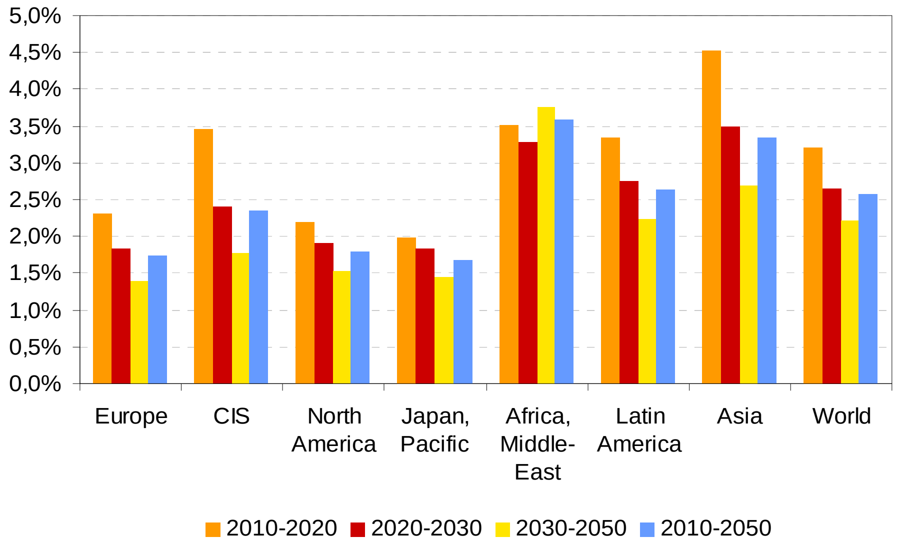


Figure 2-43: EC WETO, GDP growth rates

Cost assumptions and economic implications

Table 2-9: EC WETO CCC, Carbon price assumptions

	2010	2020	2030	2040	2050
Carbon value, Annex B (€/t CO_2)	10	57.5	105	152.5	200
Carbon value, Non-Annex B (€/t CO_2)		10	27	74	200

Table 2-10: EC WETO CCC, Investment costs for renewable energy

	2010	2020	2030	2040	2050
Wind Onshore (€/kW)	880	800	760	720	720
Wind Offshore (€/kW)	1450	1210	970	880	800
Geothermal (€/kW)	n.a.	n.a.	n.a.	n.a.	n.a.
PV (€/kW)	4500	3050	2250	1770	1450
CSP (€/kW)	2570	2250	2090	2010	1850

Table 2-11: EC WETO CCC, Fossil-fuel price assumptions

	2010	2020	2030	2040	2050
Oil (€/boe)	31	40	49	59	71
Gas (€/boe)	21	35	45	54	72
Coal (€/boe)	n.a.	n.a.	n.a.	n.a.	n.a.

Primary energy

- Total primary energy demand increases to 813,000 PJ by 2050.
- The contribution of fossil fuels is assumed to decrease after 2030, being replaced by an expanding share of nuclear energy. Its total contribution to primary energy demand will reach 178,000 PJ in 2050.

- Carbon capture and storage is supposed to play an important role, too. At average, 6.5 Gt CO_2 are expected to be stored every year.
- Nuclear energy is rising at an average of 3.8% per year (2001-2050) at a steadily rising growth rate.
- The combined category of wind and solar energy has highest growth rates to be noted of an average of 10.3% for the period 2001-2030. They peak in 2010-2020 at a rate of 17.4% and then decline.

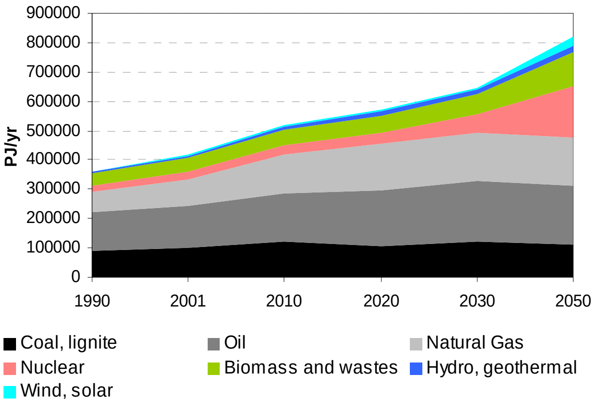


Figure 2-44: EC WETO CCC, Total primary energy demand

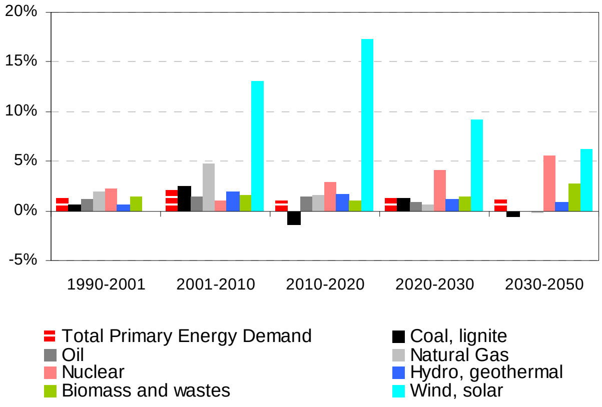


Figure 2-45: EC WETO CCC, Average annual change rates of total primary energy demand

Renewable energy's share in primary energy supply

- Considered to maintain their share in primary energy supply until 2030 at an average of 13.5%. By 2050 assumed to approach 20.7%.
- Incremental generation in renewable electricity is expected to be provided mainly by biomass and wind power. Besides the above mentioned high growth rates of the combined category wind and solar, biomass can account for an average annual rise of 1.9% and hydroenergy of 1.3% for the period 2001-2050. After 2030 the share of wind-power is assumed to grow more rapidly because of the deployment of offshore plants.

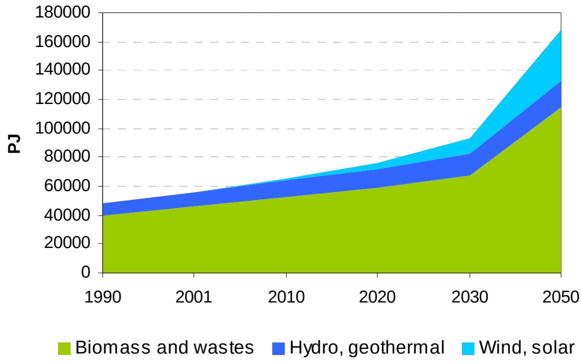


Figure 2-46: EC WETO CCC, Total contribution of renewable energy to primary energy supply

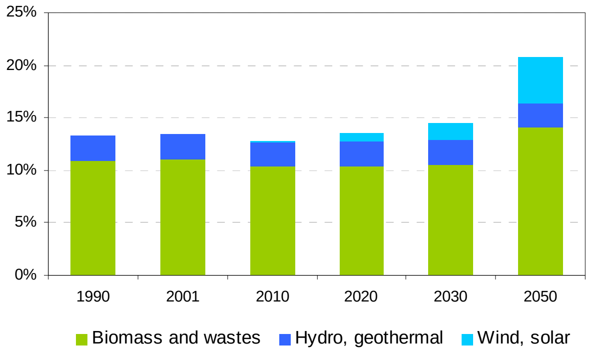


Figure 2-47: EC WETO CCC, Share of renewable energy in primary energy supply

Renewable energy's share in electricity generation

- Electricity generation shifting to low-carbon substitutes for fossil fuels leads to a cost-advantage in new markets, especially transport. As a consequence, consumption of electricity falls by less than 10% as compared to WETO's Reference Case and offsets the increase in efficiency in the end-uses of electricity.
- Renewable energy's share in power generation is growing at an average annual rate of 1.3% between 2010 and 2050 and reaches 30.2% of total electricity generation by 2050.
- In 2050, 42% of renewable electricity and 13% of total electricity is provided by wind energy and the amount exceeds that from large hydro.
- Solar electricity is expected to be appreciable from 2030 and then growing with an average annual rate of 12.7% to reach a capacity of 2326 TWh in 2050. It is generated by thermodynamic power plants and by photovoltaic systems integrated into buildings. After 2040, photovoltaic systems on buildings are supposed to become important producing three times more electricity in 2050 than the thermal systems.
- Biomass for electricity generation is assumed to increase with an average 5.9% per year in the period 2001-2050 and to approach 2650 TWh by 2050.
- As a result of the increase in wind and solar energy, the share of intermittent renewable energy in electricity generation is reaching 16.7% by 2050.

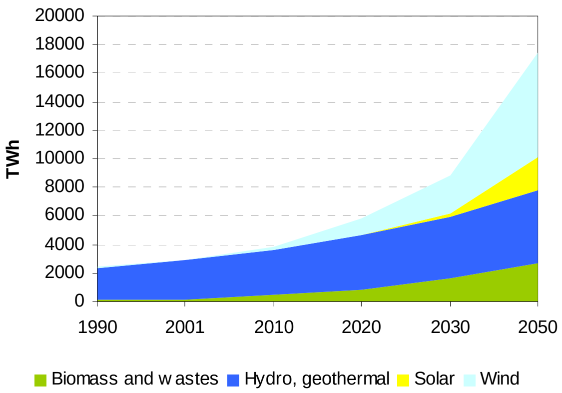


Figure 2-48: EC WETO CCC, Total contribution of renewable energy to electricity generation

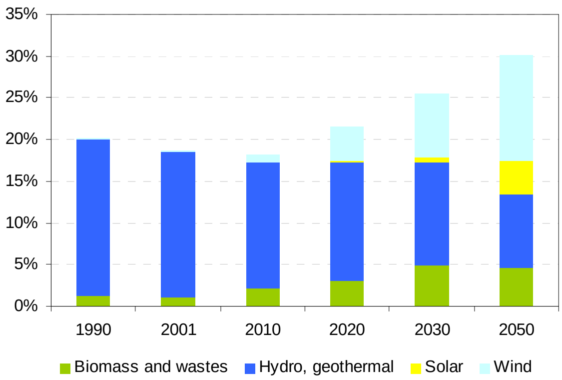


Figure 2-49: EC WETO CCC, Share of renewable energy in electricity generation

Renewable energy for heat and transport

- Heat consumption in the CCC is expected to rise from 10,470 PJ per year in 2010 to 10,760 PJ per year in 2050. No specifications for the contribution of renewables.
- For transport a high input from electricity is assumed (not further specified).

Energy efficiency

- Impacts of energy efficiency measures are not reported numerically in an disaggregated manner, but are only reflected by the overall savings in energy demand.
- While end-use efficiency measures and carbon intensity are discussed on a text-basis, efficiency of energy supply is not considered directly.
- Energy efficiency improvement is regarded as main option for emission abatement before 2020 and after 2040 when potential for CCS is largely saturated and is assumed to account for 26% of cumulative CO_2 reductions from 2010 to 2050.

End-use efficiency

- Less visible effects of end-use efficiency measures on the reduction of final energy demand as a result of an increase of the share of nuclear energy in total final energy demand. The share of low-efficient nuclear energy has increased to more than 20% in 2050 and therefore partly offsets effects from end-use efficiency gains and behavioral changes.
- Consumption of electricity in the world falls by less than 10%, because electricity generation shifts to low-carbon substitutes for fossil fuels and achieves a cost-advantage in new markets, especially transport. This partially offsets the increase in efficiency in the end-uses of electricity.
- Final energy consumption in the European residential and service sector increases partly because of demand from Information and Communication Technologies in households and services.
- The European residential sector in 2050 is characterized by wide diffusion of low energy buildings (50% of the building stock in the low energy category, 25% in the very low energy category).
- In transport and industry final energy consumption in Europe stays nearly stable while low emission vehicles diffuse rapidly (joint market share of hybrid, electric and hydrogen cars in 2050 is 45%).

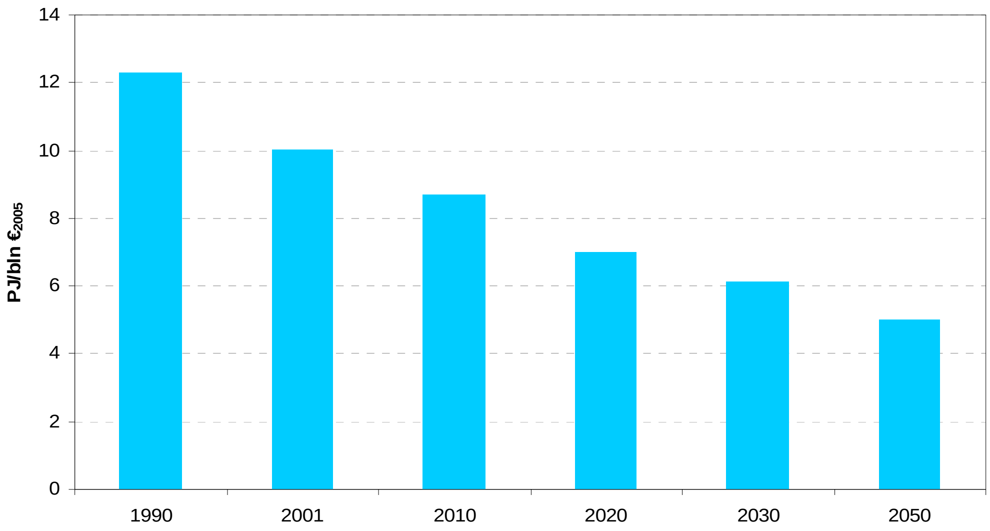


Figure 2-50: EC WETO CCC, Energy intensity

Energy supply efficiency

- Energy efficiency of supply shows an increasing trend, indicated by the decreasing energy supply loss factor (which reflects the relation of primary energy to final energy and hence, the efficiency of energy conversion as well as transmission and distribution losses).
- The decreasing trend for energy supply efficiency from biomass and wastes is not explained in the scenario.
- The trend for coal and lignite reverses in 2020. The decrease in efficiency of conversion processes recommences with the assumed introduction of the Carbon Capture and Storage (CCS) technology in 2020.

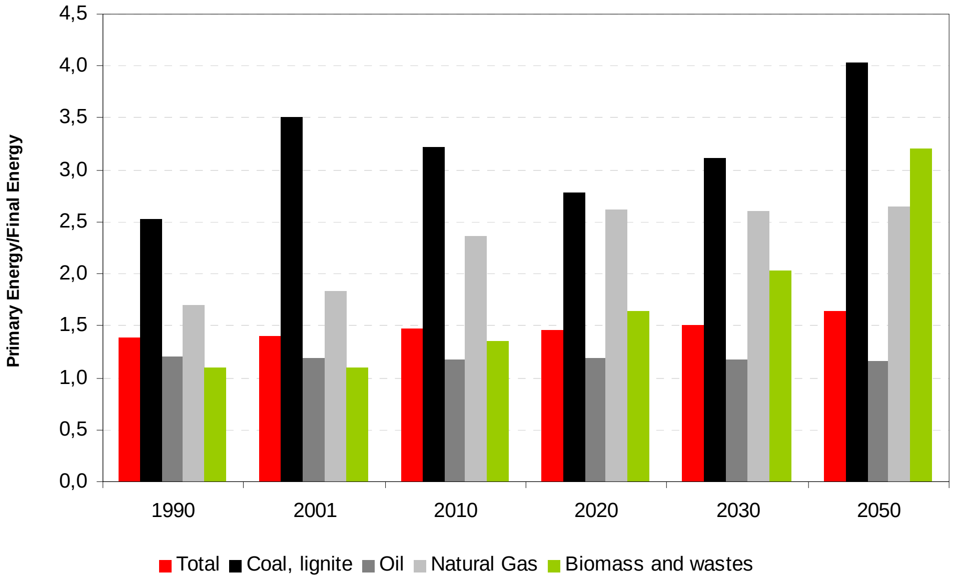


Figure 2-51: EC WETO CCC, Energy supply loss factor

Carbon intensity

- Carbon intensity in 2050 has considerably decreased for all concerned economies, while contributions of nuclear and renewable energy increase constantly over the concerned period.
- CCS is significant in the scenario. It is adopted in each region when the carbon value reaches approximately 25 €/t CO_2. This is the case after 2015 for Annex B regions and just before 2030 in the developing and transition regions.
- Between 2030 and 2040 CCS accounts for almost 40% of the worlds annual emission reductions. After 2040, the importance of CCS in abatement decreases both in share and in volume, because of high transport and storage costs of transport and storage.
- Higher efficiency and a less carbon intensive mix of fuels in final use are the main options before 2020 and after 2040 when the potential for CCS is largely saturated.
- Over the period 2010 – 2050, CCS has the largest share in carbon reduction, followed by changes in energy consumption, use of renewables, changes in the thermal power fuel-mix and use of nuclear energy.

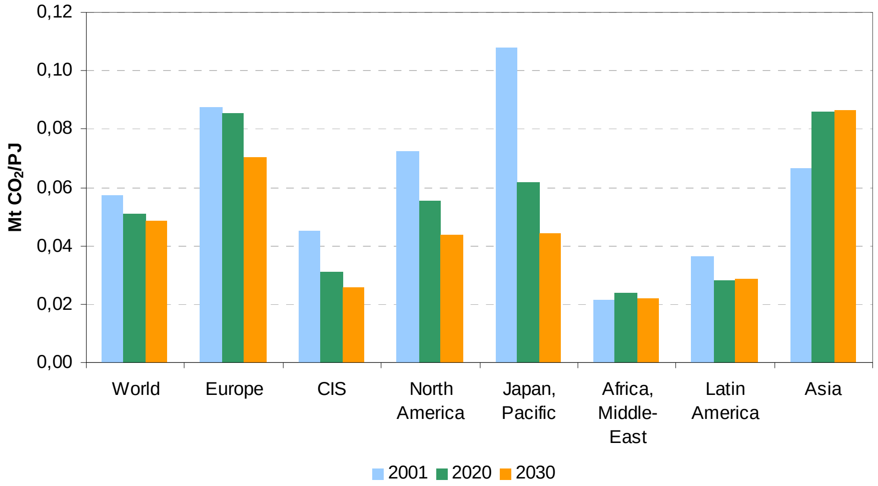


Figure 2-52: EC WETO CCC, Carbon intensity of energy supply.

3 Synopsis

3.1 Primary energy demand

Results for 2030:

- The IEA scenario following a 450 ppm climate target, the WEO 08 450, displays a primary energy demand of 601,000 PJ/yr, while energy demand in the E[R] scenario due to greater efficiency decreases to 526,000 PJ/yr.
- Another difference is the provision of nuclear power. In 2030, the IEA scenario expects about 57,000 PJ/yr. The E[R] scenario reduces the contribution of nuclear to some 7,000 PJ/yr.
- The share of renewables varies between 21.3% in the WEO 08 450 and 25.2% in the E[R] scenario. The differences in the role of hydro and biomass are not very significant across the scenarios (less hydro in the E[R]), their contribution is between 100,000 PJ and 112,000 PJ.
- Besides wind, providing 28,600 PJ/yr, no other “new” renewables are disclosed in the WEO 08 450 scenario. The E[R] scenario in contrast itemises wind (15,800 PJ), solar (26,300 PJ), geothermal (21,200 PJ) and ocean energy (540 PJ), altogether providing 64,000 PJ.
- Scenarios following a climate target of GHG concentrations not exceeding 550 ppm (WEO 08 550, WETO CCC) display quite similar amounts of total primary energy demand, though in comparison to the 450 ppm scenarios at a higher level of around 648,000 PJ/yr.
- Differences in the composition of energy sources are not significant across the three 550 ppm scenarios. WETO CCC relies on some more gas and nuclear energy, but less coal.

Results for 2050:

- Significant contrasts can be identified regarding the amount and the composition of primary energy demand.
- The two 450 ppm-scenarios - the E[R] and the ETP BLUE Map scenario - differ by around 90,000 PJ. A larger exploitation of efficiency gains contributes to the reduction of primary energy demand in the E[R] scenario to approximately 480,000 PJ/yr.
- Fossil fuels play a more important role in the ETP BLUE Map scenario, providing nearly 350,000 PJ/yr. The same applies to nuclear energy, which amounts to over 90,000 PJ/yr. In the E[R] scenario fossil fuels are reduced to 210,000 PJ/yr and nuclear power is completely phased out.
- Renewables in the E[R] scenario grow to about 271,000 PJ (56.3% of total primary energy demand), whereas the ETP BLUE Map scenario assumes beneath 233,000 PJ to be delivered by renewables (34.7% of total primary energy demand).
- The E[R] scenario discloses 19,300 PJ hydro, 94,800 PJ biomass, 27,900 PJ wind, 76,400 PJ solar, 50,100 PJ geothermal and 2,400 PJ ocean energy. In the BLUE Map scenario 151,000 PJ delivered by biomass and 81,600 PJ provided by ‘other renewables’ are displayed.

- The WETO CCC being the only 550 ppm scenario with a projection period until 2050 peaks at 820,000 PJ/yr in 2050. Fossil fuels contribute 475,000 PJ, while nuclear amounts to around 180,000 PJ/yr.
- Renewable energy in the WETO CCC reaches 168,000 PJ by 2050, that is 20.5% of total energy demand. Biomass delivers 115,000 PJ/yr, hydro/geothermal 18,500 PJ/yr and wind/solar 35,000 PJ/yr.

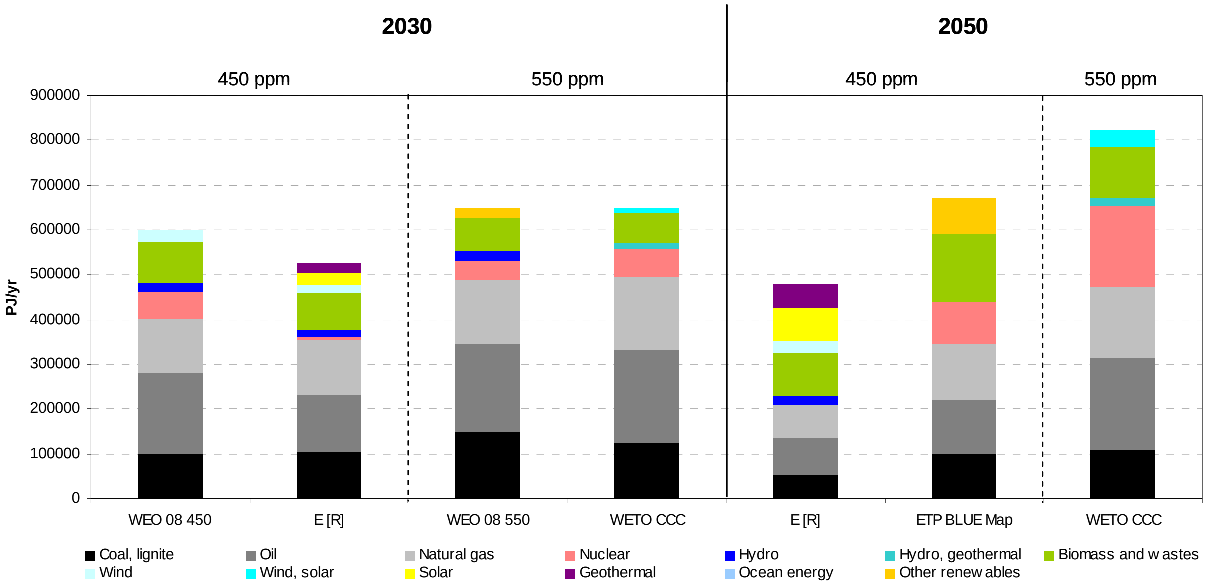


Figure 3-1: Primary energy demand. Segmentation follows time and climate target.

3.2 Final energy demand

- Final energy demand per unit of GDP decreases in all scenario studies. The lowest energy intensity on a global economy base is observed in the Energy [R]evolution scenario, which projects a total final energy demand of 390,327 PJ in 2050.
- Partly responsible for the high energy intensity projected in the WETO CCC scenario is the use of more moderate GDP projections (bln €104,461 in 2030 as compared to bln €113,968 in the WEO 08 scenarios).
- While the [R]evolution scenario and the WEO 08 550 start off with similar energy intensities in 2020, the latter decrease more steeply in the [R]evolution scenario, owing to the 450 ppm target.

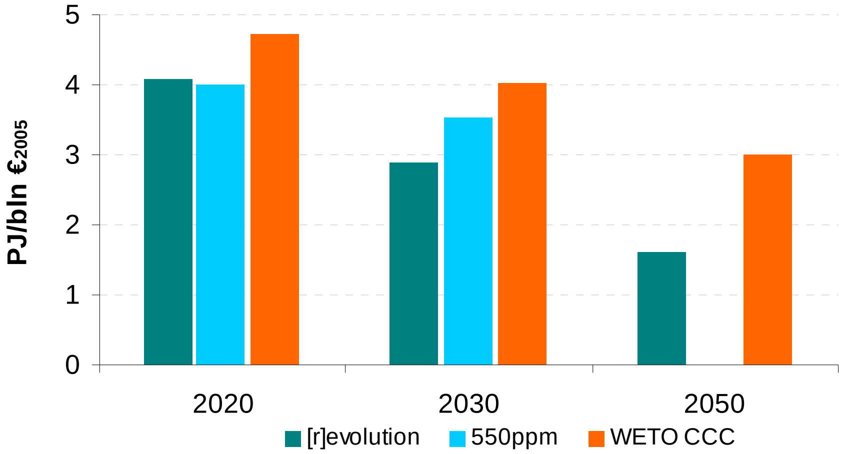


Figure 3-2: Energy intensity of economies

- Up to 2030 the transport sector is projected to have the highest carbon emissions per unit of final energy in all scenarios. In 2050, however, this trend is reversed for the two 450 ppm scenarios ETP BLUE Map and the Energy [R]evolution scenario, leaving the industry sector with highest carbon intensities.
- In 2050, for all sectors in the 450 ppm scenarios carbon intensities are halved as compared to the WETO CCC scenario, having a 550 ppm target.

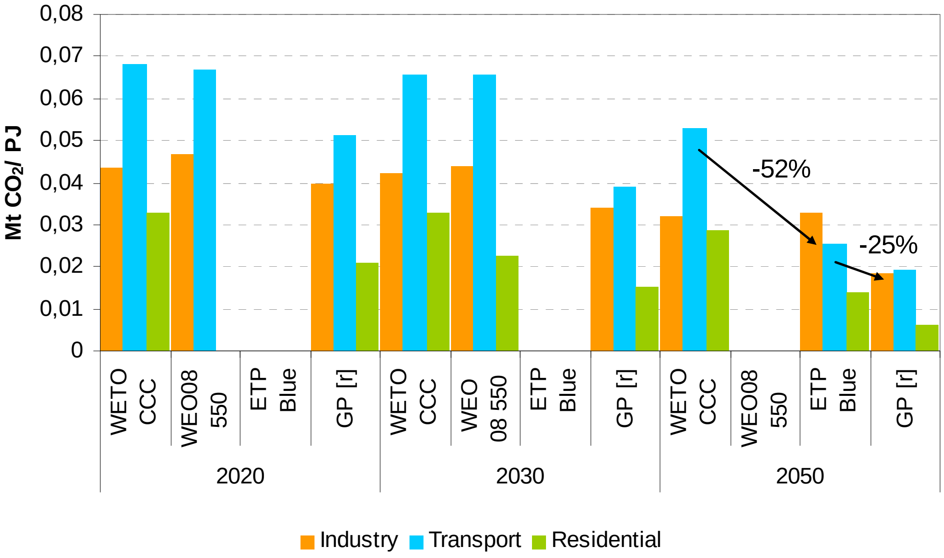


Figure 3-3: Carbon intensity of final energy demand

- The E[R] scenario shows lowest carbon emissions per unit of GDP. Total emissions are reduced to 20,981 Mt CO_2 in 2030 and to 10,589 Mt CO_2 in 2050, respectively. The WEO 08 450 arrives at 25,700 Mt CO_2 in 2030.
- Partly owned to the moderate GDP projections, the WETO CCC scenario is observed to have highest carbon emissions per unit of GDP.

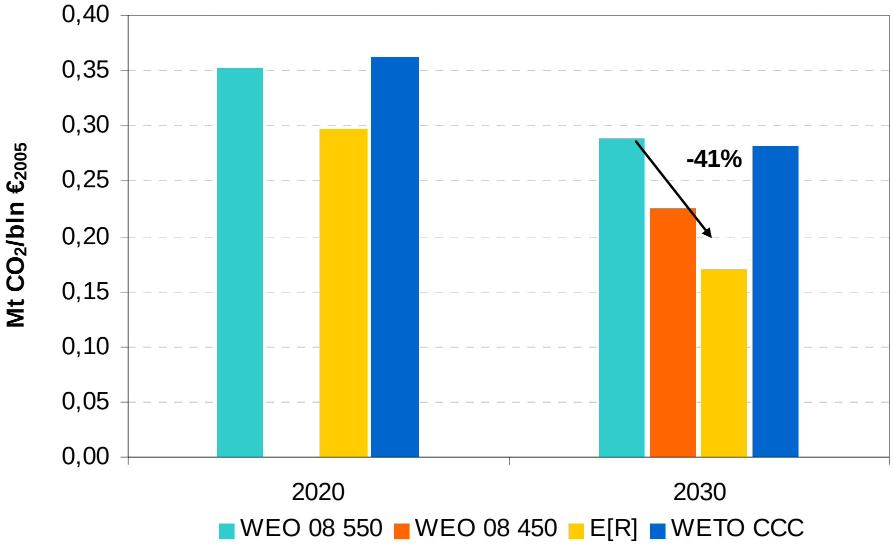


Figure 3-4: Carbon intensity of GDP

- The different assumptions made in the WEO 08 550 and the E[R] scenario result in a reduction of carbon intensity of 41% for the E[R] scenario, relative to the WEO 08 550 PS.
- Energy conversion efficiencies are assumed almost constant for all scenarios, it is interesting to note, however, that efficiency decreases slightly in the WETO CCC, while it is increasing in all other scenarios.
- In 2050, the energy supply loss factor indicates that conversion efficiency in the WETO CCC scenario is lower by approximately 25% compared to the E[R] scenario.

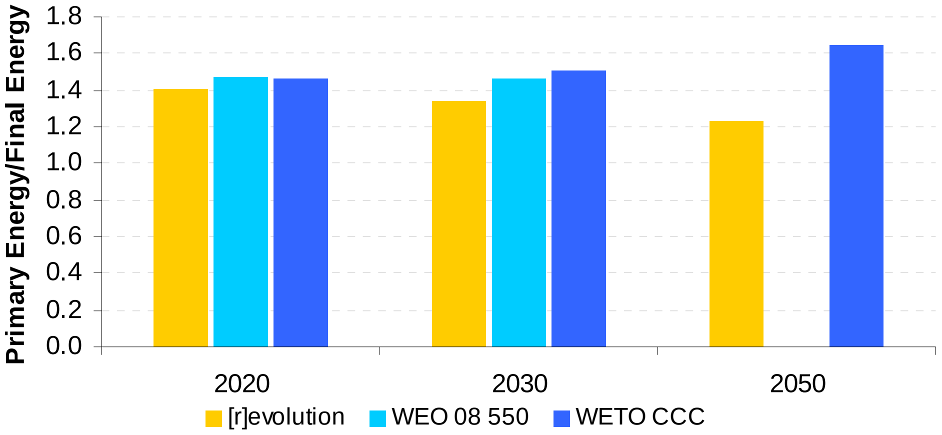


Figure 3-5: Energy supply loss factor

3.3 Electricity generation

Results for 2030:

- Electricity generation amounts to less than 30,000 TWh/yr across all 450 ppm scenarios.
- The E[R] scenario displays a greater amount of fossil fuels (approximately 14,500 TWh), but reduces nuclear power to 680 TWh (WEO 08 450: ~ 5,200 TWh).
- Renewable energy is displayed as hydro (6,400 TWh/yr) and non-hydro renewables (5,500 TWh/yr) in the WEO 08 450 scenario. This is a total of 12,000 TWh/yr (41.2% of total electricity generation).
- A more detailed subdivision is given by the E[R] scenario. Renewables amount to 14,000 TWh/yr (48.1% of total electricity generation). 4,400 TWh are provided by hydro, 1,800 by biomass, 4,400 by wind. 1,200 TWh are delivered by CSP, 1,400 TWh by PV, 680 TWh by geothermal and 150 TWh by ocean energy.
- The WEO 08 550 expects electricity generation in the amount of 30,000 TWh. Assumptions in the WETO CCC are slightly higher, at about 35,000 TWh. The provision by renewables in the WEO 08 550 is about 9,200 TWh/yr, in the WETO CC at about 8,800 TWh/yr.

Results for 2050:

- The E[R] and the BLUE Map scenario being the two 450 ppm scenarios differ in composition and amount of generated electricity. By 2050, the E[R] has phased out nuclear energy and reduced fossil fuels to 8,500 TWh/yr. In the BLUE Map scenario nuclear is providing nearly 9,900 TWh and fossil fuels contribute 12,800 TWh.
- Renewable energy amounts to 28,600 TWh/yr in the E[R] scenario (77.1% of total electricity generation) and to 19,100 TWh/yr in the BLUE Map scenario (45.1% of total electricity generation).
- Hydro contributes an equal amount of 5,300 TWh in both scenarios. To solar the BLUE Map scenario refers to at an amount of 4,800 TWh. The E[R] scenario distinguishes between CSP (5,300 TWh/yr) and solar PV (4,300 TWh/yr). Wind plays a more important role in the E[R] scenario, contributing 7,700 TWh, whereas the BLUE Map scenario assumes 5,200 TWh.
- In the WETO CCC nearly 20,000 TWh are delivered by nuclear energy. Fossil fuels amount to 12,800 TWh.
- Renewables are expected to provide 17,400 TWh (30.12% of total electricity generation). Wind is just like, as in the E[R] scenario assumed at 7,300 TWh.

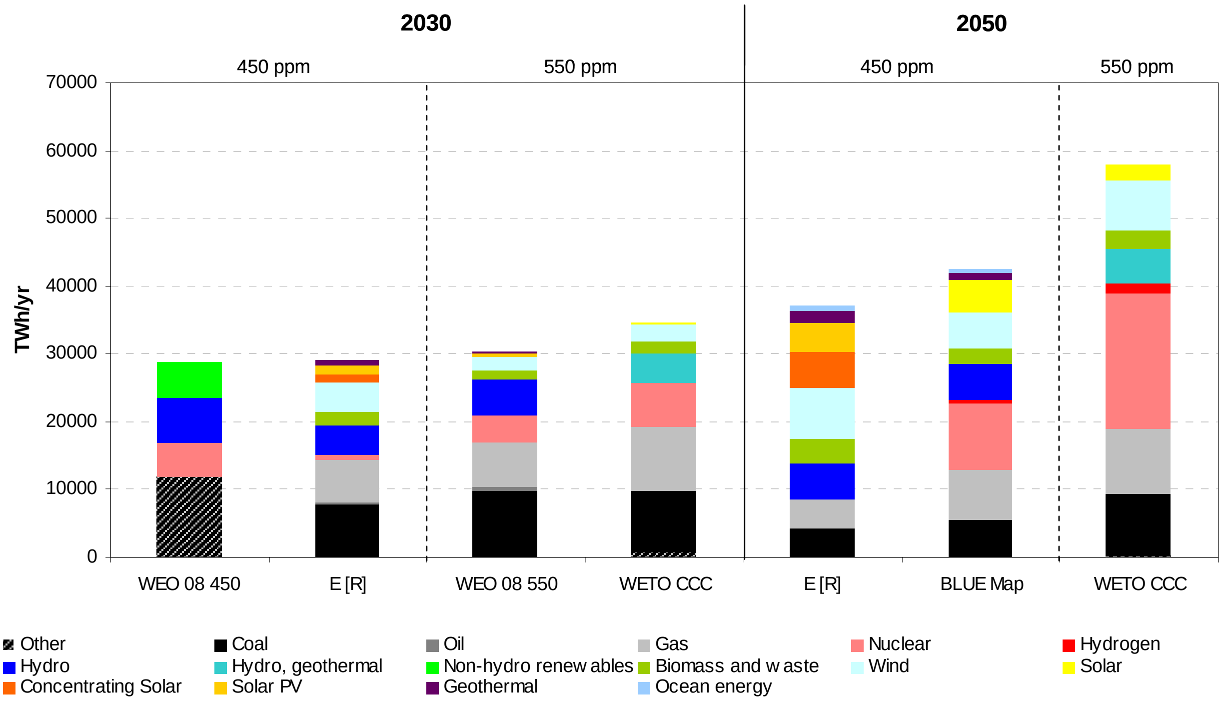


Figure 3-6: Electricity generation. Segmentation follows time and climate target.

3.4 Capacity additions

- Comparing capacity additions across the scenarios is difficult because of lack of data (no data in the EC WETO and WEO 2007) and since capacity retirements do not necessarily comply. However, the following differences are disclosed:
- In summary, it is obvious that renewable energy is faster deployed in the E[R] scenario than in the other scenarios.
- Assumptions on the development of solar energy are more optimistic in the E[R] scenario, independent from the time period considered.
- Just as well ocean energy only in the E[R] scenario appears significantly.
- In comparison with the WEO 2008 scenarios, by 2030, the E[R] scenario has a stronger deployment of wind energy, and because of sustainability criteria less of hydro. Geothermal energy is also stronger deployed.
- Comparing the 2050 scenarios reveals that wind and geothermal energy are wider deployed in the BLUE Map Scenario.
- By 2050, there is twice as much additional solar PV and a greater share of biomass in the E[R] scenario. Capacity additions in renewable energy in the period 2010-2050 amount to 7,800 GW.

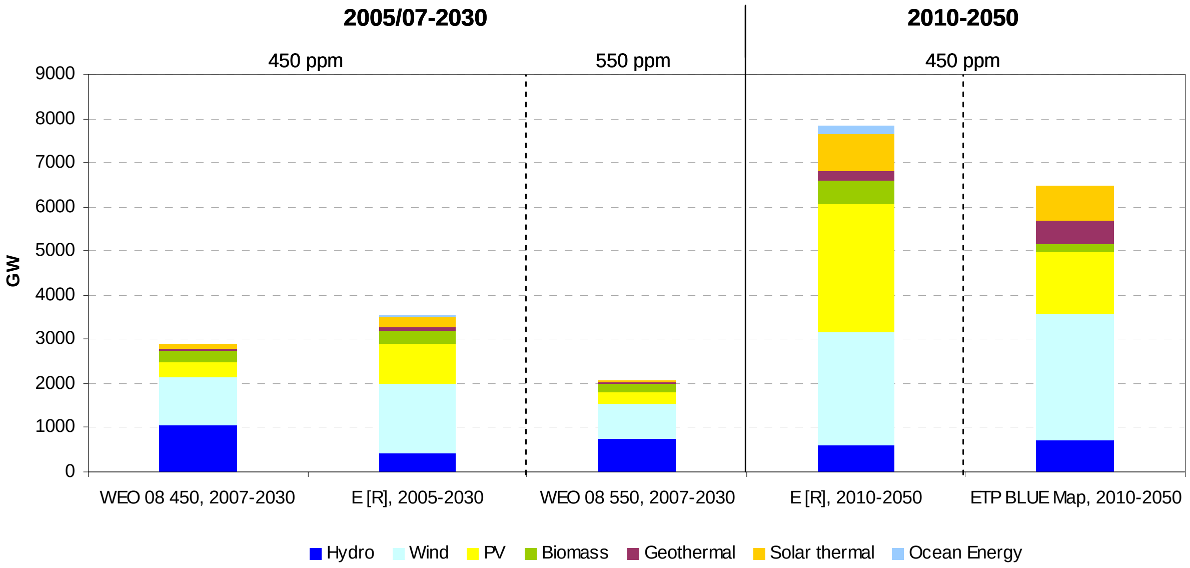


Figure 3-7: Additional capacities in renewable energy. Segmentation follows time and climate targets.

3.5 Additional investment and savings

- Comparing additional investment and savings across the scenarios is, as described above, very difficult. Regarding financial aspects further includes that assumptions made for the reference scenarios have to be regarded as well as presumptions on discount rates. This implies that concrete figures cannot be related to each other across the scenarios. Specifications can merely be related within a scenario.
- However, fuel savings are expected to exceed additional energy investment in the E[R], WEO 08 550 and BLUE Map scenario. The WEO 08 450 scenario assumes lower fuel savings due to higher electricity prices (because of increasing carbon prices).
- In the calculation avoided costs for adaptation to climate change are not considered.

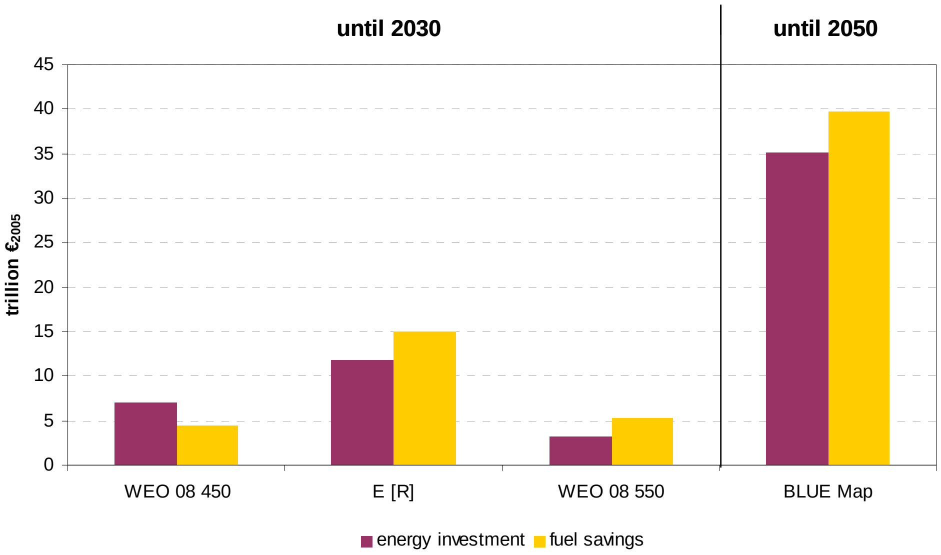


Figure 3-8: Additional investment and fuel savings. Note: Results cannot be compared across the scenarios!

3.6 Energy-related CO_2 emissions

- In 2030, scenarios following the 450 ppm target are presumed to reduce the annual CO_2 emissions to 21 Gt CO_2 (E[R]) to 24.5 Gt CO_2 (WEO 08 450).
- Aiming at 550 ppm, scenarios are assuming CO_2 emissions in the range of 29.5 Gt CO_2 (WETO CCC) to 31.6 Gt CO_2 (WEO 08 550) per year.
- Regarding the results for 2050, the variance reaches from 10.6 Gt CO_2 (E[R]) and 14 Gt CO_2 (ETP BLUE Map), both 450 ppm scenarios, to 25.5 Gt CO_2 (WETO CCC) per year.

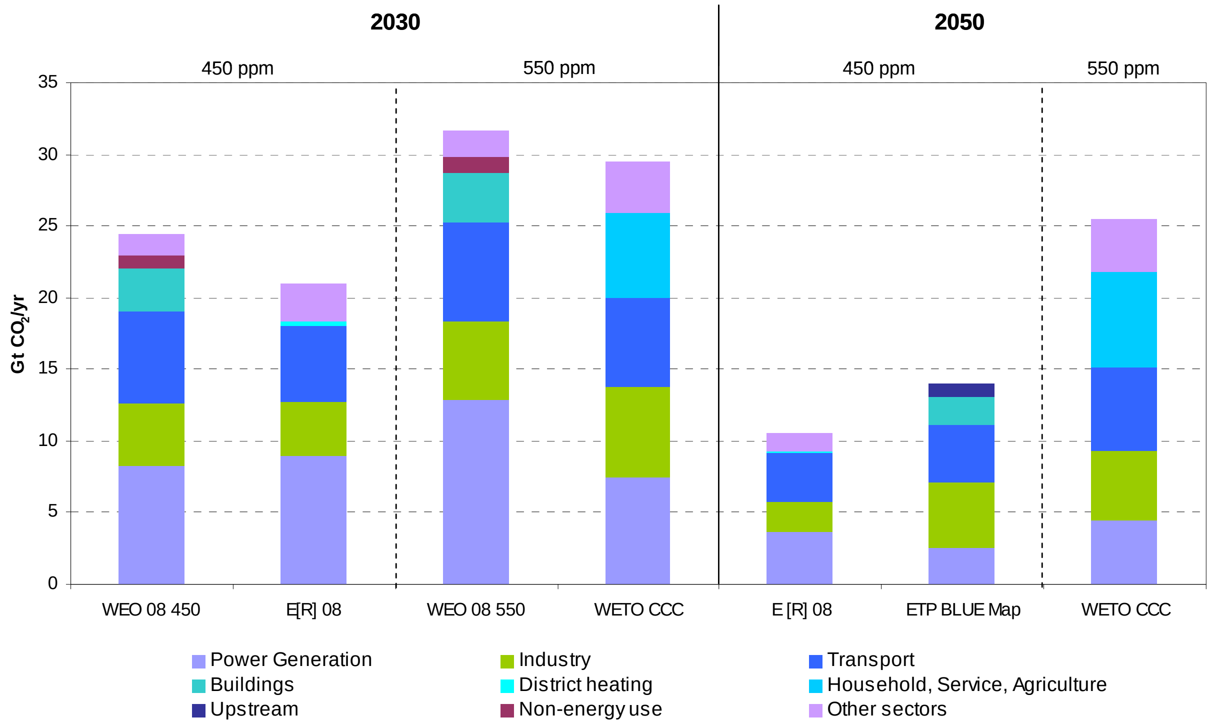


Figure 3-9: CO_2 emissions. Segmentation follows time and climate targets.

4 Conclusions

The results reveal that a significant reduction of energy-related CO_2 emissions in global energy scenarios is interrelated with an effective deployment of renewable energy and exploitation of energy efficiency potentials.

Four scenarios show feasible pathways to stabilise the greenhouse gas concentration at a level of 450 ppm. Along with three scenarios aiming at a stabilisation at 550 ppm they disclose a wide range of plausible future energy systems.

However, insufficient transparency about modelling assumptions and constraints with a lack of detailed data is impeding an in-depth analysis and comparison across all analysed global energy scenarios. So unfortunately, it is almost impossible to compare the deployment of different new renewable energy technologies across the scenarios. It remains to relate aggregated amounts.

Scenarios aiming at a stabilisation of GHG at 450 ppm show a contribution of renewables to primary energy in the range of 125,800 PJ/yr (WEO 07 450) to 163,100 PJ/yr (E[R]) (21.4% - 31% of total) by 2030. Two decades later contributions range between 232,500 PJ/yr (BLUE Map) and 270,900 PJ/yr (E[R]) (34.7% - 56.3% of total).

The scenarios aspiring a stabilisation of GHG at 550 ppm vary between 93,000 PJ/yr (WETO CCC) and 115,100 PJ/yr (WEO 08 550) (14.3% - 17.8% of total) by 2030. in 2050 the WETO CCC is assuming 168,400 PJ delivered by renewables, that is 20.5% of total primary energy demand.

Contributions of the renewable technologies hydro, biomass and wind feature strongly in most scenarios. Large differences in the depiction of so called “new” renewable energy technologies pose the question, whether and to which extend they have been considered.

Another weak point in most scenarios is a lack of data concerning the contribution of renewable energy for heat and transport. These sectors offer a wide range of potential for the implementation of renewable energy, the more it is important to integrate them into energy scenarios.

The following parts of this report will allow for relating the role of renewable energy and energy efficiency in global energy scenarios assessed within the framework of this part to the outcomes of their technical and economic potential’s analysis.

5 List of abbreviations

BtL	Biomass to Liquids
bln	billion (10^{12})
CCC	Carbon Constraint Case
CCS	carbon capture and storage
CHP	combined heat and power
CO_2	carbon dioxide
CSP	concentrating solar power
E[R]	Energy [R]evolution
EC	European Commission
EJ	exajoule (1 joule x 10^{15})
EREC	European Renewable Energy Council
ETP	Energy Technology Perspectives
EU	European Union
FE	final energy
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule (1 joule x 10^{9})
GP	Greenpeace
Gt	gigatonnes (1 tonne x 10^{9})
GW	gigawatt (1 Watt x 10^{9})
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt (1 Watt x 10^{3})
Mt	million tonnes (1 tonne x 10^{6})
MW	megawatt (1 Watt x 10^{6})
OECD	Organisation for Economic Co-operation and Development
OECD+	OECD countries, plus EU countries not in the OEC
PE	primary energy
PJ	petajoule (1 joule x 10^{12})
ppm	parts per million
PPP	purchasing power parity
PV	photovoltaic
TC	total carbon
TW	terawatt (1 Watt x 10^{12})
TWh	terawatt-hour
UNDP	United Nations Development Programme
WEO	World Energy Outlook
WETO	World Energy Technology Outlook
yr	year

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Part II:

Global Potentials of Renewable Energy Sources

Carolin Capone, Corinna Kleßmann, Wina Graus, Monique Hoogwijk (Ecofys)

Table of Contents

1 Introduction

The aim of this work package is to assess the global and regional technical potential of renewable energy sources (RES) for the period 2020 to 2050. This report provides a background on the methodology and results of the assessment. It is based on a review of existing RES potential and scenario studies and develops a set of RES potential data for the 10 world regions defined in the IEA World Energy Outlook 2007.

2 Methodology

2.1 General approach and literature sources

This report gives an overview of major studies which estimate global or regional RES potentials. It is largely based on literature research conducted within a study project for the REN21 report *Renewable Energy Potentials - Opportunities for the rapid deployment of renewable energy in large energy economies* published in spring 2008 (REN21 2008), updated by some additional literature sources. Different types of studies were used, e.g. studies that focused on all or many RE sources like the World Energy Assessment (UNDP/WEC, 2000) and Hoogwijk, 2004, and studies that only focus on one source, for instance Hofman et al, 2002, Fellows, 2001). Table 1 gives an overview of the main literature sources used.

Table 1: Overview of main literature sources analyzed

Study	**Regional scope**	**Covered technologies**	**Time horizon**
Aringhoff et al. 2004	World regions	Solar CSP	2040/2050
Bartle 2002	World regions	Hydropower	2010/2020
Bjoernsson et al. 1998	World	Geothermal	2020
De Vries et al. 2006	IMAGE regions	Wind Onshore, Solar PV, Biomass	2050
DLR 2005	Middle East	Solar CSP	2050
Doornbosch and Steenblik 2007	World	Biomass	2050
Elliot 2002	China	Onshore Wind	2050
Fellows 2000	World regions	Wind Offshore	2050
Fridleifsson 2001	World	Geothermal	2020
Gawell et al. 1999	World regions	Geothermal	--
Hofman et al. 2002	IMAGE regions	Solar PV, CSP,	2050

Hoogwijk 2004	IMAGE regions	Solar PV, Onshore Wind, Biomass	2050/2100
IPCC 4AR 2007	World	Wind, Biomass, PV, CSP, Hydropower, Geothermal	2020/2040
Koopmanns 2005	China, India	Biomass	2050
Lako et al 2003	World regions	Hydropower	2020
Pelc and Fujita 2002	World/USA/Western Europe	Ocean/Offshore Wind	2050
Ragwitz et al. 2003	EU 15	Ocean	2030
REN21 2008	IMAGE regions	all	2050
Seidenberger et al. 2008	IMAGE regions	Biomass	2050
Siegfriedsen et al. 2003	World regions	Offshore Wind	2050
Smeets et al. 2006	World	Biomass	2050
Stefansson 2005	World	Geothermal	2020
UNDP/WEC 2000 (WEA)	World / World regions	Wind Onshore, Hydropower, Geothermal, Biomass, Solar PV	2020/2050
WEC 2007	--	all	--

For each renewable energy source, assumptions and regional scope of the relevant studies are compared. Special attention is paid to environmental constraints and their influence on the overall potential. Based on this assessment, technical RES potentials for the ten world regions defined in the World Energy Outlook 2007 are derived. For some RES this technical potential is based on a combination of sources. In other cases, it is referred to only one literature source as for this source the methodology is most consistent. Where needed, existing data is recalculated according to the geographical scope and time frame of this study, using data found in the literature or own assumptions as explained in the text.

2.2 Definition of potential

When focusing on the availability of renewable energy sources, it is important to define the type of potential that is considered. In the literature, various types of potentials are defined. There is no one single definition for the various types of potentials. We distinguish and define five types of potentials (see Figure 1).

- **Theoretical potential**: The highest level of potential is the theoretical potential. This potential only takes into account restrictions with respect to natural and climatic parameters.
- **Geographical potential**: Most renewable energy sources have geographical restrictions, e.g. land use land cover that reduce the theoretical potential. The geographical potential is the theoretical potential limited by the resources at geographical locations that are suitable.
- **Technical potential**: The geographical potential is further reduced due to technical limitations such as conversion efficiencies, resulting in the technical potential.
- **Economic potential:** The economic potential is the technical potential at cost levels considered competitive.
- **Market potential**: The market potential is the total amount of renewable energy that can be implemented in the market taking into account the demand for energy, the competing technologies, the costs and subsidies of renewable energy sources, and the barriers. As also opportunities are included, the market potential may in theory be larger than the economic potential, but usually the market potential is lower because of all kind of barriers.

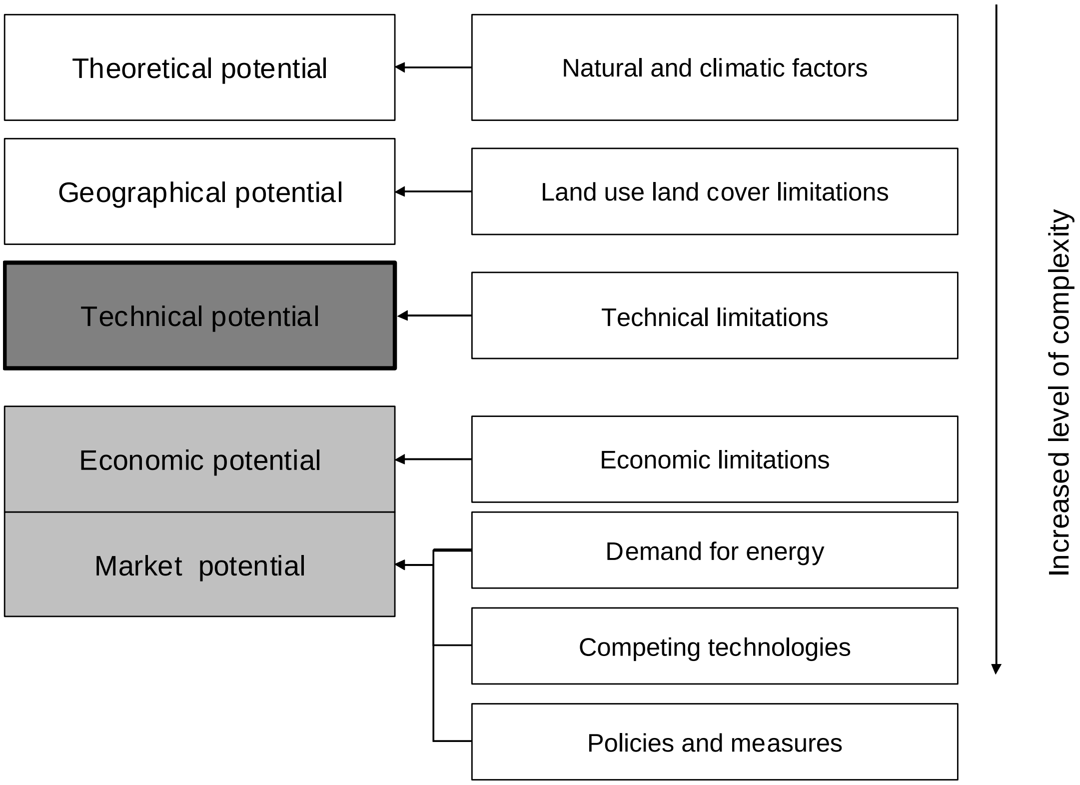

Figure 1: Categorization of five types of potentials and their main important factors and limitations

In this report we focus on the **technical potential**, but take into account **sustainability constraints** where possible. We define this technical potential as: *the total amount of energy (final or primary) that can be produced taking into account the primary resources, environmental as well as socio-geographical constraints, and the technical losses in the conversion process.* It should be noted that despite the environmental constraints taken into account, this type of technical potential cannot necessarily be considered fully sustainable, since the definition of sustainability is much more complex.

Because of the assessment of different existing studies, the potential assessed per renewable energy source is not consistently defined for all renewable energy sources. As many literature sources did not report the limitations included it was not always possible to judge the type of potential assessed. However, by taking a large amount of literature sources for comparison and adjusting some of the figures according to conservative assumptions, the technical potentials given in this report should generally meet the criteria defined above. The constraints taken into account for each renewable energy source are described in the respective sections.

2.3 Time frame

The technical RES potentials will be given for 2020, 2030, and 2050. The reference year for the assessed data is 2005. Since most RES potential studies refer to 2050, the focus will be on this period. The data for 2030 and 2020 will be derived assuming technological learning that is based on selected studies and expert assumptions. In case data sources are given for other time periods, these are taken into account by extra- or interpolation. If deviations occur, the methodology is indicated.

2.4 Renewable energy sources assessed

The technical potential was assessed for the renewable energy sources presented in Table 2. For most sources the focus was put on power and heat. For biomass energy the technical potential of primary energy is reported, since biomass can be used for different energy sectors, including fuels for transport.

Table 2: Overview of types of renewable energy sources that have been included for the technical potential assessment

	Power	Heat	Primary energy
Hydropower	Hydropower (small and large scale combined)		
Solar	PV CSP	Solar thermal	
Wind	Onshore Offshore		
Biomass	Biomass electricity from energy crops or residues		Energy crops, Residues: forest, waste and agricultural
Geothermal	Geothermal electric	Direct use	
Ocean	Wave Ocean Thermal Energy Conversion (OTEC) Tidal Osmotic		

2.5 Regional aggregation

The technical RES potentials are aggregated for ten world regions. In order to facilitate a comparison with the global RES scenarios analyzed in work package 1, the definition of the world regions follows the definition used by the International Energy Agency (IEA) in the World Energy Outlook 2007 (WEO). Table 3 gives an overview of the countries included in each region.

Table 3: The world regions used and their most important characteristics (based on IEA regions as used in the World Energy Outlook 2007)

	Equivalent	**Total land area (1000 km2)**
OECD North America	United States, Canada, Mexico	21572
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom	5028

Transition Economies	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Federal Republic of Yugoslavia, Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latria, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar and Malta[1]	21400
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe	31761
Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen	4701
Latin America	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts-Nevis-Anguilla, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay, Venezuela	18590
OECD Pacific	Japan, Korea, South, Australia, New Zealand	8489
India	India	3287
China	China, Hong Kong, Macao	9598
Rest of Asia	Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Malaysia, Maldives, Myanmar, Nepal, New Caledonia, Papua New Guinea, Pakistan, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Sri Lanka, Vietnam, Vanuatu	12123
Total area		136549

Data from the REN21 study, which used a different regional model, is disaggregated using interpolation by land area and sea area for the respective technologies (ocean and offshore wind). Where spatial variations are assumed to be high, and interpolation by land area seems not adequate, additional assumptions are used to adjust the interpolated data.

It is to be noted that no claims for disputed territory are included. As a result, results may deviate

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

for the concerned regions. A complete list of excluded territory is included in the database (see sheet “land and sea area”).

2.6 Uncertainties

Assessing long term technical potentials is subject to various uncertainties. The distribution of the theoretical resources is not always well analysed, e.g. the global wind speed or the productivity of energy crops. The geographical availability is subject to issues as land use change, future planning decision on where technologies can be installed and accessibility of resources, e.g. for geothermal energy. The technical performance will develop on the long term and the rate of development can vary significantly over time. Next to these inherent uncertainties, we are confronted with uncertainties regarding the literature sources. As will be explained in the text, the data provided in the cited studies is not always consistent, and underlying assumptions are often not explained in detail. Similarly, not all studies use well-established potential definitions; or the definition is not stated explicitly, which results in uncertainties when comparing potentials between different literature sources.

3 Literature survey and assessment of global technical RES potentials

3.1 Solar PV

Photovoltaic systems are specifically constructed semiconductor assemblies that directly convert solar energy into electricity. Two major types of PV systems exist; grid-connected systems and off-grid (stand-alone) systems, being especially viable for electricity production in rural areas. While off-grid systems are dependent on storage capacity, grid-connected systems do not need additional storage systems if the grid is able to cope with variations in electricity production. PV systems exist as ground-mounted systems (used i.e. in large centralised electricity generation facilities) or as rooftop systems, where the latter represent current dominant use. A lot of research is done and PV systems have been steadily improving over the last decades. At present, the majority of installed systems make use of single-crystalline and polycrystalline modules. Efficiencies of state-of-the-art commercially available crystalline cells range between 14-16%, while laboratory cells based on Gallium Arsenide (GaAs) and related III-V compounds have reached efficiencies of >30%.

3.1.1 Literature sources and assumptions

There are three major studies available which assess the global technical potential of solar PV for both centralised and decentralised applications. Hofman et al., 2002 assess the technical potential of all solar technologies for 2020, whereas Hoogwijk, 2004 and De Vries et al., 2006 both analyze the technical potentials for the three technologies biomass, wind and solar PV at grid cell level until 2050. In addition to these studies, global numbers are presented in the World Energy Assessment (UNDP/WEC, 2000) and by Johansson et al., 2004. All three studies considered analyze the technical potential based on solar irradiation, land use exclusion factors and assumptions on future efficiencies.

De Vries does not take into consideration decentralised PV systems. Nevertheless, the estimated technical PV potentials are much higher in comparison to the other studies. Land suitability factors are used to quantify geographical constraints and exclude certain land-use/cover classes, such as urban areas, nature reserves and inaccessible ice. The factors used in De Vries have similar values and underlying assumptions as in Hoogwijk. In his study De Vries derives two results, the focus is on an integrated approach, considering competition between the three concerned technology options (biomass, wind and solar PV), results range from 1144-4276.8 EJ/y, which would be in line with Hoogwijk and WEA; however, the inclusion of a competition factor does not suit the strict definition of technical potential. In the separate potential calculation De Vries derives a global technical potential of 14778 EJ/yr in 2050, which is more than 10 times the estimated potential in the other studies. De Vries makes use of a scenario-approach for his calculations. The A1 scenario, which is applied for the calculation of the separate potential describes a trend towards a high-tech and increasingly interconnected world, driven by an orientation on markets, deregulation and the removal of trade barriers (De Vries, 2006), which results in increased conversion efficiencies, performance ratios and land use factors, when compared to Hoogwijk. For a lack of further detailed data, it can only be assumed that the high differences in potential result from the storyline of the scenario.

Hoogwijk is more optimistic on the future potential of solar PV than Hofman et al., partly because higher efficiencies have been assumed, a higher land use suitability factor is used and no land area is excluded because of limited solar irradiation. Also it was assumed that the area is completely used for solar modules, e.g. no space factor was included.

The figures presented in this report are based on the data from Hoogwijk, 2004 but have been multiplied with a factor of 0.6 to correct for the more optimistic assumptions compared to other studies (see above), in line with REN21 2008. As a result, the global numbers are comparable to values from World Energy Assessment (UNDP/WEC, 2000) and assumptions by Hofman et al., 2002 but the regional distribution is based on detailed irradiation data. The original assumptions are presented in Table 4. Due to a lack of more detailed data, we assume a linear increase in technical PV performance for the time period 2020-2050 (conversion efficiency of 15% in 2020, 18% in 2030, based on 25% conversion efficiency used by Hoogwijk for 2050). Possible technological breakthroughs are thus not considered.

3.1.2 Geographical and environmental constraints

Geographical constraints are quantified by using the suitability factor. The factor depends on competing land use options, such as agriculture, nature or farming for centralised systems[2] and roof-tops and façade area for decentralised systems[3]. For centralised application the quantification of suitability factors follows Soerensen 1999. It is described below and shown in Table 4. For decentralised applications the suitability factor is considering roof-top area per capita based on population density and GDP data.

Available area for centralised PV-systems on crop land is restricted to small parts next to infrastructure or fallow area. Extensive grassland is given a higher suitability factor than agricultural areas, as these areas are used less intensively and PV applications would block to a lesser extent the original land use function. Furthermore there are land use functions like the conservation of bio-reserves or landscapes of natural beauty, which do not allow any installation of centralised PV-systems. Consequently, protected areas and forest areas are completely excluded for centralised applications. Due to these constraints the assumed total suitable area for centralised PV adds up to on average 1.67% of total land area.

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[2] Centralized PV systems are defined as semi- to large-scale systems (>10kWp capacity), installed at the ground in areas with little competing land use options (see Hoogwijk, 2004).

[3] Decentralized PV systems are defined as small- to medium-scale systems (100 W to 10 kWp) for domestic electricity supply, installed at or close to houses, utilities or industries (see Hoogwijk, 2004).

Table 4: Main technology-specific assumptions for solar PV in 2050 by Hoogwijk, 2004. Note: For this study, these data have been corrected with a factor of 0.6, reflecting more conservative assumptions

	Land area	**Average irradiation**	**Average land use factor for centralised PV**	**Conversion efficiency**	**Perfor-mance factor**
	Mha	W/m^2	%	%	%
Canada	950	93.6	0.50	25	90
USA	925	127.4	0.92	25	90
Central America	269	175.9	1.38	25	90
South America	1761	152.4	0.84	25	90
Northern Africa	574	203.1	4.50	25	90
Western Africa	1127	184.1	2.10	25	90
Eastern Africa	583	195.3	2.71	25	90
Southern Africa	676	180.2	2.1	25	90
Western Europe	372	108.8	0.69	25	90
Eastern Europe	116	124.4	0.63	25	90
Former USSR	2183	95.8	0.92	25	90
Middle East	592	198.1	3.32	25	90
South Asia	509	193	1.92	25	90
East Asia	1108	149.4	2.14	25	90
South East Asia	442	158.6	0.51	25	90
Oceania	838	188.5	3.32	25	90
Japan	37	126.4	0.23	25	90
Global	**13,062**		**1.69**	25	90

Table 5: The assumptions on the global suitable land area for centralised PV (Sørensen, 1999. Hoogwijk 2004)

Land use type	Land-use suitability factor f_i[4] (-)	Area per land-use type (Million km^2)	Land-use area as percentage of total terrestrial area	Suitable area for centralised PV (Million km^2)	Suitable area for centralised PV as percentage of total land area
Urban area	0	0.2	0.2%	0.00	0.00%
Bio-reserve	0	8.3	6%	0.00	0.00%
Forest	0	37.0	27%	0.00	0.00%
Agriculture	0.01	32.3	24%	0.32	0.24%
Scrubland	0.01	8.1	6%	0.08	0.06%
Savannah	0.01	5.6	4%	0.06	0.04%
Tundra	0.01	8.3	6%	0.08	0.06%
Grassland	0.01	17.1	13%	0.86	0.63%
Extensive grassland	0.05	16.9	12%	0.85	0.62%
Desert	0.05	2.3	2%	0.02	0.02%
Total		136.1	100%	2.27	1.67%

3.1.3 Results

Figure 2 shows the derived technical potential for solar PV for the different regions in 2050. The global technical potential is 1689 EJ/y. Africa is found to have by far the largest technical potential for solar PV, followed by OECD Pacific. The smallest technical potential is seen for OECD Europe.

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[4] The land-use suitability factor f_i depends on physical-geographical factors (terrain, habitation) but also on socio-geographical parameters (location, acceptability).

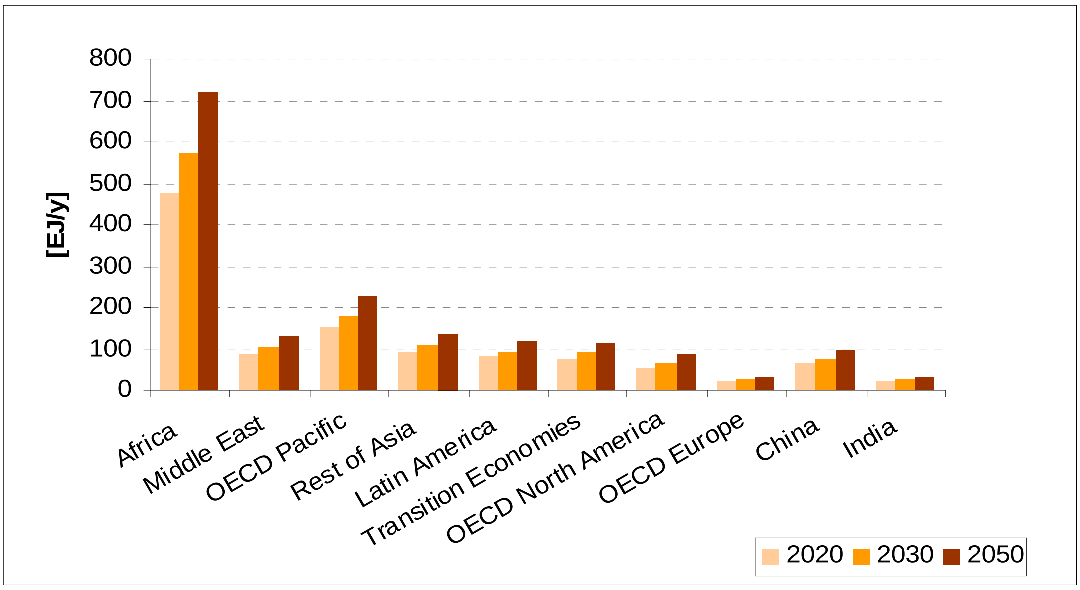


Figure 2: Technical potential for solar PV for different regions 2020-2050

3.2 Concentrating solar power (CSP)

Today there are three major commercialized technologies being summed up under the term Concentrating Solar Power (CSP). In contrast to PV systems, these solar thermal systems are based on the concentration of solar radiation and its conversion to heat. CSP plants are categorized according to whether the solar flux is concentrated by parabolic trough-shaped mirror reflectors, central tower receivers requiring numerous heliostats, or parabolic dish-shaped reflectors. The receivers transfer the solar heat to a working fluid, which in turn transfers it to a thermal power conversion system based on Rankine, Brayton, combined or Stirling cycles. Currently, about 600 MW_e have been installed worldwide, but various large projects are under construction (Molenbroek, 2006). According to the WEC Survey of Energy Resources 2007, the most promising areas are the Southwestern United States, Central and South America, Africa, the Middle East, the Mediterranean countries of Europe, South Asia, certain countries of the Former Soviet Union, China and Australia.

3.2.1 Literature sources and assumptions

The technical potential for concentrating solar power on a global scale is assessed by Hofman et al., 2002. The data covers most countries of the world, except Canada, Norway and Switzerland. However, it is expected that the potential for CSP is limited in these three countries. The technical potential for solar CSP in North Africa and the Mediterranean countries is assessed by DLR, 2005. The technical potential for the Middle East is much higher in this study compared to what has been assessed by Hofman et al., 2002 for these regions (in the order of factor 20). This is mainly due to the assumptions on the land availability and sustainability.

Both studies have limited the available areas to areas with high direct irradiation only (1800kWh/m^2y in the DLR study and 1445 kWh/m^2y in Hofman et al.). DLR excludes all areas that are unsuitable for the erection of solar fields due to ground structure, water bodies, slope (>2.1%; in comparison Hofman et al.: >5%), dunes, protected or restricted areas, forests, and agriculture. DLR, 2005 does not state explicit numbers on assumed suitable land area, but satellite pictures in the report depict that assumptions on suitable area are approximately in the same order as Hofman et al. (Africa: 65%, ME: 63%). Hofman et al. further limit the maximum area for solar electricity generation to 5% of the potentially suitable area in order to allow an increase of other types of land use, e.g. agriculture and forestry, buildings and other renewable energy sources. They argue that this should be the suitable maximum of land to be used for solar electricity generation.

Also the time horizon for the assessment differs for the two studies. Hofman et al. estimate the technical potential for 2020 whereas DLR estimates technical potentials for 2050. The DLR study projects the capacity factor for the Mediterranean countries (solar operating hours per year divided by 8760 available hours per year) to be between 25-90% for parabolic troughs, Fresnel mirror collectors and power towers in 2050, assuming an increase in thermal storage capacity (storage in concrete, ceramics or phase-change media and extraction for continuous power generation during the night), ability for hybrid operation, technical availability and capacity credit. Hofman et al. assume the demonstrated average capacity factor of 35% for all technologies and all regions. In contrast, DLR is more conservative on the technical performance of the CSP plants, using an average annual efficiency of 15% (it is stated that this is already state of the art). Hofman et al. assume an average efficiency of 18-23% in 2020.

In line with REN21 2008 we use the potentials stated in Hofman et al. as a basis for this report, since they are given for all world regions in question and constitute the only study with regional coverage and transparent approach. Building partly on DLR, 2005 and current technical developments observed by the Ecostar road map the data is adapted for 2050:

- We use a higher average capacity factor of 65% in 2050 assuming increased storage capacity of 15 hours.
- As most constraints are already excluded by the definition of suitable land, the restriction to 5% of suitable land area is reversed and set to 80%. Suitable land area for CSP installations mostly comprises desert areas, which makes competition for land rather unlikely. However, by excluding 20% of all suitable land area we still choose a conservative approach.
- It is assumed that the system efficiency increases from 18% in 2020 to about 25% in 2050.

As the capacity factors of some pilot plants with enhanced storage systems achieve values of 65% already today, we increase the potential stated by Hofman for 2020 by a factor 1.3. Increased average capacity factors will largely depend on wider application of enhanced storage capacities, plant efficiencies will not develop significantly for 2050 compared to 2030.

Table 6 shows the assumed technological developments from 2020 to 2050. Based on these we assume that the technical potential for 2030 increases by factor 1.2 compared to 2020, and by 1.3 for 2050 compared to 2030.

Table 6: Assumed average developments for CSP technologies

	2020	2030	2050
Capacity factor	45	50	65
Plant efficiency	18	23	25

DLR recently carried out a global CSP potential study within the European Union project REACCESS. The study is not published yet, however, results lie in the same order of magnitude as results calculated for the present study. Table 7 shows the technical potentials as calculated in the current DLR study in comparison to the potentials calculated in this study for 2050. As in their first study, DLR assumes a parabolic trough with an annual average efficiency of 15% as reference technology. Excluded land area is used in correspondence with DLR 2005. No competition for land is assumed. In addition, DLR does not project any technological development, the potentials are therefore not time dependent. The study is somewhat stricter in terms of exclusion of land area due to solar irradiation constraints. Suitable land is assigned a min. DNI of 2000 kWh/m2/y. It is important to note that the compared studies use different region definitions. Differences in regional distribution of potentials may result from the different DNI prerequisite as well as from these slight differences in region definition.

Table 7: Global technical potential for CSP from REACCESS (DLR 2009)

Region	Technical Potential (EJ/y)		Region	Technical Potential (EJ/y)	
	DLR 2009	Values used in this study (2050)		DLR 2009	Values used in this study (2050)
Africa	5252	4348	Middle East	1043	1153
Australia	2518	1513	Mexico	144	
Central Asia, Caucase	54	9*	Other Developing Asia	270	204**
China	450	60	EU27+	9	4
Central / South America	450	299	USA	378	347***
India	36	106	World	10791	8044

Rest of Asia **Transition Economies *(inkl.Mexico)*

3.2.2 Geographical and environmental constraints

Hofman et al. take into account slope constraints, nature area constraints, water constraints, and urban constraints. Furthermore, they reserve room for alternative development opportunities, however, these have been removed for this study as it is assumed that the full technical potential for CSP will never be exploited which leaves enough space for alternative development opportunities. All areas recognized by the IUCN (International Union for the Conservation of Nature) are excluded.

3.2.3 Results

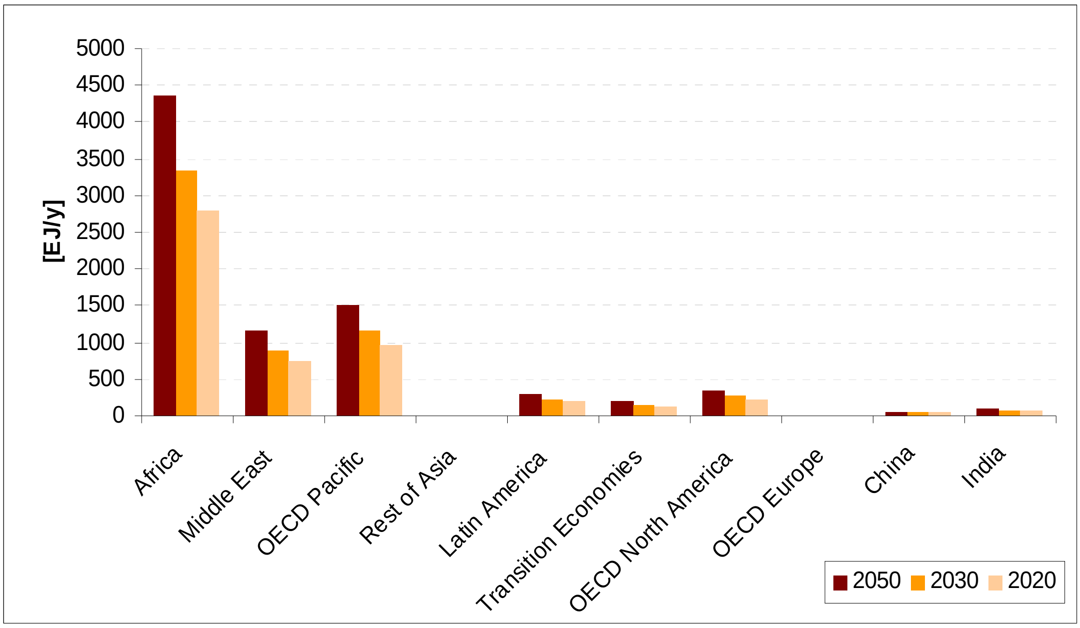


Figure 3: Technical potential for solar CSP for different regions 2020-2050

The technical potential for the RES technology solar CSP in the assessed regions in 2050 is shown in Figure 3. The global technical potential is 8043 EJ/y. Africa is found to have by far the largest technical potential for solar CSP, followed by OECD Pacific and the Middle East.

3.3 Hydropower

With a share of 87% of the world’s renewable electricity production in 2005 (WEC 2007), hydropower is by far the largest renewable energy source currently under use. It is one of the most mature and flexible renewable energy technologies, but its environmental impacts may be severe. Hydroelectricity is generated by mechanical conversion of the potential energy of water in high elevations or in the flow of rivers. The availability of hydropower depends therefore on local and geographical factors as the availability of water and the height difference for runoff water.

3.3.1 Literature sources and assumptions

Various studies have indicated the technical potential of hydropower at a regional level. Most of the sources refer to the World Atlas and Industry Guide, 1998, e.g. UNDP/WEC, 2000; WEC, 2001. The total global technical potential is estimated at around 50 EJ/y, (UNDP/WEC, 2000; Bartle, 2002; Johansson, 2004; Björnsson et al, 1998). Lako et al. 2003 present much lower figures at around 30 EJ/y. The regional distribution is slightly different but in the same order of magnitude among all studies. Slightly larger differences between the regional distribution of technical potential can be seen for OECD Europe and Asia, e.g. between the World Energy Assessment (UNDP/WEC 2000; in the following referred to as WEA) and Lako et al., 2003. For OECD Europe Lako et al. indicate a much lower technical potential at around 600 TWh/y compared to 1800 TWh/y in the WEA. This is because Lako et al. do not include large scale hydropower generated from dams, and because the definitions of the used region models are not fully consistent. Lako et al. exclude Turkey, Hungary, Slovak Republic, and Switzerland from OECD Europe as defined by the IEA. Turkey alone has an additional technical potential of 216 TWh/y. Taking into account the other excluded countries and additional electricity generated from reservoirs/dams, the technical potential in Lako et al. adds up to approximately 1200 TWh/y for OECD Europe. The exclusion of hydropower generated from reservoirs/dams is also the reason for the relatively small potential assumed for Asia (1165 TWh/y in Lako et al. vs. 3107 TWh/y in the WEA). In case of inclusion of large-scale hydroelectricity, the figures of Lako et al. sum up to a total technical potential of 6700 TWh/y for Asia. The high number compared to WEA results from the different regional definitions used in the two studies. Lako et al. include Russia and Turkey into Asia, whereas these countries are not considered in the calculations for Asia in WEA, 2000.

In line with REN21 2008, our study uses technical potentials at a regional scale from the WEA, 2000, since it has the largest coverage and is most in line with other studies. Lako et al., mainly focus on Asia and Western Europe. Since hydropower is a mature technology, only minor efficiency increases are assumed for the period 2020-2050 (the 2020 potential is 5% lower than 2050).

The WEA considers its estimate still conservative as the potential in many developing countries is weakly assessed. The report also indicates the uncertainty of the results, stating that reported technical potentials could be inflated or, because of incomplete assessments, seriously underestimated. These uncertainties thus also apply to the data used in this study.

3.3.2 Geographical and environmental constraints

The technical potentials for hydropower in the WEA, 2000 are based on the potential calculations on numbers derived from the World Atlas and Industry Guide, 1998. It is stated that few or no environmental constraints have been considered in the calculation as evaluation criteria may differ substantially by country and, especially in developing countries, may be quite unsophisticated.

Potentials estimated by the WEA 2000 and used in this study include electricity generation from large-scale hydropower installations. There is an ongoing discussion under which conditions large-scale hydropower plants suffice sustainability criteria and can be counted as a “green” energy source. For this reason Lako et al. calculate the potentials for large-scale hydropower separately. They also point out, however, that it cannot be afforded to dismiss a source of renewable energy such as large-scale hydropower if a maximum use of renewable energy is aimed at in the future. Furthermore, the sustainability of small-scale hydropower is also questionable. According to Lako et al., the simple categorization into large- and small-scale hydropower is not very practical. Environmental impacts often are not seen per unit of output, distorting possible environmental impacts. As a matter of fact, Lako et al. give detailed recommendations for a sustainable approach to renewable hydropower resource development in their study.

Results

Figure 4 provides the technical potential for hydropower at a regional level. High potentials can be found in Asia and Latin America. The global technical potential amounts to 50 EJ/y.

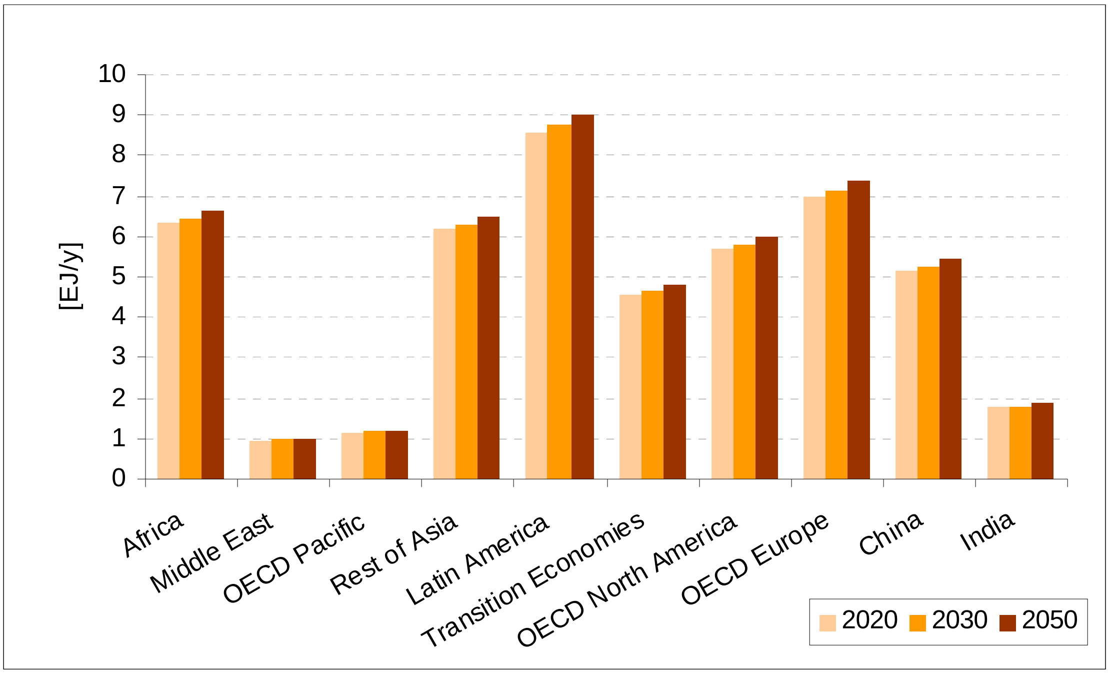


Figure 4: Technical potential for hydropower for different regions 2020-2050

3.4 Biomass energy

Primary biomass can be converted to all kinds of energy applications, i.e. heat, electricity and transport fuel. Biomass is used for energy generation throughout the world either in a traditional way or in technologically advanced ways, e.g. electricity generation, combined heat and power (CHP), liquid biofuels and modern gases. While the use of traditional biomass is increasing only in absolute figures, modern technologies are increasing both in absolute and relative terms. Still, biomass energy only accounts for approximately 2% of total world energy demand (IPCC FAR 2007), but the sustainability of bioenergy crops production and its influence on food and feed markets has already become a crucial global issue. Current installed electric capacity is estimated at 48 GW (Greenpeace, EREC, 2007). Its total use in 2004, including heat and transport fuels, is estimated at around 50 EJ/y (IPCC FAR, 2007).

Biomass resources are available from a large range of different feedstock, including energy crops and residues from agriculture, forestry, and food industry and waste. Figure 4 provides an overview of different types of biomass feedstock and the conversion to energy applications. It is important to distinguish dedicated energy crops and residues from agriculture, forestry, food industry and waste. While energy crops compete with other types of land-use, and their production needs to take into account environmental and social concerns, the use of biomass residues does not require extra agricultural land.

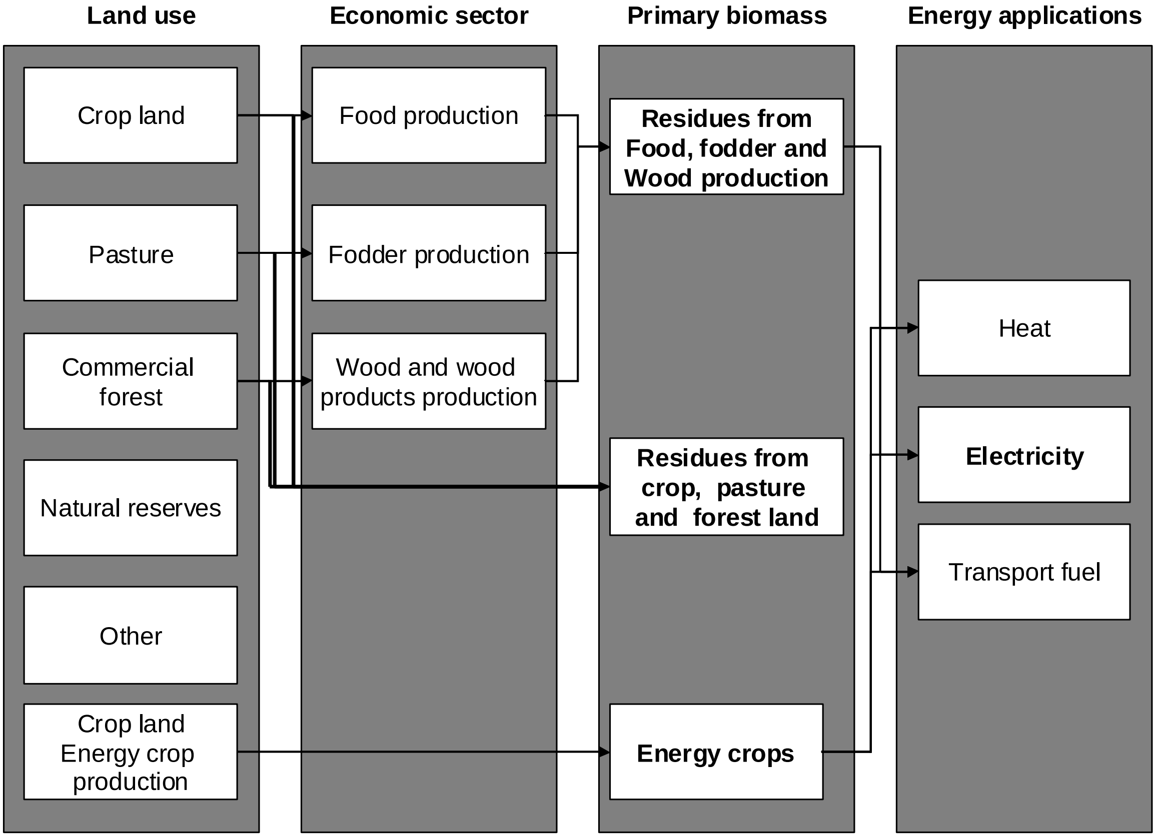


Figure 5: Schematic representation of the type of primary biomass feedstock and the conversion to energy applications.

3.4.1 Literature sources and assumptions

Different bioenergy potential studies were assessed for this study, resulting in a wide range of potentials for each region.

Table 8 shows a summary of the ranges of potentials found in literature for the regions covered by this study. Studies that have been taken into account are: Berndes, et al., 2003; Yamamoto et al., 2001; Williams 1995; Hall et al., 1993; Dessus et al., 1993, Hoogwijk, 2004; EEA, 2006; ASES, 2007; FAO/RWEDP, 2000, IPCC AR4, Smeets et al 2005.

Table 8: Ranges of the technical bioenergy potentials in 2050 found in the literature

Technical potential (EJ/y)	**Residues**		**Energy Crops**	
	Low	High	Low	High
Africa	4	11	15	69
Middle East	0.2	0.2	1	2
China	3	4	15	21
Asia (incl. India and China)	13	32	25	96
OECD Pacific	1	1	0	32
Latin America	2	25	2	66
Transition Economies	3	7	48	112
OECD North America	7	36	15	60
OECD Europe	2	5	9	15
World	*32*	*117*	*162*	*840*

The wide ranges in potentials result from different methodologies and assumptions on land availability and crop yields. Factors having an impact on future land availability for energy crops include the following:

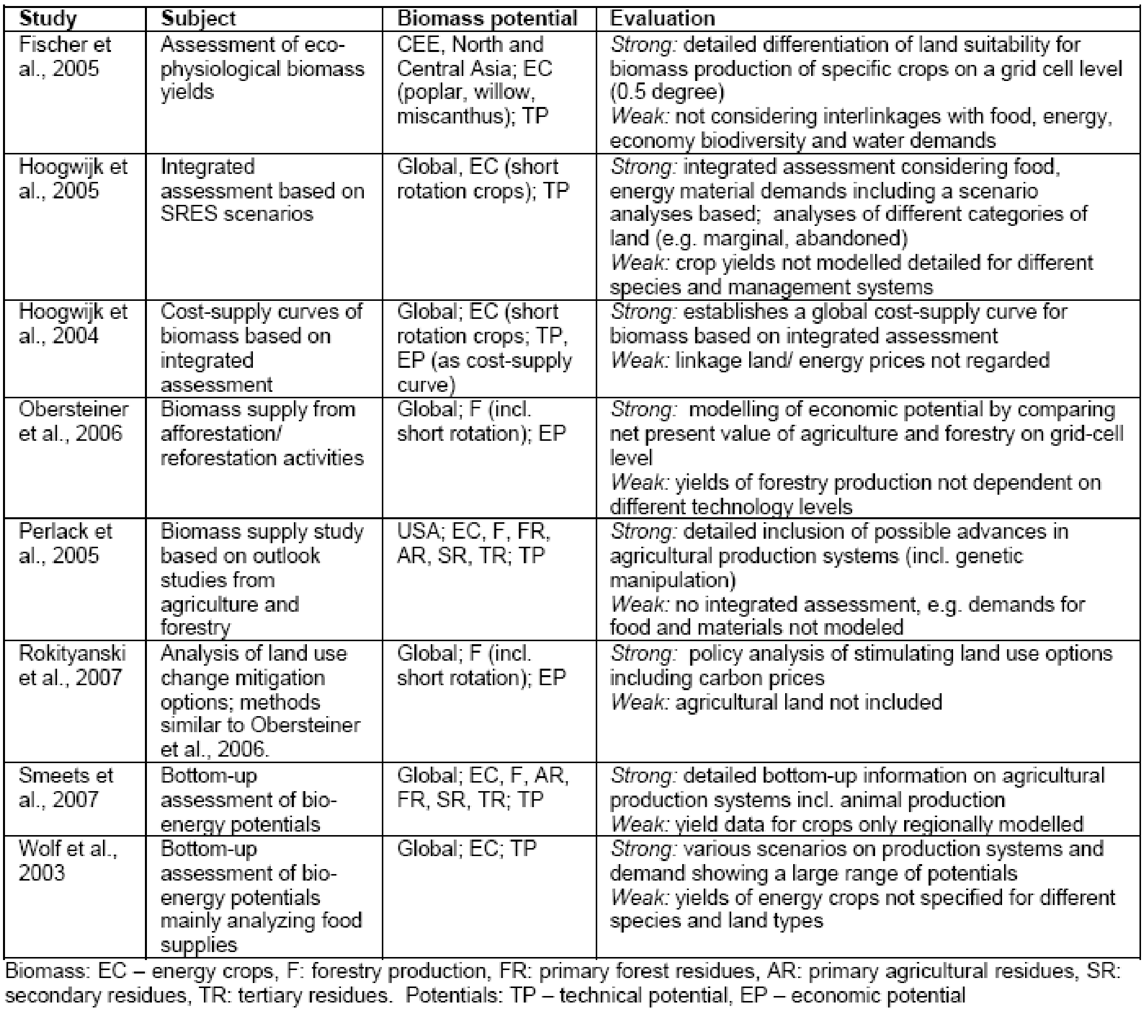
- Demographic developments and thereof resulting competition with food and feed production
- Economic growth and change in life styles/diets
- Changes in land-use management practices; an increase in intensity of e.g. cattle farming will set free land currently used for grazing
- Availability of fertilizers and pest control techniques
- Competition for water resources with other economic sectors; for areas where water is scarce competition could limit energy crop production
- Impact of Climate Change on available land area
- Loss of agricultural acreage by soil degradation (erosion, salinization) and additional need of areas for non-agricultural purposes (infrastructure, restrictions of use etc.)

- Competing needs for nature conservation
- Acreage for flood protection

Next to assumptions on crop yield and land availability the scope of the studies differs also in terms of technologies/end-uses considered and types of crops/residues concerned.

In a recent and comprehensive study, Dornburg et al., 2008 have evaluated strengths and weaknesses of different biomass potential studies (see Table 9). They also assess the impact of uncertainties on biomass potentials, which proves to be substantial (see Table 10). They explain that the total technical biomass supplies could range from about 100 EJ using only residues up to an ultimate technical potential of 1500 EJ/yr potential per year. After a thorough assessment of environmental constraints, they conclude that the global usable biomass potential is only in the range of 200-500 EJ/yr, while the medium range of estimates in other reviewed studies is between 300 and 800 EJ/yr.

Table 9: Evaluation of biomass potential studies by Dornburg et al., 2008



Study	Subject	Biomass potential	Evaluation
Fischer et al., 2005	Assessment of eco-physiological biomass yields	CEE, North and Central Asia; EC (poplar, willow, miscanthus); TP	*Strong:* detailed differentiation of land suitability for biomass production of specific crops on a grid cell level (0.5 degree) *Weak:* not considering interlinkages with food, energy, economy biodiversity and water demands
Hoogwijk et al., 2005	Integrated assessment based on SRES scenarios	Global, EC (short rotation crops); TP	*Strong:* integrated assessment considering food, energy material demands including a scenario analyses based; analyses of different categories of land (e.g. marginal, abandoned) *Weak:* crop yields not modelled detailed for different species and management systems
Hoogwijk et al., 2004	Cost-supply curves of biomass based on integrated assessment	Global; EC (short rotation crops; TP, EP (as cost-supply curve)	*Strong:* establishes a global cost-supply curve for biomass based on integrated assessment *Weak:* linkage land/ energy prices not regarded
Obersteiner et al., 2006	Biomass supply from afforestation/ reforestation activities	Global; F (incl. short rotation); EP	*Strong:* modelling of economic potential by comparing net present value of agriculture and forestry on grid-cell level *Weak:* yields of forestry production not dependent on different technology levels
Perlack et al., 2005	Biomass supply study based on outlook studies from agriculture and forestry	USA; EC, F, FR, AR, SR, TR; TP	*Strong:* detailed inclusion of possible advances in agricultural production systems (incl. genetic manipulation) *Weak:* no integrated assessment, e.g. demands for food and materials not modeled
Rokityanski et al., 2007	Analysis of land use change mitigation options; methods similar to Obersteiner et al., 2006.	Global; F (incl. short rotation); EP	*Strong:* policy analysis of stimulating land use options including carbon prices *Weak:* agricultural land not included
Smeets et al., 2007	Bottom-up assessment of bio-energy potentials	Global; EC, F, AR, FR, SR, TR; TP	*Strong:* detailed bottom-up information on agricultural production systems incl. animal production *Weak:* yield data for crops only regionally modelled
Wolf et al., 2003	Bottom-up assessment of bio-energy potentials mainly analyzing food supplies	Global; EC; TP	*Strong:* various scenarios on production systems and demand showing a large range of potentials *Weak:* yields of energy crops not specified for different species and land types

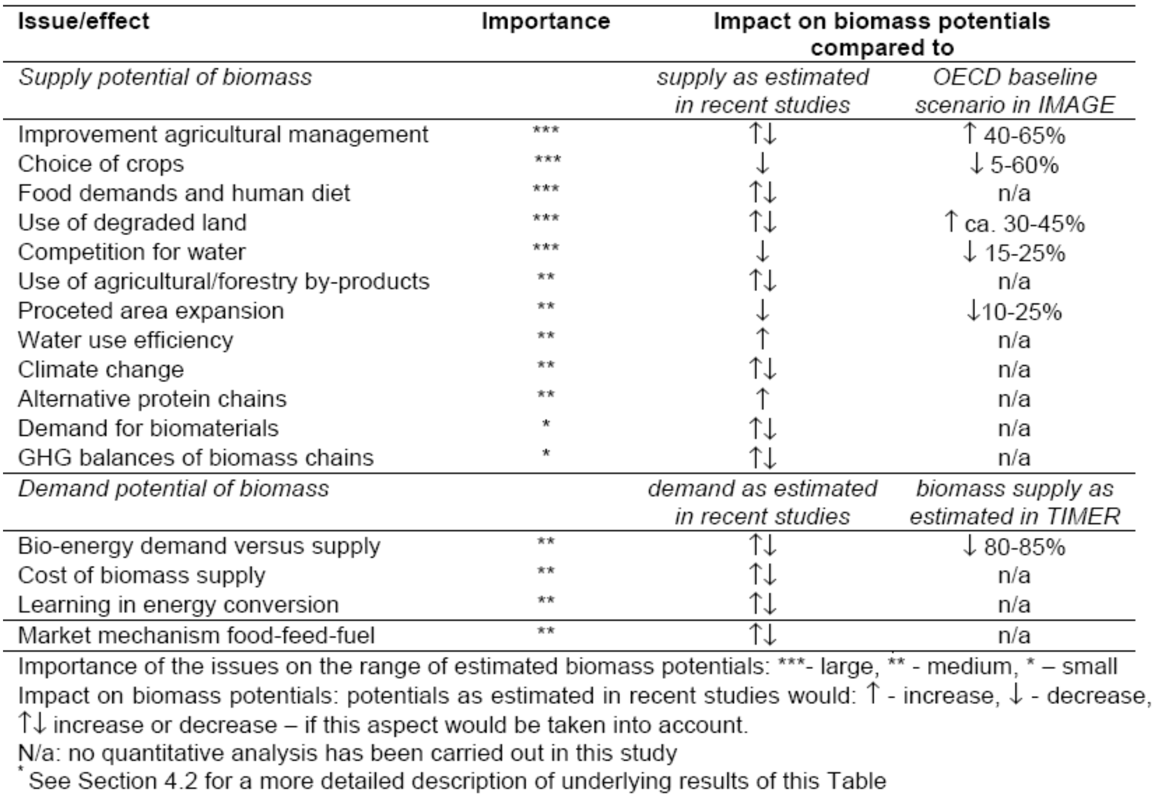
Biomass: EC – energy crops, F: forestry production, FR: primary forest residues, AR: primary agricultural residues, SR: secondary residues, TR: tertiary residues. Potentials: TP – technical potential, EP – economic potential

Seidenberger et al. 2008 carried out a global biomass potential analysis commissioned by Greenpeace and EREC for their energy [r]evolution scenario. The very recent study is even more conservative in their projections, assuming a global technical energy crops potential of less than 100 EJ/y in 2050. The scope of the study comprises figures for 2010, 2015, 2020, and

2050 for 133 countries. Final results are grouped into nine world regions.

We use Seidenberger et al. 2008 as a basis for both the residues and the energy crops potentials, as it is very transparent on the methodology of potential calculation. It also considers a comprehensive set of sustainability criteria, comprises the most recent data set, has global coverage and serves the time span included under the scope of our study. In addition, Hoogwijk´s approach of considering competition for available land is taken up to a certain extent by including the obligation to grant preference for domestic food production over other land uses. Taking into account the current discussion on sustainability of energy crop use and indirect land use changes, it seems especially important for calculating potentials on a regional scale to take into account competition for available land area.

Table 10: Overview of uncertainties and their impact on biomass resource potentials (Dornburg et al. 2008).



Issue/effect	**Importance**	**Impact on biomass potentials compared to**	
Supply potential of biomass		*supply as estimated in recent studies*	*OECD baseline scenario in IMAGE*
Improvement agricultural management	***	↑↓	↑ 40-65%
Choice of crops	***	↓	↓ 5-60%
Food demands and human diet	***	↑↓	n/a
Use of degraded land	***	↑↓	↑ ca. 30-45%
Competition for water	***	↓	↓ 15-25%
Use of agricultural/forestry by-products	**	↑↓	n/a
Proceted area expansion	**	↓	↓10-25%
Water use efficiency	**	↑	n/a
Climate change	**	↑↓	n/a
Alternative protein chains	**	↑	n/a
Demand for biomaterials	*	↑↓	n/a
GHG balances of biomass chains	*	↑↓	n/a
Demand potential of biomass		*demand as estimated in recent studies*	*biomass supply as estimated in TIMER*
Bio-energy demand versus supply	**	↑↓	↓ 80-85%
Cost of biomass supply	**	↑↓	n/a
Learning in energy conversion	**	↑↓	n/a
Market mechanism food-feed-fuel	**	↑↓	n/a

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small
Impact on biomass potentials: potentials as estimated in recent studies would: ↑ - increase, ↓ - decrease, ↑↓ increase or decrease – if this aspect would be taken into account.
N/a: no quantitative analysis has been carried out in this study
* See Section 4.2 for a more detailed description of underlying results of this Table

The residue potentials are calculated on the basis of Smeets et al. 2007 and Dessus et al 1993. Dessus is used since it is the only study with region-specific residues data for 2020. Smeets is used because it takes 2050 into consideration and defines sustainability criteria in the assessment. Moreover Smeets offers high level of transparency of methodology.

For energy crops Seidenberger et al. draw up five scenarios with differences in land availability due to different assumptions on future land use, stringency of ecological restrictions/constraints, as well as changes in eating habits. For our study we use the business-as-usual (BAU), in order to be in line with the definition of technical potential we used for other technologies. The scenario is characterized by positive population growth, and increased per-capita consumption worldwide. Current legal and economic conditions remain valid also for the future; forest clearing, change of grazing land and loss of agricultural areas for industry and traffic purposes are assumed to continue to take place. Existing intensity-suppressing measures remain in place.

Seidenberger et al. include technical potentials for 2020 and 2050. Since no information is available on growth rates or technological learning, we calculate the potential for 2030 based on the assumption of linear growth within each region.

Comparison with results of other studies

Hoogwijk et al 2004 draw up bioenergy potentials for four land use scenarios, developed by the IPCC in its Special Report on Emission Scenarios (SRES, 2000). These scenarios result in different future land use patterns. The four scenarios differ regarding aspects like population, GDP, life styles and technological changes. Stated potentials are higher than the potentials used for our study. Hoogwijk calculates a purely technical potential while Seidenberger et al. focus on establishing a “sustainable” potential.

De Vries et al. 2006 assess the technical potential for liquid transport fuel and electricity from biomass for 2050 based on the scenarios established in Hoogwijk. Heat and CHP are not included in the scope of the study. For liquid transport fuel De Vries et al. 2006 only consider woody biomass, maize and sugar cane as possible energy carriers, for electricity conversion only woody biomass is considered. As a result total biomass potentials found in De Vries et al. 2006 are in the range of data found for only energy crops in Hoogwijk et al 2004.

Koopmanns 2004 assesses the sustainable biomass potential for South and South East Asia on a country basis for 2010. Calculated potentials for China and India are in the same range as potentials calculated in the other studies considered.

Smeets et al. 2007 state a relatively high potential for energy crops (390-1550 EJ/y). Depending on the scenario all biomass resource types are included and very intensive, technologically developed agricultural practice is assumed.

Doornbosch and Steenblik 2007 arrive at estimates of similar magnitude as the study by Seidenberger et al. for the potentials from energy crops (~110 EJ/y); however, distribution of potentials differs. Doornbosch and Steenblik state relatively high potentials for Latin America and Africa, but low estimates for Europe and North America and even negative potentials for Asia, while Seidenberger et al. assume somewhat higher potentials for North America and a net-zero potential for Africa. As in Seidenberger et al., assumptions in Doornbosch and Steenblik include some sustainability criteria, such as considerations in terms of water stress for the determination of land availability and land productivity as well as the consideration of food production needs.

3.4.2 Geographical and environmental constraints

The potential for energy crops depends largely on land availability, considering that worldwide a growing demand for food has to be met, combined with environmental protection, sustainable management of soils and water reserves, and a variety of other sustainability requirements. Steeply rising bioenergy demand and increasing globalization resulted in a heated debate on the sustainability of bioenergy. Increased competition with food and fodder production as well as increasing deforestation are now associated to bioenergy production, and the clearing of virgin forests as well as high fossil energy input for machinery render the overall GHG emission balance of certain types of bioenergy questionable.

The BAU scenario by Seidenberger et al. was established for the Greenpeace [r]evolution scenario and addresses the above named sustainability concerns. Energy crop production takes only place on the surplus area of arable land and grassland and domestic food and fodder production is given priority in land use. Nevertheless, transformation from grassland and agricultural land into building land (infrastructure, industry, etc.) as well as forest clearing continue to take place under the BAU scenario. Seidenberger et al. establish further scenarios including more stringent sustainability criteria, which further reduce the overall potential. For this study, however, we used the potentials stated in the BAU scenario in order to stay in line with our definition of technical potential.

In general terms, the recent study of Dornburg et al. 2008 assesses eight recent studies on biomass resource potential, analyzing the underlying assumptions and trying to establish a comprehensive view on environmental and social constraints that should be considered in the potential calculations for bioenergy. According to the study the following critical aspects should be included in further potential studies:

- Competition for water with other economic sectors, as well as the possibilities of irrigation; existing and expected bottlenecks for water availability
- Food demand, including world population, economic aspects, production systems as well as human diets
- Options for supplying energy-related services, as well as costs for different options
- Detailed demand for wood products and other bio-materials
- Impact of large-scale biomass production on prices and subsequently demands of land and food
- Detailed impact of specific biodiversity objectives; biodiversity losses should be assessed in an LCA-approach over the whole life cycle

3.4.3 Results

Based on a literature assessment, Seidenberger et al. 2008 assume a total biomass residue potential of 87.6 EJ/y in 2050. Seidenberger et al. calculate the technical potentials for 2010, 2015, 2020 and 2050 respectively. For potentials stated in this study we used regional data for 2020 and 2050 and assumed a linear increase for 2030. Global technical potential for energy crops accounts for 43.4 EJ/y in 2020 and 96.5 EJ/y in 2050, with highest technical potentials in 2050 found for Latin America, followed by North America and the Transition Economies. Africa, Middle East and total Asia show a zero-potential for the whole time-span. The potential in OECD Pacific shows a decreasing trend.

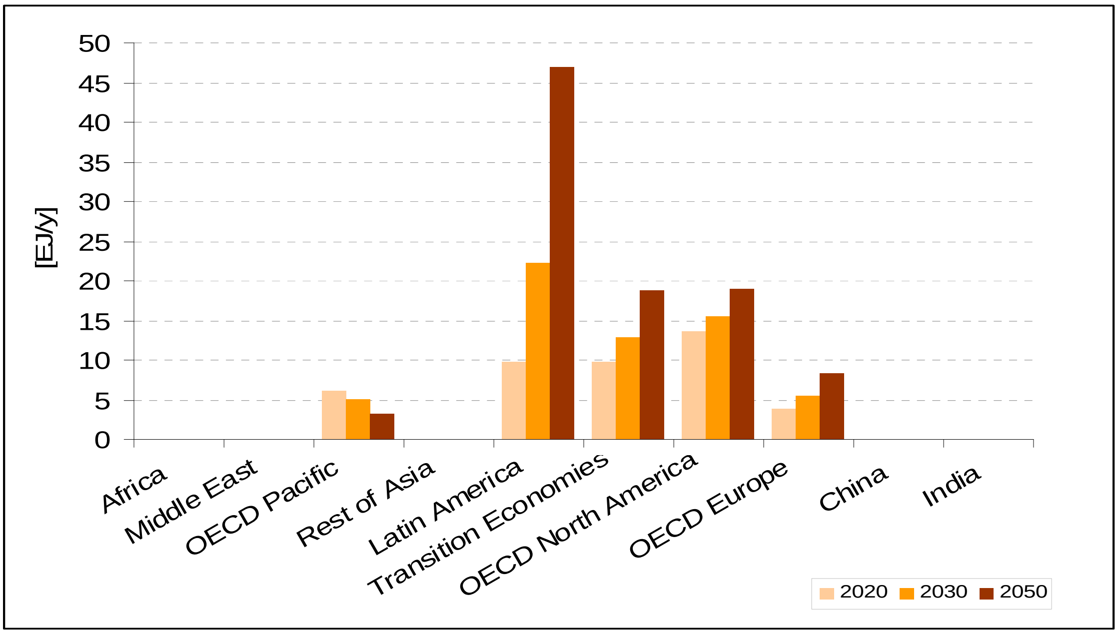


Figure 6: Technical potential for energy crops for different regions 2020-2050

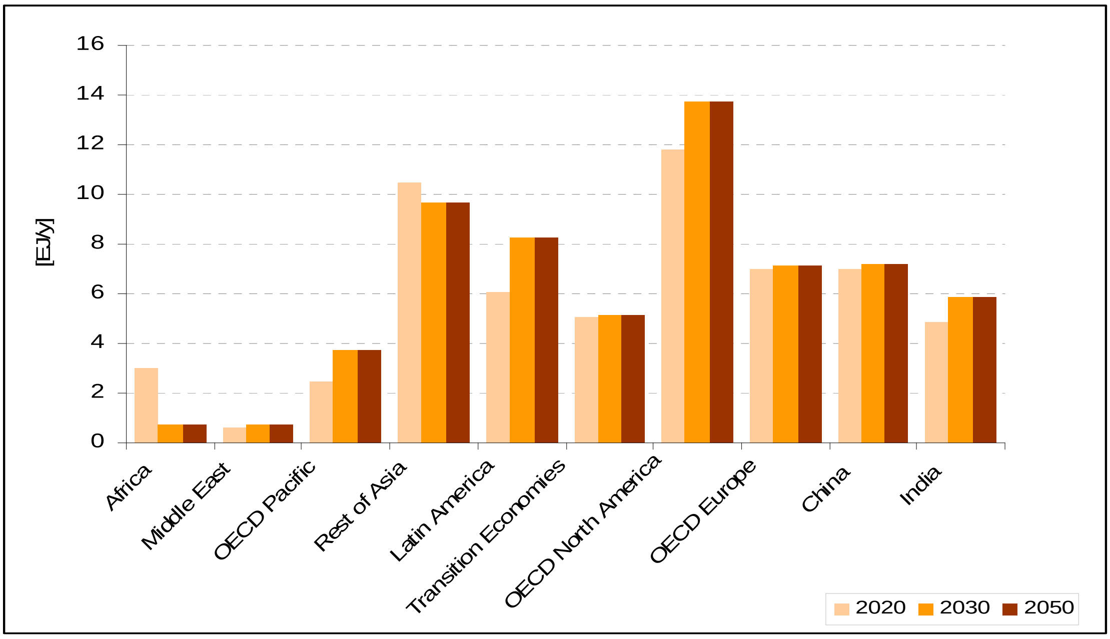


Figure 7: Technical potential for biomass residues for different regions 2020-2050

3.5 Wind onshore

According to the Global Wind Energy Council (GWEC, 2008) 94 GWe of wind power capacity were installed on a global scale at the end of 2007. The technical potential of wind onshore depends on wind resources, land available for the installation of wind turbines and the amount and rated power of wind turbines installed per unit of land area (horizontal power density). A typical wind turbine for onshore production is at present around 2 MW of size and has a hub height of around 80 m. With increasing turbine sizes, the hub heights increase and apart from cost reduction, this also gives access to higher wind speeds.

3.5.1 Literature sources and assumptions

There are various studies that have assessed the technical potential of wind energy onshore on a global scale, e.g. WEC, 1993, UNDP/WEC, 2000, Fellows, 2000, Hoogwijk et al., 2004, De Vries et al., 2006. All studies follow a similar approach but show some methodological minor differences. In general the more recent studies tend to show higher results in a comparable range of magnitude (approximately by a factor 2), which is why we will focus on the latter.

De Vries et al., 2006 assess wind potentials on a global scale for 2050. The regional definition is not congruent to the one used in this study. However, tendencies show that potentials estimated by De Vries et al. are smaller than potentials assumed in Hoogwijk et al. for all regions. This might be explained by the assumption of lower suitability factors (see below). De Vries et al. use four scenarios, assuming different assumptions on future technological development, such as conversion efficiencies and yields as well as different assumptions on full-load hours, nominal power and land-use patterns. The range of estimated global technical potentials in 2050 for the four scenarios is between 62 – 80 PWh/y. Hoogwijk et al. 2004 assume a global potential of 96 PWh/y in 2050. Both studies use similar restrictions by altitude, land use functions, and wind regime, but the definition of land use suitability factors are slightly stricter in De Vries et al. Among others, De Vries et al. use a lower suitability factor for forest and agricultural areas, as well as for desert areas and grassland. Another factor that results in higher suitability factors in Hoogwijk et al. is the assumption on dual land-use. It is assumed that the installation of wind turbines can be easily combined with e.g. agricultural use. Land categories that are more suitable for dual use, are assigned a higher suitability factor.

In line with REN21, 2008 we use the results obtained by Hoogwijk, et al., 2004 as a basis for this study, because results and estimates can be easily converted using more recent numbers. The main assumptions for 2050 are given in mates.

Table **11**. The wind speed is converted to output in terms of full-load hours using a linear relation. As described above, a suitability factor was applied in order to quantify maximum area for wind electricity production. At these suitable areas, a power density of 4 MW/km^2 was assumed. The output of a wind turbine was calculated assuming an average wind turbine size of 1 MW for 2005 and 3 MW for 2050, with a linear increase from 2020 to 2050. Here we assume that in 2050 the wind turbines have on average a higher capacity and therefore a higher hub height (100 m). This results in higher wind speeds and therefore an increased output when assuming a roughness length of 0.1 m of 10%.

The basis of the estimate by Hoogwijk et al., 2004 is the Climate Research Unit (CRU) meteorological data. This database is not specifically constructed for wind energy analyses. The CRU data, however, is currently the only set of globally available data. The CRU wind data are obtained from measurements at 10 m height and extrapolated to hub height. In general higher resolution assessment with correction for terrain, obstacles and roughness will give higher wind energy resource potentials. This was demonstrated for Mexico, Vietnam, North Africa and North China Morocco, Egypt, Madagascar, Mongolia, North- and North-western China (Hamlin 2007). The respective regional estimates for East Asia are, therefore, very conservative although, for some places, e.g. Honduras, higher resolution data give lower estimates.

Table 11: Main assumptions for the technical potential of wind onshore at a regional level for 2050 (based on Hoogwijk et al., 2004).

	Suitable area (Mha)	Average wind speed (m/s)	Average power density on total area (MW/km^2)[5]	Turbine size (MW)
Canada	199	4.1	1.08	3
USA	248	4.3	1.02	3
Central America	29	3.3	0.4	3
South America	82	3	0.26	3
Northern Africa	55	2.9	0.42	3
Western Africa	4	1.8	0.01	3
Eastern Africa	38	2.6	0.28	3
Southern Africa	3	2.2	0.03	3
Western Europe	47	4.3	0.58	3
Eastern Europe	6	3.1	0.22	3
Former USSR	206	3.4	0.47	3
Middle East	47	3.1	0.33	3
South Asia	15	2.3	0.12	3
East Asia	25	2.4	0.1	3
South East Asia	0	2	0.01	3
Oceania	199	3.6	0.91	3
Japan	1	3.3	0.08	3
Global	**1204**			3

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[5] This refers to the average installed capacity per total km^2 (based on 4 MW/km^2 on suitable land areas). To get to the amount of power generated, the power density per grid cell is multiplied by the amount of load hours, which depends on the wind speed in the grid cell.

3.5.2 Geographical and environmental constraints

Hoogwijk et al. use the internationally acknowledged dataset on environmental designations, compiled by the International Union for the Conservation of Nature (IUCN). Each land classification included in the dataset was assigned a suitability factor. High suitability factors are given to land-use and land-cover categories that facilitate dual use. Urban area, nature reserves and tropical forests are excluded entirely, whereas 10% of other forest types are assumed to be available for installation of wind turbines. The USA, Canada and Oceania have the highest suitability factors, of 27%, 21% and 24% respectively. The global average lies at 9% suitable area.

3.5.3 Results

Figure 8 shows the results for technical potential of onshore wind at a regional level. Global potential is assessed to account for 379 EJ/y. North America has a significant potential, accounting for approximately 42 % of overall global potential. It is striking that China and India are projected to have low potentials while current developments in the local wind markets follow opposed trends. Main reasons for the low potentials are the above mentioned constraints on suitable area (exclusion of nature reserves, forests, urban area; average wind speeds) as well as the projections for demographic development in both regions.

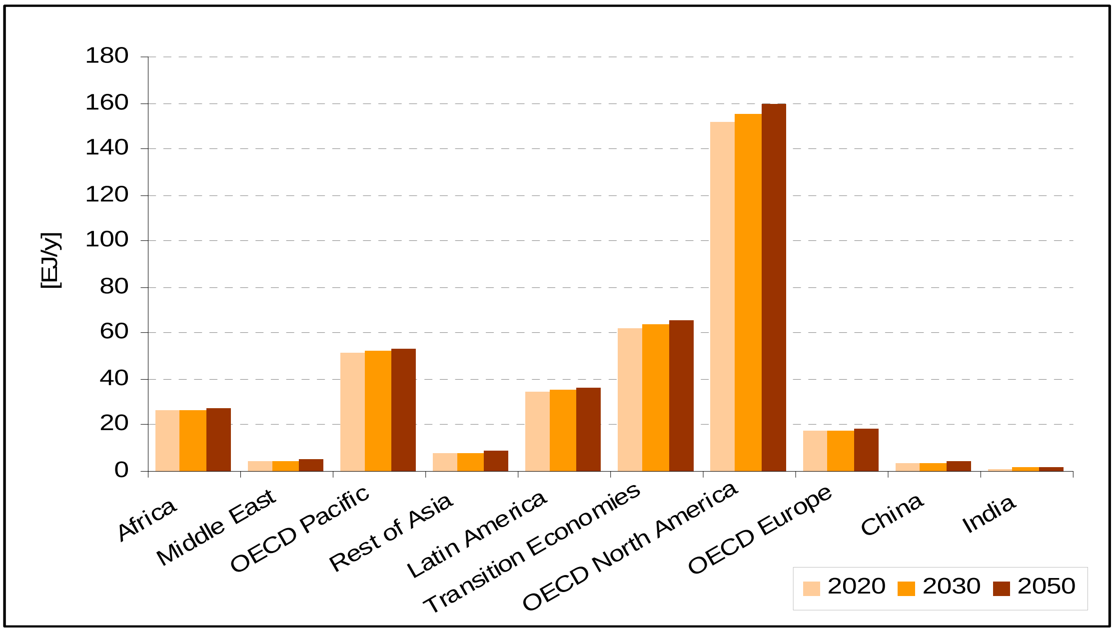

Figure 8: Technical potential for onshore wind electricity for different regions 2020-2050

3.6 Wind offshore

Offshore wind power is one of the upcoming renewable energy technologies. By far most of the over 1000 MW currently installed capacity is located in OECD Europe. Technical potential of wind offshore depends on the wind resources offshore, the competition for other functions at sea (e.g. fishery, oil and gas extraction, natural reserves) and the depth of the sea close to the shore. The distance to the shore that is included in most potential assessments is around 40 km and a representative depth that is used as a maximum around 40 m. Currently, areas with a water depth of <20 m and a distance from the shore of <50 km are considered economically viable. The depth limit for current proven installation designs is 25 m. However, already today single installations have been realized in a water depth of 45 m. Taking into consideration that the technology is still very young it can be assumed that technology design will improve substantially with increased long-term practical experience. In Norway, very recently a full-scale prototype of a floating wind turbine was realized. This turbine is designed to operate at water depth of 100-200 m.

3.6.1 Literature sources and assumptions

Various studies have assessed the technical potential for offshore wind (e.g. Leutz, et al., 2001, Fellows 2000, Siegfriedsen et al., 2003). However, only Fellows, 2000 presents the assessments on a global level (except Norway and Canada) for the timeframe to 2020. The offshore potential of Canada is assessed by Tampier, 2004.

In this study we use data from Fellows and Tampier as a basis, but correct it with more optimistic assumptions regarding output and power density, since the assumed power densities of Fellows, 2000 have already been exceeded by current offshore wind parks (currently about 10 MW/km^2 (Burges, 2008), instead of 8 MW/km^2 as assumed by Fellows for 2020). For this reason the power density was increased from 8 to 12 MW/km^2 in 2020 and 14 MW in 2030. In order to reflect further technical progress, an overall technological learning rate of 1.6 was assumed until 2050, resulting in an average power density of 16 MW/km^2 in 2050 (Burges, 2008). This factor is based on an assumed increase in turbine size and therefore in wind speed at higher hub height, resulting in a larger power density[6]. On the other hand, it is assumed that the technical data assumed by Hassing Corlin et al., 2008 is rather optimistic considering the technical constraints of offshore wind power development.

Siegfriedsen et al 2003 assess wind offshore potential for the 20 most promising countries. Global potential as stated in Siegfriedsen is about half the potential assumed in Fellows. This is mainly due to the exclusion of countries with less potential, and the difference in potential definition. Siegfriedsen incorporates some feasibility criteria into the country election methodology; however, it is not clearly stated whether this feasibility criteria are included also in the subsequent potential calculation. Furthermore regional distribution differs for both studies. Siegfriedsen states an especially high potential for China, assuming it to be approximately 20 times higher compared to Fellows.

We use Fellows as a basis for this study as it has global coverage and is more transparent. In

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[6] The power density does not increase proportionally with the increase of turbine size, however, since required distance between wind power plants increase with size.

addition, the potential for China as calculated in the present study on the basis of Fellows is in line with the potential of the China Wind Power Report 2007 (122 GW). The study furthermore states a clearly defined time frame while Siegfriedsen does not refer to a specific point of time.

3.6.2 Geographical and environmental constraints

Fellows 2000 excludes conservation areas for wilderness protection, preservation of species, tourism and recreation, as well as maintenance of cultural and traditional attributes, according to the International Union for Conservation of Nature (IUCN). Fellows constrains 19-25 % of the near-shore area and 75 % of the sea bed between 5 to 40 km offshore and <40 m depth by homogeneous “thinning” to allow for unquantified technical and environmental constraints. The constraint was applied uniformly across the whole study area as no information was available on a regional basis.

3.6.3 Results

Figure 9 shows the results for the technical potential in the IEA regions. High potentials are found in OECD Europe, Latin America and Asia excluding India and China. The global technical potential adds up to 57.4 EJ/y in 2050.

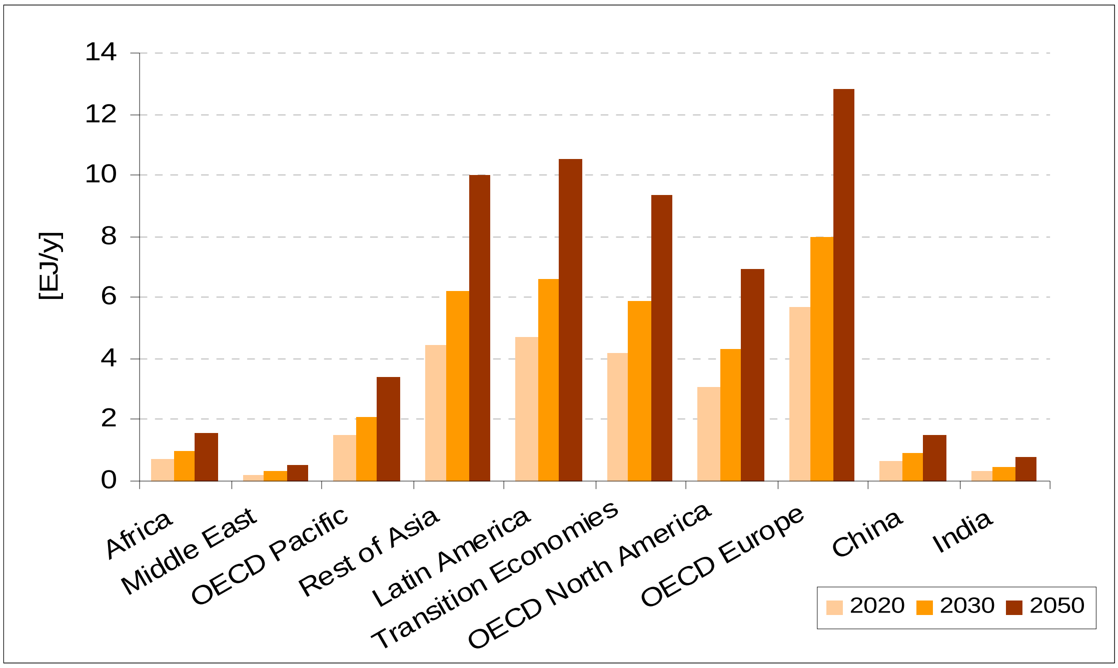


Figure 9: Technical potential for electricity from offshore wind for the different regions 2020-2050

3.7 Solar heating

The most common application of solar heat technologies is the passive use in the built environment, the use of solar energy for drying agricultural products and the use of solar water heating (SWH) for water and space heating purposes.

3.7.1 Literature sources and assumptions

The technical potential of solar energy for heating purposes is vast and difficult to assess. The implementation potential is mainly limited by the demand for heat. Because of this, the technical potential is not assessed in the literature except for REN21 2008. In order to provide a reference, REN21 has made a rough assessment of the technical potential of solar water heating by taking the assumed available roof-top-area for solar PV applications from Hoogwijk, 2004 and the irradiation for each of the regions. The global suitable roof-top-area includes roof-tops, facades and small surfaces around houses. The calculation of the total available roof-top-area in Hoogwijk, 2004 is based on two studies (IEA/OECD, 2001a and Alseman and Brummelen, 1993) and considers architectural aspects, such as orientation, morphological aspects and shading elements. Both studies do not include the least developed countries. Since no data is available for these countries, Hoogwijk assumes a lower available roof-top-area The efficiency for solar water boilers was assumed to be 55% in 2020 and 60% in 2050 (this assumption can be considered rather conservative). Based on the REN21 data, the total potential for solar water heating has been recalculated for the scope of this study.

3.7.2 Geographical and environmental constraints

As explained above, the solar water heating potential was calculated for the available roof-top-area. Ground-mounted installations were not considered; therefore no land-use competition occurs.

3.7.3 Results

Figure 10 shows the main results for the assumed technical potential of solar heat. Global potential accounts for 123 EJ/y. High potentials are projected for OECD Europe, Asia incl. China and OECD Europe.

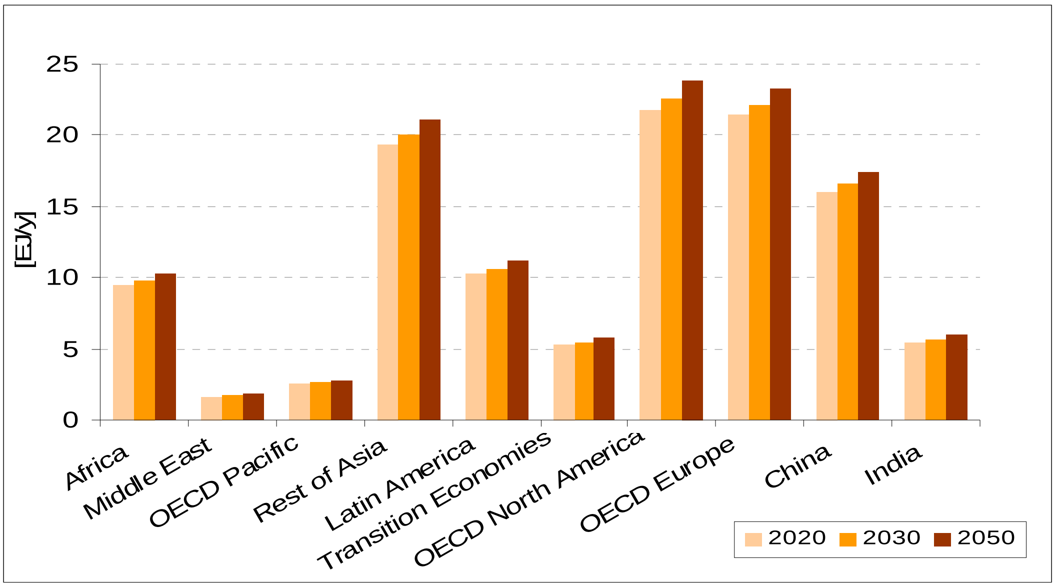


Figure 10: Technical potential for solar heat for the different regions

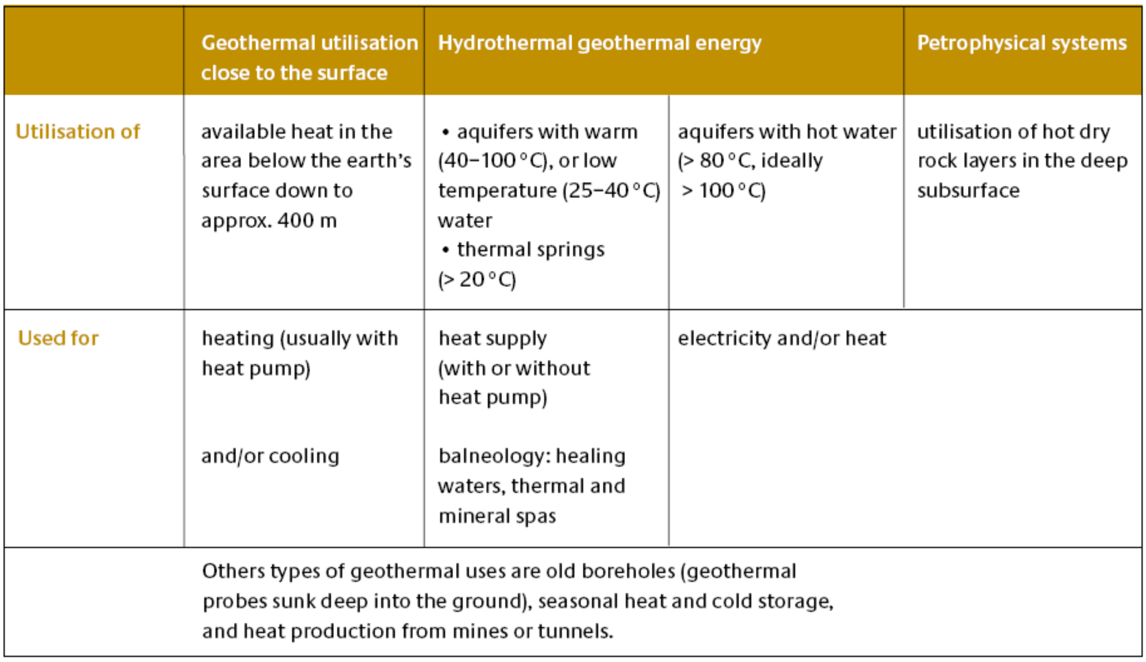
3.8 Geothermal

Geothermal energy utilization can be divided into two main sectors – direct use and electricity generation. The application largely depends on the temperature of the geothermal source.

Low temperature resources are used for direct applications, e.g. for space heating/ cooling, greenhouse and aquaculture pond heating, agricultural drying, industrial use, balneology or snow melting. Low temperature sources at shallow depth are available in most countries and are easily accessible, however, are only interesting if a suited application is situated close to the source. Long distance transportation is an alternative solution, which can be handled with good isolation material. In contrast to direct use, high temperature sources (usually above 150 °C) are required for high-output power generation. These sources are less easily available and an efficient use demands thorough geo-scientific investigations (multi-method approach) before designing a power plant.

Table 12 gives an overview of the different types of utilization.

Table 12: Different types of geothermal energy (dena, 2007)



	Geothermal utilisation close to the surface	Hydrothermal geothermal energy		Petrophysical systems
Utilisation of	available heat in the area below the earth's surface down to approx. 400 m	• aquifers with warm (40–100 °C), or low temperature (25–40 °C) water • thermal springs (> 20 °C)	aquifers with hot water (> 80 °C, ideally > 100 °C)	utilisation of hot dry rock layers in the deep subsurface
Used for	heating (usually with heat pump) and/or cooling	heat supply (with or without heat pump) balneology: healing waters, thermal and mineral spas	electricity and/or heat	
	Others types of geothermal uses are old boreholes (geothermal probes sunk deep into the ground), seasonal heat and cold storage, and heat production from mines or tunnels.			

3.8.1 Literature sources and assumptions

There are numerous studies which assess global potential of geothermal energy. The estimated potentials have a wide spectrum. Ranges for electricity generation potential lie between 3.5-144 EJ/y, whereas potentials for direct uses are estimated to concentrate in the range of 360-600,000 EJ/y.

Björnsson et al. 1998 estimate the global useful accessible resource base for electricity production at 43 EJ/y. The global overall potential is estimated to be much larger at 600,000 EJ/y. However, the latter represents the mere accessible resource base and is considered to be rather theoretical than technical. For 2020, Björnsson assumes a possible electricity production of 1.14 EJ/y and a direct use of 507.6 PJ/y. These values are rather a forecast then an estimation of technical potential. WEA 2000 estimates the global total potential for geothermal energy that could become accessible within 40 – 50 years to be 5000 EJ/y. The portion of the accessible resource base which is assumed to become technically and economically available in 10 – 20 years (i.e. the economic potential) is stated to account for 434 EJ. This is in line with GLITNIR Geothermal Research (GGR), 2007: however, the figure only refers to the pure quantity of accessible geothermal primary energy and does not consider the wide dispersion of the reserves which has impacts on the technological ability to use the geothermal energy. Gawell 1999 estimates the overall technical electricity potential to be around 3.9 EJ/y, employing advanced technology and assuming a capacity factor of 90%.

Stefansson 2005 derives technical potentials with similar dimensions as the technical potentials assumed in Gawell 1999. The study creates an empirical relation between the number of active volcanoes and the technical potential of high temperature geothermal fields. Gawell uses estimates for eight countries and regions as a basis and extrapolates the data in order to derive the global potential. The study establishes a range of potentials, creating an upper limit by inclusion of assumptions on hidden resources, as well as a lower limit, including some assumptions on statistical errors of different estimation techniques and technical difficulties arising by wide distribution of the potential. Stefansson assumes an overall potential of about 130.7 EJ/y to be most likely; however, this estimation only includes already identified resources. The upper value for electricity generation indicated in Stefansson is in the same order of magnitude as potentials stated in Björnsson.

In our study we use Stefansson 2005 as a basis for the potential calculation. Stefansson 2005 comprises most recent data and is most detailed in the description of methodology and uncertainties. The upper limit of global geothermal potential as stated in Stefansson would be most in line with Björnsson. In his calculations Stefansson refers to the heat stored in the uppermost 3km of the continental crust, however, today reservoirs of up to 5km depth are accessed by state-of-the art technology. GLITNIR Geothermal Research 2007 considers these technologies (EGS, Hot Dry Rock) at a depth of >4km and projects a global technical electricity potential of 3.6 EJ/y in 2020. Considering results of the latter study as well as technical difficulties due to wide dispersion of potential and some environmental constraints, we assume the mean value of the upper range stated in Stefansson. As Stefansson reports global aggregated potential, regional distribution based on Björnsson is used. Where needed, some additional assumptions based on land area were made.

Based on the indications in GLITNIR 2007 as well as the growth factors derived from WEA 2000 we assume a technical electricity potential of 4.5 EJ/y in 2020 and a linear development (factor 1.3/y) from 2020 to 2050.

3.8.2 Geographical and environmental constraints

Stefansson 2005 does not explicitly mention any environmental constraints. This may be explained by the fact that geothermal installations are small when compared to other renewable energy generating facilities, resulting in lower on-surface environmental impacts for both the fuel acquisition and the energy production. Adverse environmental impacts of geothermal installations may include an increase in microseismic activity as well as land subsidence, For the future it is expected, however, that the latter negative impact will be alleviated to a large extent by the increased use of reinjection technologies. Also, when balanced against the obvious advantages of geothermal energy over fossil fuels, these impacts seem less severe.

3.8.3 Results

Table 13: Overview of estimated technical potential of geothermal resources in the world[7]

	Lower limit of the potential of geothermal resources	World geothermal potential for identified resources	Upper limit for total world geothermal potential	Value assumed in this study
Resources suitable for electricity generation	0.05 $\mathrm{TW_e}$ (1.4 EJ/y)	0.2 $\mathrm{TW_e}$ (5.7 EJ/y)	1-2 $\mathrm{TW_e}$ (28 -57 EJ/y)	1.5 $\mathrm{TW_e}$ (45 EJ/y)
Resources suitable for direct use	1 $\mathrm{TW_{th}}$ (28 EJ/y)	4.4 $\mathrm{TW_{th}}$ (125 EJ/y)	22-44 $\mathrm{TW_{th}}$ (624-12480 EJ/y)	33 $\mathrm{TW_{th}}$ (1040 EJ/y)

Source: Stefansson 2005

Table 13 shows the ranges of global technical potentials as stated in Stefansson 2005. The last column indicates the value assumed in this study.

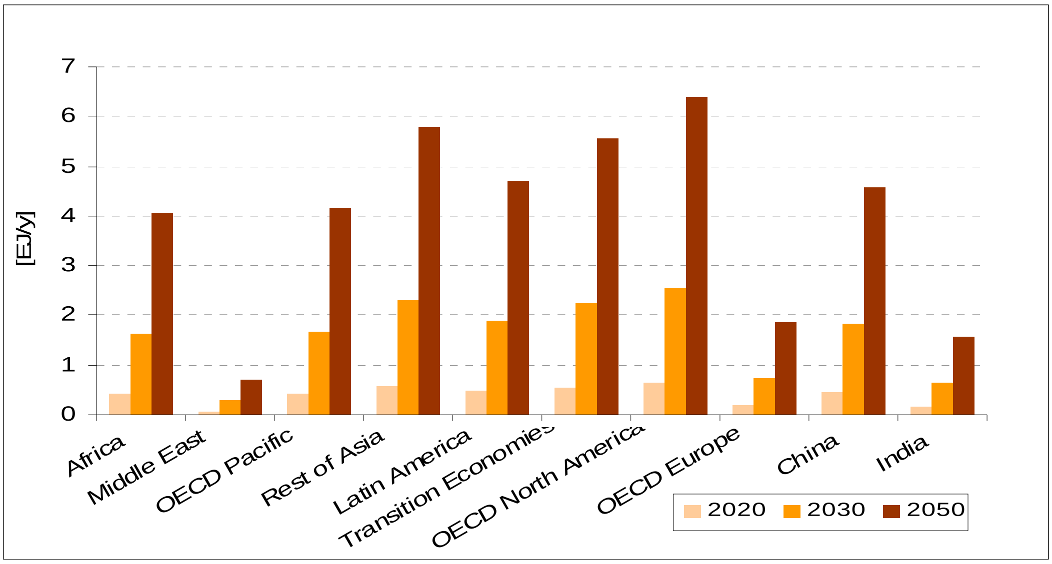


Figure 11: Technical potential for geothermal electricity 2020- 2050

Figure 11 illustrates the regional distribution of the technical potential as well as the development of potentials over the observed period. According to the literature assessed in this study, Asia and Latin America have the largest technical potential for electricity generation. Potential for geothermal heat is largest in Africa. The WEA does not offer explanations for the assumptions underlying the growth factors. However, as geothermal energy technology is still considered in the early development stage and research for enhanced geothermal systems last

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[7] Numbers in parenthesis assume a capacity factor of 90% (rounded values).

for the last 30 years, it seems reasonable to assume slower technology development up to 2030. The Geothermal Energy Association shows that using technologies currently under development will lead to a doubling in potential.

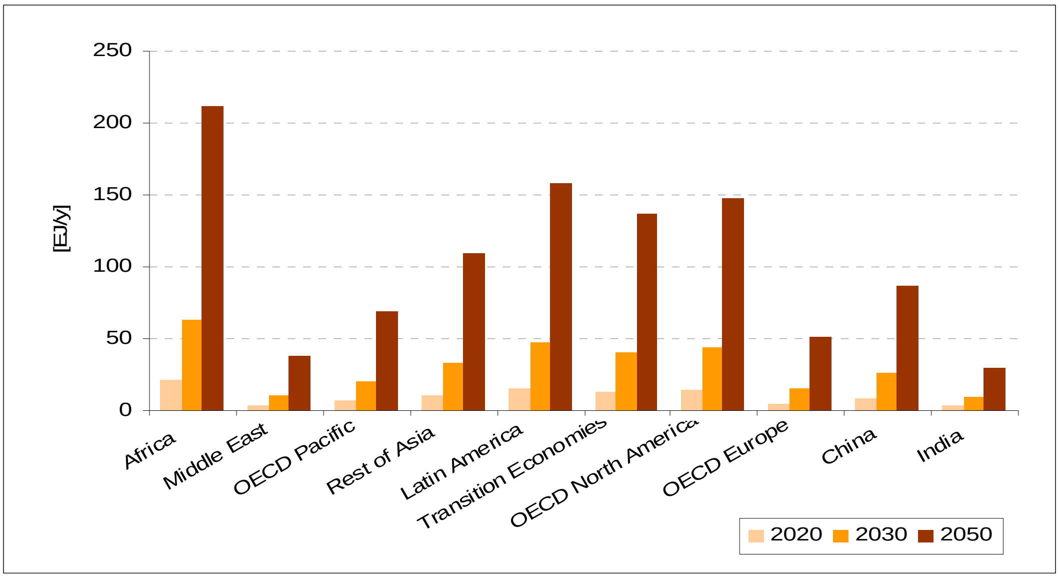

Figure 12: Technical potential for geothermal direct use 2020- 2050

3.9 Ocean energy

Ocean energy is an emerging technology which up to date counts only few installations under operation. The last years have led to significant technological improvements, a number of pilot projects have been carried out and test installations have been developed. As ocean energy is very variable depending on geographical circumstances, it is assumed that different technologies will emerge for various locations.

The energy that can be extracted from the ocean is divided into OTEC (Ocean Thermal Energy Conversion), wave, tidal and osmotic.

3.9.1 Literature sources and assumptions

The World Energy Assessment presents a total theoretical annual potential of 7400 EJ/y (UNDP/WEC, 2000). Other sources estimate the theoretical potential for ocean energy in the order of 3240 EJ/y (IPCC, 2007). Ocean thermal energy conversion (OTEC) accounts by far for the largest share of overall potential.

Below each of the technologies is described separately. The regional distribution is taken from the area of ocean for each of the regions.

OTEC

Ocean thermal energy conversion (OTEC) produces electricity from the natural thermal gradient of the ocean, using the heat stored in warm surface water to create steam to drive a turbine, while pumping cold, deep water to the surface to recondense the steam.

OTEC can be operated either in a closed loop or in an open loop system. Benefits of both types may be combined in hybrid plants, which use closed loop generation combined with a second-stage flash evaporator to desalinate water.

OTEC installations can either be built onshore or on offshore platforms, the latter being larger and not requiring valuable coastal land. However, offshore plants are also more expensive, and energy has to be transported via seafloor cables.

Greatest potential for OTEC is assumed for Small and Island Developing States (SIDS), where both, domestic power and fresh water are needed. In total, it is estimated that about 10 TW of power could be provided by OTEC without affecting the thermal structure of the ocean (Pelc and Fujita, 2002). Converting this to annual values this is about 300 EJ/y.

Wave energy

Worldwide, wave energy could potentially provide up to 2 TW of electricity (Pelc and Fujita, 2002). This can be converted into about 20 EJ/y of final energy. Greatest wave energy potentials are found at latitudes between 40° and 60° North and South, on eastern ocean shores, where high wind speeds prevail. One of the richest nations in terms of potential for wave energy is the UK, where wave energy devices are estimated to be able to contribute more than 50 TWh/y (Pelc and Fujita, 2002).

A lot of research is carried out on wave energy and a variety of technologies have been proposed, leading to increased efficiencies as well as financial feasibility. However, each is in a too early stage of development to predict which technology would be most prevalent in future commercialization.

Tidal energy

Total worldwide potential is estimated to be about 500–1000 TWh/y (1.8 – 3.6 EJ/y), though only a fraction of this energy is likely to be exploited due to economic constraints (Pelc and Fujita, 2002). This value is about a factor 20 lower compared to the values presented as theoretical potential in the World Energy Assessment.

Ocean Osmotic Energy

Ocean Osmotic Energy makes use of the salinity gradient established at the boundary between freshwater and saltwater. The entropy of mixing freshwater with saltwater is exploited e.g. by using semi-permeable membranes for energy extraction. The energy is extracted as pressurized brackish water by pressure retarded osmosis (PRO) or direct electrical current by reverse electro dialysis (RED). Potential for osmotic energy exists wherever a stream or river enters the ocean.

The global discharge of fresh water to seas is about 44.500 km^3 per year. If it is assumed that 20% of this discharge can be used for osmotic power production, the global potential is roughly 2000 TWh_e (7 EJ/y). This is about 10% of the theoretical potential assessed in the World Energy Assessment (UNDP/WEC, 2000).

3.9.2 Geographical and environmental constraints

Pelc and Fujita 2002 also describe environmental impacts for each technology, however, do not state to what extent these are considered in the calculation of technical potential. Also sustainability constraints posed by increased competition of different land use functions (fishing, habitat, wave) are not considered.

3.9.3 Results

Figure 13 shows the aggregated results for ocean energy. Global potential accumulates to 331 EJ/y. Almost 50% of the projected potential in 2050 is found in Asia, including the Pacific Islands. The Americas, together, account for 25% of the resulting potential in 2050.

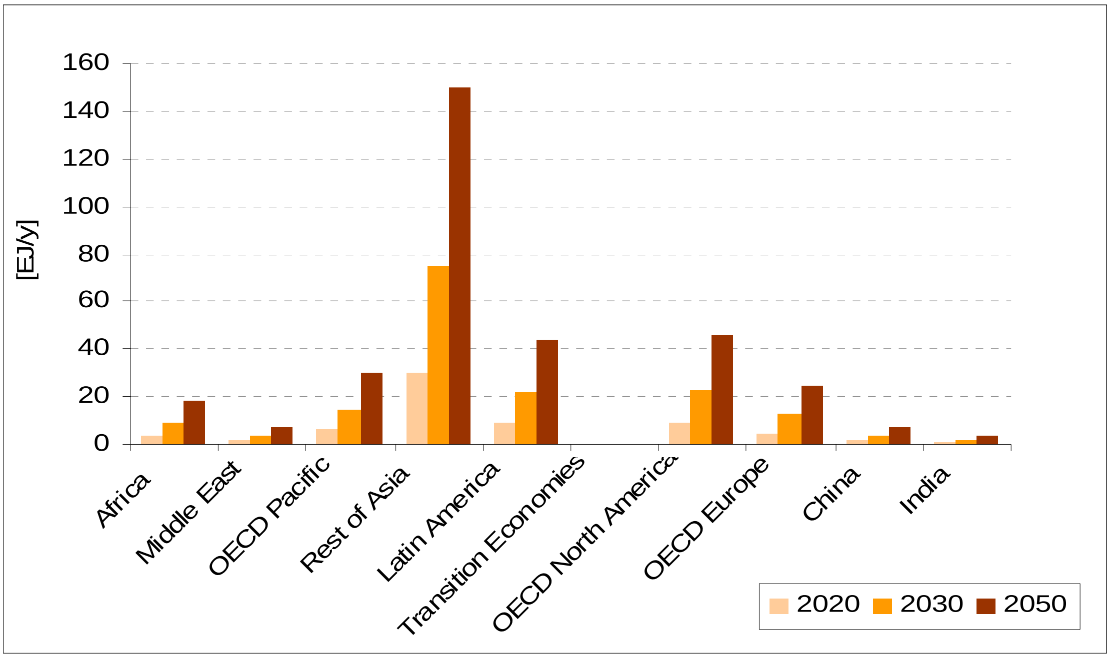

Figure 13: Technical potential for accumulated ocean energy in 2050

4 Summary of the results and conclusions

4.1 Technical potential

4.1.1 Summary of the technical potentials derived in this study

Most potentials are electricity generation potentials; however, for biomass the technical potentials are given in terms of primary energy as biomass may be converted to different kinds of energy, i.e. heat, electricity and transport fuel. In a like manner, heat potentials are reported separately for both geothermal and solar energy sources.

On a global scale, largest electricity generation potentials are projected for the solar electricity generation technologies CSP and PV. The global technical potential for CSP is about four times that of PV technologies. Both solar technologies show highest regional potential in Africa (for both technologies almost half of global potential), followed by OECD Pacific and the Middle East. Following the solar technologies, onshore wind shows the third largest potential for electricity generation on a global scale. On a regional level technical potential for onshore wind is highest in OECD North America.

Ocean energy potential is highest in the Rest of Asia and worldwide constitutes the fourth most abundant electricity generation potential, followed by the combined biomass potentials. Biomass potentials for energy crops are calculated according to high sustainability criteria. Overall global potential is therefore only in the order of magnitude of the potential for residues. Main potentials for energy crop production are allocated in Latin America. Residue potentials are equally dispersed among the regions, showing highest potentials for North America, Africa, and Latin America.

OECD Europe shows one of the smallest overall regional potentials for electricity generation from renewable energy sources. Only for India even smaller potentials are projected. For OECD Europe highest potentials can be found for the electricity generation technologies solar PV and ocean energy. Compared to the other regions, OECD Europe also shows highest potentials for wind offshore. Potential of similarly high magnitudes are revealed for Latin America and Rest of Asia.

In terms of total renewable electricity potential, Africa is the region that possesses most abundant renewable energy potential, mainly due to the huge potential for solar technologies. Africa is followed by OECD Pacific which holds about half of the potential projected for African countries. Lowest overall potentials are projected for India and OECD Europe.

Current global final energy consumption (338.5 EJ/yr according to IEA energy statistics) is less than 5% of the overall projected technical potential. The global wind onshore potential alone is able to cover current energy demand

Table 14: The total regional technical RES potential for 2020 as assessed in this study.

	Technical Potential EJ/y electric power							**EJ/y heat**		**EJ/y primary**	
	Solar PV	Solar CSP	Wind Onshore	Wind Offshore	Hydro power	Ocean	Geo-thermal	Geo-thermal	Solar	Biomass energy crops	Biomass Residues
Africa	478.1	2787.3	26.9	0.7	6.3	3.6	0.4	21.4	9.4	0	3.0
Middle East	84.8	739.1	4.8	0.2	1	1.5	0.1	3.8	1.7	0	0.6
OECD Pacific	150.2	969.9	52	1.5	1.1	5.9	0.4	6.9	2.6	6	2.5
Rest of Asia	91	5.9	8.2	4.5	6.2	29.9	0.6	11	19.4	0	10.5
Latin America	78.8	191.5	35.2	4.7	8.6	8.8	0.5	15.9	10.2	9.9	6.1
Trans. Economies	77.3	130.6	63.4	4.2	4.6	0	0.6	13.7	5.3	9.8	5.1
North America	56	222.6	154.8	3.1	5.7	9.1	0.6	14.8	21.8	13.8	11.8
OECD Europe	22.2	2.6	17.9	5.7	7	5	0.2	5.1	21.4	4	7
China	65.2	38.3	3.9	0.7	5.2	1.5	0.5	8.7	16	0	7
India	22.3	68.2	1.3	0.3	1.8	0.8	0.2	3	5.5	0	4.9
World	1125.9	5156.1	368.6	25.6	47.5	66.2	4.5	104	113.1	43.4	58.6

Table 15: The total regional technical RES potential for 2030 as assessed in this study.

	Technical Potential EJ/y electric power							**EJ/y heat**		**EJ/y primary**	
	Solar PV	Solar CSP	Wind Onshore	Wind Offshore	Hydro power	Ocean	Geo-thermal	Geo-thermal	Solar	Biomass energy crops	Biomass Residues
Africa	573.7	3344.8	26.4	1	6.5	9	1.6	63.7	9.7	0	0.8
Middle East	101.8	886.9	4.7	0.3	1	3.8	0.3	11.3	1.7	0	0.8
OECD Pacific	180.3	1163.9	51.1	2.1	1.2	14.9	1.7	20.6	2.7	5.1	3.7
Rest of Asia	109.2	7.1	8.1	6.2	6.3	74.8	2.3	32.9	20.1	0	9.7
Latin America	94.6	229.9	34.5	6.6	8.7	22	1.9	47.6	10.6	22.2	8.3
Trans. Economies	93	156.8	62.2	5.6	4.7	0.1	2.2	41	5.5	12.8	5.2
North America	67.2	267.1	152	4.3	5.8	22.8	2.6	44.4	22.6	15.5	13.7
OECD Europe	26.6	3.1	17.6	8	7.1	12.5	0.7	15.4	22.1	5.4	7.2
China	78.2	46	3.8	0.9	5.3	3.7	1.8	26.2	16.6	0	7.2
India	26.8	81.8	1.3	0.5	1.8	2.1	0.6	9	5.7	0	5.9
World	1351	6187.3	361.7	35.9	48.5	165.6	17.9	312	117.3	61.1	68.3

Table 16: The total regional technical RES potential for 2050 as assessed in this study.

	Technical Potential EJ/y electric power							**EJ/y heat**		**EJ/y primary**	
	Solar PV	Solar CSP	Wind Onshore	Wind Offshore	Hydro power	Ocean	Geo-thermal	Geo-thermal	Solar	Biomass energy crops	Biomass Residues
Africa	717.1	4348.27	27.65	1.6	6.82	17.95	4.05	212.27	10.26	0	13.8
Middle East	127.2	1152.95	4.91	0.49	1.01	7.58	0.72	37.65	1.82	0	1.1
OECD Pacific	225.32	1513.03	53.51	3.4	1.21	29.74	4.15	68.68	2.79	3.24	6.2
Rest of Asia	136.52	9.22	8.46	9.99	6.50	149.66	5.77	109.61	21.14	0	8
Latin America	118.19	298.82	36.16	10.55	9.02	44.03	4.71	158.72	21.14	46.94	12.6
Trans. Economies	115.92	203.79	65.21	9.38	4.81	0.14	5.57	136.69	5.75	18.85	5.3
North America	84.01	347.23	159.19	6.92	5.98	45.67	6.4	148	23.80	19.02	17.6
OECD Europe	33.24	4.09	18.45	12.8	7.36	25	1.84	51.25	23.32	8.41	7.5
China	97.79	59.76	4.03	1.51	5.43	7.37	4.57	87.24	17.42	0	7.7
India	33.49	106.33	1.38	0.75	1.86	4.1	1.57	29.88	5.97	0	7.8
World	1688.79	8043.49	378.95	57.4	50	331.23	44.76	1040	123	96.48	87.6

4.1.2 Ranges of technical potentials in the assessed literature

In order to get an overview of the ranges of technical potentials that can be found in literature, Table 17 shows the lowest and highest value found for each technology option. More detailed literature figures on a regional and technology level can be extracted from the tables in Annex. Note that these figures are only comparable to a limited extent as time horizons and scope of the study may differ. Details on the underlying assumptions are available in section 3 for each technology. Note also that some figures will not sum up correctly due to regional overlap (e.g. inclusion of China in *Rest of Asia*) and rounding.

Table 17: Ranges of global potentials by RES technology found in the assessed literature

EJ/a	**low**	**high**	**this study**
Solar PV	1338	14766	1689
Solar- CSP	248	10603	8043
Wind Onshore	67.3	453.2	378.9
Biomass energy crops	48.7	1550	96.5
Biomass Residues	30	170	87.6
Hydropower	45.4	51.5	50
Wind Offshore	14.1	18.9	57
Geothermal electric	1.4	144	45
Ocean power	329.5	331.2	331.2
Geothermal heat	3.9	12590	1040
Solar heating	-	-	123[8]

4.2 Discussion and Uncertainties

4.2.1 Comparison of RES potentials and scenarios

In its Alternative Policy Scenario (APS), the WEO 2007 projects an overall share of 29% of renewable energy sources in global electricity production in 2030, mainly contributed by biomass, wind, and hydropower. The share of the expected contribution of the so-called “new” or “other” renewables - wind, solar, geothermal and tide and wave - is assumed not to exceed 7% of total electricity generation by 2030 in the APS scenario. The share of renewables in the 450 PS scenario of the WEO 2008 projects a somewhat higher share of approximately 37% of renewables in global electricity production in 2030. Half of the share in the 450 PS scenario is contributed by hydropower, whereas the other 50% are provided by other renewable energy sources including wind.

Figure 14 compares technical potentials derived in this study to actual projected renewable electricity production in 2030 as assumed in the WEO´s Alternative Policy Scenario 2007 and

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[8] Rough estimate of rooftop potential based on REN21 (2008)

the 450 PS scenario of WEO 2008. It perfectly illustrates the high unexploited potential, especially of the “other” (i.e. “new”) Renewable Energy Sources. Only biomass and hydropower are exploited to a significant extent.

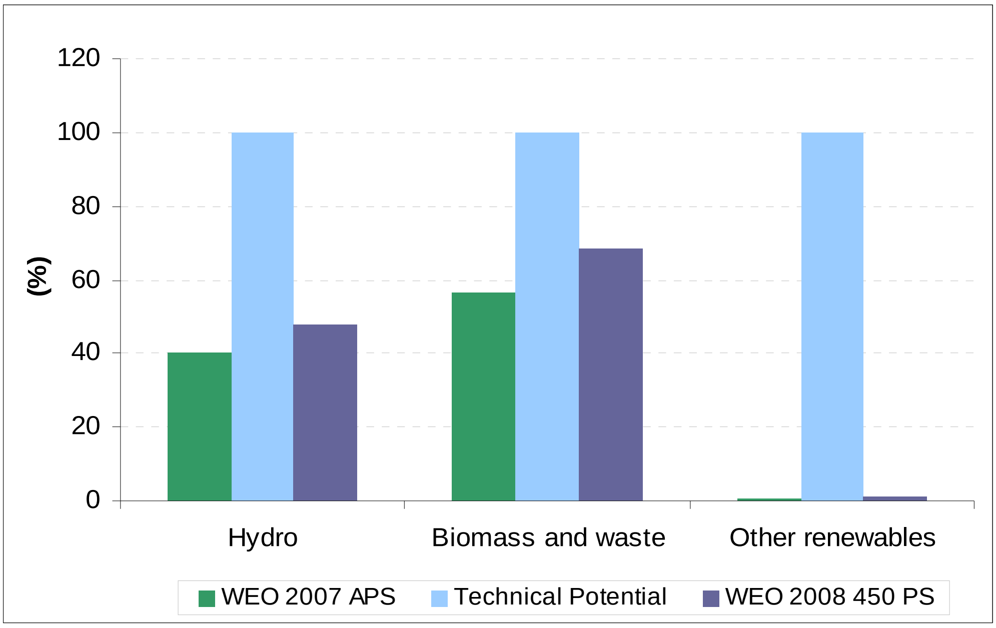

Figure 14: Percentage of technical potential exploited in 2030 according to global energy scenarios

In the 450 PS scenario growth of other renewable energy sources is highest among all renewable energy sources (10.2% average annual growth rate); yet the overall installed capacity in 2030 is extremely low when compared to the large technical potentials of these energy sources. Growth rates for hydropower and biomass are much lower, however also the overall technical potentials are quite moderate when compared to the potentials of other Renewable Energy Sources as e.g. solar PV. The rate of overall exploitation for hydropower and biomass therefore appears higher when compared to the younger technologies.

Given the high unexploited potentials it can be concluded that technical potential is not the limiting factor to expansion of renewable energy generation. Barriers to the growth of installed capacities may rather be posed by economical, political, and infrastructural constraints.

It should be noted that the technical potential by definition does not include economic and implementation constraints. The comparability of exploited potential and technical potential is therefore limited.

4.2.2 Uncertainties

Potential studies include numerous assumptions on future developments. They are therefore in general subject to considerable uncertainties.

The scope of the present study only comprises a literature assessment of existing potential studies. Lack in transparency of the methodology description for the single studies makes the comparison of the content data difficult and leads to uncertainties. In addition, each study is associated with inherent uncertainties. The projection of technical potentials requires assumptions on a variety of impacting parameters, as e.g. future technological developments and demographic developments. Future developments are hard to foresee, and also assessment methods are not inerrable.

Often, definitions of scope (observation period, regional coverage, assessment methods, etc.) differ between the studies. This requires further assumptions which bring along uncertainties. Next to differences concerning the coverage of the study, also deviations in interpretation of essential concepts can be observed. Two prominent examples are the extent of consideration of time-dependency in the calculation of technical potentials as well as the inclusion or exclusion of sustainability concerns.

In order to address these uncertainty issues, we made - where possible - use of

- consistent studies
- studies with transparent approach
- similar regional coverage
- potentials incorporating rather conservative assumptions
- some sensitivity analysis in form of comparison with other literature sources
- detailed description of own assumptions

Furthermore, we attempted to point out all issues of uncertainty encountered that may have an effect on potential calculation in this study. Nevertheless, some uncertainties are inevitable in potential studies and will remain.

4.3 Conclusions

The goal of this study is to summarize the current knowledge on global renewable energy potentials, and derive a comprehensive data set of most probable potentials based on literature as well as on expert assessments.

The study mainly comprises an enhancement of the potential study carried out by the Renewable Energy Policy Network REN21. For most technologies, potential results are in line with the results derived by REN 21. However, for some Renewable Energy Sources the use of more recent data, deviating assumptions according to current technology development and use of studies that consider sustainability criteria lead to somewhat lower/higher potentials.

The overall technical potential for all renewable energy technologies is high, when compared to current and future energy needs as prospected in the IEA´s World Energy Outlook 2008. Consequently, availability of renewable energy potential is not a constraint for future development of renewable energy sources. Constraints rather originate from economical, infrastructural and political issues.

The largest electricity generation potential on a global scale is seen for the solar technologies CSP and PV, followed by wind onshore and ocean power. Thermal/direct use potentials (geothermal/solar) are virtually endless but limited in practice by regional heat demand.

Africa is projected to possess largest potentials for both solar technologies, PV and CSP. While wind onshore appears to have high potentials in North America, Latin America is assigned most abundant biomass resources.

The quality of analysed literature was not always satisfactory: Often methodologies are not sufficiently transparent, scope and definition of individual parameters differ among the single studies. The assessment of technical potentials for all technologies in one comprehensive study is therefore desirable. This is especially important if coherent assumptions on environmental criteria are wished for.

The concept of technical potential is rather theoretical and does not consider economical, infrastructural and political constraints, which in practice limit actual implementation potential. In order to assess a more practical/realizable potential of renewable energy sources, the assessment of costs and infrastructural constraints is inevitable.

5 List of Abbreviations

APS	Alternative Policy Scenario
ASES	American Solar Energy Society
BAU	Business-as-usual
CRU	Climate Research Unit
CSP	Centralised Solar Power
dena	Deutsche Energie-Agentur
EEA	European Environmental Agency
EREC	European Renewable Energy Council
FAO	Food and Agriculture Organization
GGR	GLITNIR Geothermal Research
GWEC	Global Wind Energy Council
IEA	International Energy Agency
IPCC	International Panel on Climate Change
IPCC FAR	International Panel on Climate Change First Assessment Report
IUCN	International Union for the Conservation of Nature
LCA	Life Cycle Assessment
OECD	Organisation for Economic Co-operation and Development
OTEC	Ocean Thermal Energy Conversion
PRO	Pressure Retarded Osmosis
PV	Photovoltaic
RE	Renewable Energy
RED	Reverse Electro Dialysis
REN21	Renewable Energy Policy Network of the 21st Century
RES	Renewable Energy Source
RWEDP	Regional Wood Energy Development Programme
SIDS	Small Island Developing States
SRES	Special Report on Emission Scenarios
SWH	Solar Water Heating
TP	Technical Potential
UNDP	United Nations Development Programme
WEC	World Energy Council
WEO	World Energy Outlook

6 Annex: Comparison of technical potential values found in the assessed literature

The following tables show a quantitative comparison of the assessed literature sources. Please note that the definition of world regions differs considerably from study to study (see section 2.5). For this reason, regional differences might appear larger than they actually are.

Table 18: Ranges of technical potential found in the assessed literature – Solar PV

EJ/a	**De Vries et al. 2007**	**Hoogwijk 2004**	**REN21 2008**	**Hofman et al 2002**	**UNDP/WEC 2000**	**this study**
Africa	3802	541	863	605		717
Middle East	626	1342		154		127
OECD Pacific	1601	187	239	199		225
Rest of Asia	90	200	286	11		137
Latin America	2119	103	131	122		118
Transition Economies	2151	95	118	88		116
OECD North America	1212	62	72	61		84
OECD Europe	165	15	13	6		33
China	2302			78		98
India	691			17		33
World	14778	1338	1689	1341	1575	1689

Table 19: Ranges of technical potential found in the assessed literature – Solar CSP

EJ/a	**REN21 2008**	**DLR 2009**	**Hofman et al. 2002**	**this study**
Africa	678	5252	134	4348
Middle East		1043	36	1153
OECD Pacific	187	2518	47	1513
Rest of Asia	22	270	0	9
Latin America	59	450	15	299
Transition Economies	25	54	6	204
OECD North America	21	522	5	347
OECD Europe	1	9	0	4
China		450	2	60
India		36	3	106
World	992	10791	248	8044

Table 20: Ranges of technical potential found in the assessed literature – Hydropower

EJ/a	**UNDP/WEC 2000**	**DLR EU-MENA 2005**	**IPCC 4 AR 2007**	**REN21 2008**	**Bartle 2002**	**Lako et al. 2003**	**this study**
Africa	7.2			7.6		2.6	6.8
Middle East	0.6	0.8				0.9	1
OECD Pacific	0.8			0.8		0.6	1.2
Rest of Asia	11.2			6.5	24.5	4.2	6.5
Latin America	10.3			11.0		11.8	9
Transition Economies	5.2			5.2		4.6	4.8
OECD North America	5.4			5.4	15.6	2.9	6
OECD Europe	6.6			6.6	4.4	2.3	7.4
China							5.4
India							1.9
World	51.5		50.4	51.5	45.4	29.8	50

Table 21: Ranges of technical potential found in the assessed literature – Biomass energy crops

EJ/a	**Seidenberger et al 2008**	**Smeets et al 2006***	**De Vries et al. 2006**	**REN21 2008**	**Koopmanns A. 2005**	**IPCC 4 AR 2007***	**Hoogwijk 2004**	**this study**
Africa	0		32.4	38		145		0
Middle East	0		3.6	0				0
OECD Pacific	3.2		18	16				3.2
Rest of Asia	0		50.4	53				0
Latin America	46.9		32.4	34		41		46.9
Transition Economies	18.9		43.2	80				18.9
OECD North America	19		25.2	38				19
OECD Europe	8.4		7.2	12				8.4
China	0		39.6	0	28.3	21		0
India	0		0	0	12.8			0
World	96.5	390-1550	212.2	271		396	48.7-576	96.5

**total biomass energy potential*

Table 22: Ranges of technical potential found in the assessed literature – Biomass residues

EJ/a	**Seidenberger et al 2008**	**Dornburg et al. 2008**	**REN21 2008**	**Hoogwijk 2004**	**Doornbosch, Steenblik 2007**	**this study**
Africa	13.8		7			13.8
Middle East	1.1		0			1.1
OECD Pacific	6.2		1			6.2
Rest of Asia	8		23			8
Latin America	12.6		15			12.6
Transition Economies	5.3		5			5.3
OECD North America	17.6		17			17.6

OECD Europe	7.5		5			7.5
China	7.7					7.7
India	7.8					7.8
World	87.6	40-170	73	30-76	135	87.6

Table 23: Ranges of technical potential found in the assessed literature – Wind onshore

EJ/a	**De Vries et al. 2006**	**WEC 1997**	**UNDP/ WEC 2000**	**Grubb and Meyer 1994**	**REN21 2008**	**Hoogwijk 2004**	**IPCC 4AR 2007**	**DLR EU-MENA 2005**	**this study**
Africa	7.2		38.1		33.3	21.6			27.7
Middle East	3.6	5.8				7.2		3.2	4.9
OECD Pacific	21.6				56.9	50.4			53.5
Rest of Asia	10.8			17.6	10.5	10.8			8.5
Latin America	25.2	7.6		19.4	40	36			36.2
Transition Economies	43.2	15.5		38.1	66.5	57.6			65.2
OECD North America	93.5	18		50.4	155.4	143.9			159.2
OECD Europe	18	4.7		17.3	16.4	14.4			18.4
China	7.2	2.5							4
India									1.4
World	223-287	67.3	378.9	190.6	379	345.3	453.2		378.9

Table 24: Ranges of technical potential found in the assessed literature – Wind offshore

EJ/a	**REN21 2008**	**Fellows 2000**	**Siegfriedsen et al. 2003**	**this study**
Africa	0.6	0.3		1.6
Middle East				0.5
OECD Pacific	2.9	2.2	2.9	3.4
Rest of Asia	2.1	1.2		10
Latin America	4.3	3.2		10.6
Transition Economies	3	2.2		9.4
OECD North America	1.7	1.2	3.1	6.9
OECD Europe	4.4	3.4		12.8
China		0.2	3.7	1.5
India		0.1	1.1	0.8
World	18.9	14.1		57

Table 25: Ranges of technical potential found in the assessed literature – Solar heating

EJ/a	**REN21 2008**	**this study**
Africa	2852.3	10.3
Middle East	1.8	1.8
OECD Pacific	2.8	2.8
Rest of Asia	21.1	21.1

Latin America	11.2	11.2
Transition Economies	5.7	5.7
OECD North America	23.8	23.8
OECD Europe	23.3	23.3
China	17.4	17.4
India	6	6
World	123.4	123.4

Table 26: Ranges of technical potential found in the assessed literature – Geothermal electricity

EJ/a	**Glitnir 2007**	**Gawell et al. 1999**	**REN21 2008**	**Bjoernsson et al. 1998**	**IPCC 4AR 2007**	**Stefansson 2005**	**this study**
Africa		0	5	5			4.0
Middle East							0.7
OECD Pacific		1.2	4	4			4
Rest of Asia			12	12			5.8
Latin America		1	11	11			4.4
Transition Economies		0	6				5.6
OECD North America		1	5	5			6.4
OECD Europe			2	7			1.8
China							5
India							1.6
World	3.5-144	4	45	43	50	1.39-56.8	45

Table 27: Ranges of technical potential found in the assessed literature – Geothermal direct use

EJ/a	**Glitnir 2007**	**Gawell et al.1999**	**Bjoernsson et al. 1998**	**Stefansson 2005**	**REN21 2008**	**this study**
Africa		0.4	529		1217	212
Middle East						38
OECD Pacific			142		328	69
Rest of Asia		1.2	469		1080	110
Latin America		1.3	363		836	159
Transition Economies		0.3			667	137
OECD North America		0.7	272		626	148
OECD Europe			378		203	51
China						87
India						30
World	360-600000*	3.9	2153	28 - 12480	4955	1040

**maximum theoretical potential*

Table 28: Ranges of technical potential found in the assessed literature – Ocean energy

EJ/a	**Pelc and Fujita 2002**	**REN21 2008**	**Ragwitz et al. 2003**	**this study**
Africa		19.3		18
Middle East		8.2		7.6
OECD Pacific		51		29.7
Rest of Asia		103.2		149.7
Latin America		32.2		44
Transition Economies		26.5		0.1
OECD North America		68		45.7
OECD Europe		20.1	4.2	25
China				7.4
India				4.1
World	329.5	331.2		331.2

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Part III:

Costs of Renewable Energy Technologies

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Table of Contents

1 Introduction

Assumptions on technical performance and costs of future technologies are key input into long term energy scenarios. In Particular when economic optimisation models are used for scenario development, costs are an important parameter determining the market uptake of a specific technology und thus its role in the future supply mix.

This section of the report derives cost estimates of future renewable energy technologies. The analysis is based on the evaluation of recent major studies on renewable energy exploitation, together with background information on underlying assumptions. The authors of this section have been involved in several of these studies, and as part of these studies participated in an intensive communication and review process together with relevant stakeholders from academia and industry. The objective of the present report is to derive a robust range of cost projections as guidance and reference for further scenario analysis. The focus of this report is on two recent analytical studies which provide a detailed assessment of technology deployment strategies:

- The NEEDS project (New Energy Externalities Developments for Sustainability) is a major EU funded Integrated Project in the field of energy related socio-economic research (for details see http://www.needs-project.org). The NEEDS sub-project ‘Life cycle approaches to assess emerging energy technologies’ (co-ordinated by DLR) develops technology scenarios providing a specification of future technical, economic and environmental characteristics under various socio-economic framing conditions.
- The ‘Energy Technology Perspectives’ (ETP) of the International Energy Agency (IEA, 2008) reviews the status and prospects of key energy technologies in electricity generation and other demand sectors. It highlights the potential for technologies and their costs, and discusses the barriers that each technology must overcome to fully exploit its potential.

Both the ETP and NEEDS provide learning curves for a broad range of renewable energy technologies. Results from ETP and NEEDS are complemented by summarising cost assumptions from other relevant scenario studies, in particular the Energy [R]evolution scenario of Greenpeace and the European Renewable Energy Council (EREC), and the ‘Leitstudie’ of the German Federal Ministry for the Environment (BMU), which is of particular importance for a German position in the context of energy and climate scenarios. Note that due to the involvement of DLR in NEEDS, the Greenpeace/EREC scenarios and the BMU ‘Leitstudie’ there might be an institutional bias in the respective results, which however is kept to a minimum because of the involvement of many other partners from academia and industry in these projects.

Unfortunately, in most of the scenario studies information on renewable heating and cooling technologies is less detailed than for electricity generation. The NEEDS project does not address future heating and cooling technologies. The Greenpeace/EREC scenario does not quantify costs related to the provision of heat and cooling. Although the heat demand sectors are addressed in the IEA’s WEO and ETP scenarios, neither the WEO nor the ETP publications provide consistent information on technology and cost developments. The IEA report on ‘Renewables for Heating and Cooling’ (IEA 2007) provides information on future cost estimates up to 2030 for renewable heating and cooling technologies, it is likely that these cost estimates were used in the IEA’s scenario activities. Also the German BMU

Leitstudie does not fully report all assumptions on future cost estimates for renewable heating technologies up to the year 2050.

The following sections are structured by technology, i.e. technical data and cost projections are presented separately for each individual technology/technology cluster. Taking into account the unavoidable uncertainties related to long term technology projections, as a result of the analysis a robust range of future cost estimates is derived which helps to put existing scenario studies in a context, and which shall serve as a guidance and reference for further scenario analysis.

All prices and costs in this report are given in $€_{2005}$ (1 $€_{2005}$ = 1,244 $\$_{2005}$)

2 Costs of renewable electricity generation technologies

2.1 Photovoltaics

Market trends

Historically, PV stand-alone systems for rural areas have been the first most diffused application of PV because they often represent the most economically viable solution for rural electricity supply. More recently, the diffusion of grid-connected systems has been increasing exponentially. This type of application has been prevailing on the total PV market since 1998 and it accounts for around 90% of total global installed capacity, which amounts to 8800 MW in 2007. Currently crystalline silicon technologies (single and multi crystalline silicon) still dominates the market, while thin-film technologies (amorphous silicon, cadmium telluride, copper indium diselinide) represent about 10% in terms of installed capacity. New concept devices, including ultra-low cost cells (dye-sensitized nanocrystalline cells, organic cells) and ultra-high efficiency cells, are still in an early development state.

Today three countries (Germany, Japan, US) account for approximately 70% of global cumulative capacity. These countries are also the three largest PV-manufacturing countries. China, India, Australia, Spain and Korea are expected to become important global players in PV in the near future, both in terms of installed capacity and in manufacturing. Global installed PV capacity has been growing at an average rate of more than 35% since 1998.

Technology development projections

(based on Frankl et al. 2008)

Wafer based crystalline silicon: Present c-Si modules base their success so far on the reliability of the product and the production process, on the well-known technology exploiting the experience in the electronics industry and on the availability of feedstock. However, a series of technological developments are needed in order to achieve higher efficiencies, much larger production volumes and the target cost of less than 1 €/W_p. Technology developments are related to materials, equipment, and device concepts and processes.

According to the PV industry, by 2030 single crystalline c-Si based on Czochralsky (Cz) and/or Float zone (Fz) crystal growth will reach a cell efficiency range of 16%-25%. These module types are expected to mainly serve for niche market applications requiring high power at a premium price. Less efficient but less costly multi-crystalline and ribbon silicon modules are expected to reach efficiencies of 14-16%, which will ensure large-scale, cost effective power applications. Starting from 2020, micro-crystalline silicon thin films are expected to diffuse into the market (see also below), thus further augmenting the role of silicon in the total PV market.

Thin film technologies: At present, thin films modules are dominated by the amorphous silicon (a-Si) technology. Despite their promising potential, a-Si has not proven to reach its original expected target efficiency goals (>10%) needed for large-scale power applications so far.

In the medium term, a combination of crystalline and thin film technology will appear on the market, i.e. a-Si/µc-Si and thin Si film modules. These devices take advantage of both technologies, e.g. high efficiencies of Si and lower material consumption, larger deposition areas, and eventually monolithic series connection of cells of thin films. By 2030 such Si thin film modules might reach an efficiency as high as 18%, thus representing viable additional solutions for cost effective power applications.

The family of II-VI compound thin films, e.g. CdTe and CIS/CIGS, have recently proven technological maturity and entered industrial production. In particular, CIS/CIGS modules seem very promising in the short-medium term, since they combine all main advantages of thin films with interestingly high efficiency (around 11% in 2005, with a significant potential for improvement). CdTe module efficiencies are around 2% lower, but also with lower production costs. A target module efficiency of 22% for CIS modules in 2030 has been reported by NEDO (2004). It is expected that thin films will play a significant role in the PV market, although it is not fully clear, which specific technology will prevail after 2030.

New concept devices: This category of future PV technologies can be further subdivided into two main areas: Ultra-low cost, low-medium efficiency cells and modules, and Ultra-high efficiency cells and modules. In the first area, the technology closest to a transfer to pilot production is the dye-sensitized nanocrystalline solar cell concept, which has shown an efficiency of 10,5% in laboratory (NEDO 2004). These “Colour to PV” modules are expected to reach a 10 to 15% efficiency by 2030. Organic solar cells today reach efficiencies around 2%. While it is too premature to make any reasonable prediction with regard to the role of these cells in the future PV market, it can be said that they represent the “low-cost option” for special applications, which do not have space problems.

The field of ultra-high efficiency cells comprises a set of technologies, sometimes referred to as “3rd generation” PV cells, utilizing advanced concepts of solid-state matter physics, such as hot electrons, multiple quantum wells, intermediate band gap structures and nanostructures. While the theoretical limit of these cells is dramatically higher than the one of conventional cells, it is of course very difficult to predict the efficiency range that will be actually reached in industrial production. PV-TRAC (2005) reports that PV modules may ultimately reach efficiencies of 30%-50%. These new concepts are still in the fundamental research stages. Reaching the projected targets still requires a thorough understanding of the underlying chemistry, physics and materials properties.

It is expected that all three categories of PV technology will co-exist in the long-term, each one responding to specific applications needs and market segments. The main expected features of the different types and applications of PV devices in 2050 as reported in NEEDS are summarised in Table 2-1: Technology and market characterisation of PV technologies in 2050 (Frankl et al., 2008). IEA-ETP uses the work of Frankl et al. (2008) from the NEEDS project as the main reference for the PV technology characterisation, thus the same technical data for future PV technologies are used. Figure 2-1 gives an indication of the potential development of PV technology market shares until 2050. It is expected that each PV technology ‘family’ will expand especially within its own most suitable market sector. Thin film technologies will most likely expand from today’s 10% market share to approximately 45% by 2025, with growing contributions of CIS and CdTe technologies. Novel devices, which still need time to move from laboratory to mass production, might reach a market share of 5% in 2025, and 30% in 2050. Such long term technology scenarios are of course a matter of large uncertainties, and any technological break-through in new concept technologies will change these projections.

Table 2-1: Technology and market characterisation of PV technologies in 2050 (Frankl et al., 2008)

	Wafer-based crystalline-Si		**Thin films**		**New concept devices**	
	single-crystalline	multi-crystalline	CIS, CdTe, a-Si/μc-Si	Pin-ASI, ASI-THRU	Ultra-high efficiency	Ultra-low cost
Module efficiency	24 - 28%	20 - 25%	CIS: 22-25% Si: 20%	6 – 8%	> 40%	10 – 17%
Module lifetime (a)	40 - 50	40 - 50	30 - 35	30	> 25	10 - 15
Provided services	High power at premium price	Cost-effective power applications	Additional solutions for cost effective power applications	Low cost/low efficiency "Solar electricity glass"	High power supply	"Colour to PV"
Market segment	Niche markets, space	Mass market	Mass market	Mass market	Niche/mass market	Mass market

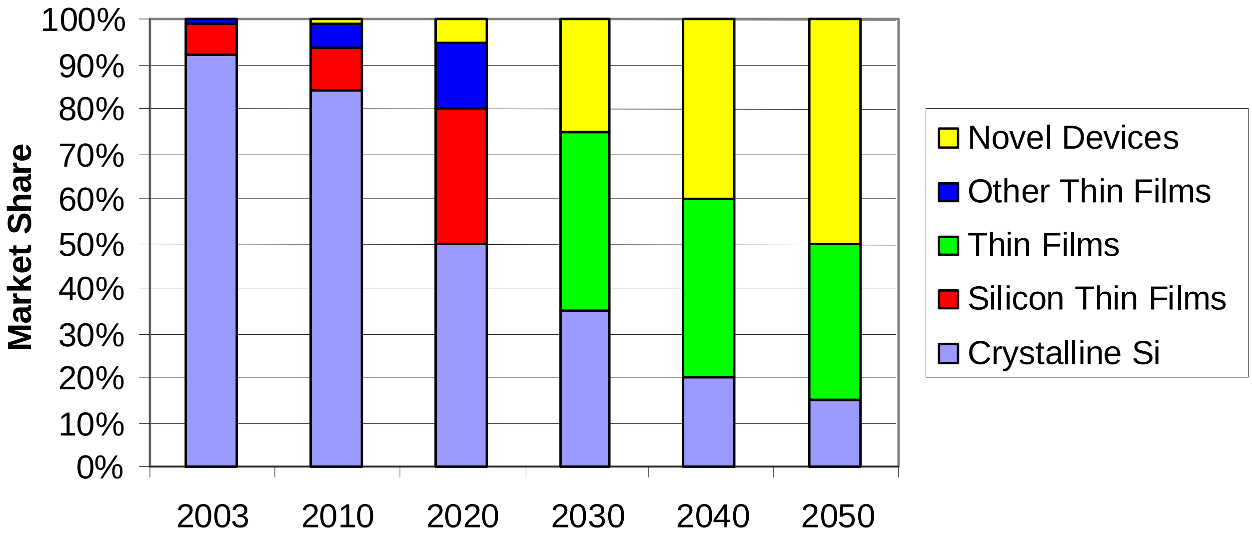


Figure 2-1: Development of PV technology market shares until 2050 (Frankl et al., 2008)

Cost projections

The historical data for the last two decades indicate a fairly constant learning rate for PV systems at 20%. In NEEDS it is assumed that this value will be maintained for all PV components at least to 2010. Different assumptions are then made from 2011 onwards, assuming specific learning rates for the various PV components (Frankl et al., 2008). NEEDS also differs between three different technology deployment scenarios ('pessimistic', 'realistic-optimistic', 'very optimistic'). The assumptions made for estimating PV costs up to the year

2050 under the NEEDS ‘realistic-optimistic’ scenario are as follows:

- Fixed learning rate for PV modules = 20% (the assumption of such a constant learning rate is consistent with the foreseen market penetration of thin films after 2010, and then with the major technological shift to third generation devices after 2025);
- Variable learning rate for the electrical balance of system = 20% until 2010; 10% 2011-2025; 5% after 2025;
- Variable learning rate for mechanical balance of system = 20% until 2010; 10% from 2011;
- Variable allocation of mechanical balance of system to PV for building integrated PV: 100% until 2010, then -1% each year to 85% in 2025; fixed at 85% afterwards (PV will become more and more a standard component of buildings, however the sheer bulk of the installations will be inferior, hence the more limited reduction of the allocation factors).

In the IEA Energy Technology Perspectives a constant learning rate of 18% for PV systems is assumed, without taking into account a differentiation between system components. Unfortunately the ETP does not report the cumulative installed capacity, so that it is not possible to rebuild the IEA cost projections over time. IEA reports total system investment costs of PV systems of 1530 $€_{2005}/kW_p$ in 2030, and 860 $€_{2005}/kW_p$ in 2050.

Table 2-2 provides a comparison of PV cost projections. There is some uncertainty on the comparability between studies because in most cases there is no clear specification of a reference technology. Only NEEDS provides detailed disaggregated data for different PV system configurations (different size classes, building integrated, open field, etc.). Nevertheless there is a quite good agreement between the four studies analysed (Figure 2-2). The IEA mid-term (2030) cost estimate is higher than in the other studies. It is likely that this results from a slower market uptake in the earlier years and thus a delay in running through the learning curve. Towards 2050 however the IEA estimate is at the lower end, in close agreement with the other studies.

It is not apparent from the IEA-ETP report to which extend the underlying ETP-model reflects the fact that PV is expected to reach grid parity in many world regions within the next 5 to 10 years (under specific conditions grid parity has been reached already today). PV is thus not competing against electricity costs at the power plant gate, but against electricity customer prices. While the ETP assumes a ‘commercialisation’ of PV under the ACT Map scenario only in 2030-2035, after reaching grid-parity PV is a competitive option for many electricity consumers much earlier, thus boosting PV market uptake and accelerating technical learning. Neglecting this effect results in an underestimation of PV deployment.

Table 2-2: PV investment cost projections

	2010	2020	2025	2030	2040	2050
NEEDS ('optimistic-realistic scenario'; building integrated systems)						
- global cumulated capacity (GW_p)		206	434	755	1520	2360
- investment costs in $€_{2005}/kW_p$	2810		1300			900
IEA-ETP 2008 (BLUE Scenario)						
- global cumulated capacity (GW_p)						
- investment costs in $€_{2005}/kW_p$	4420 [a)]			1530		860
Energy [R]evolution 2008						
- global cumulated capacity (GW_p)						
- investment costs in $€_{2005}/kW_p$	3000	1320		1020	905	860
BMU Leitstudie 2008						
- investment costs in $€_{2005}/kW_p$	2950	1300		1000	940	900

[a)] 'current' investment costs, without specification of reference year

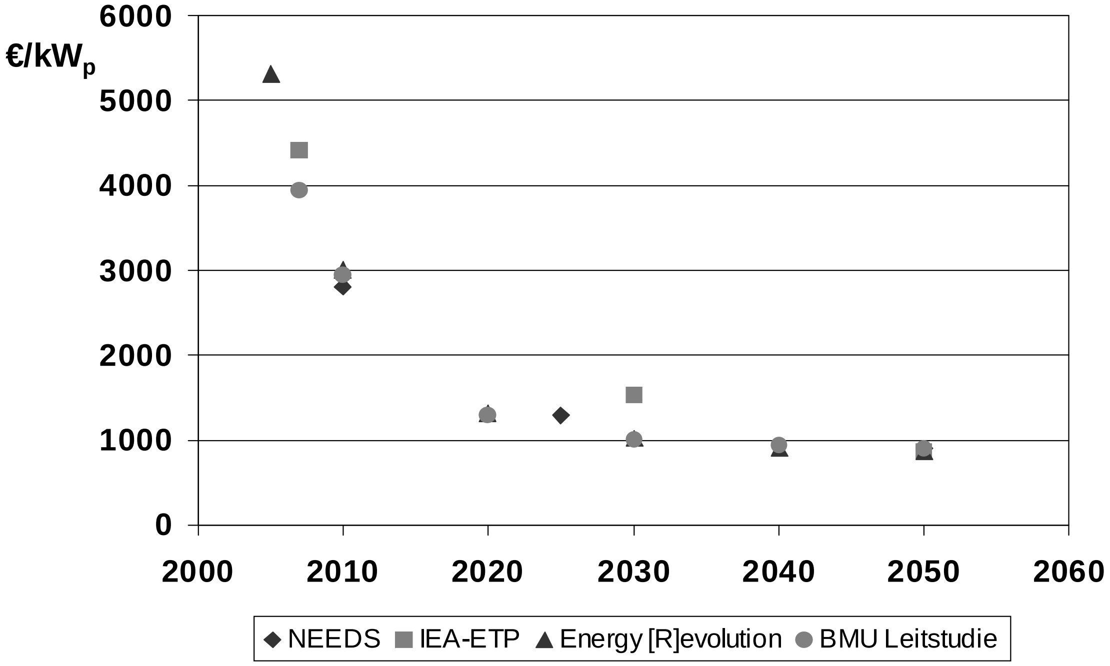


Figure 2-2: Comparison of PV cost projections

2.2 Concentrating solar thermal power plants (CSP)

Market trends

After nine CSP power plants with a total capacity of 354 MW were built in the 1980ies in the US, we now observe a new and rapidly growing interest in CSP technology. A 64 MW plant was put into operation in Nevada (USA) last year, and today 7 plants with a capacity of together 350 MW are under construction in Spain. Another 280 MW plant is planned in Arizona, and there are several expressions of interest for building CSP power plants in Middle East and North Africa countries as well as in China. The ‘Solar Action Plan’, which has been launched as part of the EU-Mediterranean Union by the French EU Presidency in July this year, aims at building up a solar thermal power plant capacity of 20 GW by 2020 in the North African countries, partly dedicated for exporting solar electricity to Europe. Because CSP uses a thermal energy intermediate phase, it has the potential to deliver power on demand, e.g. by using stored heat in various forms. Firm capacities have a particularly high value for utilities.

The parabolic trough collector is the most mature CSP technology in the market. The 10 MW PS10 plant in Seville is the only central receiver system in operation today, two central receiver systems are under construction in Spain. Dish-Stirling systems are particularly well suited for decentralised power generation, but until now only few systems are in operation, mostly as demonstration units.

Technology development projections

The maximum nominal efficiency of parabolic trough plants today is about 16%, it is limited by the temperature of the working fluid (thermo oil). Ongoing research activities aim at finding more efficient heat transfer fluids such as molten salt or direct steam generation. Cost reductions due to improvements in the concentrator performance are expected to be realised through new reflector materials and improved supporting structure (lower weight, more accurate tracking, simplified assembly) (Pitz-Paal et al., 2005). Because of their more simple design, linear Fresnel collectors are considered as an option for further cost reduction. The difference to parabolic troughs is the fixed absorber position above a field of horizontally mounted flat mirror stripes tracked to the sun. Fresnel systems are in a developing stage with first demonstrators recently built and operated. The efficiency of central receiver systems can be increased by producing compressed air at a temperature of up to 1000 °C, which is used to run a combined gas and steam turbine. First pilot projects are in operation.

Thermal storage systems are a key component for reducing CSP electricity generation costs. The Spanish Andasol 1 plant is equipped with a molten salt storage with a capacity of 7.5 hours of nominal capacity. More cost effective concrete storage systems are in an early development phase. In the long term, phase change materials are expected to increase storage density and to further reduce costs of storage systems.

The IEA-ETP does not provide a specification of future CSP technology configurations. In NEEDS, various potential technology development pathways are described (Viebahn et al., 2008). Under the NEEDS ‘optimistic-realistic’ scenario it is assumed that parabolic trough systems in the future will be operated with direct steam generation instead of using thermo oil as an intermediate heat transfer fluid. Phase change materials will be available for more efficient heat storage. Linear Fresnel technology, also operated with direct steam generation, is expected to enter the market. Central receiver systems with high efficiency combined gas and steam turbine will be commercially available. Depending on site specific conditions, CSP systems can be operated also as combined heat and power plants. The heat will be used for cooling and/or seawater desalination. The main characteristics of future CSP technologies are summarised in Table 2-3.

Table 2-3: Specification of future CSP technology configurations (Viebahn et al., 2008)

	today		2025			2050		
	Parabolic trough	Central receiver	Parabolic trough	Fresnel trough	Central receiver	Parabolic trough	Fresnel trough	Central receiver
Capacity	46 MW	15 MW	200 MW	200 MW	180 MW	400 MW	400 MW	180 MW
Heat transfer fluid	Thermo oil	Molten salt	Direct steam	Direct steam	Molten salt/compr. air	Direct steam	Direct steam	Compressed air
Storage system	Molten salt	Molten salt	PCM	PCM	Molten salt	PCM	PCM	Molten salt
Capacity factor	44%	71%	73%	73%	73%	73%	73%	73%
Annual total efficiency	15%	15.5%	19%	12%	18%	19%	12%	25%

Cost projections

The empirical basis for deriving a learning curve for CSP is quite weak, as there is only a limited number of commercial power plants in operation, most of them built between 1984 and 1990 in the US. Several studies present learning curves which are not based on historic data, but rather apply the concept of learning curves and an assumed learning rate.

IEA-ETP assumes a constant learning rate of 10% for CSP technologies. It is stated that 'there is a considerable scope to reduce costs on all elements of CSP through RD&D' (IEA 2008), but assumptions on future CSP costs are not reported. The cost target to commercialisation is assumed to be 1205 €/kW, and it is suggested that CSP does not achieve commercialisation under the ACT Map scenario (IEA 2008, p. 207, Table 5.3). Other statements in the same report indicate that CSP will be competitive by 2030 both under the ACT and the BLUE scenario.

In NEEDS a learning curve is derived based on learning rates for individual key components of a CSP power plant. The power block represents conventional technology, which however requires adaptation to the specific conditions of a solar thermal power plant, thus a low learning rate of 5% is assumed. For the collector field and the storage system a higher learning rate of 12% is assumed, as these less mature components are expected to have a higher potential for future cost reduction.

Consideration of a thermal storage system significantly affects investment costs, not only due to the direct costs for the thermal storage itself, but also because of the effects on the overall power plant configuration (i.e. larger collector field). High capacity factors can be realised by using a thermal storage system and a large collector field and thus lead to higher investment costs, but at the same time to reduced levelised electricity generation costs. A direct comparison of investment costs is not possible without a specification of the related storage configuration. Some of the CSP plants currently built in Spain are designed for using a 7.5 hours thermal storage. In NEEDS it is assumed that after 2020 CSP plants are equipped with a 16 hours storage system.

It is likely that investment costs of a current CSP plants reported by IEA (see Table 2-4) are relatively low because they do not include a storage system. Cost estimates from the other studies are in reasonable agreement (Figure 2-3). (Note: DLR was the lead analyst for CSP technologies in NEEDS, Energy [R]evolution, and BMU Leitstudie).

Table 2-4: CSP investment cost projections

	'today'	2020	2025	2030	2040	2050
NEEDS ('optimistic-realistic scenario'; building integrated systems)						
- global cumulated capacity (GW)	0.4		63			405
- investment costs in €$_{2005}$/kW	5300 a)		3720			2770
IEA-ETP 2008 (BLUE Scenario)						
- global cumulated capacity (GW)				250		630
- investment costs in €$_{2005}$/kW	3620 b)					
Energy [R]evolution 2008						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	6000 c)	4170		3530	3480	3440
BMU Leitstudie 2008						
- investment costs in €$_{2005}$/kW		3600		3300	3200	3100

a) 2007; b) no specification of reference year; c) 2005

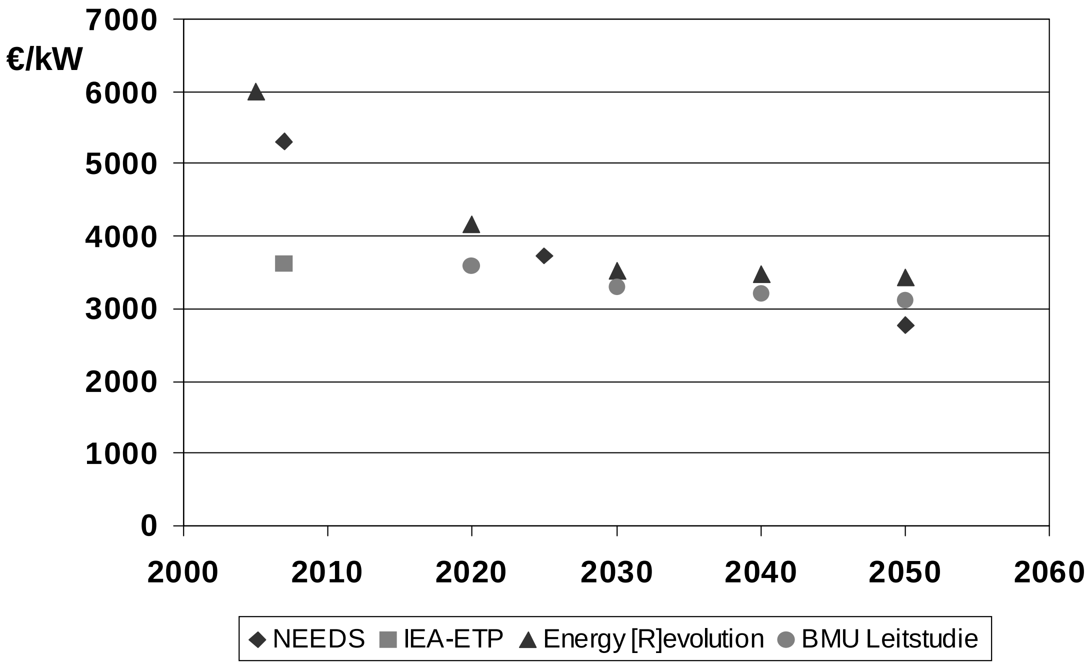


Figure 2-3: Comparison of CSP investment cost projections

2.3 Wind

Market trends

Since the mid 1990s, Germany has been the world's largest wind power market. The United States is leading the market in terms of annual installations, Spain and China rank second and third in new installations. For the first time in decades, in 2007 more than half of the annual wind market (57%) was outside of Europe, and this trend is likely to continue into the future. The large scale development of offshore wind energy is further delayed. However, it is expected that offshore development will lend new momentum to growth in Europe during the next decade.

The boom in demand for wind power technology has led to supply constraints. Prices have increased by about 20% since 2004 (IEA 2008). Factors contributing to the bottlenecks include uncertainty about policy frameworks, price increases in raw materials such as copper and steel as has been observed in the years 2007/2008, and the lead time for component suppliers to ramp up to meet demand. Industry expects to resolve the tightness in the supply chain by 2009 to 2010. Due to the continuous high demand for onshore wind turbines there was little incentive for wind turbine manufacturers to invest and push ahead new offshore technologies.

Technology development projections

Onshore wind

The size of onshore wind turbines has increased steadily over the past 25 years. The largest turbines commercially available today have a capacity of about 6 MW. Feasibility studies and concepts for a turbine size of up to 10 MW are available. The efficiency of electricity production, measured as annual energy production per unit of swept area (kWh/m^2), has improved significantly over time. More efficient equipment and higher hub heights have increased overall efficiency by 2% - 3% annually over the last 15 years (IEA 2008).

As wind turbines grow in size, it is necessary to reduce the overall load on wind turbine components. It is expected that the use of high-temperature superconductor materials can reduce size and weight of the generator by 50% - 60%. Improved control systems that continuously adjust the pitch angle of individual blades ('smart rotors') increase the efficiency of the turbine and reduce the load. Advancements in power electronics will enable wind turbines to provide grid services, thus facilitating a better integration of wind turbines into the grid.

Offshore wind

Offshore sites have the advantage of higher wind speeds and more stable wind conditions, which results in higher energy production and longer turbine lifetime. At the same time the cost of installation increases with distance to the coast and with water depth. Floating platform concepts are of interest for deep water sites. Several demonstration projects following different technical foundation concepts are planned or in operation to demonstrate the feasibility of the concept.

While the IEA Energy Technology Perspectives do not provide a technical specification of a long term future offshore wind turbine configuration, the NEEDS project makes an attempt to describe a set of technology development pathways. Key characteristics of an offshore wind turbine under the NEEDS 'optimistic-realistic' scenario are summarised in Table 2-5 (Hassing Corlin et al., 2008). It is expected that until 2050 the rated capacity of a single turbine increases to 24 MW. The foundation will be based on a guyed steel tower which allows operation in large water depth. Rotor blades which achieve a length of more than 100 m will be produced from carbon fibre and natural fibre composite materials.

Table 2-5: Specification of future offshore wind turbines (Hassing Corlin et al., 2008)

	2005	2025	2050
Capacity	2 MW	12 MW	24 MW
Hub height	60 m	140 m	160 m
Rotor diameter	80 m	160 m	250 m
Water depth	10 – 30 m	20 – 60 m	> 100 m
	Monopile steel foundation, steel tower, composite blades, gearbox	Monopile steel foundation, steel tower, gearbox upscale	Guyed steel foundation, gearless turbine, rotor: 67% carbon fibre and 33% natural fibre, hybrid system with wave generator with shared grid connection

Cost projections

Onshore wind

There is a number of studies that analysed historic wind turbine cost data. Experience curves derived from these studies quite consistently indicate a learning rate for wind turbine investment costs in Europe of 4% to 10% (see e.g. Neij et al., 2003). Some studies point out that the learning rate in terms of levelised electricity generation costs is higher than for investment costs, which means that due to wind turbine efficiency improvements the electricity generation costs were reduced faster than the investment costs (see Neij 2007). Onshore wind turbines will probably continue to decrease in costs. On the short term, prices may however increase due to the large demand. The increase in world market prices in the years 2007/2008 for steel and copper resulted in growing wind turbine manufacturing costs.

IEA-ETP assumes a constant learning rate of 7% for onshore wind turbines, but it does not report the development of cumulated installed capacity, so that it is not possible to reproduce the learning curve. The IEA's 'current investment costs' of 965 €/kW seem to be at the lower end of cost estimates, they perhaps do not fully reflect the 2007/2008 increase in steel prices. Unfortunately IEA does not provide projections of future investment costs, but it suggests onshore wind generation costs to be about 4.3 ct/kWh at a high wind site and 5.1 ct/kWh at a medium wind site in 2015. Compared to other studies this is a quite low estimate. As shown in

Table 2-6 and Figure 2-4, the investment cost estimates from the Energy [R]evolution scenario and the BMU Leitstudie are in good agreement, which is perhaps not a surprise as the lead analyst (DLR) in both studies is the same. The cost assumptions used in these studies however have been extensively discussed with representatives from industry and policy. Onshore wind is considered to be a relatively mature technology, with only limited potential for further cost reduction beyond 2020.

Offshore wind

Historic experience in offshore wind technical learning is still limited. The installations are few, they have different size and different types of foundations. The locations of offshore wind turbines have moved further out into the sea – from low water depth close to the coast to more distant locations with deep water.

In spite of the lack of empirical data, the NEEDS project made an attempt to use a learning curve for long term future cost estimates (Hassing Corlin et al., 2008). A break-down of offshore wind investment costs reveals that turbines and foundation accounts for about 70% of the total investment, while the costs of legal assistance, design and grid connection (balance of system) account for 30%. As it is expected that the costs of turbines and foundations are subject to a different learning curve than cost reduction related to grid connection, different learning rates are used. For the foundations and turbines a learning rate of 10% is used, which from 2025 and beyond is reduced to 5%, as the technology becomes more mature. For the balance of system (design, grid connection etc.) a learning rate of only 2.5% is assumed (Hassing Corlin et al., 2008). The combination of these learning rates with the NEEDS projection of global installed capacity leads to the cost estimates given in Table 2-7.

IEA-ETP assumes a constant learning rate of 9% (IEA 2008). Current investment costs are reported as 2090 €/kW. While this starting point of the learning curve is lower than in the Energy [R]evolution Scenario and in the BMU Leitstudie (Table 2-7), the decrease in costs is slower than in the other studies.

It is likely that data from NEEDS (published in 2007) and IEA-ETP (published in July 2008) do not fully reflect the high prices observed in 2008, which resulted from the high worldwide demand for wind turbines and high world market prices for components and raw materials. The learning rate applied in NEEDS seems to be better justified than the IEA learning rate, but the starting point of the learning curve should be adjusted upwards, which then would be in agreement with the projections of Energy [R]evolution and BMU Leitstudie.

Table 2-6: Onshore wind investment cost projections

	'today'	2020	2025	2030	2040	2050
NEEDS ('optimistic-realistic scenario')						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.
IEA-ETP 2008 (BLUE Scenario)						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	965 [a)]	n. a.	n. a.	n. a.	n. a.	n. a.
Energy [R]evolution 2008						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	1200 [b)]	940		880	870	870
BMU Leitstudie 2008						
- investment costs in €$_{2005}$/kW	1120 [c)]	875		865	860	855

[a)] year not specified; [b)] 2005; [c)] 2005

Table 2-7: Offshore wind investment cost projections

	'today'	2020	2025	2030	2040	2050
NEEDS ('optimistic-realistic scenario')						
- global cumulated capacity (GW)	0.7		85			160
- investment costs in €$_{2005}$/kW	1800 [a)]		1100			1000
IEA-ETP 2008 (BLUE Scenario)						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	2090 [b)]	1610		1450		1370
Energy [R]evolution 2008						
- global cumulated capacity (GW)						
- investment costs in €$_{2005}$/kW	3000 [e)]	2070		1755	1580	1510
BMU Leitstudie 2008						
- investment costs in €$_{2005}$/kW	2800 [d)]	1800		1500	1300	1200

[a)] 2005; [b)] 2006; [e)] 2005; [d)] 2007

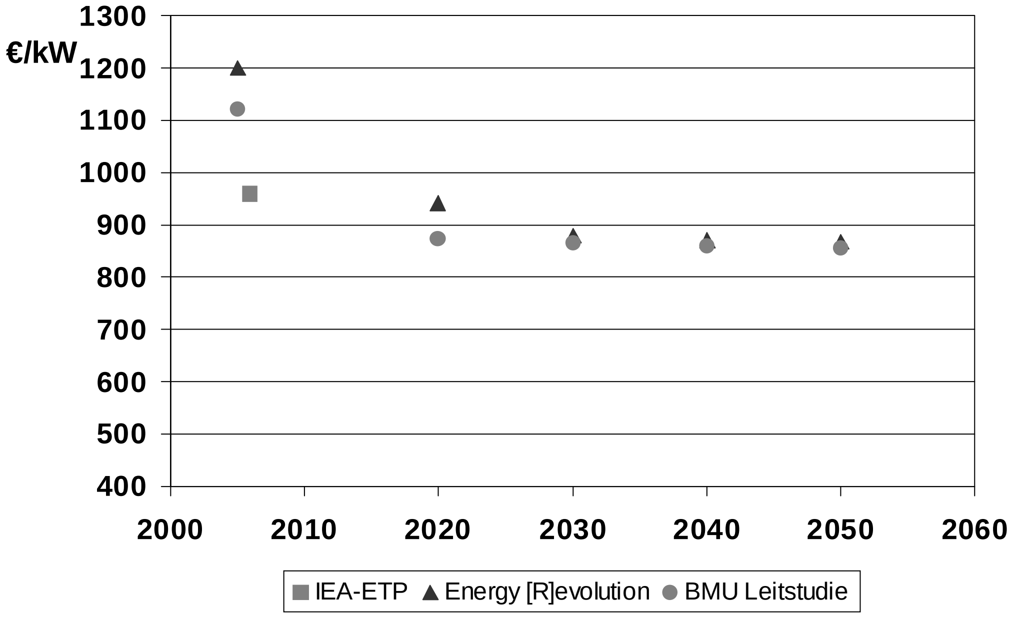


Figure 2-4: Comparison of onshore wind investment cost projections

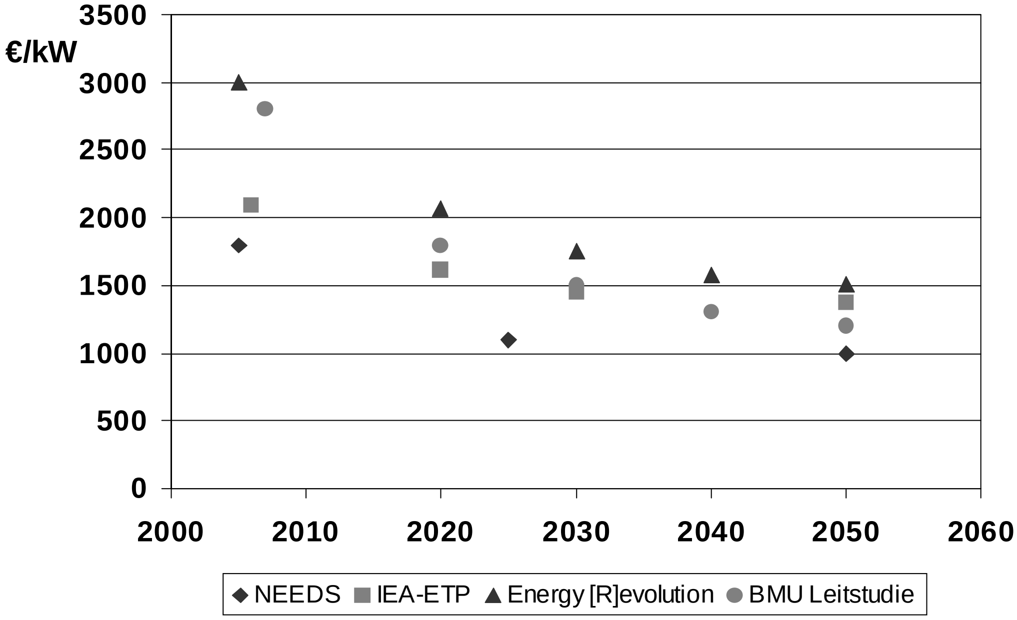


Figure 2-5: Comparison of offshore wind investment cost projections

2.4 Biomass

Market trends

Biomass is the third most important renewable energy source of electricity at the global level, and the second one in developing countries. Most of the biomass comes from woodfuels, but the contribution of agricultural, municipal and industrial wastes is also significant.

In contrast to other renewable energy sources biomass is a scarce resource. Due to limitations in agricultural land availability there are constraints to the sustainable production of biomass. As biomass can be used for electricity and heat generation as well as for the production of transport fuels there is a competition for biomass between the demand sectors. In addition, agricultural land for growing energy crops competes with food production. Ambitious targets for biofuels in several countries were a main driver for increasing biomass prices, which affected the costs of biomass electricity. In contrast to other renewable energy technologies the economic performance of biomass technologies does not only depend on the power plant investment costs, but is heavily influenced by the fuel costs. Recent increase in biomass prices resulted in some reluctance in new investments into biomass power plants.

Technology development projections

A large range of technologies that differ in size and typical application are available for electricity generation from biomass. Presently, biomass co-firing in modern coal power plants is the most cost effective biomass use for power generation. Due to feedstock constraints, another economic option is the use of solid biomass in dedicated steam turbine combined heat and power plants (CHP), which represent state-of-the-art technology. Biomass integrated gasification in gas turbine plants is not yet commercial.

IEA-ETP provides a description of the range of biomass electricity generation technologies, including grate boilers, fluidised bed combustion, biomass co-firing, biomass gasification, and combined heat and power generation. The IEA technology descriptions however focus on current technologies only, and do not provide any specification of future technologies. IEA-ETP considers the technical potential for biomass carbon capture and storage (CCS) as being theoretically large, but it is concluded that ‘due to high uncertainties at this early stage of development, none of the scenarios included it as a marketable technology at any material level’ (IEA 2008, p. 331). In contrast to this statement ‘Bio+CCS’ is reported to contribute up to 1103 TWh/a (BLUE loREN scenario) to global electricity generation in 2050 (page 85).

Figure 2-6 shows the future pathways of bioenergy raw materials and use options in power plants/CHP that were considered to be most relevant under European conditions in NEEDS. A detailed assessment of technical development options is carried out for direct biomass combustion in decentralised CHP applications, and for biomass gasification combined with the use of syngas in fuel cells (Gärtner 2008). Technical characteristics of a future biomass CHP plant are summarised in Table 2-8. The capacity of the plant is assumed to remain at 6 MW_{el}, thus avoiding larger biomass input and longer transport distances.

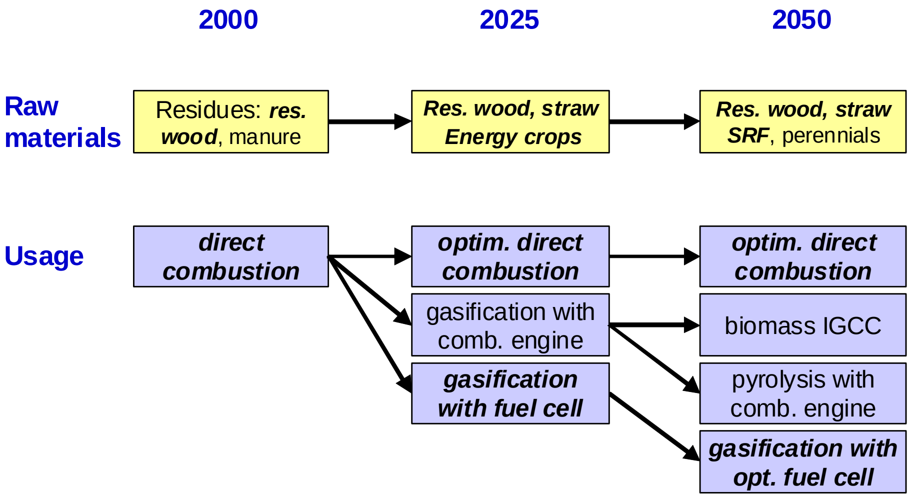


Figure 2-6: Future pathways of the main bioenergy raw materials and biomass use options in power plants and CHP plants (Gärtner, 2008) (SRF: short rotation forest)

Table 2-8: Specification of future biomass CHP technology configurations (Gärtner 2008)

	2005	2025	2050
Capacity	6 MW_{el}	6 MW_{el}	6 MW_{el}
Electrical efficiency	20%	20%	30%
Thermal efficiency	65%	65%	50%
Capacity factor	90%	90%	90%

Cost projections

The electricity generation from biomass covers many types of combinations of conversion technologies and fuel supply chains. Experience curves for estimating future cost developments have only been developed for a few systems, and these curves have been based on a broad set of data (Neij, 2007). Because of the diversity of different biomass energy technologies, care must be taken when applying generic learning rates derived from ‘average’ biomass technologies.

IEA-ETP provides cost data only for a biomass integrated gasifier, operated together with a combined cycle power plant (BIG/CC) (IEA 2008). A constant learning rate of 5% is applied to BIG/CC systems. Current investment costs are given as 2010 €/kW. It is assumed that under the BLUE scenario investment costs are reduced to 1410 €/kW by 2050.The installed BIG/CC capacity in 2050 in the BLUE scenario is 65 GW.

The evaluation of learning curve studies in NEEDS resulted in recommending a 5% learning rate for conversion technologies, and a 15% learning rate for biofuel production technologies (wood chips, short rotation forests). Because of the unspecific nature of the learning curves available for biomass technologies, future cost data estimates for the NEEDS CHP reference technologies are based on a bottom-up assessment of cost developments rather than on the application of learning curves. The cost projections for the two CHP technologies derived under the NEEDS ‘optimistic-realistic’ technology scenario are given in Table 2-9.

Table 2-9: Biomass electricity generation investment cost projections

	‘today’	2020	2025	2030	2040	2050
NEEDS (‘optimistic-realistic scenario’)						
straw CHP, 6 MW_{el}, ($€_{2005}$/kW)	2500 a)		2500			2150
wood chips CHP, 6 MW_{el}, ($€_{2005}$/kW)	1750 a)		1650			1600
IEA-ETP 2008 (BLUE Scenario)						
BIG/CC ($€_{2005}$/kW)	2010 b)					1410
Energy [R]evolution 2008						
biomass power plant ($€_{2005}$/kW)	2425 a)	2015		1970	1940	1925
biomass CHP ($€_{2005}$/kW)	4600 a)		3080	2690	2480	2355
BMU Leitstudie 2008						
biomass power plant, 10-20 MW_{el} ($€_{2005}$/kW)	2590 a)	2320		2320	2320	2320
biomass CHP, 5-10 MW_{el}, 20-40 MW_{th} ($€_{2005}$/kW)	3500 a)	3200		3120	3120	3120
CHP, 0.5-5 MW_{fuel}, wood gasification ($€_{2005}$/kW)	4500	2500		2250	2125	2000

a) 2005; b) no specification of reference year

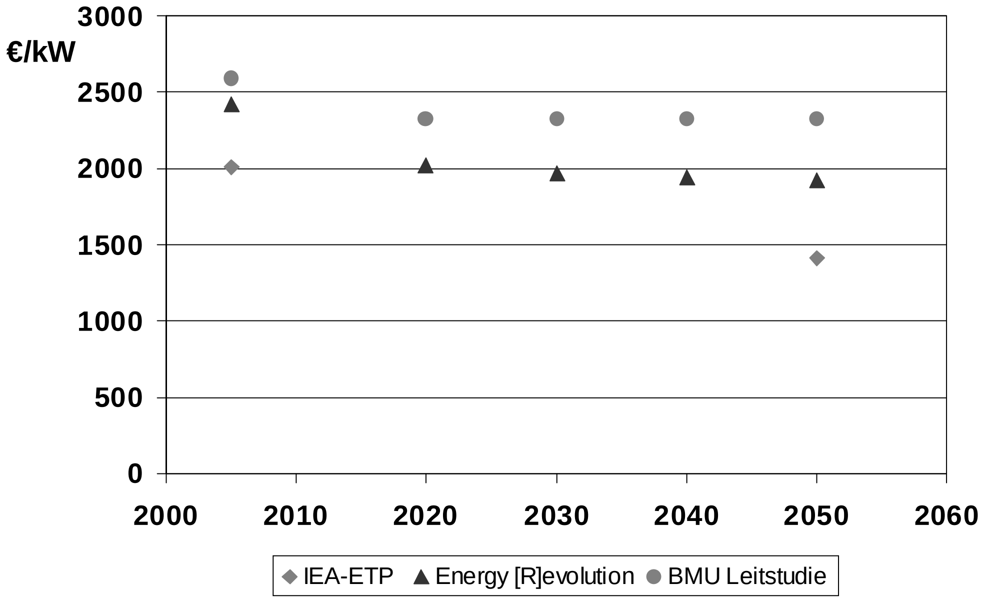


Figure 2-7: Comparison of biomass power plant investment cost projections

2.5 Geothermal

Market trends

Geothermal electricity generation most commonly takes place in conventional steam turbines. The steam, which typically has a temperature of above 150 °C, is piped directly from dry steam wells or after separation from wet wells through a steam turbine. Unit sizes are commonly 20 – 110 MW_{el} (Fridleifsson et al., 2008). Binary plants (organic Rankine cycle) utilise geothermal fluids at lower temperatures than conventional plants (74 °C – 170 °C). They use a secondary working fluid, usually an organic fluid that has a low boiling point and high vapour pressure at low temperatures. Binary plants are usually constructed in small modular units of up to a few MW_{el} capacity. The Kalina cycle is a relatively new binary fluid cycle which utilises a water-ammonia mixture as a working fluid to allow more efficient power production (Fridleifsson et al., 2008). The efficiency of geothermal utilisation is enhanced considerably by cogeneration of heat and electricity.

Large scale geothermal development is currently limited to tectonically active regions (Indonesia, Philippines, Japan, New Zealand, Central America, Iceland, East Africa). These areas are likely to be the most promising ones for large developments in the near term. If current enhanced geothermal systems R&D efforts are successful, geothermal potential could lead to an expansion into other regions (IEA 2008).

Technology development projections

Current research activities aim at improving the productivity of geothermal resources by using Enhanced Geothermal Systems (EGS). Enhanced Geothermal Systems are engineered reservoirs that have been created to extract an economical amount of heat from low permeability and/or porosity geothermal resources. Still a number of basic problems need to be solved for the realisation of EGS systems, in particular techniques need to be developed for creating, characterising, and operating the deep fracture system that can be tailored to site specific subsurface conditions (Fridleifsson et al., 2008). Worldwide several EGS pilot and demonstration plants are in operation.

The NEEDS project does not cover geothermal power generation technologies, so that no long term technology projections similar to those of the other RES technologies covered in NEEDS are available. IEA-ETP summarises current research activities and requirements for future deployment of geothermal resources, and provides cost estimates for future geothermal, but does not give a technical characterisation of future power plant configurations.

The report of the Massachusetts Institute of Technology on the ‘Future of Geothermal Energy’ (MIT 2006) provides a comprehensive assessment of future geothermal power systems. Geothermal power plant configurations very much depend on key site specific parameters like the geofluid temperature or the achievable mass flow rate. The MIT study uses detailed procedural models to specify technical parameters of a broad range of different configurations (Table 2-10). The modelling aims at determining the thermodynamic optimum conditions, and does not take into account the expected technology development pathway. Results from the MIT study thus can be considered as describing ‘ideal’ future configurations, but the study does not give an indication on when such a configuration will be available.

The most important option for future large scale exploitation of geothermal energy might be electricity generation from high-temperature EGS resources. It is expected that EGS reservoirs will be created in deep granitic basement rocks where in situ temperatures will range from about 250 °C to more than 500 °C in special circumstances. For fluids at the subcritical temperatures of 200°C and 250 °C the MIT study considers a single flash plant (200 °C) and a double-flash plant (250 °C) as reference technologies. Selected parameters resulting from an optimised process design are shown in Table 2-11. The maximum reasonable sustainable mass flow rates from EGS reservoirs to-date have been around 20-22 kg/s, this would be sufficient to generate 1 MW from a 200 °C fluid, and about 2.4 MW from a 250 °C fluid (MIT 2006).

Supercritical fluids from an EGS reservoir can be used in a triple-expansion power plant, or – at very high pressure – in a single-expansion power plant. The MIT report however points to the uncertainties of the economic performance of such quite complex systems, and uncertainties related to the availability of adequate reservoir conditions.

Table 2-10: Geothermal power generation systems (MIT 2006)

Geofluid temperature (°C)	Energy conversion system	Typical application	Working fluid	Cooling system
100	Basic binary	O&G waters	R-134a [a)]	Water
150	Binary with recuperator	O&G waters	Isobutane	Air
200	Binary of single-flash	EGS	Isobutane of Geofluid	Air or water
250	Double flash	EGS	Geofluid	Water
400	Single or triple expansion	Supercritical EGS	Geofluid	Water

[a)] according to EC Regulation No. 842/2006 is not allowed any more in Europe

Table 2-11: Performance parameters for thermodynamically optimised single- and double flash plants (MIT 2006)

Geofluid temperature (°C)	Energy conversion system	Separator temp. (°C)	Flash temp. (°C)	Specific turbine power (kW/(kg/s))	Mass flow rate in kg/s needed for		
					1 MW	10 MW	50 MW
200	Single-flash	121	n.a.	53,9	19.5	195.	975.
250	Double-flash	185	122	123,5	8.5	85.2	426.2

Cost projections

The basic components of the capital costs of geothermal power plants are the drilling costs (including exploration costs), stimulation costs (in the case of EGS), and the power plant costs. The MIT study provides a detailed analysis of the drilling costs and power plant costs. Costs for EGS wells of mid-range depth (4000 - 5000 m) are estimated to range from 4.3 Mill € to 6.9 Mill €. Drilling costs for deep EGS wells (6000 – 10000 m) are expected to be in the range of 8 to 16.6 Mill €. Sanyal et al. (2007) estimate EGS well drilling and stimulation costs of 4.4 Mill € to 5.6 Mill €, which is in good agreement with the MIT estimates. Emerging drilling technologies, which have yet to be demonstrated in geothermal applications, are expected to significantly reduce the cost of in particular deep wells (> 4000 m), and thus to enable economic access to low grade EGS resources.

The specific investment costs (€/kW) for power plants are inversely dependent on the fluid temperature and mass flow rate. MIT estimates (MIT 2008) suggest that over the temperature range from 150 – 340 °C the specific cost varies from 1400 to 1520 €/kW (1- or 2- flash power plant) for a mass flow rate of 100 kg/s, and from 790 to 1415 €/kW for a flow rate of 1000 kg/s.

Taking into account the varying resource quality and the related broad range of different technologies, IEA-ETP (IEA 2008) provides a range of investment cost estimates for future geothermal power plants for the years 2005, 2030, and 2050 (Table 2-12). IEA data differ between hydrothermal systems, which is the dominating technology today, and hot dry rock (EGS), which is expected to be the dominating future application. For both technologies, the IEA low and high estimates differ by more than a factor of two. It remains unclear which cost data are used in the scenario modelling.

Compared to cost data from the Energy [R]evolution Scenario and the BMU Leitstudie, the IEA costs are at the lower end. Both Energy [R]evolution and BMU Leitstudie assume higher costs for current EGS systems, which is well backed up by actual data from pilot and demonstration plants. For later years, the Energy [R]evolution data are within the range of the IEA cost data, but tend to be more in the upper range of the IEA estimates. The German BMU Leitstudie assumes that there are no further cost reductions beyond 2030, which might be too pessimistic.

Due to the focus on EGS systems only, the Energy [R]evolution scenario tends to slightly overestimate costs of geothermal power generation, as it neglects the less expensive hydrothermal plants which are the dominating technology today. Future large scale deployment of geothermal power production will however mainly rely on EGS systems, so that this overestimation is expected to be very small. The MIT study reports total specific costs (i.e. drilling cost plus plant cost) of 3900 to 4500 €/kW (2000 – 3000 m drilling depth) and 6770 to 7410 €/kW (4000 – 5000 m drilling depth). While the MIT study does not link these cost estimates to a specific future year, these cost estimates correspond to the upper range of the long term IEA estimates.

Table 2-12: Geothermal electricity generation investment cost projections (in €$_{2005}$/kW)

	2005	2020	2030	2040	2050
IEA-ETP 2008					
- hydrothermal	1370 – 4580		1205-4020		1125-3940
- Enhanced geothermal systems	4020-12060		3215-8040		2410-6030
Energy [R]evolution 2008					
- Enhanced geothermal systems	14000	7580	6340	5530	5030
BMU Leitstudie 2008					
- Enhanced geothermal systems	14500	8100	8000	8000	8000

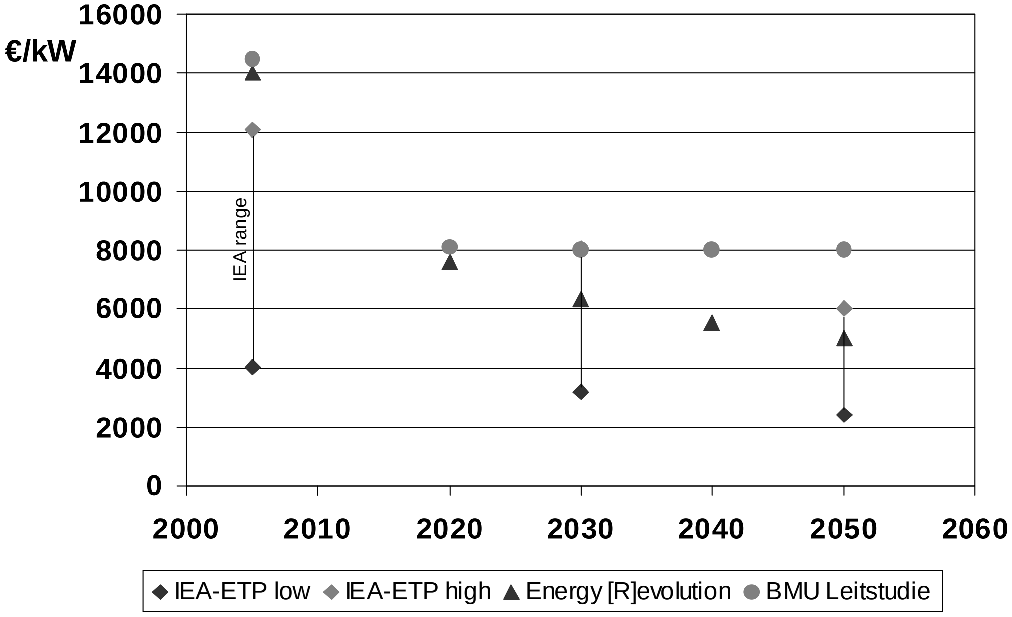


Figure 2-8: Comparison of geothermal EGS power plant investment cost projections

2.6 Hydropower

Market trends

Hydropower is a mature technology that has long been used for economic generation of electricity. Hydropower currently provides about 16% of global electricity supply. OECD countries today produce roughly half of the hydroelectricity produced worldwide. Most of the large hydro potential in the OECD countries has been developed. A further exploitation of the remaining potential is partly constrained due to environmental concerns. Additional potential can be exploited by modernising and expanding existing systems. The growth rate of new hydro development in non-OECD countries today is around 10%. The fastest growth takes place in Asia, but also Central and South America see still significant growth (Taylor, 2008).

Hydro reservoirs provide built-in energy storage, and the fast response time of hydropower enables it to be used to level out fluctuations in electricity demand and supply (IEA 2008). Pumped hydro storage systems are not covered here, as they are considered to be an energy storage facility.

Technology development projections

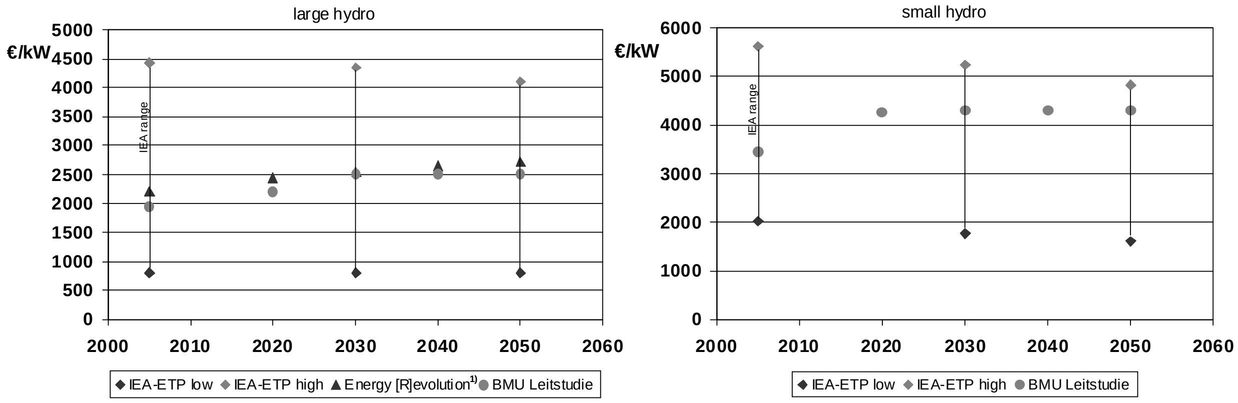
Although hydropower technologies gained a high level of maturity, continuous advances in hydropower equipment aim at improving efficiencies, reduce costs, improve dependability and to minimise environmental impacts. Cost reduction of small-capacity systems enables the exploitation of smaller rivers and shallower reservoirs.

Cost projections

One of the cheapest ways of producing electricity is the use of existing hydro power plants, as for many of them their initial costs have been fully amortised. Taylor (2008) reports current capital costs for new plants of 800 €/kW to 4000 €/kW, with an average of less than 1600 €/kW. IEA-ETP provides a range of future cost estimates for large and small hydro power plants respectively (without specifying ‘small’ and ‘large’) (IEA 2008). The difference between the ‘low’ and ‘high’ values is significant (factor ~ 5 in the case of large, factor ~ 3 in the case of small hydro plants), which reflects the strong influence of site specific conditions on investment costs. IEA expects a small but continuous reduction of future costs, while both the Energy [R]evolution scenario and BMU Leitstudie assume increasing costs for new hydro plants because of more stringent environmental regulation. Cost estimates from both Energy [R]evolution and BMU Leitstudie are nevertheless well within the range of costs reported by IEA. For small hydro power plants, cost data from BMU Leitstudie are towards the upper range of IEA estimates, while for large plants cost data from both Energy [R]evolution and BMU Leitstudie correspond to the average of the IEA cost data. The Energy [R]evolution scenario reports only aggregated costs for small and large hydro plants. As large hydro plants dominate the total installed capacity, this average value is a better representation of large hydro power plant costs than of small hydro power plant costs.

Table 2-13: Hydropower electricity generation investment cost projections (in €$_{2005}$/kW)

	2005	2020	2030	2040	2050
IEA-ETP 2008					
- small hydro	2010-5630		1770-5230		1610-4820
- large hydro	800-4420		800-4340		800-4100
Energy [R]evolution 2008					
- hydro power plant	2200	2440	2550	2650	2730
BMU Leitstudie 2008					
- small hydro (< 1 MW)	3450	4250	4300	4300	4300
- large hydro (> 1 MW)	1950	2200	2500	2500	2500



[1] aggregate of small and large hydro power plants

Figure 2-9: Comparison of hydropower investment cost projections

2.7 Ocean energy

Market trends

Ocean energy technologies for electricity generation are at an early stage of development. Ocean energy represents a number of energy conversion principles (Soerensen and Weinstein, 2008):

- Wave energy is represented by surface and subsurface motion of the waves,
- Hydrokinetic energy that harvests the energy of ocean currents and tides,
- Ocean thermal energy conversion uses the temperature differential between cold water from the deep ocean and warm surface water,
- Osmotic energy is the pressure differential between salt and fresh water.

Wave energy and tidal current energy are the two main areas under development. Today there are few operational ocean energy systems. The largest one is the tidal barrage system at La Rance, France, that has a capacity of 240 MW and was built already in 1966. Other operational systems are much smaller (5 MW China, 20 MW Canada) (Soerensen and Weinstein, 2008).

The environmental impacts of dammed tidal energy projects are often unacceptable. Offshore tidal projects with reduced environmental impacts could be combined with wind turbines to reduce costs. New projects with tidal current turbines comprised of modules of up to 2-3 MW have been planned in the UK, Canada and the US (IEA 2008). Planned new wave energy capacity in the coming years is in the order of 10 MW per year. Today several demonstration power plants with a capacity of up to 0.3 MW are operational.

Technology development projections

At present there is no commercially leading technology amongst ocean energy conversion systems. It is expected that different principles of energy conversion will be used at various locations to take advantage of the variability of ocean energy resources.

Wave energy

Among the different types of ocean energy, wave energy represents the highest density resource. Various concepts for wave energy conversion exist, including oscillating water columns, overtopping devices, heaving devices, pitching devices, and surging devices (for a more detailed description see e.g. Soerensen and Weinstein, 2008). Wave energy installations will consist of farms of wave energy converters. The main challenge for wave power is the irregularity in wave amplitude, phase and direction, which makes it difficult to obtain maximum efficiency over the entire range of excitation frequencies, and the high structural loads in the event of extreme weather conditions.

In NEEDS an attempt was made to provide a detailed assessment of four reference technologies: an ascillatory water column test facility (400 kW) operated at Pico Island, Azores, a 1-200 kW buoy system, a 750 kW pitching device (Pelamis), and an overtopping device with a capacity of up to several MW (Wave Dragon) (Soerensen, 2007). Because of data availability, only the overtopping device was analysed in more detail. As shown in Figure 2-10, size and performance of such a system depends on the wave climate. In

NEEDS it is assumed that near future projects will have a capacity of up to 10 MW, while a typical system in 2025 is expected to have a capacity of 40 MW.

IEA-ETP provides a qualitative description of the various wave energy systems, but does not report any technical details of future system configurations.

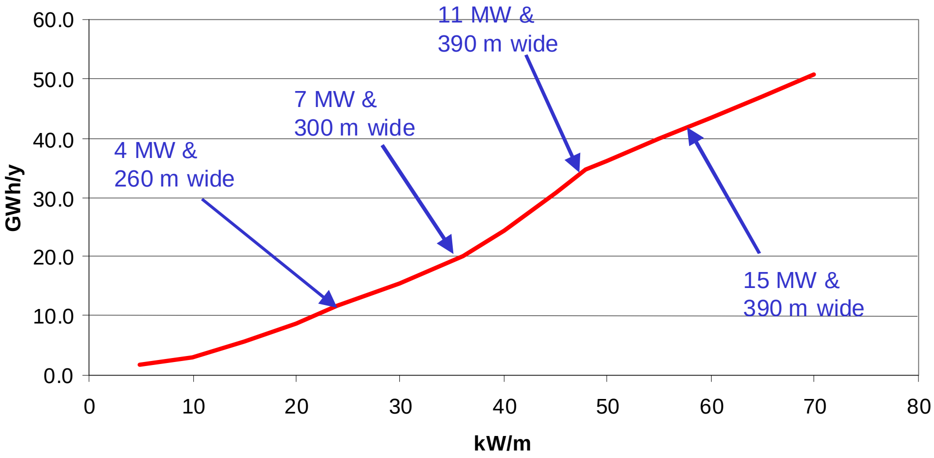


Figure 2-10: Wave dragon unit power production as a function of wave climate (Soerensen, 2007)

Tidal energy

The principle of converting tidal range into electricity is similar to the technology used in hydro power plants. Tidal range energy conversion is considered mature. Potential environmental impacts might be critical for future projects.

Tidal currents can be harnessed using technologies similar to those used for wind energy conversion, i.e. turbines with horizontal or vertical axis. Several pilot and demonstration plants are in operation and in the planning phase. There are no long term technology development projections available that provide a reasonable specification of technical data and costs up to the year 2050.

Ocean thermal energy and *ocean osmotic energy* systems are in a very early development phase. First experimental systems have been installed to produce electricity from ocean thermal energy, while the use of ocean osmotic energy rather is in a conceptual phase. It is completely open if there is a long term potential for exploiting these energy resources in an economic way.

Cost projections

Because of the early development stage any future cost estimates for ocean energy systems are a matter of large uncertainties. Due to the very limited amount of historic data there are no learning curves available for ocean energy technologies.

Without providing a technical specification of future systems, IEA-ETP reports ranges of future cost estimates for tidal barrage, tidal current and wave energy systems (Table 2-14). It remains unclear which technology is used in the ETP scenarios. Not surprisingly, the cost range is particularly large in the case of wave energy systems. As the potential for ocean energy in Germany is only very small, BMU Leitstudie does not consider ocean energy at all. NEEDS and Energy [R]evolution provides data for wave energy only. Estimates in Energy

[R]evolution are based on NEEDS data, but today's cost data were adjusted upwards. The long term NEEDS estimates correspond to the lower values of the future IEA-ETP estimates.

Table 2-14: Ocean energy electricity generation investment cost projections (in €$_{2005}$/kW)

	2005	2020	2025	2030	2040	2050
NEEDS ('optimistic-realistic scenario')						
- wave	3000		1500			1200
IEA-ETP 2008						
- tidal barrage	1610-3215			1370-2810		1205-2410
- tidal current	5630-8040			4020-6430		2810-4820
- wave	4820-12060			2010-4020		1610-3215
Energy [R]evolution 2008						
- wave	7210	2320		1790	1490	1330

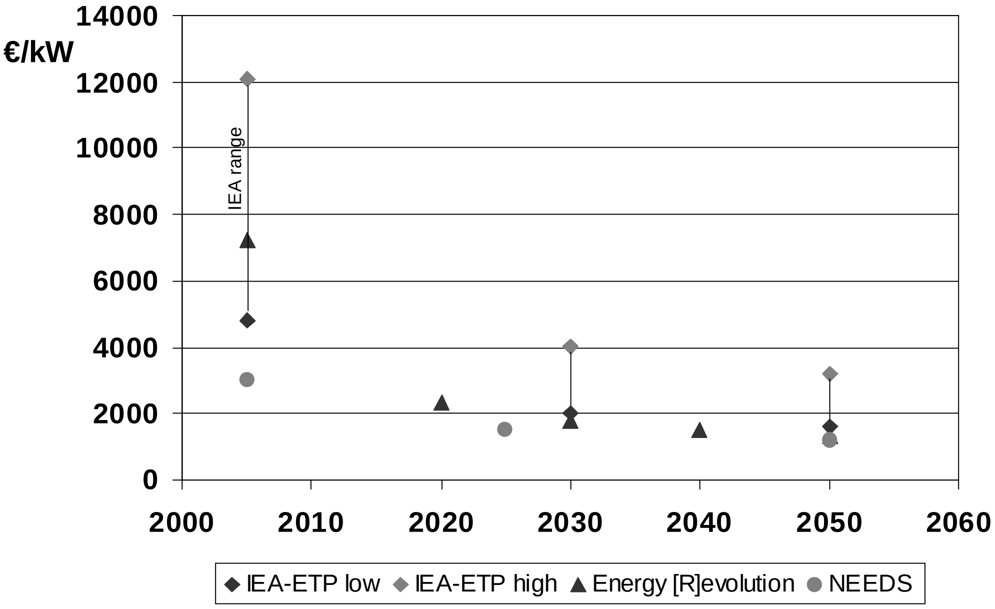


Figure 2-11: Comparison of wave energy investment cost projections

2.8 Costs of renewable electricity generation technologies - summary

The previous chapters provide a review of cost estimates and long term cost projections of renewable energy technologies from various sources. Key studies analysed like the IEA's Energy technology Perspectives, the Greenpeace/EREC Energy [R]evolution study or the German BMU Leitstudie are meta-studies in itself with respect to cost estimates. In all these studies relevant stakeholder groups were involved in the specification of technical data and future cost projections of renewable energy technologies. In the Greenpeace/EREC study, the European Renewable Energy Council (EREC) representing the European renewable energy industry was actively involved in the scenario work and the specification of technical and cost data of future renewable energy technologies. During the development of the IEA-ETP scenarios, dedicated workshops on future renewable energy technologies were hold, with active participation from representatives from industry and academia.

The NEEDS project of the European Commission made an attempt to come up with new estimates of long term cost projections for emerging energy technologies by combining the learning curve approach with a technology oriented bottom-up assessment of future costs. There was a both personal and institutional interaction between experts involved in NEEDS with stakeholder groups contributing to the other key studies.

Because of this high degree of interactions between the relevant actors and the resulting active exchange and review of information, it is not surprising that in general the cost estimates and even long term cost projections across the key studies are in reasonable agreement. For well known technologies like PV or wind the differences in future cost assumptions are quite small. Differences are larger for technologies in a very early development stage, for which there is not yet an established lead technology (like wave energy). Differences between cost estimates can be large when site specific conditions influence investment costs, like in the case of hydropower or geothermal energy. The variation in cost data is also large when a variety of different technical concepts and different applications exist, like in the case of biomass use. A problem here is that the energy system models used for scenario analysis in many cases do not support a too detailed differentiation between individual technologies. Different choices of the respective analyst with respect to the 'typical representative' of a technology cluster might suggest differences in cost assumptions, although there is agreement on the cost data of a specific technology.

An interesting result of the analysis is the fact that for most renewable energy technologies costs of renewable energy technologies in IEA-ETP in general are towards the lower range of cost estimates, although the share of renewables in the IEA scenarios in general is smaller than in the other scenario studies. Costs for renewable energy technologies in the Greenpeace/EREC scenario, which is a dedicated 'renewables' scenario, in most cases are higher than the IEA estimates.

This finding underlines the importance of understanding better other parameters that limit the market uptake of renewables in the relevant scenario models. One important parameter is of course the price of fossil fuels, and the IEA projections on future fuel prices are quite low compared to other scenarios. But there are many other bounds and constraints, and tracing them back is sometimes extremely difficult, as in many cases they are not reported in a transparent way (in neither of the scenario studies analysed). It might be noted that in any modelling activity some of the key settings result from the mental model of the analyst running the simulation model.

The following Table 2-15 provides a summary of the cost estimates and future cost projections for the renewable energy technologies. For each of the technology clusters a plausible range of cost estimates is reported for three points in time (~ 2010, 2020/2030, ~ 2050). As energy system models used for scenario analysis in general require a single input value rather than a range, in addition to the range of cost estimates we also report an ‘indicative estimate’, which is based on the review of the available key studies. It is emphasised that care must be taken in using such a single value ‘indicative estimate’, as it may not very well represent specific conditions. This is in particular true in the case of biomass technologies as there exist a wide range of different technology configurations and different applications, and in the case of hydropower and geothermal power plants, for which site specific conditions might have a strong influence on investment costs.

The future costs of electricity generation from renewable energies depend on the development of investment costs, but also on site specific conditions like e.g. the solar irradiation, which differs significantly between world regions. In Table 2-16 we give an exemplary indication of full load hours for renewable energy technologies. For wind and solar we differ between ‘typical’ average conditions for Europe and the US, as specified in the Energy [R]evolution scenario. We do not report electricity generation costs for biomass applications, as the generation costs heavily depend on biomass fuel costs and – in the case of CHP applications – on the heat credit gained, which both differs significantly across regions and the type of applications. Results in Table 2-17 show that for all renewable technologies except hydro we expect that a significant reduction in electricity generation costs can be realised over the next twenty years. Taking into account an expected increase in fossil fuel prices and CO_2 emission costs, it is most likely that by 2030 most of the renewable electricity generation technologies will be competitive against electricity generation from fossil fuels.

Table 2-15: Future cost projections for renewable electricity generation technologies

			~ 2010		2020 – 2030		~ 2050	
			range	‘indicative estimate’	range	‘indicative estimate’	range	‘indicative estimate’
Photovoltaics	Invest. costs	€/kW	2800 - 4420	3000	1000 - 1530	1050	860 - 900	880
	O&M costs	€/(kW.a)		30		10		9
Concentrating solar thermal power plants	Invest. costs	€/kW	3600 - 5050	5050	3300 - 3700	3500	2770 - 3440	3400
	O&M costs	€/(kW.a)		200		140		135
Wind								
- wind onshore	Invest. costs	€/kW	970 - 1100	1050	850 - 900	880	800 - 900	870
	O&M costs	€/(kW.a)		40		35		30
- wind offshore	Invest. costs	€/kW	1800 - 3000	2770	1100 - 1800	1700	1000 - 1500	1400
	O&M costs	€/(kW.a)		120		75		40
Biomass								
- biomass power plant	Invest. costs	€/kW	2000 - 2600	2200	1500 - 2300	2000	1400 - 2300	1900
	O&M costs	€/(kW.a)		130		120		110
- biomass CHP	Invest. costs	€/kW	1750 - 4600	3900	1650 - 3100	2600	1600 - 2400	2000
	O&M costs	€/(kW.a)						
Geothermal (EGS)	Invest. costs	€/kW	4000 - 15000	12000	3200 - 8050	6350	2400 - 8000	5050
	O&M costs	€/(kW.a)		450		235		190

			~ 2010		2020 – 2030		~ 2050	
			range	‘indicative estimate’	range	‘indicative estimate’	range	‘indicative estimate’
Hydro								
-large hydro	Invest. costs	€/kW	800 - 4400	2000	800 - 4350	2200	800 - 4100	2500
	O&M costs	€/(kW.a)		80		90		95
-small hydro	Invest. costs	€/kW	2000 - 5600	3500	1800 - 5200	4000	1600 - 4800	4000
	O&M costs	€/(kW.a)		180		200		200
Ocean energy								
- tidal barrage	Invest. costs	€/kW	1600 - 3200	2400	1400 - 2800	2100	1200 - 2400	1800
	O&M costs	€/(kW.a)		95		85		70
- tidal current	Invest. costs	€/kW	5600 - 8000	6800	4000 - 6400	5200	2800 - 4800	3800
	O&M costs	€/(kW.a)		270		210		150
- wave	Invest. costs	€/kW	3000 - 12000	7000	1500 - 4000	2000	1200 - 3200	1300
	O&M costs	€/(kW.a)		280		80		50

Table 2-16: Full load hours and depreciation periods for renewable electricity generation technologies

	full load hours [h/a]			depreciation period [a]
	2010	2030	2050	
PV				
- 'Europe'	1050	1150	1150	20
- 'US'	1800	1800	1800	20
Concentrating solar thermal				
- 'Europe'	2700	3250	4000	25
- 'US'	4060	7150	7500	25
On-shore wind				
- 'Europe'	1690	2100	2300	20
- 'US'	2200	2300	2400	20
Off-shore wind	3300	3800	4000	20
Geothermal	7000	7000	7000	20
Hydro large (> 1 MW)	2900	2900	2900	30
Hydro small (< 1 MW)	2380	2380	2380	30
Wave energy	2200	3200	3200	20

Table 2-17: Renewable electricity generation costs (under the conditions specified in Table 2-15 and Table 2-17)

	Electricity generation costs [€ct/kWh]		
	2010	2030	2050
PV			
- 'Europe'	27.8	8.9	7.4
- 'US'	16.2	5.7	4.8
Concentrating solar thermal			
- 'Europe'	22.1	12.7	10.0
- 'US'	14.7	5.8	5.4
On-shore wind			
- 'Europe'	7.8	5.3	4.6
- 'US'	6.0	4.9	4.4
Off-shore wind	11.0	5.9	4.1
Geothermal [a)]	21.4	11.3	9.0
Hydro large (> 1 MW)	7.8	8.6	9.5
Hydro small (< 1 MW)	18.2	20.6	20.6
Wave energy	40.5	7.9	5.1

[a)] without heat credits

3 Costs of renewable heating (and cooling) technologies

3.1 Solar thermal heating

Market trends

The solar thermal collector capacity in operation worldwide was 127.8 GW_{th} at the end of 2006, corresponding to 182.5 m² (Weiss et al. 2008). About 80% of the installed collectors are flat-plate and evacuated tube collectors, 19% are unglazed plastic collectors, and the rest are unglazed solar air collectors. The use of solar thermal energy varies significantly between countries. In China, Europe and Japan, plants with flat-plate and evacuated tube collectors are mainly used to prepare hot water and to provide space heating, while in North America swimming pool heating is the dominant application. Europe has the most sophisticated market for different solar thermal applications. It includes system for hot water preparation, plants for space heating of single- und multi-family houses, large-scale plants for district heating as well as a growing number of air conditioning, cooling and industrial applications.

Leading countries in flat-plate and evacuated tube collectors installed at the end of the year 2006 are China (65.1 GW_{th}), Turkey (6.6 GW_{th}) and Germany (5.6 GW_{th}). China is by far the largest market, representing 64% of the world market of flat-plate and evacuated tube collectors (Weiss et al. 2008). The most dynamic markets for flat-plate and evacuated tube collectors worldwide are in China and Europe, as well as in Australia and New Zealand. The average annual growth rate between 1999 und 2006 was 22% in China and Taiwan, 20% in Europe, and 16% in Australia and New Zealand.

Technology development projections

Solar thermal technologies are relatively mature and have proved to be reliable and cost-competitive in appropriate circumstances. Small-scale water heating applications in single-family houses dominate the solar thermal market, but there is an increasing market for combi-systems that combine water and space heating. The solar share of a supply system can be increased by using solar collectors in combination with high-efficiency storage applications and well-insulated buildings.

Larger-scale systems for solar assisted district heating or for industrial applications need further development. Thermal storage options are key components for such applications. Current research and development aim at increasing the storage density by using new materials and design concepts. Medium and high temperature levels for industrial process heat can be achieved using concentrating solar heating technologies, which are in an early development stage. Collector and component designs need to be optimised for medium temperature use and to meet the requirements of industrial applications (IEA 2008).

Architectural design will play a major role in the future market penetration of solar heating and cooling options. Standardised components will facilitate the integration of energy production, energy storage, building insulation, and indoor climate control elements. Configurations are possible in which the total energy production exceeds the total domestic energy use.

Cost projections

The dominant factor for solar heating costs is the capital investment. Investment costs depend on the system configuration. According to IEA (2007) specific investment costs for solar heating systems are between 240 and 800 €/m², with an average at around 500 €/m². It is expected that by 2030 costs can be reduced by 35% to 50%. It remains unclear whether these cost assumptions from IEA's renewables heating and cooling report are used in the World Energy Outlook or in the Energy Technology Perspectives. The German BMU Leitstudie reports slightly higher costs for 2005 systems, but assumes a more rapid decrease of costs to 240 €/m² in 2020. It is expected that beyond 2020 the potential for further cost reduction is limited.

Table 3-1: Solar collector investment cost projections (in €$_{2005}$/m²) (1 m² ~ 0.7 kW$_{th}$)

	2005	2020	2030	2040	2050
IEA-Renewables for heating & cooling	240 - 800 Average:500		-50% to -35% compared to 2005		
BMU Leitstudie 2008 (weighted average)	615	240	230	220	210
- individual small scale systems	630	250	240	235	230
- large scale systems for local heating networks	300	225	210	200	190

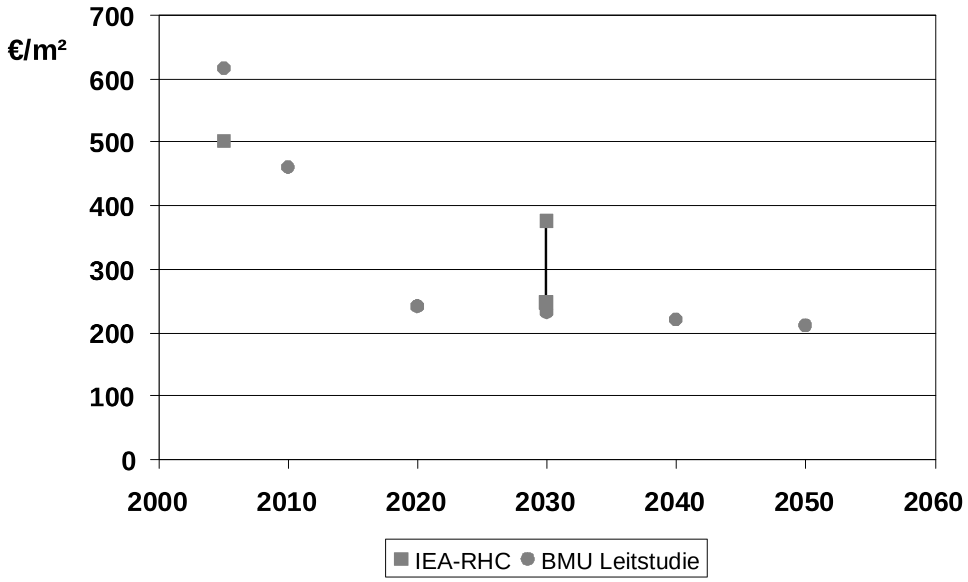


Figure 3-1: Comparison of solar collector investment cost projections

3.2 Geothermal heating

Market trends

The direct utilisation of geothermal energy to supply heat through district heating to a larger number of customers is limited to regions with specific geological settings. Decentralised geothermal ground source heat pumps facilitate the utilisation of the ubiquitous shallow geothermal resources. China is the country with the highest direct use of geothermal heat (12.6 TWh/a), about 55% of the geothermal energy is used for bathing and swimming, 14% for conventional district heating, and 14% for geothermal heat pumps and space heating (Fridleifsson et al. 2009). Due to favourable geologic conditions and efficient hot water distribution networks, in Iceland, 88% of all households use geothermal energy directly.

The European heat pump market is growing progressively in most European countries, with the highest growth rates currently in Italy (33%) and France (30%) (EHPA 2008). The best developed market segment is the application in new residential one/two family houses, in which markets like Sweden and Switzerland show a heat pump market penetration rate of 95% and 75% respectively. The segment for renovation of one/two family houses is currently gaining importance, but the efficient use of heat pumps in this segment requires extra investments in new windows, heat distribution system or insulation.

Technology development projections

Deep geothermal systems use heat from depths of 500 - 5000m drilled at favourable geologic conditions. Shallow geothermal systems provide low grade heat from depths of less than 300m for use in association with heat pumps (IEA 2007).

Where high temperatures exist, the heat can be used in conventional geothermal developments for combined heat and electricity generation (see section 2.5) or for direct heat use applications. Large scale geothermal applications have been in use for more than 45 years, demonstrating their technical reliability and maturity. Further development aims at reducing the operational costs (see also section 2.5) and the improved integration into heating networks.

Ambient heat stored at shallow depths (< 300m) can be an essential component of energy efficient heating and cooling systems in buildings. Heat can be extracted with heat pumps and usefully applied for space of water heating. Heat pumps are a fully developed technology with a relatively low cost gap, which depends on the price of the conventional fuel to be substituted (IEA 2007). In most cases the stored heat can be collected or replenished to provide a seasonal source for both heating and cooling. Most heat pumps operate on a vapour-compression cycle and are driven by an electric motor, some heat pumps use the absorption principle, with gas or waste heat as the driving energy. A conventional ground-coupled system has a coefficient of performance (COP, ratio of heat output to energy input) of 3 to 4, although higher COPs are possible depending on the system configuration. Future development aims at increasing the COP and to improve system integration.

Cost projections

The IEA Renewables for Heating and Cooling report (IEA 2007) provides cost data and cost projections for both deep geothermal and shallow geothermal heat supply. The range in investment costs for deep geothermal direct use is quite large due to differences in the type of use, including e.g. ground heat pumps, bathing/swimming, district heating, or industrial process heat. IEA assumes minimum costs to be within a range of 50 €/kW$_{th}$ to 500 E/kW$_{th}$, with average costs representing a mix of different types of applications to be at 200 €/kW$_{th}$. Due to the fact that some remaining geothermal sources will be more difficult to unlock than those already developed, IEA expects that investment costs increase by 10% until 2030.

For shallow geothermal heating and cooling with ground source heat pumps IEA estimates investment costs to be between 200 and 1150 €/kW$_{th}$, with an average at 500 €/kW$_{th}$. IEA expects that costs can be reduced by 15% until 2030.

Cost assumptions in the BMU Leitstudie are significantly higher than the IEA cost estimates for both deep geothermal direct heat use and for shallow geothermal heating with heat pumps. BMU Leitstudie assumes that costs for heat pumps can be reduced by 25% until 2030. A further 5% cost reduction is expected between 2030 and 2050. A recent evaluation of cost data for heat pumps in Germany suggests that costs in the BMU Leitstudie are slightly overestimated, but it does not provide evidence for the quite low cost assumptions of IEA.

Table 3-2: Geothermal heating investment cost projections (in €$_{2005}$/kW$_{th}$)

	2005	2020	2030	2040	2050
IEA-RHC 2007					
- deep geothermal – max	500		550		
- deep geothermal – min	50		55		
- deep geothermal – average	200		220		
- shallow geothermal (heat pump) – max	1150		980		
- shallow geothermal (heat pump) – min	500		425		
- shallow geothermal (heat pump) – average	200		170		
BMU Leitstudie 2008					
- deep geothermal	720	600	600	600	600
- shallow geothermal (heat pump)	1470	1310	1220	1190	1160

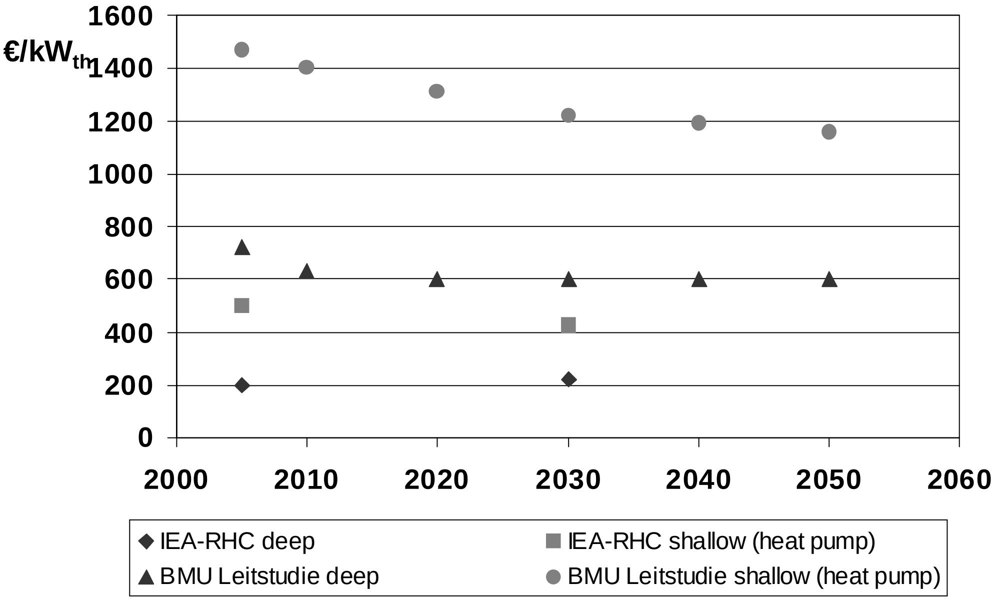


Figure 3-2: Comparison of geothermal heating investment cost projections (IEA data show the 'average' value)

3.3 Biomass heating

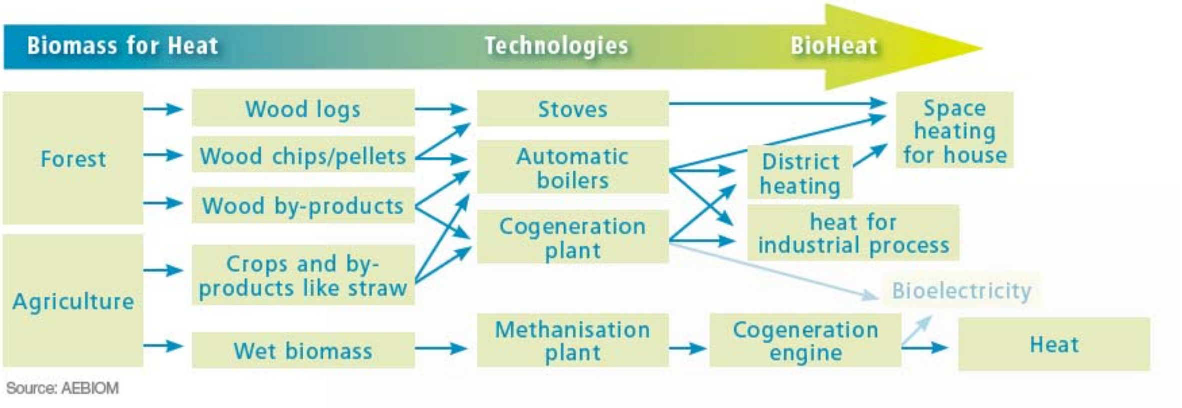
Market trends

Biomass heat applications currently contribute to around 96% of renewable heat production in Europe. The main part of this contribution comes from domestic heating with fuel wood, followed by large-scale use of biomass wastes for industrial process heat applications and biomass use in district heating plants. In countries like Sweden, Finland, Denmark, the Baltic countries and Austria between 5 and 30% of the heat demand is covered by biomass district heating systems. Small-scale heating systems for households typically use wood logs or pellets. Medium-scale users typically burn wood chips in grate boilers while large-scale boilers are able to burn a larger variety of fuels, including wood waste and refuse-derived fuel. Heat can also be produced on a medium or large-scale through cogeneration which provides heat for industrial processes and can supply district heat networks (see section 2.4). In parallel to the rise in oil and gas prices in recent years bioheat applications boomed in many European countries. All bioheat chains have increased their market volume, backed up with an industrial development related to the biomass preparation and distribution and technology manufacturing. In Germany for example the number of wood pellet heating systems increased by a factor of more than 10 between the year 2000 (2400 systems) and 2006 (25000 systems) (EREC 2007).

Technology development projections

The generation of bioenergy heat can involve various pre-treatment, upgrading and conversion processes that can follow many possible pathways from raw feedstock material through to energy carriers (Figure 3-3). This report focuses on conversion technologies represented in the relevant scenarios, and does not provide a full discussion of biomass production chains.

The revival of biomass use and active R&D efforts resulted in improved combustion technologies. High-efficiency and environmental friendly biomass boilers are available for small-scale heating systems. Due to full automatic operation the operating comfort of woodchips- and pellet-boilers has been significantly improved and reaches a similar comfort as oil or gas fired boilers. In general, biomass combustion technologies today are considered to be a mature technology. Current technical development aims at a further optimisation of combustion processes to reduce particle emissions. Another objective is the development of combined solar-biomass heating systems which allow 100% coverage of heating demand with renewables. Future biomass applications could also aim for tri-generation to produce electricity, heating and cooling simultaneously and hence maximise the overall conversion efficiency. Future cost reduction is expected from optimised fuel handling and storage.



Source: AEBIOM

Figure 3-3: Biomass chains for biomass heat production (EREC 2007)

Cost projections

Biomass combustion to produce heat in many cases today is competitive with fossil fuels. The cost however depends on various parameters, including e.g. the type and quality of the fuel, the fuel demand (individual user or large scale industrial customer), and the organisation of the procurement chain.

Both the IEA World Energy Outlook and the Energy Technology Perspectives do not provide cost data for future biomass heating systems. The IEA Renewables for Heating and Cooling (IEA 2007) provides investment costs biomass pellet heating systems and CHP systems. As CHP is covered in section 2.4, we only IEA assumptions on pellet systems are reported.

IEA (2007) considers biomass combustion as a mature technology. Investment costs (including civil work and fuel and heat storage) for current biomass heating systems ranging from 5 kW (low-energy single-family dwelling) to 100 kW (apartment building) are estimated to be between 380 €/kW$_{th}$ and 1800 €/kW$_{th}$, with an average of 880 €/kW$_{th}$ (Table 3-2). IEA does not expect any future cost reduction for pellet heating systems.

BMU Leitstudie differs between small-scale biomass heating systems with a capacity of 10 to 15 kW$_{th}$, and biomass heating plants for district heating systems with a capacity of 1 to 10 MW$_{th}$. Cost estimates of the small-scale current system are in reasonable accordance with IEA estimates, but BMU Leitstudie expects the potential for a further 18% reduction of investment costs until 2040. Also for large-scale biomass heating plants BMU assumes a significant future reduction of costs.

Table 3-3: Biomass heating investment cost projections (in €$_{2005}$/kW$_{th}$)

	2005	2020	2030	2040	2050
IEA-RHC 2007 – biomass pellet heating					
- max	1800		1800		
- min	380		380		
- average	880		880		
BMU Leitstudie 2008					
- biomass heating system (10-15 kW$_{th}$)	790	750	700	650	650
- biomass heating plant (1-10 MW$_{th}$)	650	500	470	450	450

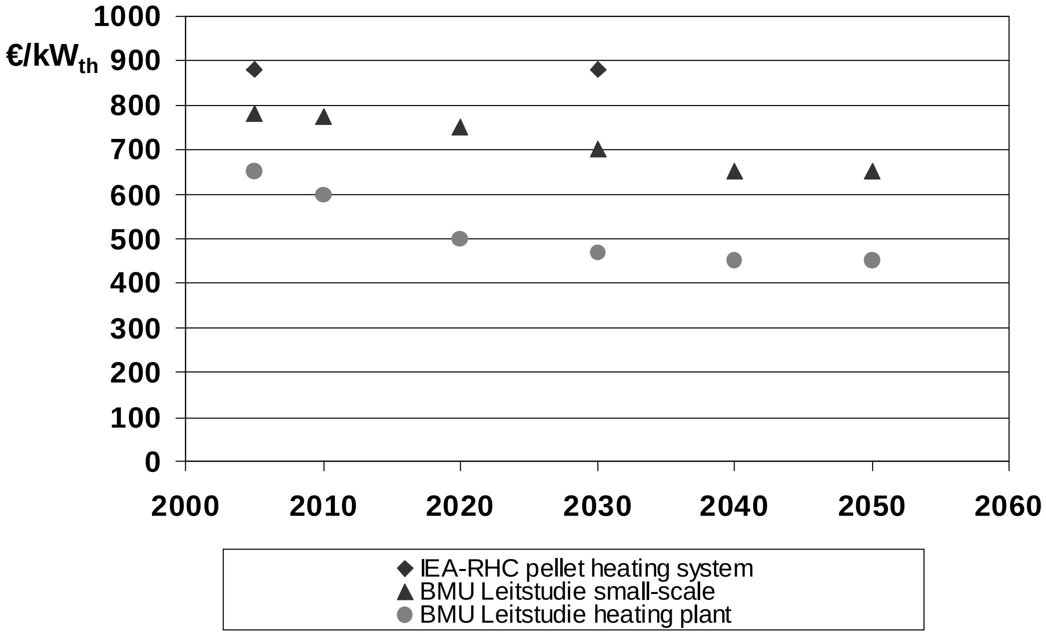


Figure 3-4: Comparison of biomass heating investment cost projections (IEA data show the 'average' value)

3.4 Costs of renewable heating technologies – summary

The previous chapters provide a review of cost estimates and long term cost projections of renewable heating (and cooling) technologies. It is an obvious observation that the assessment and reporting of costs for heating and cooling in all the relevant scenario studies seems to be a second order priority. Both the IEA's World Energy Outlook and the Energy Technology Perspectives do not report cost data and assumptions on future cost development for heating and cooling technologies. We here use the IEA report on Renewables for Heating and Cooling to provide an IEA dataset. The Greenpeace/EREC Energy [R]evolution scenario does explicitly not take into account costs for heating and cooling. For the German BMU Leitstudie we had access to the detailed cost data for renewable heating technologies, which are however not fully available in the published report. A more stringent and comprehensive treatment and reporting of underlying assumptions related to the heating and cooling sector is desirable in any kind of future energy scenario work, in particular as heat supply currently is a main contributor to CO_2 emissions and fossil fuel consumption.

A problem all the energy scenario models are facing is the large variation in heating technologies, which differ significantly by size and type of application. To keep energy system models operational, a reasonable clustering of technologies is necessary. Due to differences in defining the respective reference technologies, cost data for a specific type of technologies sometimes are not directly comparable across studies.

The present comparison shows that - taking into account the large uncertainties which partly are due to differences in plant size and in the type of application – there is a reasonable agreement between cost assumptions in the IEA Renewables for Heating and Cooling and the BMU Leitstudie for solar collectors and biomass heating systems. There is however little evidence for the IEA's assumption that there is no further potential for reducing costs of pellet boilers, as there is ongoing technical development aiming at system improvement and cost reduction.

We observe a significant difference in assumptions on investment costs for heat pumps using shallow geothermal resources between IEA and the BMU Leitstudie. Cost data in the BMU Leitstudie are slightly higher than the upper cost range reported by IEA. Cost data in the BMU Leitstudie are well in line with data derived from an ongoing evaluation of the German Market Incentive Programme. We have doubts that regional differences can sufficiently explain the large difference to the IEA data. Further work is required to explain the remaining difference.

The following Table 3-4: **Future projections of investment costs for renewable heating technologies** provides a summary of the cost estimates and future cost projections for renewable heating technologies. Because of the limited number of studies available, it is not always possible to give a reasonable range of values. Like in the case of electricity generation technologies, in addition to the range of cost estimates we also report an 'indicative estimate', which is based on the review of the relevant studies. It is emphasised that care must be taken in using such a single value 'indicative estimate', as it may not very well represent specific conditions.

Table 3-4: Future projections of investment costs for renewable heating technologies

		2005		2020 – 2030		~ 2050	
		range	'indicative estimate'	range	'indicative estimate'	range	'indicative estimate'
Solar collectors							
- small scale systems	€/kW	240 – 800	630		250		230
- large scale systems (for heating networks)	€/kW	240 - 800	300		220		190
Geothermal							
- deep geothermal	€/kW	50 - 720	500	55 - 600	500		500
- shallow geothermal/heat pump	€/kW	500 - 1500	1300	170 - 1220	1100		1050
Biomass							
- small-scale heating system	€/kW	380 - 1800	790		700		650
- heating plant	€/kW		650		480		450

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Part IV:

Global Potentials of Energy Efficiency

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Table of Contents

1 Introduction

In the period 1990-2005 global primary energy demand increased by 30% from 367 EJ to 479 EJ. It is expected that by 2030, global energy demand will have grown by another 55% to 742 EJ (IEA, 2007a). Fossil fuels account for 80% of primary energy supply in 2005 (380 EJ) and are expected to have the same share in energy supply in 2030 (590 EJ). Fossil fuel combustion is a major source for greenhouse gas emissions and accounted for 75% of total greenhouse gas emissions in 2005 (WRI, 2008). Energy-efficiency is a key measure to reduce fossil fuel consumption and thereby greenhouse gas emissions and other impacts of fossil energy use (i.e. pollution, unsecurity of energy supply).

The goal of this work package (Work Package 4) is to develop data set with global energy-efficiency potentials on by world regions for the years 2020, 2030 and 2050. This is done by (1) giving an overview of energy-efficiency potentials in global scenario studies (Chapter 2) and by (2) developing a data set for energy-efficiency potentials (Chapter 3). This data set is partly based on work done for the 2008 Greenpeace / EREC [r]evolution scenario. For the [r]evolution scenario, Ecofys developed energy demand scenarios that cover energy demand in the period 2005-2050 for ten world regions for the sectors industry, transport and buildings. In this study we will further elaborate the potentials that have been calculated and include potentials for the transformation sector. Also we calculate intermediate potentials for the years 2020 and 2030.

2 Energy-efficiency in global scenarios

Energy-efficiency improvement potentials are covered by different energy scenarios to a varying degree of detail. While some studies cover potentials on a country by country basis, others use a sectoral approach or even look at single measures or subsectors (e.g. industry, buildings, transport). Energy-efficiency improvement may be expressed in terms of potential energy savings or potential GHG emission abatement potential, thus either [GJ] or [tCO_2eq] may be resulting units. This section gives an overview on the energy-efficiency potential data available in global energy scenarios.

The **WEO 2007 Alternative Policy Scenario** observes energy market development over the time span 2005-2030. Improvement of energy efficiency potentials are projected differentiated by fossil energy carriers. Potentials for single measures are not assessed in detail. Focus is laid on the energy market developments for the emerging economies India and China. For the latter, some more detailed sector-specific projections are made, quantifying energy saving potentials for some exemplary measures. In general, data provided is of a more qualitative than quantitative nature.

According to WEO 2007 APS highest contributions to decreased electricity consumption arise from more efficient appliances in the residential and services sectors. More efficient motors in industry account for most of the rest of energy savings. By 2015 nearly two-thirds of oil savings come from the transport sector, triggered by increased fuel efficiency in new conventional vehicles and the faster introduction of alternative fuels and vehicles. Most of the remaining savings result from more efficient oil use in industry and in residential and commercial buildings. More than three-quarters of the coal is saved in the power sector, largely due to fuel switching and lower electricity demand.

In both China and India, the largest energy demand reductions in absolute terms occur in the power sector, resulting mainly from lower demand for electricity compared to the reference scenario, higher thermal efficiency of coal-fired power stations and reduced network losses. In China, industrial energy demand falls by 18% in 2030 in the APS relative to the Reference Scenario (frozen policy). Savings in energy use in iron and steel industry represent the largest share of the savings, resulting from increased use of scrap steel recycling and energy intensity improvements in the APS. Savings in chemicals and petrochemicals are limited. More stringent efficiency standards for refrigerators and air conditioners alone cut electricity use by 83 TWh in 2020, compared with the Reference Scenario. Improvements in lighting, water heating, and other appliances bring about savings of around 110 TWh in 2030. In the transport sector, total energy savings in 2030 are 20.2% higher than in the reference scenario.

Since the WEO 2007 energy savings data is not on a per measure base, and it is not stated how much of the technical energy-efficiency potential has been taken into account in the scenario, it is difficult to compare the data provided to the potentials calculated in this report.

The **IEA ETP BLUE Map** scenario includes an entire section on each sector providing qualitative information for each measure on state of employment and commercialization as well as challenges for deployment. Energy-efficiency potentials are projected for single measures for the distinct sectors for a period up to 2050. Relative to the Reference (frozen policy), energy savings are achieved across all end-use sectors in the BLUE Map scenario. On a global basis, largest saving potentials are seen for the transport sector. In comparison to the reference, energy use is projected to grow by 1.3 percentage points less per year in the BLUE Map scenario. The large saving potential reflects innovations in both engine technologies and vehicle design. Industry, on the other hand, makes somewhat smaller changes (0.4 percentage points less per year), reflecting the high efficiencies already achieved in a number of energy-intensive sectors and the need for energy that is intrinsic in most industrial processes. Savings in electricity come mainly from the building sector, accounting for approximately 70% of total savings.

Specific measures to improve energy-efficiency are looked at in terms of market share or percentage of improvement in 2050. Explicit quantitative potentials are not stated. Table 1 shows end-use energy savings in 2050 for four sectors under the BLUE Map scenario relative to the Baseline.

Table 1: End-use energy savings in 2050 under BLUE Map relative to Baseline scenario

	Demand 2005 (EJ/y)	Demand Baseline 2050 (EJ/y)	BLUE Map annual change 2005-2050 (%/y)	BLUE Map change compared to baseline 2050 (%)	BLUE Map demand in 2050
Industry	107	227	1.3	-16	190
Transportation	90	198	0.5	-43.8	111
Buildings	122	219	0.2	-39.8	132
Non-energy use	5	13	1.4	-20.2	10
Total end use	324	657	0.7	-32.9	441

Source: IEA ETP 2008

Projections on assumed employment rates as well as on assumed energy-efficiency improvement up to 2050 are made for the following subsectors and measures:

Table 2 : Measures covered by the ETP Blue Map scenario

	Sub-sectors	Measures
Industry	Iron and steel	Electric arc furnace
		Advanced blast furnace
		Pulverized coal injection
		Reactor designs
		Increased steel recycling
	Pulp and Paper	Mechanical pulping
		Advanced paper drying
		Black-liquor gasification
	Cement	
	Chemicals and Petrochemicals	Increased plastics recycling and energy recovery
		Steam cracking
		Membrane separation technologies
		Process intensification
Transport	Buses	
	Light duty vehicles (electric plug in, fuel cell vehicles, hybrids…),	Electric Plug-in
		Fuel Cell Vehicles
		Hybrids
	Trucks and Rails Freight Transport	Low rolling resistance tyres
		Logistic improvements
		Downsizing and Downweighting
		Hybrid drivetrains
		Operational improvements
	Aviation	Propulsion technology
		Improved aerodynamics
		Improved materials/structure
		Operational system improvements
	Water	
Buildings	Appliances	LCD televisions with back-light modulation or organic LEDs
	Space and water heating	Ground source heat pumps

Source: based on IEA ETP 2008

The **WETO CCC** (Carbon Constraint Case) scenario pictures energy-efficiency as one of the main options to respond to the carbon constraint set for the scenario. The Reference Scenario is a business as usual policy scenario. On a global scale not much information is given on energy-efficiency potentials for distinct sectors, more detailed information is provided for Europe. Higher efficiency is assumed a main option before 2020 and after 2040 when the potential for CCS is largely saturated.

On a global scale, in 2020 and in 2030, primary energy consumption is 4% and 6% lower than in the Reference. Significant improvements in energy-efficiency are already included in the reference projection. As a result world energy consumption only increases by a factor of 2.2. Quantitative data is provided for all POLES regions also on a sectoral level, however, potentials for single measures within these sectors are not considered.

Table 3: Changes in global final energy demand

	Demand 2001 (EJ/y)	Annual change 2010-2030 (%/y)	Annual change 2030/2050 (%/y)	Energy demand 2050 (EJ/y)
Industry	110	1.3	0.6	161
Transportation	72	1.3	1	114
Residential	115	1.8	1.4	217
Electricity generation	0			0
Total end use	297	1.5	1.1	498

Source: WETO 2006

Table 4 shows the comparison of final energy use divided by sector for the different global scenarios up to 2050 (BLUE Map, [r]evolution 2008 and WETO CCC):

Table 4: Comparison of final energy demand for analysed global scenarios

	BLUE Map demand in 2050 (EJ/y)	[R]evolution 2008 Energy demand in 2050 (EJ/y) *Confidential*	WETO CC Energy demand 2050 (EJ/y)
Industry (incl. feedstocks)	190	150[1]	161
Transportation	111	93	114
Buildings	132	167	217
Non-energy use	10	Excluded	0
Total end use (EJ/y)	**441**	**410**	**498**
GDP growth (2005-2050)	*430%*	*440%*	*320%*
Energy-intensity decrease	*2.5 %/yr*	*2.7 %/yr*	*1.5 %/yr*

In 2001 the **EU Commission** has compiled a number of sector-specific bottom-up studies on GHG emission reduction options for Europe which include data on abatement potentials induced by energy-efficiency measures as well as their specific costs. Emission reduction potentials are given in high detail for a large number of measures, the time horizon of the studies is 2010.

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[1] 116 EJ excluding feedstocks

Table 5: CO_2 emission reduction potential in 2010 sorted for sectors considered

Sector	Measure	Emission reduction potential (Mt CO_{2eq})
Residential		**189**
	Energy efficient TV and video equipment	1
	Very energy efficient refrigerators and freezers	0.5
	Efficient lightning best practice (fully implemented)	2
	Wall insulation retrofit houses	28
	Roof insulation retrofit houses	26
	New energy efficient residential houses: best practice	12
Service		**123**
	Efficient space cooling	1
	Efficient lighting	2
	Very efficient lighting	1
	Building Energy Management Systems (BEMS)	42
Industry		**375**
	Application of continuous casting	1
	Cement – new capacity	5
	Pulverized coal injection up to 30% in the blast furnace (primary steel)	1
	To be continued for other subsectors	
Transport		**116**
	Rolling resistance	11
	Aerodynamics – Cab roof fairing	3
	Aerodynamics – Cab Roof Deflector	2
	Lightweight structure –petrol cars	10
	Lightweight structure – Diesel cars	2

Source: based on EU Commission 2000, 2001

The study does not map global potential, data is provided for EU 15. New member states which in general are assumed to have lower specific abatement costs from employing energy-efficiency measures are not considered. Reports were published in 2001, since then a lot of developments as a result, assumed efficiency levels and best practice performances may have changed considerably. The transport sector does not include aviation and ship traffic, but concentrates on road traffic. The residential sector is further divided into service and households.

The **Greenpeace/EREC Energy [R]evolution Scenario 2008** is characterized by significant efforts to exploit the potentials for energy-efficiency and ultimately stabilization of global energy consumption within the next two decades. It assumes continuous technology innovation, intelligent energy use and fairly even distribution of energy savings over the three sectors; industry, transport and residential. Of all scenarios reviewed the Energy [r]evolution Scenario contains most detailed qualitative and quantitative data on energy-efficiency. The scenario dedicates a whole chapter to an analysis of energy-efficiency measures and potentials and includes an in-depth analysis of the energy-efficiency potential in the transport sector. Included information comprises state-of-the-art of technologies, current penetration of selected measures, and future projections and potentials for energy-efficiency measures. The reference scenario (business-as usual) is based on the reference scenario published by the IEA in the World Energy Outlook 2007 and has been extended to 2050 by extrapolating its key macroeconomic indicators.

In the scenario worldwide overall energy consumption is reduced by 38% in 2050 in comparison to the reference. Most efficient energy saving options are efficient passenger and fright transport, and improved building design and heat insulation. The scenario results in a reduction in energy intensity by 73% from 2005 in 2050 by employing energy-efficiency measures. In the heat sector, current per capita consumption can be decreased by 30% due to energy-efficiency measures, in spite of improved living conditions.

Quantitative data on energy-efficiency measures is mainly given for OECD Europe in 2050. Potentials are subdivided into the three sectors residential, industry, and transport, and are further broken down into single measures. Some sectors are covered in less detail then others. The transformation sector is not taken into consideration.

Changes in energy demand on a sector-basis are given in percentages compared to the 2005 level. Electricity/fuel savings are given in percent versus the reference in 2050. Table 6 and Table 7 give examples of the representation of the results in the scenario. Table 6 shows electricity savings per measure compared to the reference, whereas Table 7 shows energy savings for the measure “efficient lightning” per region.

Table 6 : Electricity savings in households in 2050 versus reference scenario:

Energy-efficiency Measure	**Electricity savings in 2050**
Lightning	14%
Stand-by	13%
Air Conditioning	8%
Appliances	21%
Cold Appliances	22%
Computers/Servers	2%
Other	22%

Table 7: Lightning energy savings from implementing energy efficient lightning

Region	**[R]evolution scenario**
OECD Europe	60%
OECD North America	49%
OECD Pacific	42%
Transition Economies	67%
China	18%
Other Developing Regions	67%

3 Data set technical energy-efficiency potentials

3.1 Introduction

In this chapter the methodology and results are given for the development of a data set with global energy-efficiency potentials by world regions for the years 2020, 2030 and 2050.

As a starting point for this, work done for the 2008 Greenpeace/EREC [r]evolution scenario is used. For the [r]evolution scenario, Ecofys developed three energy demand scenarios. The energy demand scenarios cover energy demand in the period 2005-2050 for ten world regions for the sectors industry, transport and buildings. Besides one reference scenario, two low energy demand scenarios for energy-efficiency improvement have been defined. The first one is based on technical energy-efficiency potentials and the second scenario is based on more moderate energy savings.

In this study we further elaborated the technical potentials that have been calculated in the [r]evolution scenario for 2050. Where available more specific detailed information was added. Also intermediate potentials for the years 2020 and 2030 were calculated.

Since, the potentials developed for the [r]evolution scenario's only focus on final energy demand, another step in this study is the extension of the potentials to the transformation sector. This means that we developed a reference scenario and calculated technical potentials for the years 2020, 2030 and 2050.

This chapter first explains the methodology and reference scenario, which is the basis for the technical potentials. Then specific assumptions and results are given per sector: industry, transport, buildings and transformation sector.In Work Package 5 we made estimates of the costs of implementing the energy-efficiency potentials by doing a case study for the regions OECD Europe and China. Also this Work Package gives more general information regarding bounds for energy-efficiency improvement.

3.2 Methodology and reference scenario

This section explains the methodology for developing the data set regarding global technical potentials. The approach includes two steps:

1. Definition of reference energy demand scenario
2. Giving details for technical potentials for energy-efficiency improvement

3.2.1 Step 1: definition of reference scenario

Step 1 is the definition of a reference scenario. In order to estimate potentials for energy-efficiency improvement in 2050 it is necessary to develop a detailed reference scenario that projects the development of energy demand when current trends continue. This means that no large changes take place in the production and consumption structure of the current economy and that only currently adopted energy and climate change policies are implemented.

In this study we take the reference scenario that has been developed for the [r]evolution scenarios and we extend this to the transformation sector. The reference scenario is based on the World Energy Outlook (WEO) of the International Energy Agency (IEA, 2007). The IEA WEO 2007 edition (shortly WEO 2007) provides the most detailed energy scenario on the global level. The WEO 2007 scenario runs from 2005-2030. For the period 2030-2050 the WEO scenario is extended by assumptions regarding GDP (taken from DLR (2008)) and energy intensity developments.

The reference scenario covers energy demand development in the period 2005-2050 for ten world regions and four sectors. These sectors are (1) transport, (2) industry, (3) buildings and agriculture and (4) transformation sector. Per sector a distinction is made between (1) electricity demand and (2) fuel and heat demand. Fuel and heat demand is shortly referred to as fuel demand. The energy demand scenario focuses only on energy-related fuel, power and heat use. This means that feedstock consumption in industries is excluded from the analysis. This is done by assuming that the share of feedstock use in industry remains the same as in the base year 2005.

Since the WEO 2007 only provides total final energy consumption without a sector breakdown, the sector breakdown for the years 2015 and 2030 from the WEO 2006 is used. An exception is China and India, where the detailed WEO 2007 data are available and used.

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

- Definition of world regions
- Population development
- GDP development
- Energy-intensity[2] development
- Reference Scenario for final energy demand and primary energy demand

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

Definition world regions

This study focuses on ten world regions. The regional disaggregation in this study is the same as the one used in the WEO 2007 edition. The regional definitions are given in the table below.

Table 8: Specification of world regions (IEA, 2007)

World region	**Countries**
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom
OECD North America	Canada, Mexico, United States
OECD Pacific	Japan, Korea, South, Australia, New Zealand
Transition Economies	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Federal Republic of Yugoslavia, Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latria, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar and Malta[3]
China	China, Hong Kong, Macao
India	India
Rest of developing Asia	Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Malaysia, Maldives, Myanmar, Nepal, New Caledonia, Papua New Guinea, Pakistan, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Sri Lanka, Vietnam, Vanuatu
Latin America	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts-Nevis-Anguilla, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay, Venezuela
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

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[3] Allocation of Gibraltar and Malta to Transition Economies for statistical reasons.

Population development

The WEO 2007 is based on the most recent United Nation projections for population development (UNPD, 2007) up to 2030. For the reference scenario, the same population trends are applied, for the expanded time frame until 2050. Figure 1 shows the population per region in the reference scenario.

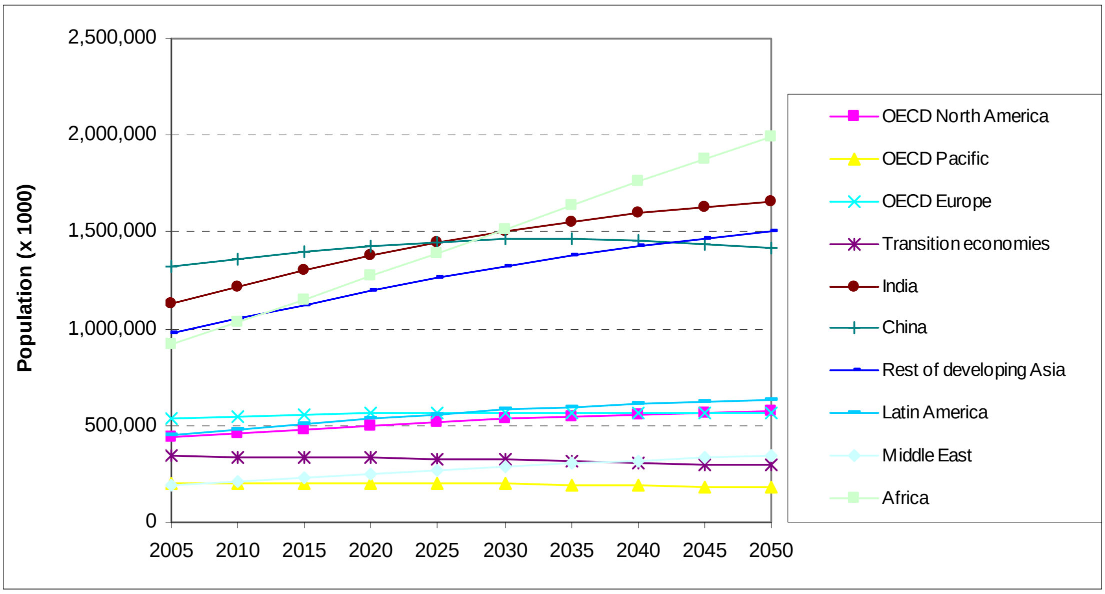


Figure 1: Population projection in reference scenario

According to the projection, Africa will have the highest number of inhabitants in 2050, around 2 billion, followed by India, Rest of Developing Asia and China, which are estimated to have around 1.5 billion inhabitants each. OECD North America, OECD Europe and Latin America are around 0.5 billion respectively and Middle East, Transition Economies and OECD Pacific between 0.2 - 0.3 billion inhabitants.

GDP growth rate

The WEO projects energy demand by world regions for the period 2005 to 2030. This scenario is extended for the period 2030-2050 based on:

- The growth rate of gross domestic product (GDP), corrected for purchase power parity for the period 2030-2050 (% per year), assessed by DLR (Simon et al., 2008).
- An assumed energy intensity decrease based on the trend in the WEO for the period 2005-2030 (% per year).

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

All data on economic development in the WEO 2007 refer to GDP adjusted by purchasing power. We follow this approach, and all GDP data in this report are expressed in year-2006 US dollars using (constant over time) purchasing power parities (PPP). Purchasing power parities (PPP) compare costs in different currencies of a fixed basket of traded and non-traded goods and services and yield a widely-based measure of living standard. Therefore they have a more direct link with energy use than GDP based on market exchange rates.

Since the WEO only covers the time period up to 2030, assumptions are made regarding the economic growth between 2030 and 2050. DLR assessed GDP growth rates for the period 2030-2050 (Simon et al., 2008), where the GDP growth in all regions is expected to slow gradually over the next decades.

The economic growth assumptions are summarised in Table 9.

Table 9: GDP development projections (average annual growth rates) (2010-2030: IEA (2007a) and 2030-2050: Simon et al. (2008))

	2010	**2015**	**2020**	**2030**	**2040**	**2050**
OECD Europe	2.6%	2.2%	2.0%	1.7%	1.3%	1.1%
OECD North America	2.7%	2.6%	2.3%	2.2%	2.0%	1.8%
OECD Pacific	2.5%	1.9%	1.7%	1.5%	1.3%	1.2%
Transition Economies	5.6%	3.8%	3.3%	2.7%	2.5%	2.4%
India	8.0%	6.4%	5.9%	5.7%	5.4%	5.0%
China	9.2%	6.2%	5.1%	4.7%	4.2%	3.6%
Rest of Developing Asia	5.1%	4.1%	3.6%	3.1%	2.7%	2.4%
Latin America	4.3%	3.3%	3.0%	2.8%	2.6%	2.4%
Africa	5.0%	4.0%	3.8%	3.5%	3.2%	3.0%
Middle East	5.1%	4.6%	3.7%	3.2%	2.9%	2.6%
World	***4.6%***	***3.8%***	***3.4%***	***3.2%***	***3.0%***	***2.9%***

Prospects for GDP growth in WEO 2007 have increased considerably compared to WEO 2006. In the period 2030-2050, GDP growth in all regions is expected to slow gradually. China and India are expected to grow faster than other regions, followed by the Rest of developing Asia, Africa and the Transition economies. The figure below shows the resulting development for GDP per capita.

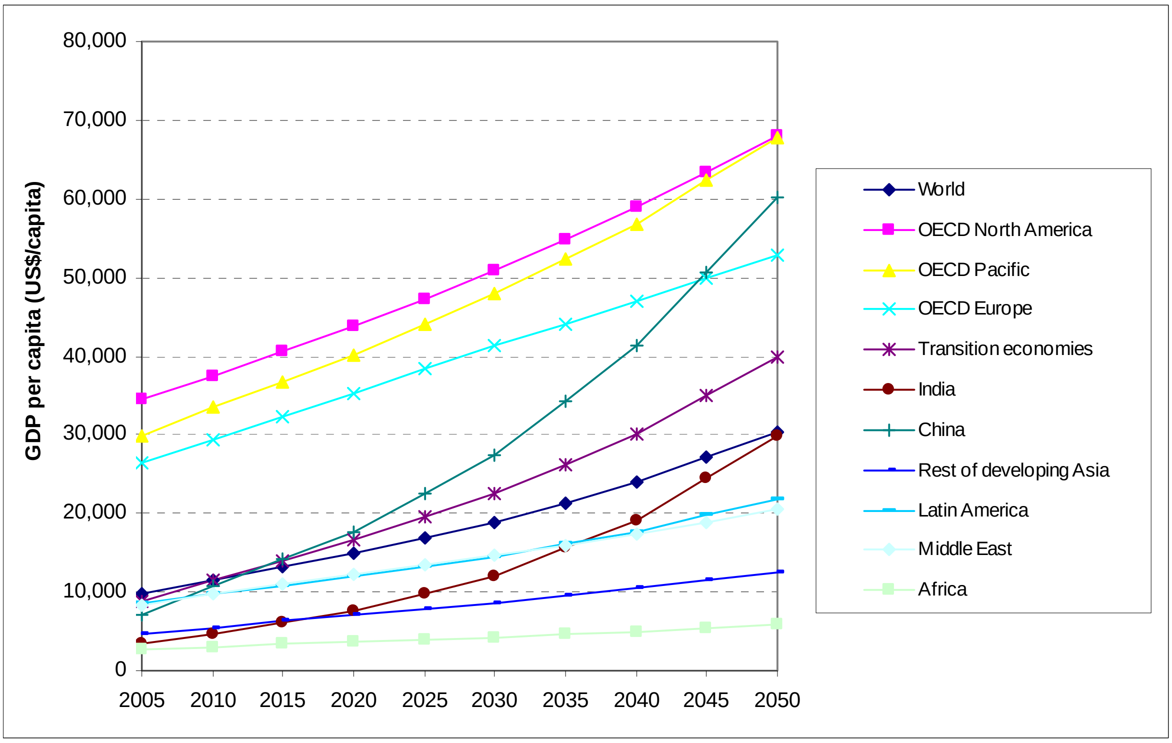


Figure 2: GDP / capita development

The figure shows that GDP per capita is expected to be highest in OECD North America and OECD Pacific (68,000 US$ per capita), followed by China (60,000 US$ per capita) and OECD Europe (53,000 US$ per capita). Africa and Rest of Developing Asia is expected to have the lowest GDP per capita (6,000 and 13,000 US$ per capita, respectively).

Energy-intensity decrease in reference scenario

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

- Autonomous energy-efficiency improvement. These energy-efficiency improvements occur because due to technological developments each new generation of capital goods is likely to be more energy efficient than the one before. This is mainly caused by (temporary) increases in energy prices, which leads economic actors to try to save energy e.g. by investing in energy-efficiency measures or changing their behaviour.
- Policy-induced energy-efficiency improvement as a result of which economic actors change their behaviour and invest in more energy efficient technologies.
- Structural changes in the economy. A decline of the ratio of energy over GDP ratio is not caused only by energy-efficiency improvement (that includes technical changes and operational improvements). In addition, structural changes can have a downward effect on the energy over GDP ratio. E.g. a shift in the economy away from energy-intensive industrial activities to services related activities.
- Decoupling of energy use. Some types of energy use do not grow linear with economic growth but show a certain decoupling due to saturation effects. E.g. energy use for heating tends to grow in proportion to floor surface rather than in proportion to economic growth.

The energy intensity decrease in the reference scenario results from a mix of these factors and differs per region and per sector. For the period 2005-2030 the energy-intensity decrease is taken directly from the WEO 2007. For the period 2030-2040 and the period 2040-2050 the development is extrapolated based on the energy intensity per region and sector in the period 2020-2030 in WEO.

The resulting energy intensity in the reference scenario is shown in Figure 3.

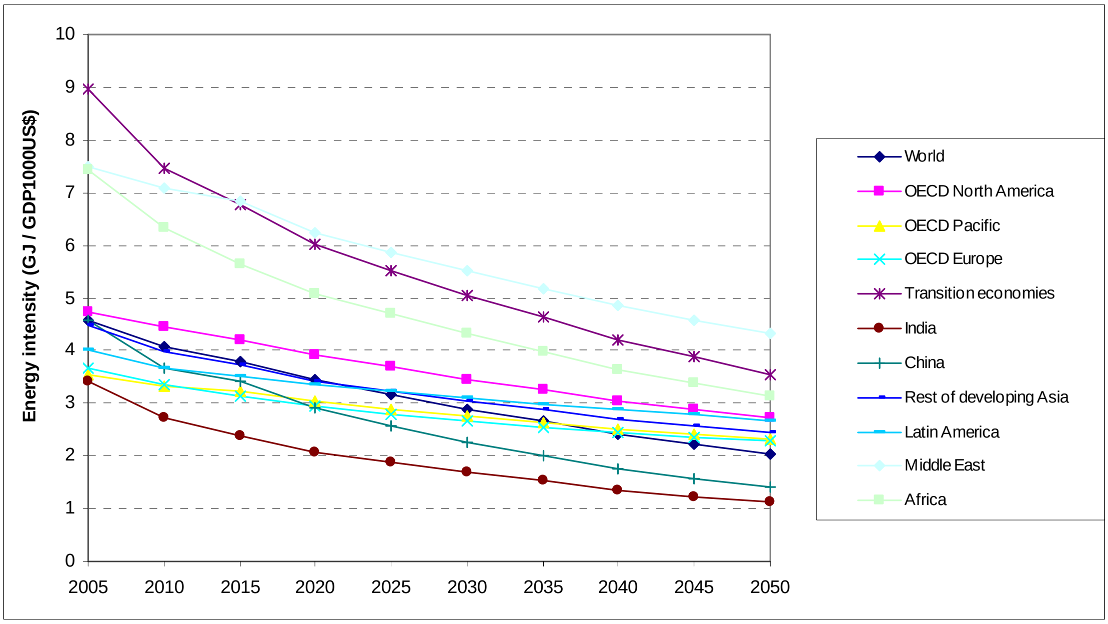


Figure 3: Energy intensity in the reference scenario (2005-2030 from WEO (IEA, 2007) and 2030-2050 based on extrapolation)

In Figure 3 it can be seen that there is a converging trend for energy intensities mainly due to a strong decrease in developing regions. Energy intensities range from 3-9 MJ/$1000GDP in 2005 and from 1-4 MJ/$1000GDP in 2050.

Figure 4 shows annual GDP growth rates, annual energy intensity decrease and the resulting annual growth in final energy demand per region for the reference scenario.

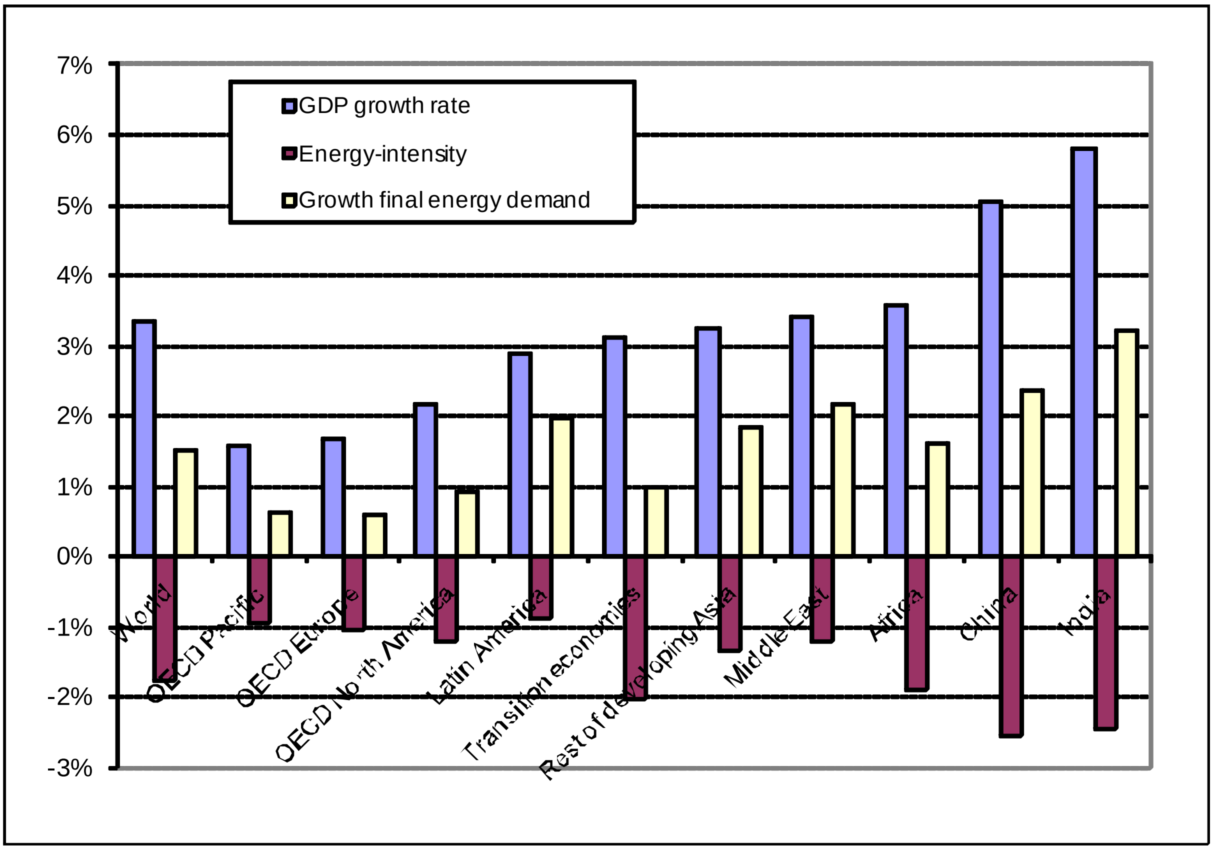


Figure 4: Growth final energy demand in % per year in period 2005-2050

The figure shows that final energy demand is projected to increase most in India and China (3.2%/y and 2.4%/y, respectively), followed by Middle East (2.2%/y) and Latin America (2.0%/y). Energy demand increase is lowest in OECD Europe, OECD Pacific and OECD North America (between 0.6%/y and 0.9%/y), due to lower GDP growth rates.

For the calculation of the technical potentials we need to know the share of energy-intensity decrease in the reference scenario as a result of energy-efficiency improvement and the share of energy-intensity decrease as a result of other factors (decoupling of economic growth, structural shifts). Energy-efficiency improvement is defined as the decrease in specific energy consumption per physical unit (e.g. GJ/tonne crude steel, MJ/passenger km, MJ/m2 floor surface etc.). The energy-intensity decrease in the reference scenario differs per region, ranging from 1 to 2.5%/year. The share of this, which is due to energy-efficiency improvement is unknown. We therefore assume that the energy-efficiency improvement is equal to 1% per year for all regions, based on historical developments of energy-efficiency (see e.g. Ecofys (2005), Blok (2005), Odyssee (2005)).

Reference scenario

Figure 5 shows the reference scenario for final energy demand for the world per sector.

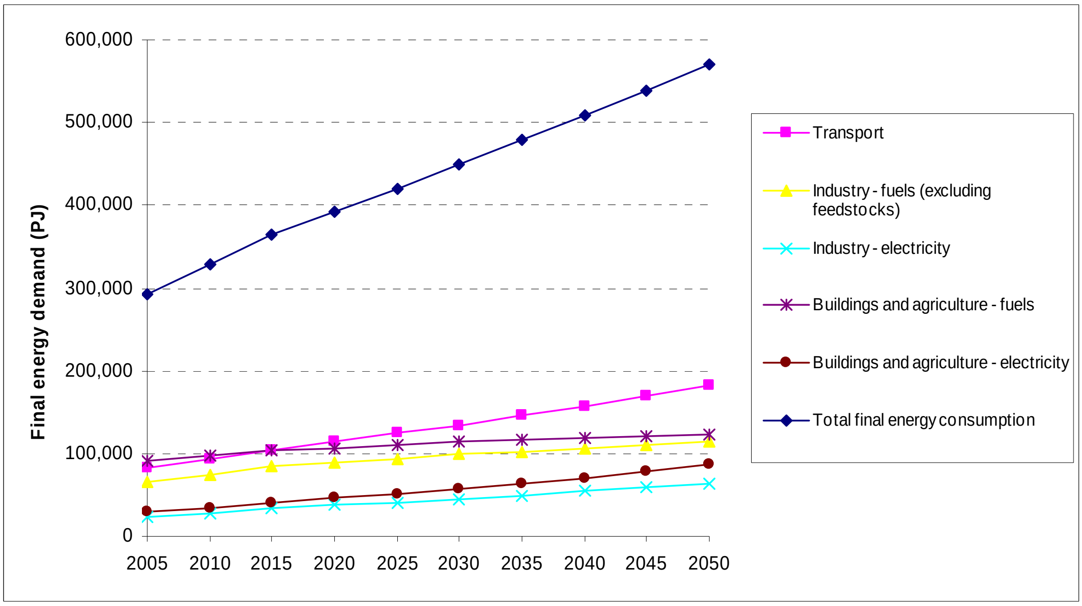


Figure 5: Final energy demand (PJ) in reference scenario per sector worldwide

Worldwide final energy demand is expected to grow by 95%, from 293 EJ in 2005 to 571 EJ in 2050. The relative growth in the transport sector is largest, where energy demand is expected to grow from 84 EJ in 2005 to 183 EJ in 2050. Fuel demand in buildings and agriculture is expected to grow slowest from 91 EJ in 2005 to 124 EJ in 2050.

Figure 6 shows the final energy demand per region in the reference scenario.

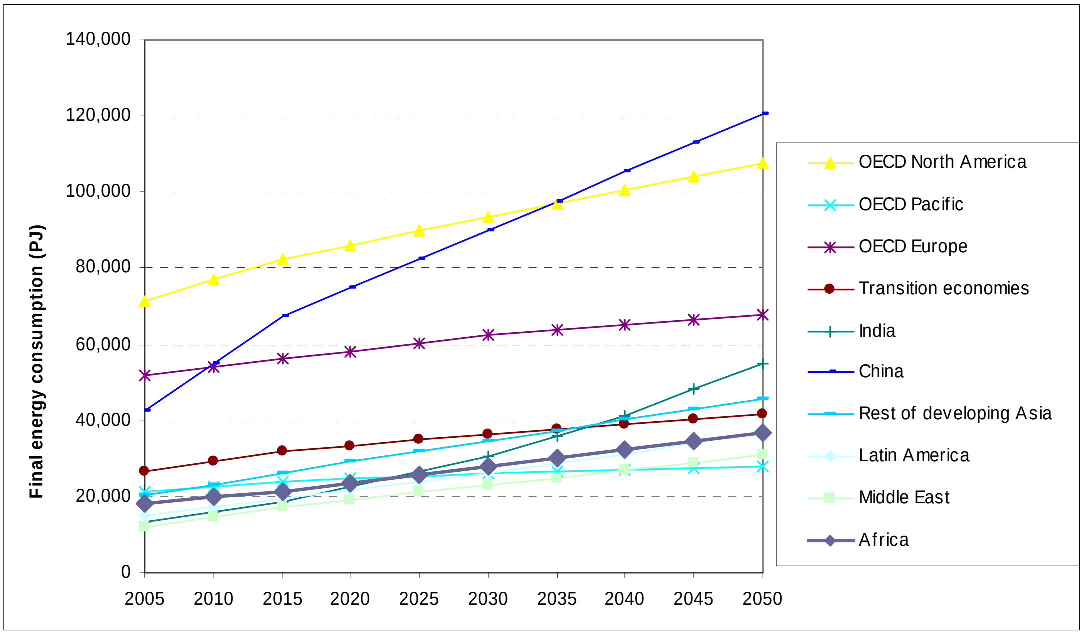


Figure 6: Final energy demand (PJ) in reference scenario per region

In the reference scenario, final energy demand in 2050 will be largest in China (121 EJ), followed by OECD North America (107 EJ) and OECD Europe (68 EJ). Final energy demand in OECD Pacific and Middle East will be lowest (28 EJ and 31 EJ respectively).

Figure 7 shows the development of final energy demand per capita per region.

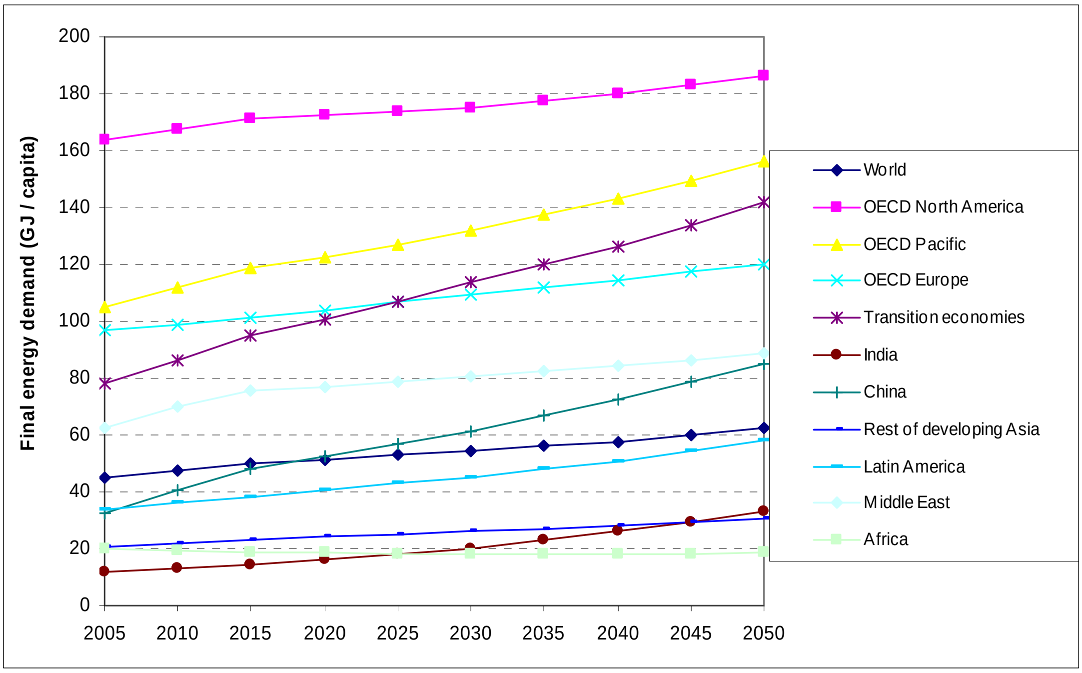


Figure 7: Final energy demand per capita in reference scenario

In terms of final energy demand per capita, there are still large differences between world regions in 2050. Energy demand per capita is expected to be highest in OECD North America (186 GJ/capita), followed by OECD Pacific and Transition Economies (156 respectively 142 GJ/capita). Final energy demand in Africa, India, Latin America, and Rest of developing Asia is expected to be lowest, ranging from 19-58 GJ/capita.

Figure 8 shows the conversion efficiency of the transformation sector for the years 1990 and 2005 per region. This is based on the ratio of final energy demand and primary energy demand per region in WEO 2007.

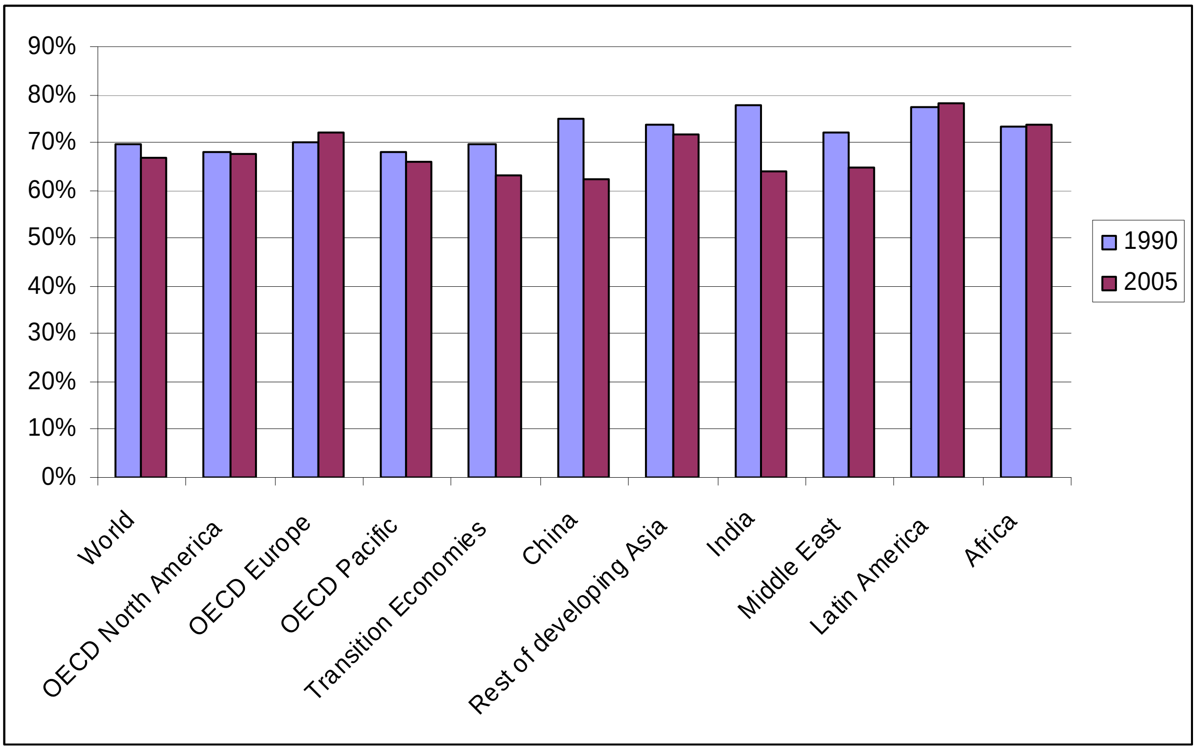


Figure 8: Conversion efficiency of the transformation sector (ratio: final energy demand / primary energy demand)

The conversion efficiency ranges from 62% for China to 78% for Latin America, with a worldwide average of 68%. The low conversion efficiency for China is mainly a result of the large share of coal-fired power generation at low efficiency. The relatively high efficiency for Latin America is mainly a result of a high share of hydropower in power generation. In IEA statistics the conversion of electricity generated by hydropower to primary energy input is 100%.

Figure 9 shows the development of primary energy use per region. This is based on the conversion efficiency per region in WEO 2007. For the period 2030-2050, the conversion efficiency is assumed to remain constant and equal to the one in 2030.

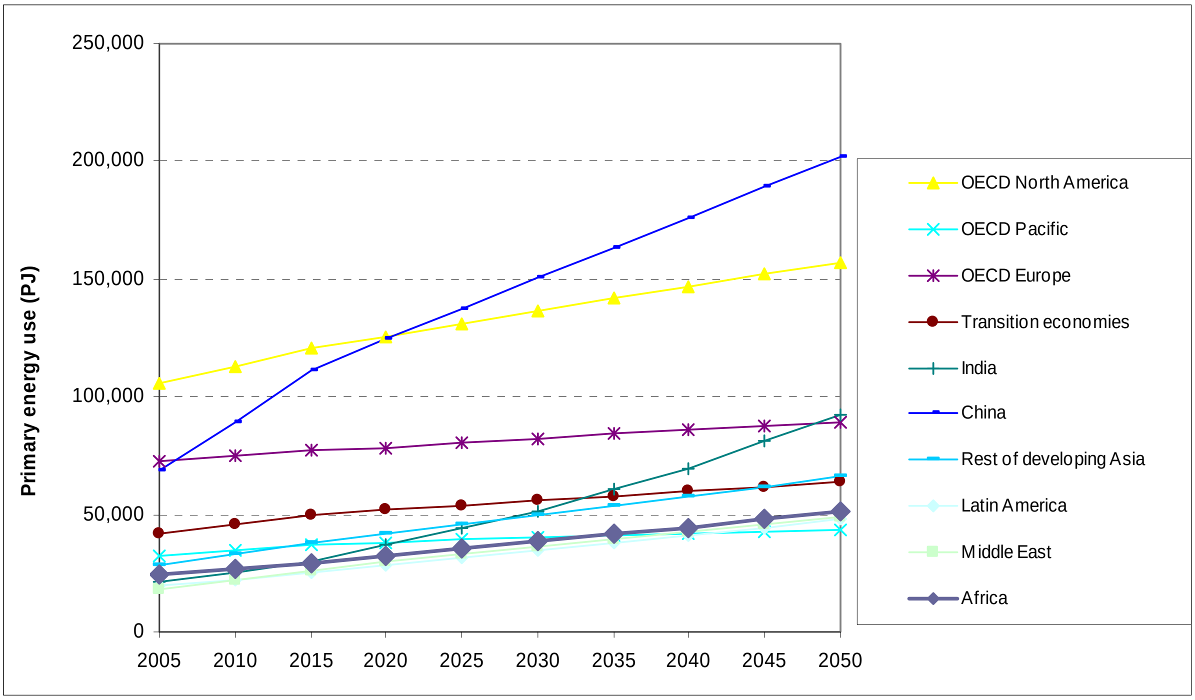


Figure 9: Primary energy use (PJ) in reference scenario per region

3.2.2 Step 2: defining technical potentials

The technical potentials are based on:

- Current best practice technologies
- Emerging technologies that are currently under development
- Continuous innovation in the field of energy-efficiency, leading to new technologies in the future.
- No behavioural changes or loss in comfort.
- No structural changes in the economy, other than occurring in baseline.

The key assumptions for calculating technical potential are:

- Measures can be implemented after 2010
- Equipment is replaced at the end of the (economic) lifetime of equipment.

The selection of measures is based on the current worldwide energy use per sector and sub sector. Figure 10 shows a breakdown of final energy demand in the world by the most important sub-sectors in the base year 2005.

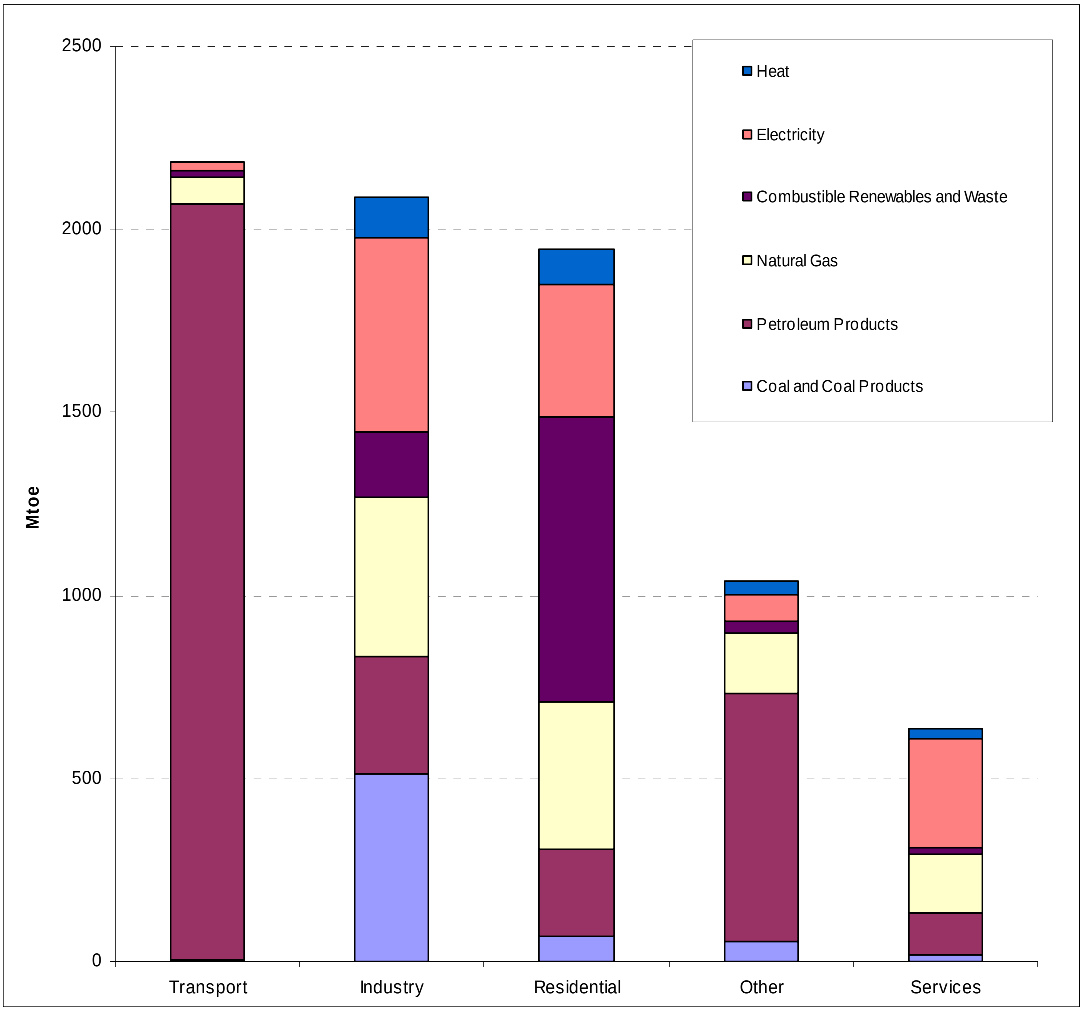


Figure 10: Final energy demand for the world by sub sector and fuel source in 2005 (IEA, 2007b)

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

The energy savings potential of a measure is based on the estimated energy savings in comparison to the reference scenario. The resulting energy savings of a certain option is thus additional to energy-efficiency improvement already occurring in the reference scenario. Table 10 shows the parameters that are used to calculate the energy savings per measure.

Table 10: Parameters used for calculating energy savings per measure

	Indicator	**Definitions**
R	Reference final energy demand (PJ) per sector	Final energy demand by sector or sub sector in reference scenario.
EIR	Energy intensity in reference scenario (PJ / unit), per subsector	This indicator is different per sector and if applicable per sub sector. Where possible the energy intensity is based on physical indicators (vehicle km, m^2 floor surface in buildings, tonne steel etc).
EIM	Energy intensity after implementation of measure (PJ / unit)	This indicator refers to the specific energy demand after implementing the measure (e.g. the minimum energy demand per tonne steel in 2050 etc).
T	Technical energy savings potential (%)	The technical energy savings potential is defined as the percental decrease of energy demand resulting from the implementing of the measure in comparison to the energy demand in 2005 and is calculated by the following formula: 1- EIM/EIR.
E	Energy savings in comparison to the reference scenario (PJ)	R x T
	Example	The energy demand for passenger cars is 100 PJ in 2050. The energy intensity for passenger cars in the reference scenario EIR is 12 MJ per vehicle km in 2050. The energy intensity after implementing the measure EIM is 6 MJ per vehicle km. This means the technical energy savings potential for efficiency passenger cars in comparison to the reference scenario is 50% or 50 PJ.

The savings of the measures are calculated in such a way that there is no double counting of energy savings. This means that the total savings of final energy demand can be determined by adding the energy savings of the separate options. This is done by applying the measures to the share of the energy use in the sector that the measure influences. For instances if passenger cars in 2050 consume 30% of energy demand in transport, the improvement of energy-efficiency of passenger cars by 50% reduces total energy demand in transport by 15% in 2050. In cases where measures influence the same share of the baseline, the measures are implemented one after the other. E.g. the measure to reduce passenger car transport demand is implemented before energy-efficiency improvement of passenger cars. This is done by using the remaining energy demand for passenger cars, after implementation of the first measure, for calculating the potential for energy-efficiency improvement.

Detailed assumptions and indicators per measure are given in the sections below.

3.3 Technical potentials per sector

This section gives an overview of global technical potentials for energy-efficiency improvement in 2020, 2030 and 2050. The technical potentials and the underlying assumptions are largely based on work done for the [r]evolution scenario, where potentials for 2050 have been estimated. Where available, extra information and data is added to illustrate and explain the meaning of the potentials. Also intermediate potentials for the years 2020 and 2030 are calculated and potentials for the transformation sector.

This section is organised by sector: buildings and agriculture, industry, transport, and the transformation sector.

3.3.1 Buildings and agriculture

Energy consumed in buildings and agriculture represents approximately 40% of global energy consumption. In all regions, the share of agriculture in final energy demand is much smaller than the share of buildings (see Figure 11) and the share of residential energy demand is larger than the share of commercial and public services energy demand (except in OECD Pacific).

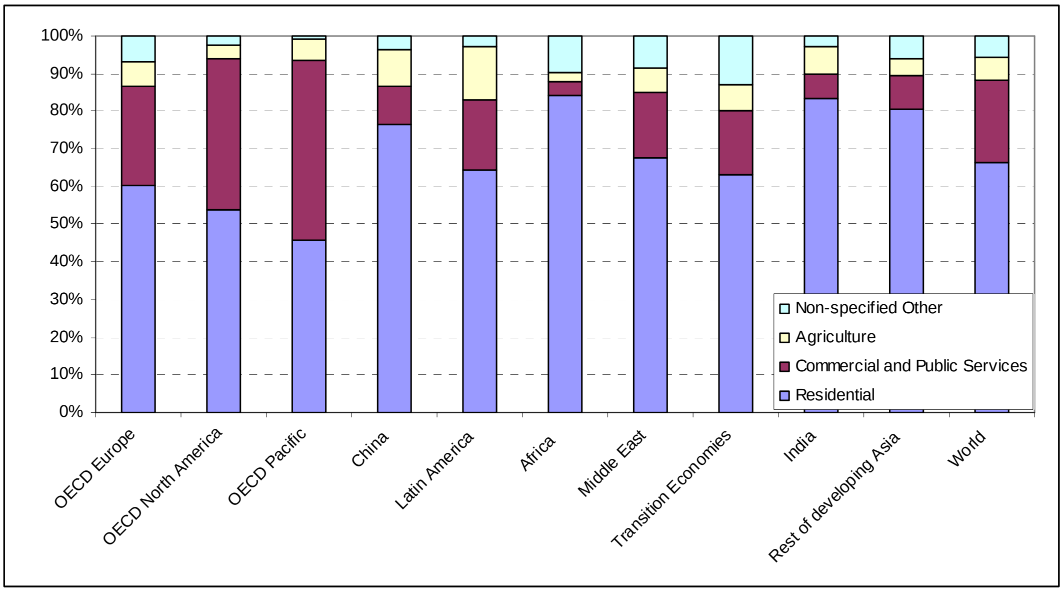


Figure 11: Breakdown of energy demand in the buildings and agriculture sector in 2005 (IEA, 2007b)

In the reference scenario, energy demand in buildings and agriculture is forecasted to grow considerably (see Figure 12).

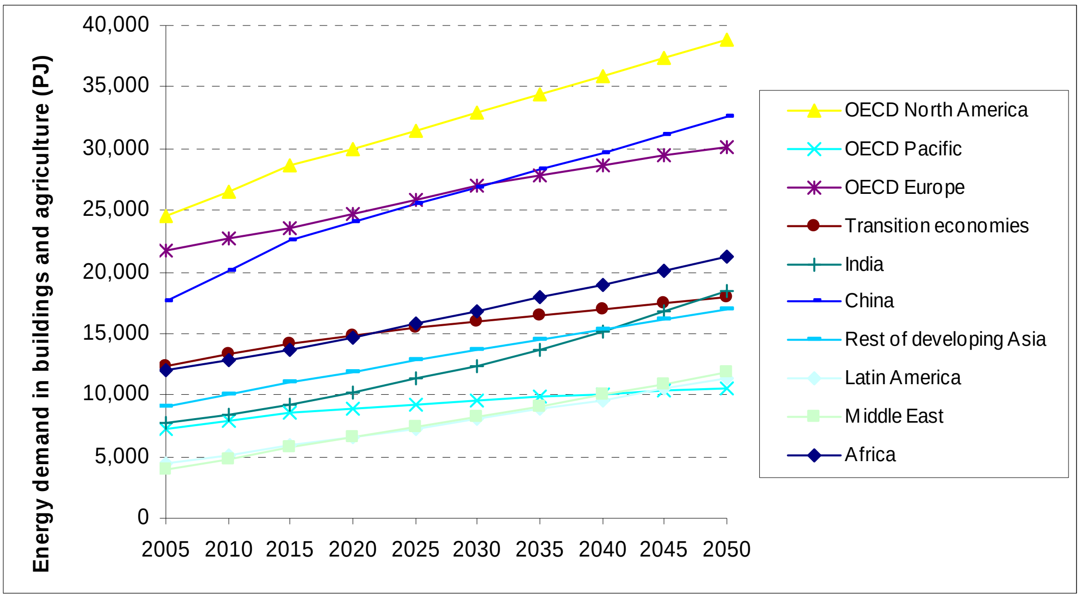
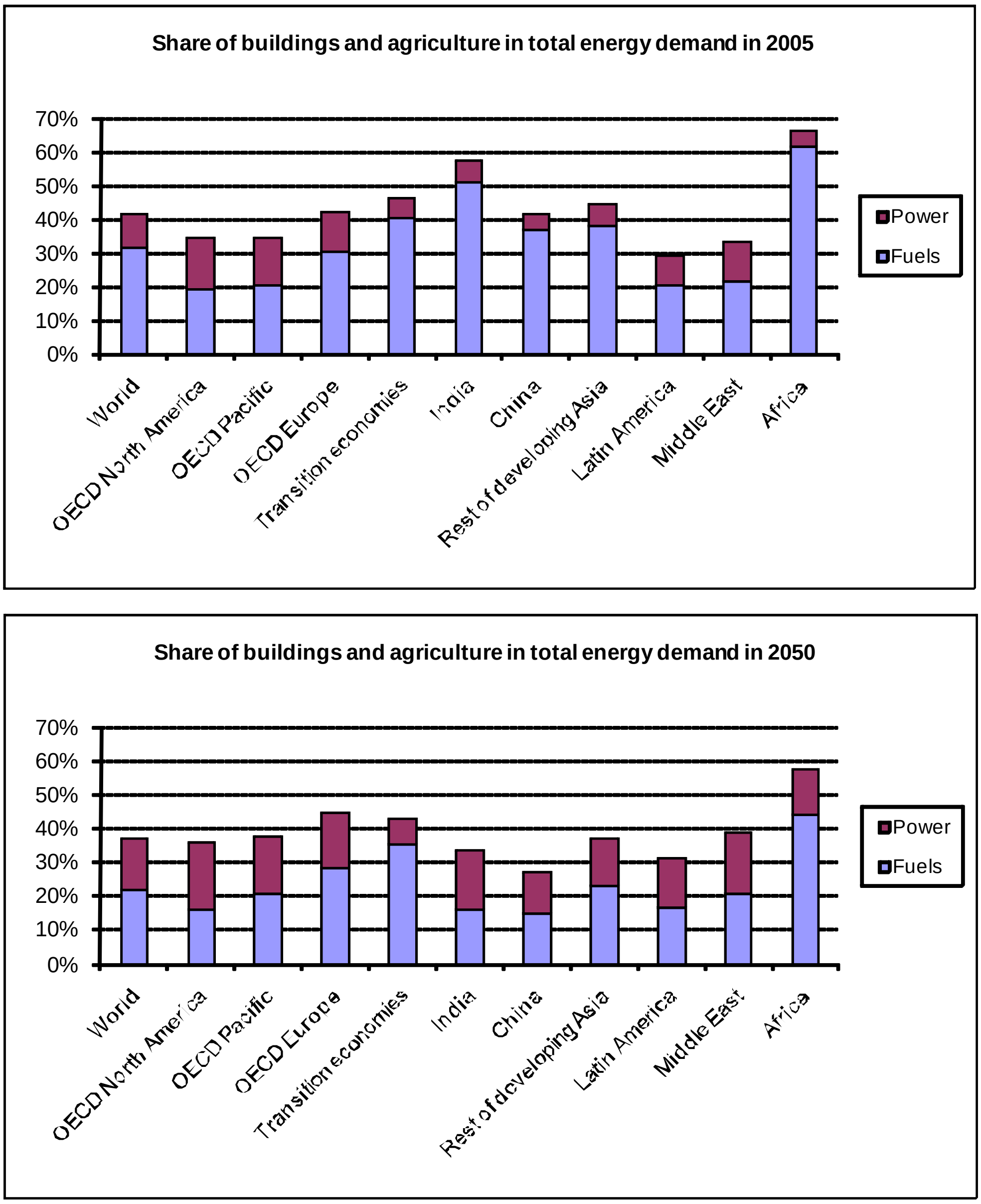


Figure 12: Energy demand in buildings and agriculture in reference scenario per region

Figure 12 shows that energy demand in buildings and agriculture in 2050 is highest in OECD North America. OECD Pacific and Middle East have the lowest energy demand for buildings and agriculture. In the reference scenario, China will have caught up with OECD Europe by 2050.

The share of buildings and agriculture in total energy demand in 2005 and 2050 are shown in Figure 23. The share of energy demand for electricity will increase, signifying an increase in the use of appliances in all regions. India and Africa currently have the highest share of buildings and agriculture in total energy demand. In 2050, Africa will be slightly higher than India. Overall shares are not forecasted to change much until 2050.


Share of buildings and agriculture in total energy demand in 2005

Share of buildings and agriculture in total energy demand in 2050

Figure 13: Breakdown of share of energy demand for buildings in total final energy demand in 2005 and 2050 per region with a breakdown of power consumption and fuel consumption

Figure 14 and Figure 15 show the development of energy use per capita and GDP per region. As can be seen there are still large differences expected between world regions in terms of energy use per capita.

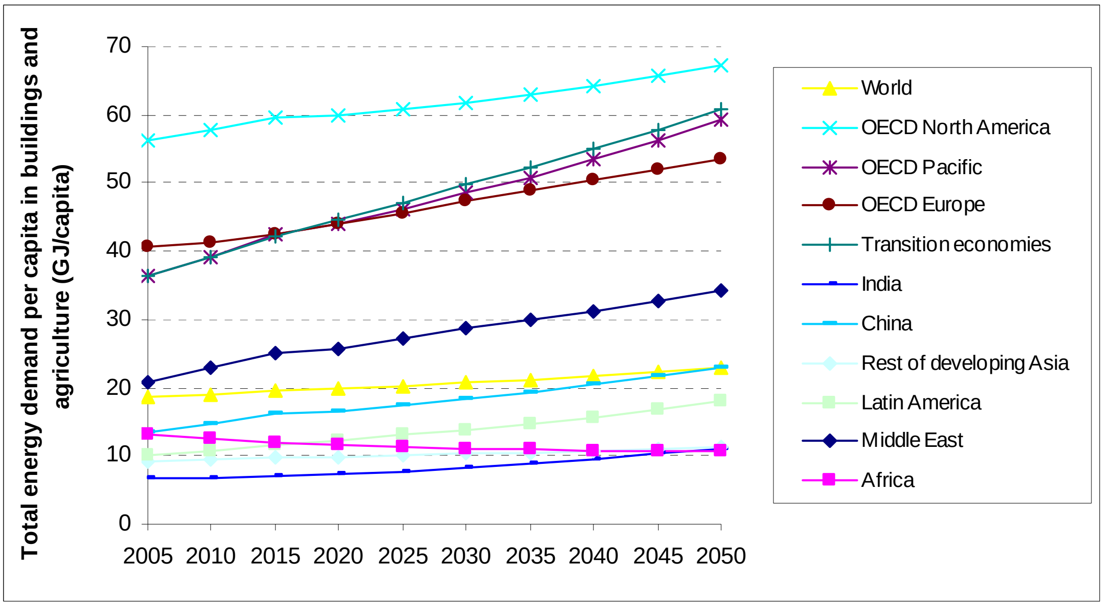


Figure 14: Final energy demand per capita per region in reference scenario

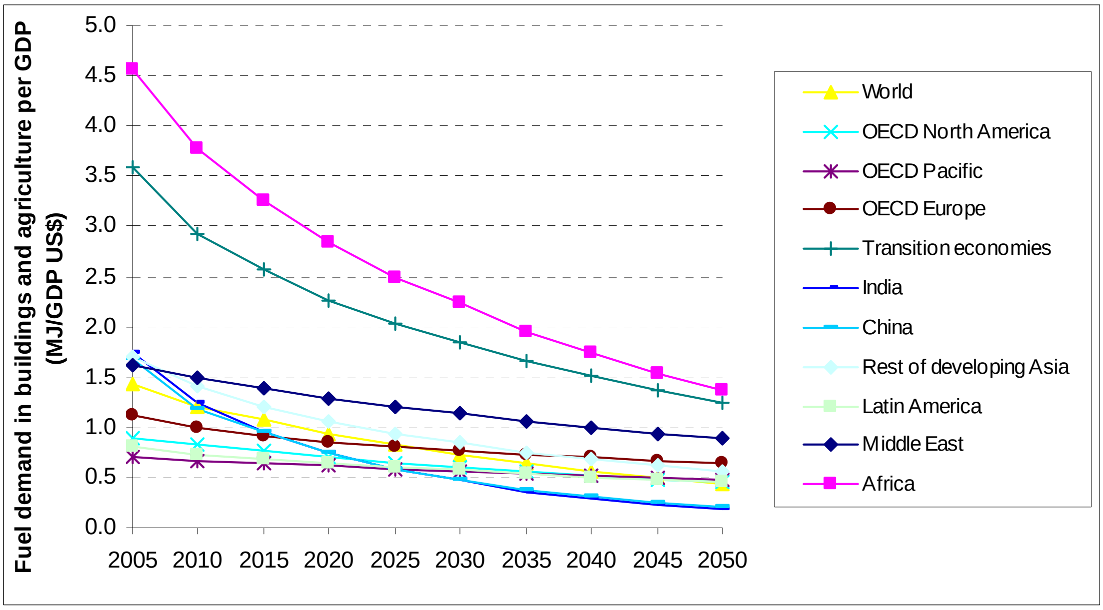


Figure 15: Final energy demand per unit of GDP per region in reference scenario

Fuel and heat use

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

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

Space heating

An indicator for energy-efficiency improvement for space heating is the energy demand per m^2 floor area per heating degree day (HDD). Heating degree day is the number of degrees that a day's average temperature is below 18^o Celsius, the temperature below which buildings need to be heated. Typical current heating demand for dwellings is 70-120 $kJ/m^2/HDD$ (based on IEA, 2007c). Dwellings with a low energy use consume below 32 $kJ/m^2/HDD$[4].

Technologies to reduce energy demand of new dwellings below 32 $kJ/m^2/HDD$ are: (based on WBCSD (2005), IEA (2006), Joosen et al (2002):

- Triple-glazed windows with low-emittance coatings. These windows greatly reduce heat loss to 40% compared to windows with one layer. The low-emittance coating prevents energy waves in sunlight coming in and thereby reduces cooling need (see section on air conditioning on page 214).
- Insulation of roofs, walls, floors and basement. Proper insulation reduces heating and cooling demand by 50% in comparison to average energy demand.
- Passive solar energy. Passive solar techniques make use of the supply of solar energy by means of building design (building's site and window orientation). The term "passive" indicates that no mechanical equipment is used. All solar gains are brought in through windows.
- Balanced ventilation with heat recovery. Heated indoor air passes to a heat recovery unit and is used to heat incoming outdoor air.

Current specific space heating demands in kJ per square meter per heating degree day OECD dwellings are given in Table 11.

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

Table 11: Space heating demands in OECD dwellings in 2004 (IEA, 2007c):

Region	**Specific space heating ($kJ/m^2/HDD$)**
OECD Europe	113
OECD North America	78
OECD Pacific	52

For the technical potentials in the [r]evolution scenario, it is assumed that starting in 2010, all new dwellings can be low-energy dwellings using 32 $kJ/m^2/HDD$ for OECD regions. For Transition Economies we assume the average OECD savings potential. Table 12 shows the savings potential for space heating in new dwellings in comparison to current average dwellings.

Table 12: Savings for space heating in new buildings in comparison to current average dwellings

Region	**Technical potential**
OECD Europe	72%
OECD North America	59%
OECD Pacific	38%
Transition Economies	56%

For the other non-OECD regions the potentials for space heating are based on Ürge-Vorsatz & Novikova (2008). They estimate a total energy-efficiency improvement potential of 1.4% for developing regions for new dwellings and for replacing existing houses with more energy efficient houses (‘retrofitting’).

For OECD countries, the potential for retrofitting of existing buildings is based on IEA (2006). Important retrofit options are more efficient windows and insulation. According to IEA (2006), the former can save 39% of space heating energy demand of current buildings, while the latter can save 32% of space heating or cooling energy demand. IEA (2006) reports that average energy consumption in current buildings in Europe can decrease by more than 50%. In the [r]evolution study, 50% is used as the Technical potential for OECD Europe. For the other regions the same relative reductions is assumed as for new buildings, to take into account current average efficiency of dwellings in the regions. For existing dwellings, the savings compared to average current dwellings are given in the table below.

Table 13: Savings for space heating in existing buildings in comparison to current average dwellings

Region	Technical scenario
OECD Europe	50%
OECD North America	41%
OECD Pacific	26%
Transition Economies	39%

To calculate overall potentials for space heating demand in dwellings in OECD countries and Transition Economies, the share of buildings build after 2010 in total dwelling stock in 2050 is estimated. The UNECE database (UNECE, 2008) contains data on total dwelling stock, dwelling stock increase (new construction), and population. It is assumed that the total dwelling stock grows along with population. The number of existing dwellings decreases every year due to a certain replacement. On average this is about 1.3% of total dwelling stock per year, meaning 40% replacement in 40 years (this is equivalent to an average house lifetime of 100 years). Table 14 gives the share of new dwellings in the total dwelling stock per region.

Table 14: Forecasted share of new dwellings (of share of dwelling stock) in 2050

Region	Existing buildings	New dwellings due to replacement of old buildings as share of total dwellings in 2050	New dwellings due to population growth as share of total in 2050
OECD Europe	52%	41%	7%
OECD North America	36%	29%	35%
OECD Pacific	55%	44%	1%
Transition Economies	55%	45%	0%

Total savings for space heating energy demand are calculated by multiplying the savings potentials for new and existing houses with the forecasted share of dwelling in 2050 to get a weighed reduction percentage.

For space heating in buildings in the services sector the same percentual savings as for dwellings are assumed.

Other fuel use

For fuel use for hot water and cooking we assume the same percentual reduction as is assumed for space heating per region. Measures for reducing fuel use for hot water consumption are e.g. the use of heat recovery units to use waste heat from exhaust water and the use of efficient boilers. Hot water that goes down the drain carries energy with it. Heat recovery systems capture this energy to preheat cold water entering the water heater. A heat recovery system can recover as much as 70% of this heat and recycle it back for immediate use (Enviroharvest, 2008).

Electricity use

The breakdown of electricity use per type of appliance is different per region. In the [r]evolution scenario a convergence is assumed for the different types of electricity demand per region in 2050. Based on Bertoldi & Atanasiu (2006), OECD/IA (2006), and WBCSD (2005), the following breakdown for electricity use in 2050 is assumed for all regions:

- standby (8%)
- lighting (15%)
- cold appliances (15%)
- appliances (30%)
- air conditioning (8%)
- other (e.g. electric heating) (24%)

Standby power consumption

Standby power consumption is the "lowest power consumption which cannot be switched off (influenced) by the user and may persist for an indefinite time when an appliance is connected to the main electricity supply" (UK MTP, 2008). In other words, the energy used when an appliance is connected to a power supply but is not being used. Some appliances also consume energy when they are not on standby and are also not being used for their primary function, for example when an appliance has reached the end of a cycle but the ‘on’ button is still engaged. This consumption does not fit into the definition of standby power consumption, but could account for a notable amount of energy use (UK MTP, 2008).

Reducing standby losses provide a major opportunity for cost-effective energy savings. Nowadays, many appliances can be remotely and/or instantly activated or have a continuous digital display, and therefore require a standby mode. Standby power accounts for 20–90W per home in developed nations, ranging from 4 to 10% of total residential electricity use (Meier et al., 2004) and 3-12% of total residential electricity use worldwide (Meier, 2001). Printers use 30-40% of full power requirements when idle (likewise for TV and music equipment). Set-top boxes even consume more energy in standby than in use, due to the time spent in standby. Typical standby use of different types of electric devices is shown in Figure 16.

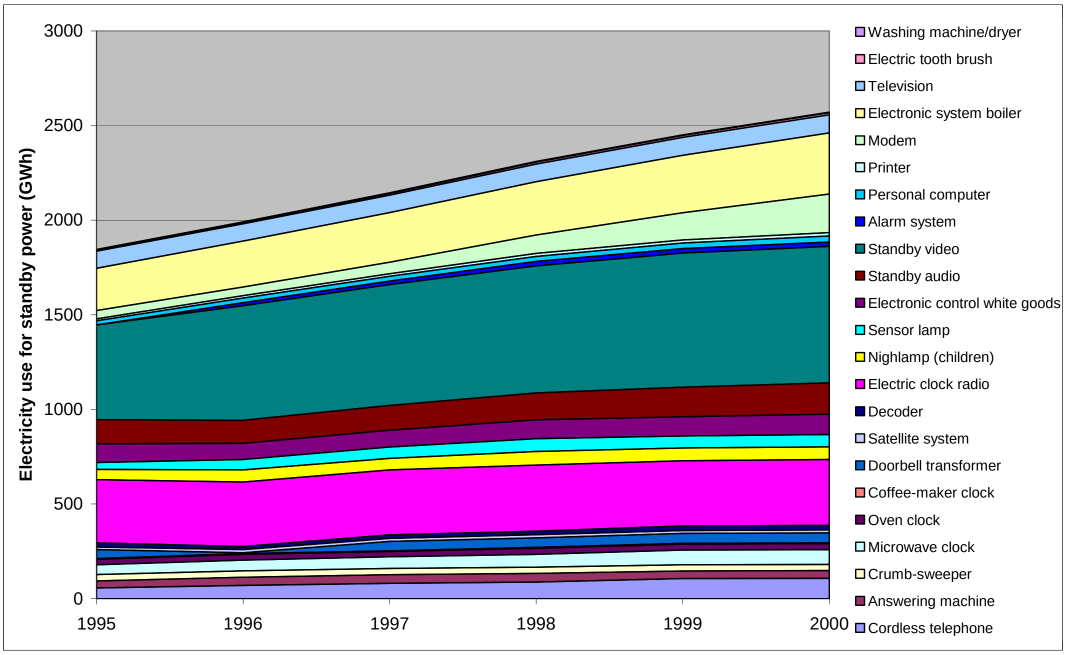


Figure 16: Global electricity use of standby power of different devices (Harmelink et al., 2005)

In developing nations, the amount of appliances per household is growing (see Figure 17 for China). In China, standby energy use accounts for 50–200 kWh per year in an average urban home. Levels of standby power use in Chinese homes are below those observed in developed countries but still high in part because Chinese appliances have higher standby than similar products in developed countries. Existing technologies are available to greatly reduce standby power at low costs (Meier et al., 2004).

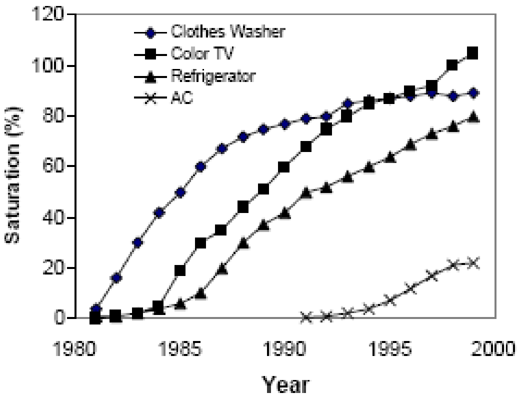


Figure 17: Appliance saturation of major appliances in China (Meier et al., 2004)

Meier and Lebot (1999) described some of these technologies and even proposed that standby in all devices could be reduced to about 1W. Efficiency recommendations of the US FEMP and Energy Star Label (US FEMP, 2007) also assume best practice levels for all equipment of 1 W or less (except microwaves: 2W and integrated computers: 3W). A study by Harmelink et al. (2005) reported significant savings (up to 77%) if a standby standard of 1W per appliances would be enforced. WBCSD (2005) reports a worldwide savings potential between 72% and 82%. For the technical potential, the [r]evolution study assumes 82% energy-efficiency improvement in 2050 (equivalent to 4.2% per year).

Lighting

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

The shares of different lighting technologies used in a number of countries/regions is shown in Figure 18 (LFL = linear fluorescent lamp).

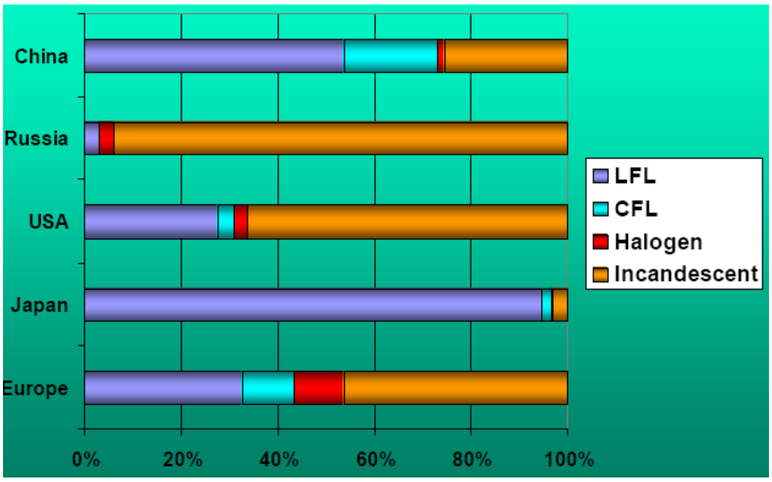


Figure 18: Share of residential lighting taken up by different lighting technologies in different regions (Waide, 2007)

Globally, people consume 3 Mega-lumen-hrs (Mlmh) of residential electric light per capita/year. There is a positive relationship between GDP per capita and lighting consumption in Mlmh/cap/y (see Figure 19).

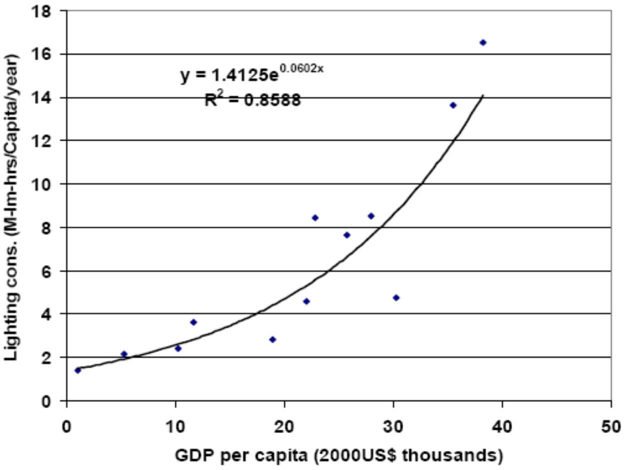


Figure 19: Lighting consumption Mlmh/capita/yr as a function of GDP per capita (Waide, 2006)

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

In a study by Bertoldi & Atanasiu (2006), national lighting consumption and CFL penetration data is presented for EU-27 countries (and candidate Croatia). We used this study to deduce household penetration rates and lighting electricity consumption in OECD Europe, in combination with Waide (2006).

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

In order to determine the savings potentials for lighting, it is important to know the penetration of efficient lamps in the regions. This can be measured with the luminous efficacy (mW/lm) of average lamps used in a region. The luminous efficacy is a ratio of the visible light energy emitted (the luminous flux) to the total power input to the lamp. It is measured in lumens per watt (lm/W). The maximum efficacy possible is 240 lm/W for white light. The current best practice is 75 lm/W for fluorescent lights (future fluorescent lights 100 lm/W) and 115 lm/W for white LEDs (future LEDs 150 lm/W). The luminous efficacy of incandescent lamps is 10-17 lm/W. For the technical potential in 2050 we assume that the average luminous efficacy can be increased to 100 lm/W in all regions.

Table 15 below shows the luminous efficacy per region and the technical potential in 2050. The luminous efficiency is estimated based on the penetration of different types of lamps in Bertoldi & Atanasiu (2006) and Waide (2006).

These technical potentials only include using energy efficient lamps. Additional savings can be achieved by e.g. occupancy control and maximizing daylight use.

Table 15: Average luminous efficacy of residential lamps

Region	**Luminous efficacy (lm/W)**	**Technical potential 2050**	**% energy-efficiency improvement per year**
OECD Europe	40	60%	2.3%
OECD Pacific (based on Japan)	65	35%	1.1%
OECD North America	30	70%	3.0%
Transition Economies (TE)	20	80%	3.9%
China	50	50%	1.7%
Developing regions	No information, we assume 20, same as for TE	80%	3.9%
Global	**40**	**60%**	**2.4%**

Cold appliances (food refrigeration and cooling)

The average household in OECD Europe consumed 700 kWh/year of electricity for food refrigeration in 2000 compared with 1000 kWh/year in Japan and 1300 kWh/year in OECD North America. These figures illustrate differences in average per household storage capacities, the ratio of frozen to fresh food storage capacity, ambient temperatures and humidity, and food storage temperatures and control (IEA, 2003). European households typically either have a refrigerator-freezer in the kitchen (sometimes with an additional freezer or refrigerator), or they have a refrigerator and a separate freezer. Practical height and width limits place constraints on the available internal storage space for an appliance. Similar constraints apply in Japanese households, where ownership of a single refrigerator-freezer is the norm, but are less pressing in OECD North America and Australia. In these countries almost all households have a refrigerator-freezer and many also have a separate freezer and occasionally a separate refrigerator (IEA, 2003).

The energy-efficiency improvement for cold appliances is based on the situation in the EU. In 2003, 103 TWh were consumed by household cold appliances in the EU-15 countries (15% of total 2004 residential end use). An average energy label A++ cold appliance uses 120 kWh per year, while a comparable appliance of energy label B uses on average 300 kWh per year (and C label 600 kWh per year) (EuroTopten, 2008). The average energy label of appliances sold in EU-15 countries is still label B. If only A++ appliances were sold, energy consumption would be 60% less. The average lifetime of a cold appliance is 15 years, meaning that 15 years from the introduction of only A++ labelled appliances, 60% less energy would be used in EU-15 countries (EuroTopten, 2008).

European Commission (2005) estimates a savings potential for cold appliances of 3.5% per year for the period 2003-2010. We use this energy-efficiency improvement rate for the technical potential in 2050 for all regions. This means that for EU-15 the average cold appliance would use 72 kWh per year in 2050.

Appliances

Computers

The average desktop uses about 120 W (the monitor 75 W and the central processing unit 45 W) and the average laptop 30 W per hour (Bray, 2006). Current best practice monitors (Best of Europe, 2008) use only 18W (15 inch), which is 76% less than average. Savings for computers are especially important in the commercial sector.

According to a study performed by Bray (2006), computers and monitors have the highest energy consumption in office environments after lighting (in the USA). In Europe, office equipment use is estimated to be less important, but estimates widely differ (see Bertoldi & Atanasiu, 2006 for a more elaborate account).

Bray (2006) states that studies have shown that automatic and/or manual power management of computers and monitors can significantly reduce their energy consumption. A power managed computer consumes less than half the energy of a computer without power management (Webber et al., 2006), and depending on how computers are used, power management can reduce the annual energy consumption of computers and monitors by 80% (Webber et al., 2006). Approximately half of all office computers are left turned on overnight and on weekends (75% of the week), so all computers should be turned off at night. Also, LCD monitors require less energy than CRT monitors (average 15W when active, 1.5W in low power mode, and 0.5W when turned off (Kawamoto et al: 2004).) An average LCD screen uses 79% less energy than an average CRT monitor (both power-managed) (Webber et al., 2006). Further savings are made by ensuring computers enter low power mode when they are idle during the day (Bray, 2006).

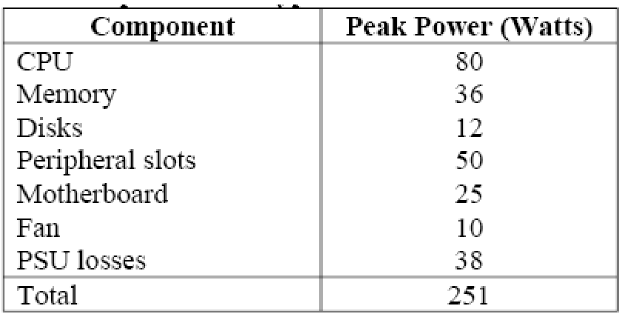
Another benefit of decreasing the power consumption of computers and monitors is an indirect effect. In addition to the direct contribution of computer and monitors to office energy consumption, they also increase the load on air conditioning. According to a study by Roth et al (2002), office equipment increases the load on air conditioning by 0.2-05 kW per kW of office equipment power draw.

The average computer with CRT monitor that is always on uses 1236 kWh/y (482kWh/y for the computer and 754 kWh/y for the monitors (Bray, 2006)). The average computer with CRT monitor that is power managed uses 190 kWh/y (86+104). Effective power management can save 1046 kWh per computer and CRT monitor per year; a reduction of 84%, or 505 kWh (613-108) per computer and LCD monitor per year (Webber et al: 2006); a reduction of 83%.

These examples illustrate that power management can have larger effects than just more efficient equipment. To compare: the German website EcoTopten states that more efficient computers save 50-70% with respect to older models and efficient flat-screens use 70% less energy than CRTs (EcoTopten.de, 2008).

Servers

Servers are multiprocessor systems running commercial workloads (Lefurgy et al., 2003). Typical component peak power breakdown is given in Figure 20.



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

Figure 20: Component peak power breakdown for a typical server (Fan et al., 2007, US EPA, 2007a). PSU = power supply unit

Data centres are facilities that primarily contain electronic equipment used for data processing, data storage, and communications networking (US EPA, 2007a). 80% of servers are located in these data centres (Fichter, 2007). Worldwide, about 3 million data centres and 32 million servers exist (Fichter, 2007).

The installed base of servers is growing rapidly due to increasing demand for data processing and storage. New digital services (like music downloads, video-on-demand, online banking, electronic trading, satellite navigation, Internet telephone communication) spur this rapid growth, as well as increasing penetration of computers and Internet in developing countries. Since systems become more and more complex to handle increasingly large amounts of data, power and energy consumption (mainly used for cooling, about 50% (US EPA, 2007a)) grow along. Power density of data centres is rising by approximately 15% per year (Humphreys & Scaramella, 2006). Aggregate electricity use for servers doubled over the period 2000 to 2005 both in the U.S. and worldwide (Koomey, 2007), see Figure 21. Data centres consumed roughly 1% of global electricity use in 2005 (14 GW) (Koomey, 2007).

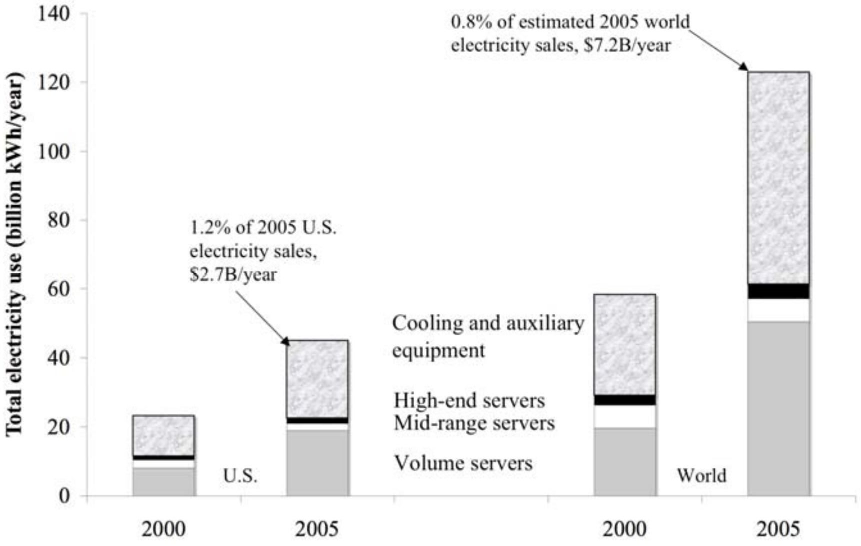


Figure 21: Total electricity use for servers in the U.S. and the world in 2000 and 2005, including the associated cooling and auxiliary equipment (Koomey, 2007)

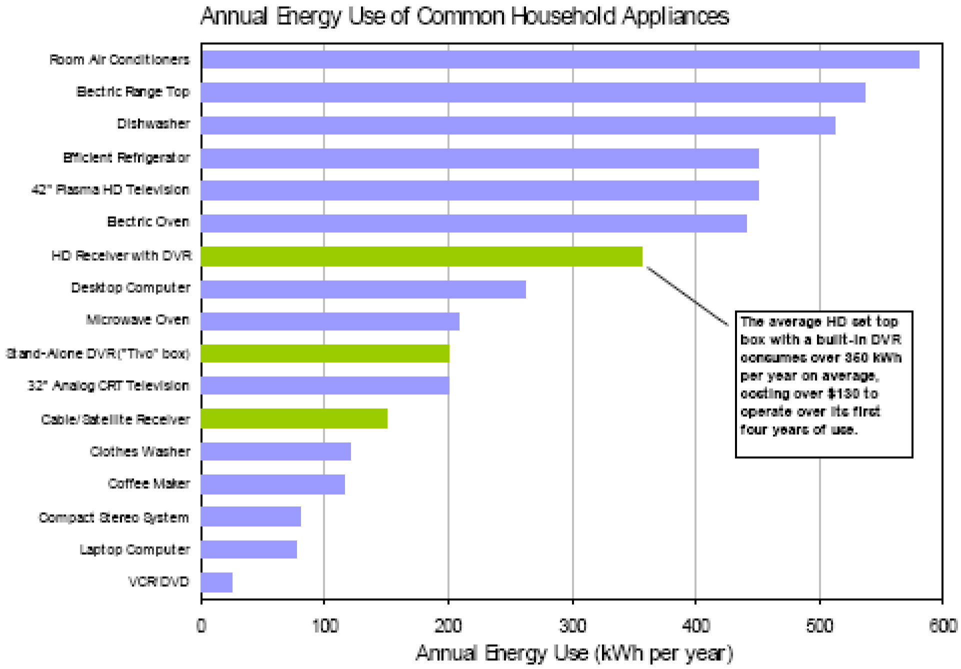
Power and energy consumption are key concerns for Internet data centres (Bianchini and Rajamony, 2004). There is significant potential for energy-efficiency improvements in data centres. Existing technologies and design strategies have been shown to reduce the energy use of a typical server by 25% or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

The US EPA state-of-the-art scenario (measures: adopt energy efficient servers, enable power management on all servers and other equipment, consolidate servers and storage, liquid cooling instead of air cooling, improve efficiency chillers, pumps, fans, transformers, and use combined heat and power; for more measures see US EPA (2007a)) could reduce electricity use by up to 56% compared to current efficiency trends (or 60% compared to historical trends), representing the maximum technical potential in 2011, assuming that only 50% of current data centres can introduce these measures before 2011. This indicates a significant savings potential for servers and data centres around the world until 2050.

Set-top boxes

Set-top boxes (STBs) are used to decode satellite or cable television programmes and are a major new source of energy demand. More than a billion are projected to be purchased worldwide over the next decade (OECD/IEA, 2006). The energy use of an average set-top box is 20-30 W, but it uses nearly the same amount of energy when switched off (OECD/IEA, 2006; Horowitz, 2007). In the USA, STB energy use is estimated at 15 TWh/year or about 1.3% of residential electricity use (Rainer et al., 2004). With more advanced technological uses (e.g. using digital video recorders), STB energy use is forecasted to triple to 45 TWh/year by 2010 – an 18% annual growth rate and 4% of 2010 residential electricity use. Because of their short life times (on average 5 years) and high ownership growth rates, STBs provide an opportunity for significant short term energy savings compared to the reference(Rainer et al., 2004).

According to Horowitz (2007), cable/satellite boxes without DVRs use 100 to 200 kWh of electricity per year. High definition cable and satellite boxes use only slightly more energy on average. Cable and satellite set-top boxes with digital video recorders use between 200 and 400 kWh per year. Media receiver boxes use less energy (around 35 kWh per year) but must be used in conjunction with existing audiovisual equipment and computers, thus adding another 35 kWh to the annual energy use of existing home electronics. Figure 22 shows annual energy use of common household appliances. The figure shows that the energy use of some set-top boxes approaches that of the major energy consuming household appliances.



The average HD set top box with a built-in DVR consumes over 350 kWh per year on average, costing over $130 to operate over its first four years of use.

Figure 22: Annual energy use of common households appliances (Horowitz, 2007).

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

The study by Rainer et al (2004) reports a savings potential between 32% and 54% in 5 years (2005-2010).

Technical potential of appliances

The current savings potential for computers is 70%, for servers 60% and for set top boxes 44%. WBCSD (2005) estimates a savings potential for appliances of 70% in 2050. Taking into account future developments, we assume that by 2050 the average potential for energy-efficiency improvement for appliances can be equal to 70% (equivalent to 3.0% per year improvement in the period 2010-2050).

Air conditioning

Today in the USA, some 14% of the total electrical energy is used to air condition buildings (source: US DOE/EIA, 2007). Also in southern European countries, widespread and increasing use of small air conditioning units (less than 12 kW output cooling power), mainly during the summer months, drives increases in electricity consumption. Total residential air-conditioners' electricity consumption in EU-25 in year 2005 was estimated to be between 7 and 10 TWh per year (Bertoldi & Atanasiu, 2006).

However, we should not underestimate the influence of developing countries. Many of these are located in warm climatic zones. Owing to the rapid development of economy and the stable improvement of people's living standard, central air conditioning units are broadly used in China. Currently, central air conditioning units account for 20% of total electricity consumption in China (Lu, 2007).

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

However, behavioural changes should not be overlooked. In households and offices all over the world, complete buildings are being cooled. One example of a smart alternative to cooling the whole house was developed by the company Evening Breeze (Evening Breeze, 2008). They combined a mosquito net, bed and air conditioning such that only the bed has to be cooled instead of the whole bedroom.

There are also other options for cooling, such as geothermal cooling by heat pumps. This uses the same principle as geothermal heating, namely that the temperature at a certain depth in the Earth remains constant year-through. In the winter we can use this relatively high temperature to warm our houses. Conversely, we can use the relatively cold temperature in the summer to cool our houses. There are several technical concepts available, but all rely on transferring the heat from the air in the building to the Earth. A refrigerant is used as the heat transfer medium. This concept is cost-effective (Duffield & Sass, 2004). Heat pumps have been gaining market share in different countries (OECD/IEA, 2006). Solar energy can also be used for heating and cooling.

Solar cooling is the use of solar thermal energy or solar electricity to power a cooling appliance. Basic types of solar cooling technologies are: absorption cooling (uses solar thermal energy to vaporize the refrigerant); desiccant cooling (uses solar thermal energy to regenerate (dry) the desiccant); vapour compression cooling (use solar thermal energy to operate a Rankine-cycle heat engine); evaporative cooling; and heat pumps and air conditioners that can be powered by solar photovoltaic systems (Darling, 2005). To drive the pumps only 0.05 kW of electricity is needed (instead of 0.35 kW for regular air conditioning) (Austrian Energy Agency, 2006), this calculates to a savings potential of 85%.

Not only is it important to use efficient air conditioning equipment, it is as important to reduce the need for air conditioning. Important ways to reduce cooling demand (see section on fuel sue on page 201) are: use insulation to prevent heat from entering the building, reduce the amount of inefficient appliances present in the house (such as incandescent lamps, old refrigerators, etc.) that give off unusable heat, use cool exterior finishes (such as cool roof technology (US EPA, 2007), or light-coloured paint on the walls) to reduce the peak cooling demand (as much as 10-15% according to ACEEE (2007)), improve windows and use vegetation to reduce the amount of heat that comes into the house, and use ventilation instead of air conditioning units.

For air conditioning we assume a savings potential of 70% in 2050, similar to the potential reported in WBCSD (2005). The potential takes into account that a certain share of conventional air conditions is replaced by solar cooling and geothermal cooling and that the remaining units use refrigerant Ikon B.

Summary of efficiency potentials in buildings

Table 16 gives a summary of the assumptions for the technical potentials in 2020, 2030 and 2050 per type of energy use.

Table 16: Summary assumptions global potentials

Sector	**Unit (specific final energy consumption)**	**Specific energy consumption**	**Current best practice**	**Technical potential**			**Reference scenario**	**Efficiency improvement 2010-2050**
		2005	**2005**	**2020**	**2030**	**2050**	**2050**	**%/yr**
		(unit)						
Space heating and other fuel and heat demand	kJ/ m^2/ HDD	95	32	80	67	47	60	1.7%
Stand-by	kWh per household per year	75	14	49	32	13	48	4.2%
Lighting	1 / Luminous efficacy (mW/lm)	45	9	35	28	17	29	2.4%
Cold appliances	kWh per year	300	120	210	147	72	191	3.5%
Air-conditioning	Index 2005 = 100	100	15	74	54	30	64	3.0%
Appliances	Computers (kWh/year)	75	20	55	41	22	48	3.0%
Appliances	Servers (index 2005 = 100)	100	40	74	54	30	64	3.0%
Appliances	Set top boxes (index 2005 = 100)	100	56	74	54	30	64	3.0%
Appliances	Average (index 2005 = 100)	100		74	54	30	64	3.0%

Table 17 shows the technical potentials per region per type of energy use for the period 2010-2050 as percentage per year.

Table 17: Technical potential for different types of energy uses within the buildings sector (% per year for the period 2010-2050)

	Fuel and heat consumption	**Electricity consumption**					
	Space heating and others	Stand-by	Lighting	Appliances	Cold appliances	Airco	Other / average
OECD Europe	2.3%	4.2%	2.3%	3%	3.5%	3%	3.1%
OECD N.-Am.	1.8%		3.0%				3.2%
OECD Pac.	0.9%		1.0%				2.8%
Transition Ec.	1.6%		3.9%				3.4%
China	1.4%		1.7%				3.0%
India	1.4%		3.9%				3.4%
Rest dev. Asia	1.4%						
Middle East	1.4%						
Latin America	1.4%						
Africa	1.4%						
World	**1.7%**	**4.2%**	**2.4%**	**3%**	**3.5%**	**3%**	**3.1%**

The overall technical potential for energy demand reduction in buildings is 2.2% per year.

The potential for electricity demand reduction is typically 3% per year and thereby higher than the potential for fuel demand reduction, which is 1.5-2% per year. The reason for this can be found in the longer life time for buildings (typically more than 50 years), in comparison to the lifetime for electric appliances (typically 5-15 years).

3.3.2 Industry

Figure 23 shows the reference scenario for final energy demand in industries in the period 2005-2050.

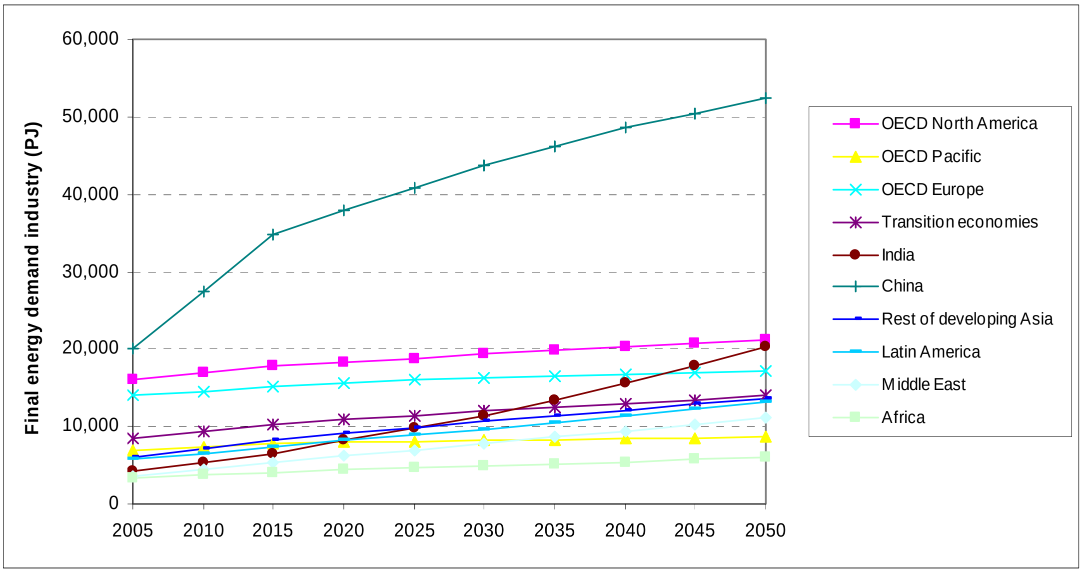


Figure 23: Projection of industrial energy demand in period 2005-2050 per region

As can be seen, the energy demand in Chinese industries is expected to be huge in 2050 and amounts to 52 EJ. The energy demand in all other regions together is expected to be 125 EJ, meaning that China accounts for 29% of worldwide energy demand in industries in 2050.

Figure 24 shows the share of industrial energy use in total energy demand per region for the years 2005 and 2050.

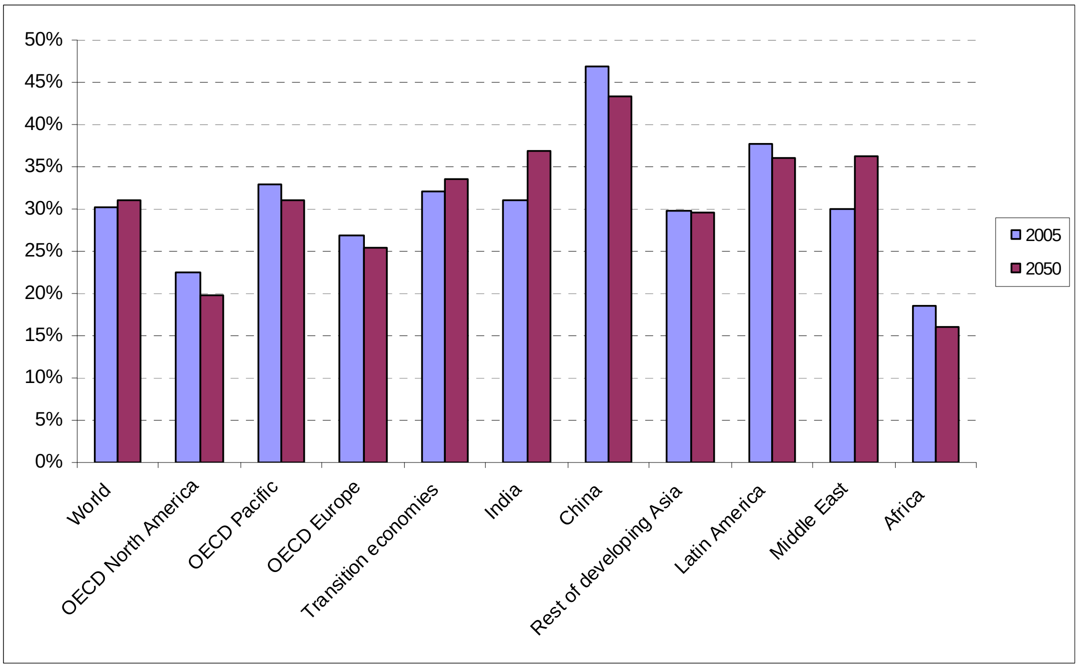


Figure 24: Share industry in total final energy demand per region in 2005 and 2050

The worldwide average share of industry in total final energy demand is about 30%, both in 2005 and in 2050. The share in Africa is lowest with 16% in 2050. The share in China is highest with 43% in 2050.

Figure 25 shows a breakdown of final energy demand by sub sector in industry worldwide for the base year 2005.

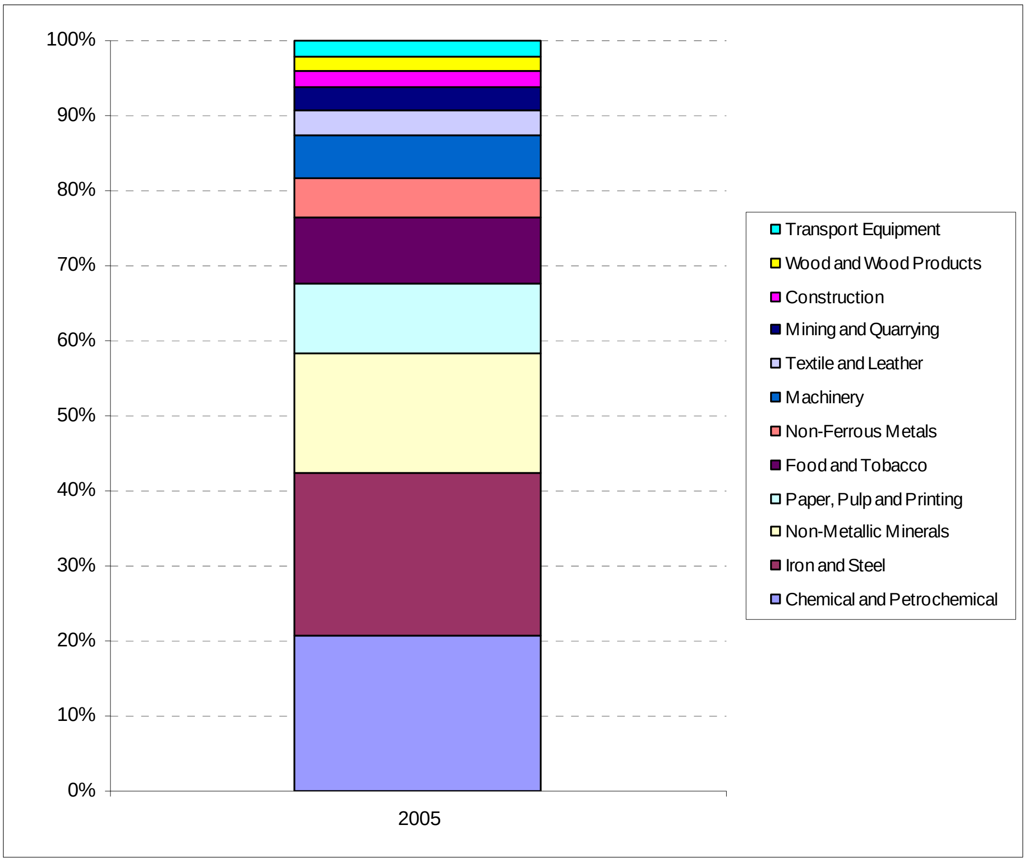


Figure 25: Breakdown of final energy consumption in 2005 by sub sector for industry (IEA, 2007b)

The largest energy consuming sectors in industry are chemical and petrochemical industry, iron and steel and non-metallic minerals. Together the sectors consume more than 50% of industrial energy demand. Since these three sectors are relatively large we look at them in detail. Also we look at aluminium production in detail, which is part of the category non-ferrous metals. This is because the share of aluminium production in total industrial power demand is quite large, corresponding to nearly 10%[5] in 2005. For all sectors we look at effects of implementing best practice technologies, increased recycling and increased material efficiency. Where possible the potentials are based on specific energy consumption data in physical units (MJ/tonne steel, MJ/tonne aluminium etc.).

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[5] Please note that the share of non-metallic minerals in total final energy consumption is lower than 10%. However the largest share of energy use in aluminium production is power consumption, hence the share in power consumption in industry is relatively larger.

Iron and steel

The iron and steel industry is mainly made up of

(1) integrated steel mills that produce pig iron from raw materials (iron ore and coke), using a blast furnace and produce steel using a basic oxygen furnace (BOF) or an open hearth furnace (OHF), and

(2) secondary steel mills that produce steel from scrap steel, pig iron, or direct reduced iron (DRI) using an electric arc furnace (EAF).

In the figure below you can see the share of steel production per region by technology. The basic oxygen furnace is most often used and accounts for 66% of worldwide steel production. The share of open hearth furnace is very small and only used on a larger scale in the region “Transition Economies”. Open hearth furnace is an older and less efficient technology for producing steel than basic oxygen furnaces. The share of electric steel in total steel production is increasing and accounts for around 34% of worldwide steel production in 2005.

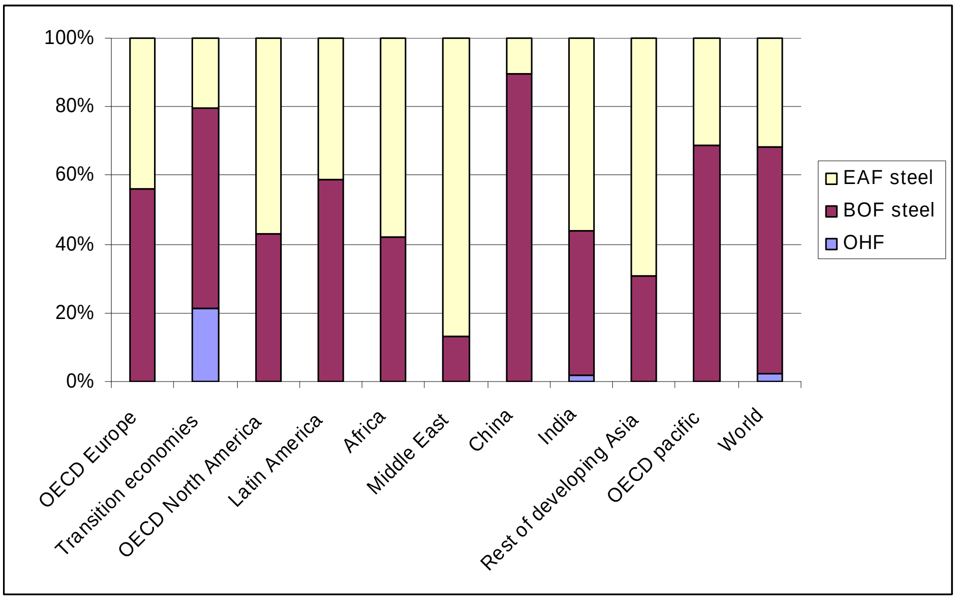

Figure 26: Steel production per region by technology in 2005 (based on IISI, 2007)

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

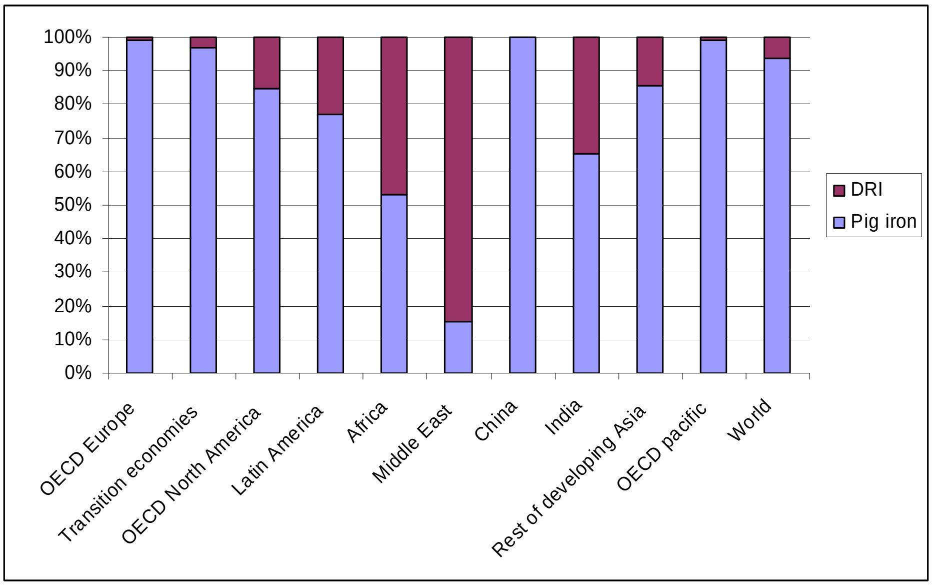

Figure 27: Iron production per region by technology in 2005 (based on IISI, 2007)

Figure 28 shows specific energy consumption for iron and steel production by region in 2005 and in the reference scenario in 2050. The specific energy consumption in 2050 is based on an energy-efficiency improvement in the reference scenario of 1% per year (see section 3.2.1 for more details regarding energy-efficiency improvement in the reference scenario). The specific energy consumption in 2005 is based on final energy demand of the iron and steel sector in IEA Energy Balances 2007 and the total crude steel production by region in IISI Statistical Yearbook 2007. The Middle East is excluded in the figure due to data unreliability.

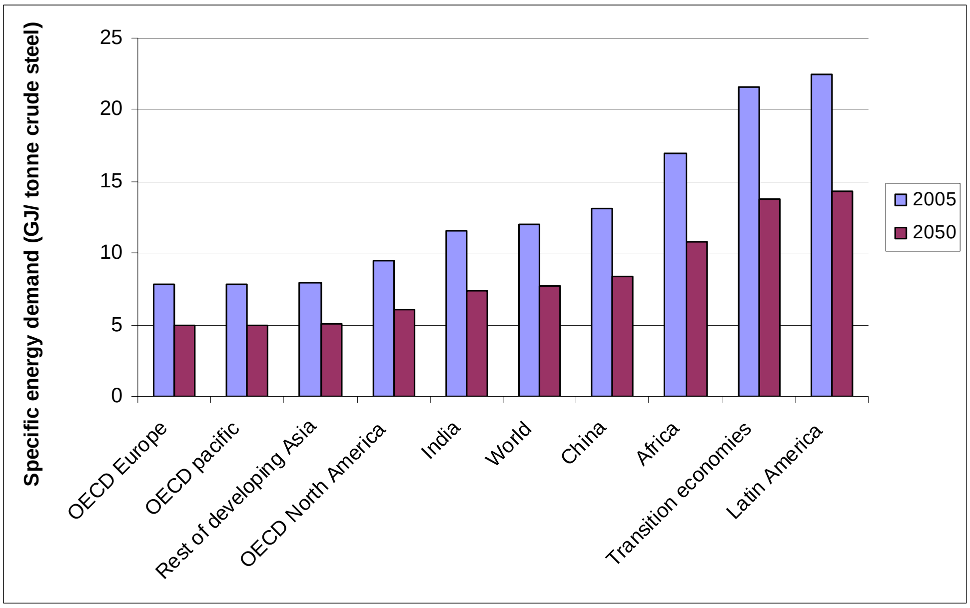

Figure 28: Specific final energy consumption (GJ/tonne steel) for iron and steel production in the reference scenario

The energy-efficiency for iron and steel production is influenced by the technologies used and the amount of scrap input. The most energy intensive part of steel making is the production of pig iron and direct reduced iron (DRI). The higher the share of pig iron and DRI in total steel production (i.e. the lower the share of scrap input used) the higher the specific energy consumption.

Table 18 shows the current best practice specific energy consumption for steel production.

Table 18: Best practice final energy consumption for iron and steel production [Kim and Worrell (2002), IISI (1998) and IEA (2006) for current best practice and Fruehan et. al (2000) for theoretical and practical minimum]

Product	**Specific final energy consumption (GJ/tonne steel)**			
	Current global average	**Current best practice**	**Theoretical minimum (practical minimum)**	**Estimated best practice in 2030**
Primary steel production in basic oxygen furnace (BOF) including energy consumption in blast furnace for pig iron production[6]	10	6.4	1.3 (1.6)	4.3
Steel production in electric arc furnace (EAF) with scrap input	2.2	1.6	1.3 (1.6)	1.6
Direct reduction processes	N/A	5	N/A	3.3
Smelting reduction processes	N/A	6.1	N/A	4.1
Hot rolling	2.2	1.7	0.03 (0.9)	1.1
Cold rolling	1.2	0.8	0.02 (0.02)	0.1

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

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

The energy-intensity for recycled steel is around 70-75% lower than the energy-intensity for primary steel. Increasing the amount of recycled steel is therefore an important energy savings option. Currently 35% of all crude steel production is derived from scrap (IEA, 2006). The potential for recycling steel depends on the availability of scrap. Neelis and Patel (2006) estimate the potential for the share of scrap in total steel production to be between 60-70% by 2100. We assume that the amount of recycled steel in total steel production can be 60% in 2050.

Together with the best practice values for steel production in 2030 this leads to a specific final energy consumption for iron and steel production of 3.5 GJ/tonne crude steel by 2050 in all

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[6] Including energy consumption blast furnace, excluding process energy consumption (6.6 GJ per tonne steel).

regions[7]. This is based on the following assumptions:

- 60% of the steel is produced from scrap in EAF furnaces
- 20% of steel is produced in blast furnace - BOF combination
- 20% of steel is produced by direct reduction process
- 92% of the steel production is hot rolled, same as in 2005
- 74% of the steel is after hot rolling also cold rolled, same as in 2005

The practical minimum specific energy consumption for iron and steel production, based on the above assumptions, is 2.4 GJ/tonne crude steel. Therefore, after 2050, energy-efficiency could further be reduced by 30%.

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

Non-metallic minerals

Non-metallic minerals include cement, lime, glass, soda, ceramics, bricks and other materials. Since cement accounts for two-thirds of total energy use in the production of non-metallic minerals (IEA, 2006), we discuss specifically the energy-efficiency of cement production.

Two important processes in producing cement are clinker production and the blending of clinker with additives to produce cement. Clinker is produced by burning a mixture of mainly limestone ($CaCO_3$), silicon oxides, aluminium oxides and iron oxides in a kiln. Production can take place in the wet process, the dry process and some intermediate forms (referring to the conditions of raw materials processing). The dry process is more energy-efficient than the wet process. After the melt has cooled down, clinker is blended with gypsum and with (depending on the desired product) fly ash, blast furnace slag, or other additives. Product qualities depend on the relative amount of clinker in the cement (ranging from 95% in Portland cement to 30% for blast furnace cement). Clinker production is the most energy intensive step in cement production. The current state of the art kilns consume 3.0 GJ/tonne clinker. The thermodynamic minimum is 1.8 GJ/tonne clinker, but strongly depends on the moisture content. The current typical energy use for cement production is between 3.5 and 5 GJ/tonne clinker (Phylipsen et al., 2003). The current energy use per tonne cement ranges from 1.2 to 5 GJ/tonne cement and depends largely on the share of clinker in cement production (ENCI, 2002)[8]. Substantial energy savings can be obtained by reducing the amount of clinker required. One option to reduce clinker use is by substituting clinker by industrial by-products such as coal fly ash, blast furnace slag or pozzolanic materials (e.g. volcanic material). The relative importance of additive use can be expressed by the clinker to cement ratio. The clinker to cement ratio for current cement production ranges from 25-99% (ENCI, 2002).

The energy use for cement production can be reduced by implementing best practice technologies and by reducing the clinker content in cement. The global average specific energy consumption per tonne cement equals 3.7 GJ per tonne cement in 2005 and 4.2 GJ per tonne clinker. The average clinker to cement ratio equals 80% and the average electricity consumption for grinding of 110 kWh per tonne cement (based on REEEP, 2008).

We assume that the specific energy consumption for cement production can be reduced to 1.7 GJ/tonne cement in 2050, based on implementation of best practice technology (2.8 GJ/tonne clinker on average in 2050) and reduction of clinker content (from 80% in 2005 to 70% in 2050). This is an energy-efficiency improvement of 45% in 2050 and corresponds quite well to the estimate by Sinton et al (2002) who estimate a technical energy savings potential in cement of 50% by applying current state-of the art processes and the use of waste fuels.

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

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[8] ENCI, 2002, energy data for cement production, ENCI, Maastricht.

Recycling of aluminium

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

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

Around 16 million tonnes of aluminium was recycled in 2006 worldwide, which fulfilled around 33% of the global demand for aluminium (46 million tonnes).[9] Of the total amount of recycled aluminium, approximately 17% is due to packaging, 38% from transport, 32% from building and 13% from other products. Recycling rates for building and transport applications range from 60-90% in various countries. Recycling rates can be further increased e.g. by improved recycling of aluminium cans. In Sweden, 92% of aluminium cans are recycled and in Switzerland 88%. The European average is however only 40%.

We assume that by 2050, 40% of primary aluminium production can be reduced by increased recycling of aluminium, bringing the share of recycled aluminium to 60% of total aluminium production. This saves 38% of the electricity consumption for aluminium production (assuming secondary aluminium uses 5% of the energy demand for primary production). This means that the energy-efficiency improvement by increased recycling of aluminium equals 1.2% per year in the period 2010-2050.

Primary aluminium production and associated electricity consumption per region is given in Table 19.

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[9] http://www.world-aluminium.org/iai/stats/ (March 2008)

Table 19: Primary aluminium production per region in 2005[10]

Region	**Primary aluminium production (Mtonnes)**	**Electrical power used (MWh/tonne)**	**Electricity consumption (TWh)**	**Share in electricity consumption industry (%)**
OECD Europe	5.4	15.5	84	7%
OECD North America	5.4	15.5	83	7%
OECD Pacific	2.3	14.9	34	5%
Transition Economies	4.7	15.3	71	14%
China	7.8	15.1	118	9%
India	0.9	15.1	14	7%
Rest of developing Asia	0.3	15.1	4	1%
Latin America	2.4	15.1	36	10%
Africa	1.7	14.2	25	12%
Middle East	1.7	15.4	26	26%
World	***32.5***	***15.3***	**498**	**8%**

Additional to the recycling of aluminium, the energy-efficiency can be improved by applying (future) best available technologies. The current worldwide energy intensity for aluminium production is 15.3 MWh per tonne of aluminium. The theoretical minimum energy requirement for electrolysis is 6.4 MWh/tonne (IEA, 2008b). The current best practice is 12-13 MWh per tonne. By 2015 the best practice is estimated by Sinton et al (2002) to be 11 MWh/tonne.

Here we assume that in 2050 the average specific electricity consumption for primary aluminium production can be reduced to 9.5 MWh/tonne in 2050. The average electricity consumption for aluminium production then equals 4.2 MWh/tonne in 2050 (based on 0.7 MWh/tonne for secondary aluminium and 60% recycling).

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[10] http://www.world-aluminium.org/iai/stats/
http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/myb1-2006-alumi.xls

Chemical and petrochemical industry

For the chemical and petrochemical industry we look specifically at the energy-efficiency in ammonia production, chlorine production and in the petrochemical industry.

Ammonia production consumed more energy than any other process in the chemical industry and accounted for 18 percent of the energy consumed in this sector. Ammonia is mainly applied as a feedstock for fertilizer production. Current best practice energy-intensity is 8 GJ/tonne ammonia (excluding feedstocks, which are around 20 GJ/tonne NH_3) (Sinton et al, 2002). Current average energy use for ammonia production is equivalent to 15 GJ//tonne[11] NH_3 (REEEP, 2008). This corresponds to an average savings potential of 45% based on current best practice technology.

Chlorine production is the main electricity consuming process in the chemical industry, followed by oxygen and nitrogen production. The most efficient production process for chlorine production is the membrane process which consumes 2600 kWh/tonne chlorine, which is already close to the most efficient technology considered feasible (IEA, 2008b and Sinton et al, 2002). At the moment however, the mercury process is still commonly used for chlorine production, with an energy-intensity of around 4000-4500 kWh/tonne chlorine. Worldwide the average energy-intensity for chlorine production is around 3600 KWh/tonne[12] chlorine (IEA, 2008b and Sinton et al, 2002). This corresponds to a savings potential of 28%, based on the application of membrane technology for all chlorine production.

In the **petrochemical industry**, oil and gas feedstocks are commonly converted to monomers and building blocks such as ethylene, propylene, aromatics and methanol, which are further processed into polymers, solvents and resins. An important energy consuming step in the petrochemical industry is cryogenic, pressurized product separation. An alternative to this is separation by membranes. Although membranes are used for a number of products, like the recovery of hydrogen in refineries, it is not yet used for bulk chemicals. A membrane can be described as a selective barrier between two phases. This barrier is not equally permeable for different components. A driving force, e.g. a (partial) pressure difference, is applied over the membrane. The result is a separation of the feed stream into two streams: the stream that flows through the membrane (permeate) and the remaining stream (retentate). The use of membranes for product separation reduces compression energy requirements by 50% and separation energy requirements by 80% (Phylipsen et al, 1999). In total this corresponds to 35% of the overall energy consumption of an ethylene plant.

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

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[11] 15 GJ/tonne NH_3 for the European Union, 18 for the United States, 20 for Russia, 30 for China, 23 for India

[12] 3000 kWh/tonne in Japan, 3500 kWh/tonne in Western Europe and 4300 kWh/tonne in the United States

Other industries

For the energy-efficiency potential of the remaining industries, corresponding to roughly 50% of industrial energy demand, we base the potential for energy-efficiency improvement on an estimate of decrease in energy-intensity (MJ/unit of GDP).

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

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

Examplary, the first two are discussed in more detail below.

Electric motor systems

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

1. Variable Speed Drives (VSDs), which can lead to savings of electricity consumption of 15% to 35% of the electricity consumption of electric motor systems (EC, 1999). VSDs can be applied in approximately 40% to 60% of the cases.

2. High Efficiency Motors (HEMs), which reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. The specific energy savings depend on the efficiency of the current motor. For large motors the savings are likely to be small (1-2%) and for smaller motors larger (up to 75%) (Keulenaer et al, 2004). On average HEMs can lead to an electricity savings of 3% to 5% (UU, 2001).

3. Implementing efficient pumps, compressors and fans.

    a. A case study has shown that 25% of the electricity consumption of a compressor can be saved by measures as process control, heat recovery and improvement of air treatment. Compressors account for about 15% of the electricity consumption of industrial motor systems. (Keulenaer et al, 2004)

    b. A case study has shown that 30% of the electricity consumption of a pump system can be saved by adapting the design. The payback time is twelve weeks. Pumps account for about 35% of electricity consumption of industrial motor systems. The technical electricity savings potential for conventional pumping systems is 55%. This includes low friction pipes, with an efficiency of 90% in comparison to 69% for conventional pipes. (Keulenaer et al, 2004)

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

Process Optimization and Integration (pinch analysis)

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

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

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

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

Summary energy-efficiency potentials in industry

Table 20 gives a summary of the assumptions used for the technical potentials in industries in 2020, 2030 and 2050. These assumptions are largely based on the work done for the update of the [r]evolution scenario. Please note that the energy-efficiency improvement in the reference scenario is assumed to be 1% per year (for full discussion see section 3.2.1).

Table 20: Summary table regarding assumptions technical potentials in 2050

		Specific energy consumption (GJ/tonne)	**Current best practice**	**Thermo-dynamic minimum**	**Technical potential in [r]evolution scenario**			**Refer-ence scenario**
Sector	**Unit (specific final energy**	**2005**	**2005**		**2020**	**2030**	**2050**	**2050**
Iron and steel	Primary steel BF/BOF route (GJ/tonne crude steel)	10	6.4	1.3				
Iron and steel	Primary steel OHF route (GJ/tonne	23						
Iron and steel	Secondary steel EAF route (GJ/tonne crude steel)	2.2	1.6	1.3				
Iron and steel	Hot/cold rolling (GJ/tonne crude steel)	2.9	2.2	0.05				
Iron and steel	Share secondary steel	35%	35%		41%	48%	60%	
Iron and steel	**GJ/tonne crude steel**	**12.5**	**5.5**	**1.3**	**10.3**	**8.0**	**3.5**	**8.0**
Iron and steel	***Index (GJ/tonne crude steel)***	***100***	***44***	***10***	***82***	***64***	***28***	***64***
Non-metallic minerals	GJ/tonne clinker	4.2	3.1	1.8	3.9	3.5	2.8	
Non-metallic minerals	Clinker to cement ratio	80%	25%	<25%	75%	70%	60%	
Non-metallic minerals	Electricity use grinding/blending (kWh/tonne cement)	110	105	<100				
Non-metallic minerals	**GJ/tonne cement**	**3.7**	**1.2**	**<0.5**	**3.2**	**2.7**	**1.7**	**2.4**
Non-metallic minerals	***Index (GJ/tonne)***	***100***	***31***	***<14***	***86***	***73***	***45***	***64***
Aluminium	Primary aluminium (MWh/tonne aluminium)	15.3	12.5	6.4	13.85	12.4	9.5	
Aluminium	Secondary aluminium (GJ/tonne aluminium)	0.8	0.8	<0.8	0.7	0.7	0.7	
Aluminium	Share secondary aluminium	33%	33%	100%	40%	47%	60%	
Aluminium	**GJ/tonne aluminium**	**10.5**	**8.6**	**<0.6**	**8.9**	**7.4**	**4.2**	**6.7**
Aluminium	***Index (GJ/tonne aluminium)***	***100***	***82***	***<6***	***85***	***70***	***40***	***64***
Ammonia production	GJ/tonne ammonia	15	8					
Ammonia production	Ammonia (index)	100	53					
Chlorine production	MWh/tonne chlorine	3.6	2.6					
Chlorine production	Chlorine (index)	100	72					
Ethylene production	Ethylene production by naphtha (GJ/tonne)	25-40	18					
Ethylene production	Ethylene production (index)	100	60					
Chemical and petrochemical	Index best practice implementation (GJ/tonne)	100	62		89	77	55	
Chemical and petrochemical	Index improved material efficiency and recycling (GJ/tonne)	100			95	90	80	
Chemical and petrochemical	***Index (GJ/tonne)***	***100***			***86***	***72***	***45***	***64***
Other industries	***Index (GJ/tonne)***	***100***			***84***	***68***	***35***	***64***
Total industry	**Index (GJ/tonne)**	**100**			**84**	**69**	**38**	**64**

Table 21 shows the resulting potentials per region and per sector as % per year in the period 2010 to 2050. The potentials range from 2.2% per year for OECD Europe to 2.8% per year for the Middle East. The global potential for energy demand reduction in industry is 2.4% per year. The regional differences are caused by the current energy-efficiency for iron and steel production. For the other industrial sectors we assumed the same reduction potential for all regions based on worldwide average specific energy consumption.

Table 21: Technical potential for different types of industry sectors (% per year period 2010-2050)

	Iron and steel	Aluminium production	Chemical industry	Non-metallic minerals	Other industries	**Total Industry**
OECD Europe	0.9	2.2	2.0	1.5	2.6	**2.2**
OECD N.-Am.	1.4					**2.3**
OECD Pac.	0.9					**2.2**
Transition Ec.	3.4					**2.3**
China	2.2					**2.6**
India	1.8					**2.6**
Rest dev. Asia	0.9					**2.4**
Middle East	0.0					**2.8**
Latin America	3.5					**2.5**
Africa	2.8					**2.3**
World	**3.0**	**2.2**	**2.0**	**1.5**	**2.6**	**2.4**

3.3.3 Transport

The energy demand projection in the [r]evolution scenario is based on the WBCSD mobility database, which gives worldwide energy-intensity data for transport, including energy use and mileage for different transport modes. This database was finished in 2004 after a collaboration between the IEA and the WBCSD's Sustainable Mobility Project (SMP) to develop a global transport spreadsheet model. The total energy demand for transport in the WBCSD scenario is quite close to the energy demand in the reference scenario. We therefore assume that we can safely use the modal shares and energy intensities as in the WBCSD scenario.

Please note that international marine shipping is not included in this study. The WEO world final energy demand does not include estimates for international bunker fuels. Energy use from international marine shipping amounts to 9% of worldwide transport energy demand in 2005 and 7% in 2050.

The WBCSD scenario distinguished between the following road transport modes (Fulton & Eads, 2004):

- Light-duty vehicles (LDVs) are defined as 4-wheel vehicles used primarily for personal passenger road travel. These are typically cars, SUVs, small passenger vans (up to 8 seats) and personal pickup trucks. We also refer to LDVs as passenger cars or cars.
- Heavy duty trucks are defined here as long-haul trucks operating mostly on diesel fuel. These trucks carry large loads, with relatively low energy intensity (energy use per tonne-kilometre).
- Medium-duty trucks are smaller with a higher energy intensity. These include medium-haul trucks and delivery vehicles.
- Buses have been divided into two size classes, essentially full size buses and “minibuses”, with the latter encompassing small buses and large passenger vans, typically used for informal “paratransit” services.

Figure 29 and Figure 30 give the breakdown of final energy demand in the reference scenario for transport by mode in 2005 and 2050.This scenario does not take into account energy demand reduction by a modal shift in transport (e.g. from road to rail). This is considered to be a behavioural change to reduce transport energy demand and not a technical measure for energy-efficiency improvement aimed at e.g. reducing energy use by vehicle km.

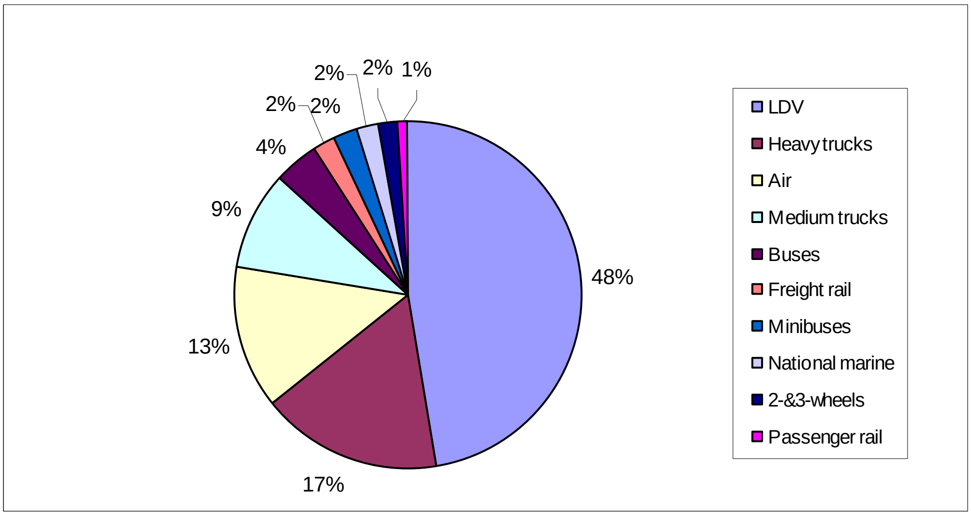

Figure 29: World final energy use per mode 2005

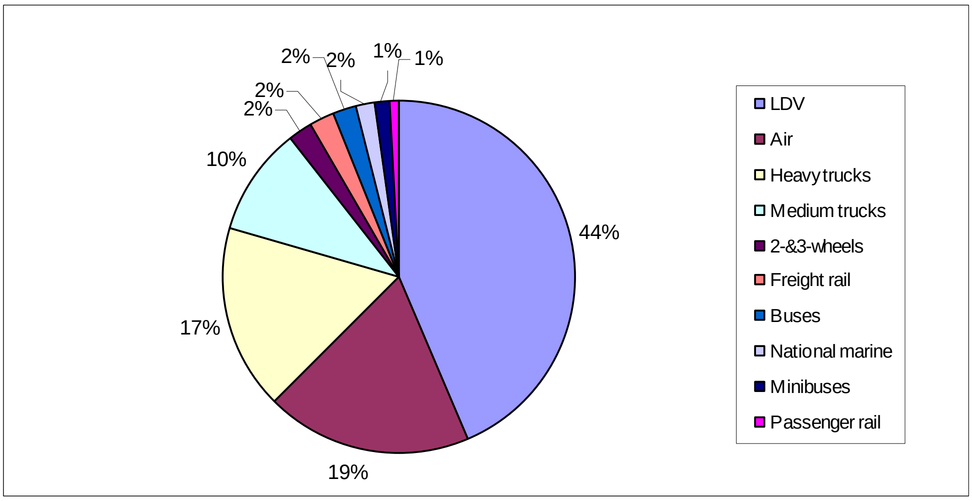

Figure 30: World final energy use per mode 2050

As can be seen in the above figures, the share of energy demand for cars in total energy demand is largest and slightly decreases from 48% in 2005 to 44% in 2050. The share of air transport increases from 13% to 19%. Remarkable is the high share of road transport in total transport energy demand; 82% in 2005 and 74% in 2050.

Figure 31 shows the share of energy demand for transport in total final energy demand per region in 2005 and 2050.

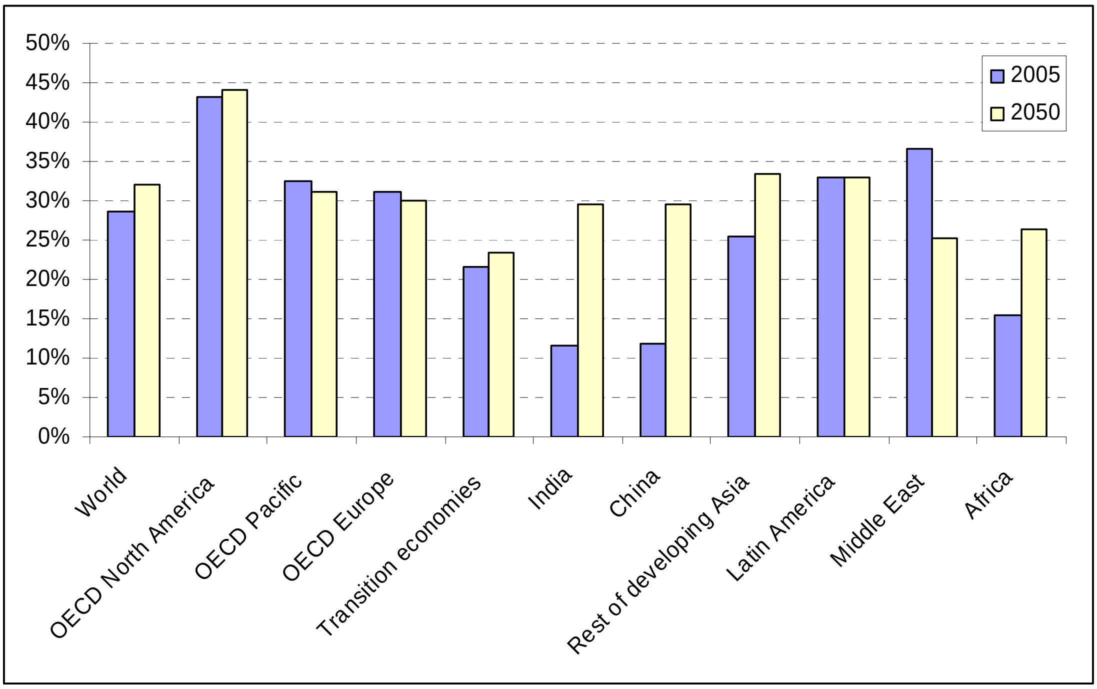

Figure 31: Share of transport in total final energy demand per region in 2005 and 2050

Worldwide, transport accounts for nearly 30% of final energy demand. For most regions the share of transport in energy demand is expected to increase by 2050. Especially developing regions show a sharp increase from 12-15% for India, China and Africa in 2005 to 26-30% in 2050.

The technical potentials for transport are discussed per type of mode. For passenger transport (cars, air, rail, 2 and 3-wheel and buses) the potentials are based on data regarding specific energy use in MJ per passenger-km. For freight transport (road, rail, national marine) the potentials are based on data regarding MJ per tonne-km.

Passenger cars

Many technologies can be used to improve the fuel efficiency of passenger cars. Examples are energy-efficiency improvements in engines, weight reduction and friction and drag reduction (see for instance Smokers *et al.*, 2006).

The impact of the various measures on fuel efficiency can be substantial. Hybrid vehicles, combining a conventional combustion engine with an electric engine, have relatively low fuel consumption. The most well-known today is the Toyota Prius, which originally had a fuel efficiency of about 5 litre of gasoline-equivalent (g.e.)[13] per 100 km (litre g.e.$_{g.}$/100 km). Recently, Toyota presented an improved version with a lower fuel consumption of 4.3 litre ge/100 km. Further developments are underway of new concept cars with specific fuel use as low as 3 litre g_e/100 km. There are suggestions that applying new light materials, in combination with the new propulsion technologies can bring fuel consumption levels down to 1 litre g_e/100 km.

Table 22 shows an overview of best practice efficiencies now and in the future.

Table 22: Efficiency of cars and new developments (Blok, 2004)

	Fuel consumption (litre g.e./100 km)	**Source**
Present average	10.4	IEA/SMP (2004)
Hybrids on the market (medium-sized cars)	~5 (1997) 4.3 (2003)	EPA (2003)
Improved hybrids or fuel cell cars (average car)	2 – 3	USCAR (2002) Weiss et al (2000)
Ultralights	0.8 - 1.6	Von Weizsäcker et al (1998)

Based on SRU (2005), the technical potential in 2050 for diesel cars is 1.6 liter g_e/100 km and for petrol cars 2.0 litre g_e/100 km. We assume that fuel consumption of average cars in OECD Europe can be as low as 2.0 litre g_e/100 km in 2050 and we adapt the same improvement percentage in efficiency (about 3% per year) for other regions. In order to reach this on time, these cars should be on the market by 2030 assuming the maximum lifetime of a car is 20 years.

Figure 32 shows the results in fuel intensity per region. OECD Europe has currently the lowest energy-intensity for passenger cars. We do not assume that the energy-intensity for cars in all regions can be as low as 2 litre g_e/100 km because the difference in energy-intensity per region is caused by factors as difference in car size/type and quality of roads, which are difficult to influence. Therefore we apply the percental improvement in OECD

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[13] Gasoline equivalent is the amount of alternative fuel it takes to equal the energy content of one litre of gasoline: 32 MJ (lower heating value).

Europe to the other regions.

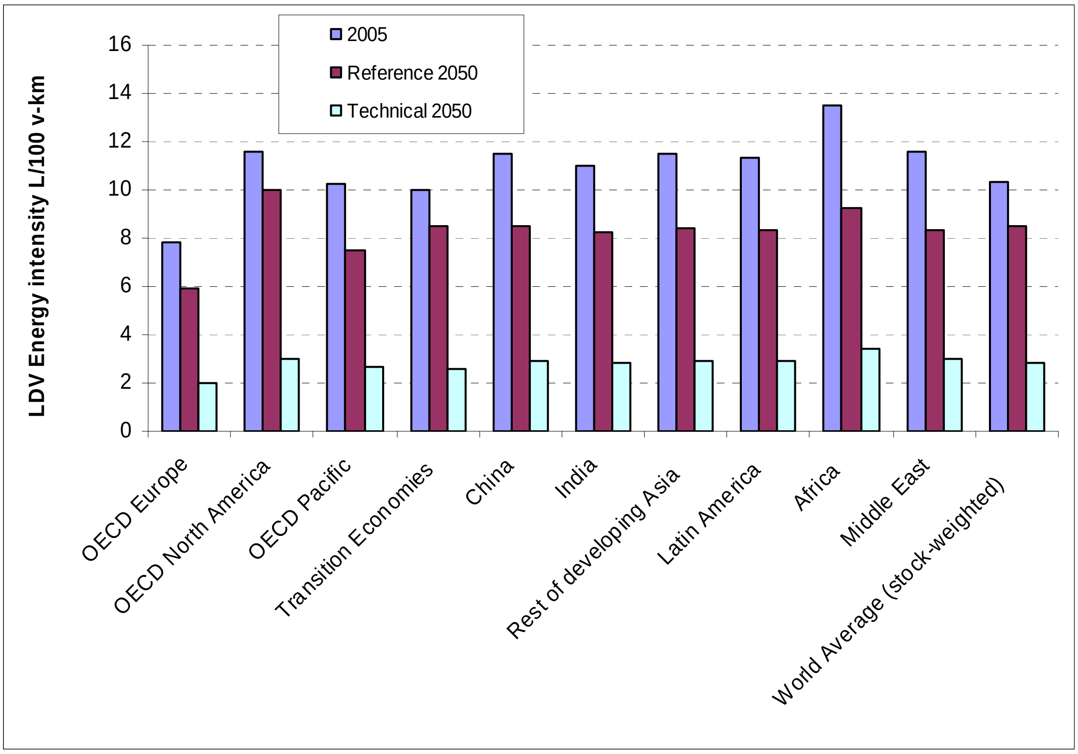


Figure 32: Reference scenario and 2050 technical potential energy intensities for different regions for LDV transport

Air transport

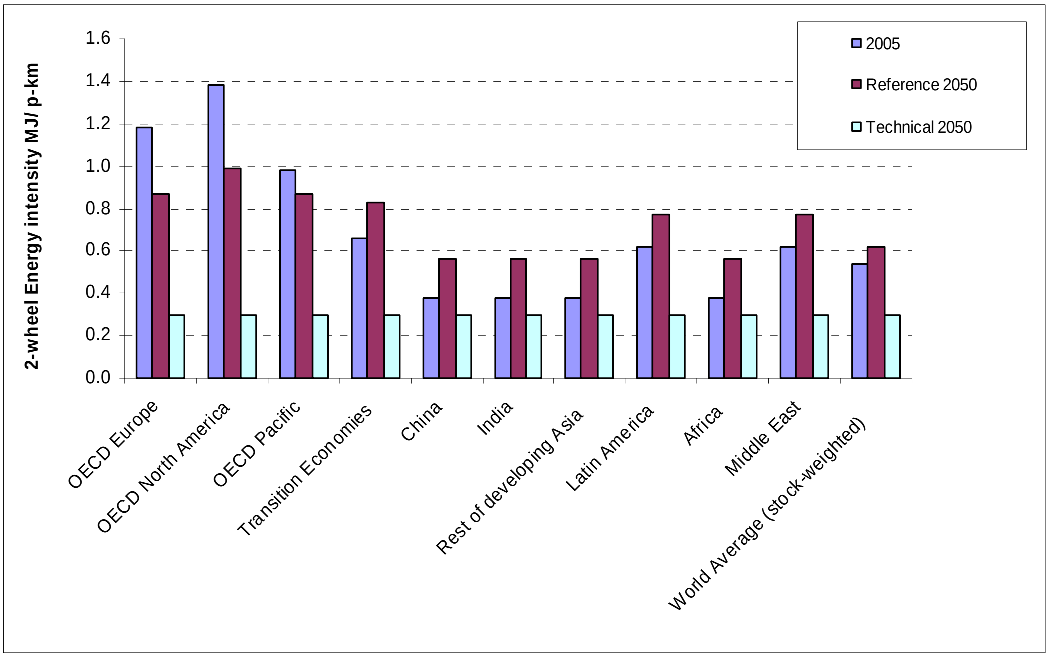
Savings for air transport are taken from Akerman (2005). He reports that 65% lower fuel intensity is technically feasible by 2050. This is applied to 2005 energy intensity (2.5 MJ/p.km) data in order to calculate the technical potential. All regions have the same energy intensities in 2005 and 2050 due to lack of regionally-differentiated data.

Passenger rail

Savings for passenger and freight rail were taken from Fulton & Eads (2004). They report a historic improvement in fuel economy of passenger rail of 1% per year and freight rail between 2 and 3% per year. Since no other sources are available for this study we assume for the technical scenario 1% improvement of energy-efficiency per year for passenger rail and 2.5% for freight rail. The average energy-intensity for passenger rail transport per region in 2005 is 0.3 MJ/p.km. All regions have the same energy intensities in 2005 and 2050 due to lack of regionally-differentiated data.

2-wheel and 3-wheel

For 2-wheelers the potential is based on IEA/SMP (2004), where 0.3 MJ/p-km is the lowest value. For 3-wheelers we assume the technical potential is 0.5 MJ/p-km in 2050. The uncertainty in these potentials is high. However 2 and 3-wheelers account only for 1.5% of transport energy demand. Figure 33 shows the energy-intensity per region in 2005 and 2050 for 2 and 3-wheel vehicles.



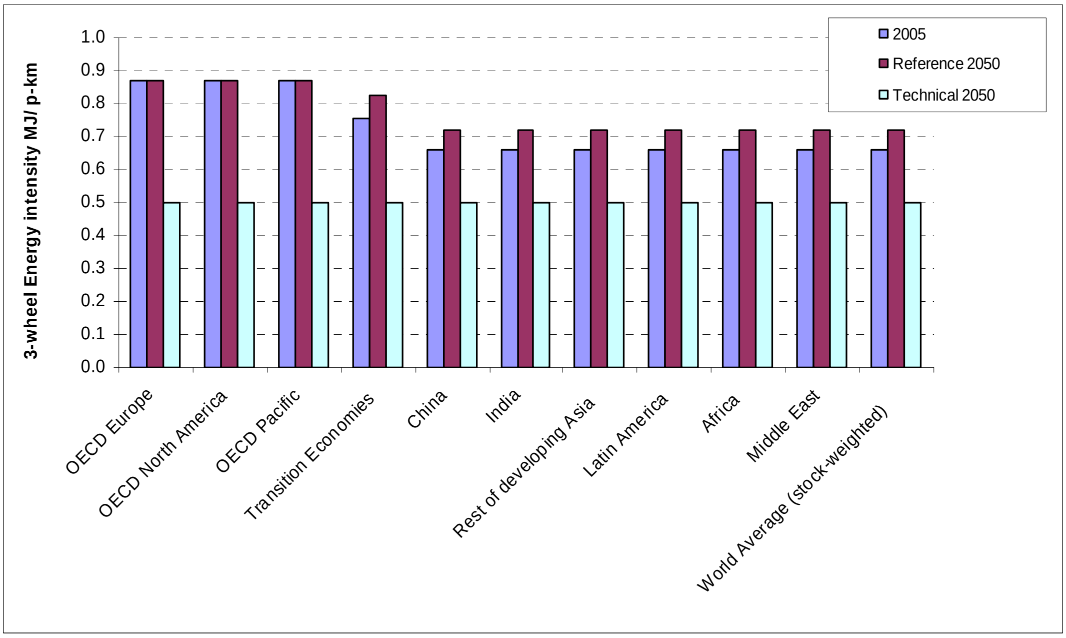
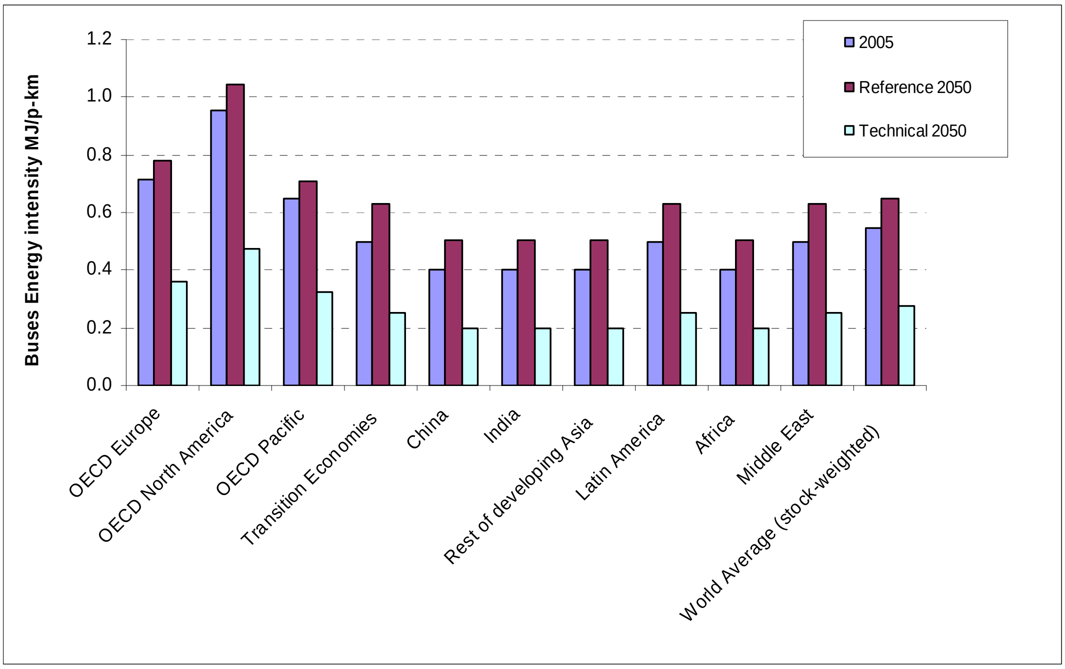


Figure 33: Reference scenario and 2050 technical potential energy intensities for different regions for 2 and 3-wheel vehicles, respectively

Buses

The company Enova Systems estimates possible energy savings for buses of 50% on average. We have used this improvement potential and applied it to 2005 energy intensity numbers per region. For minibuses the ACEEE reports (DeCicco *et al.*, 2001) a 55% fuel economy improvement by 2015. Since this is a very ambitious target and will most likely not be reached by 2015, we use this potential for 2050. Figure 34 shows the energy-intensity per region in 2005 and 2050 for buses and minibuses.



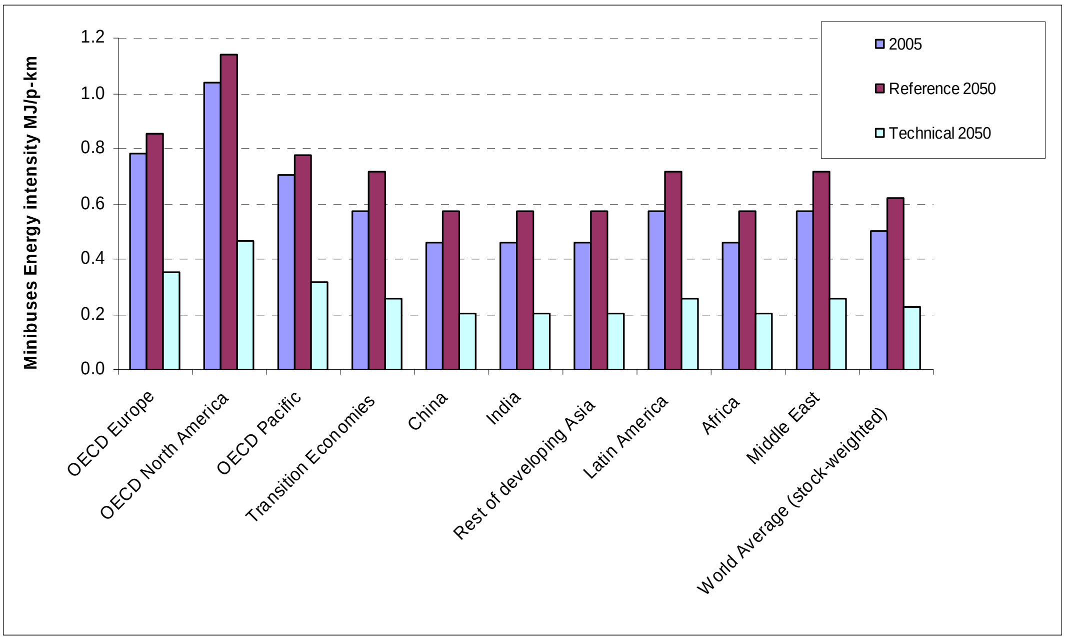


Figure 34: Reference scenario and 2050 technical potential energy intensities for different regions for buses and minibuses

Freight road

Elliott et al., 2006 give possible savings for heavy- and medium-duty freight trucks. The list of reduction options is expanded in Lensink and De Wilde, 2007. For medium-duty trucks a fuel economy saving of 50% is reported in 2030 (mainly due to hybridization), for heavy-duty trucks savings are estimated of 39% in 2030. We applied these percentages to 2005 energy intensity data, calculated the fuel economy improvement per year and extrapolated this yearly growth rate until 2050. Figure 35 and Figure 36 show the results per region.

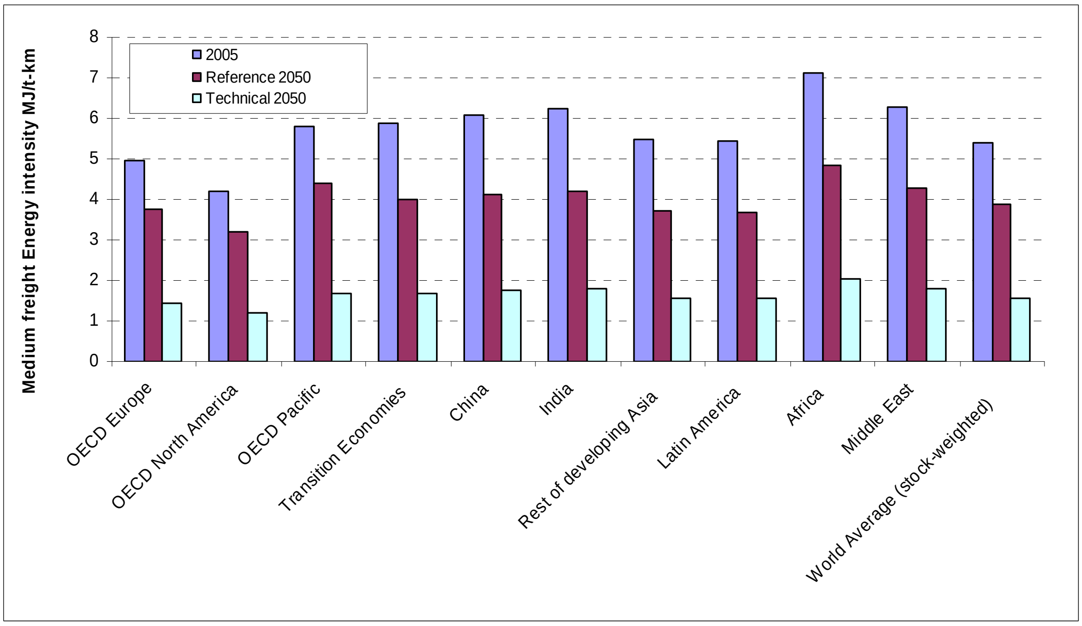


Figure 35: Reference scenario and 2050 technical potential energy intensities for different regions for medium freight transport

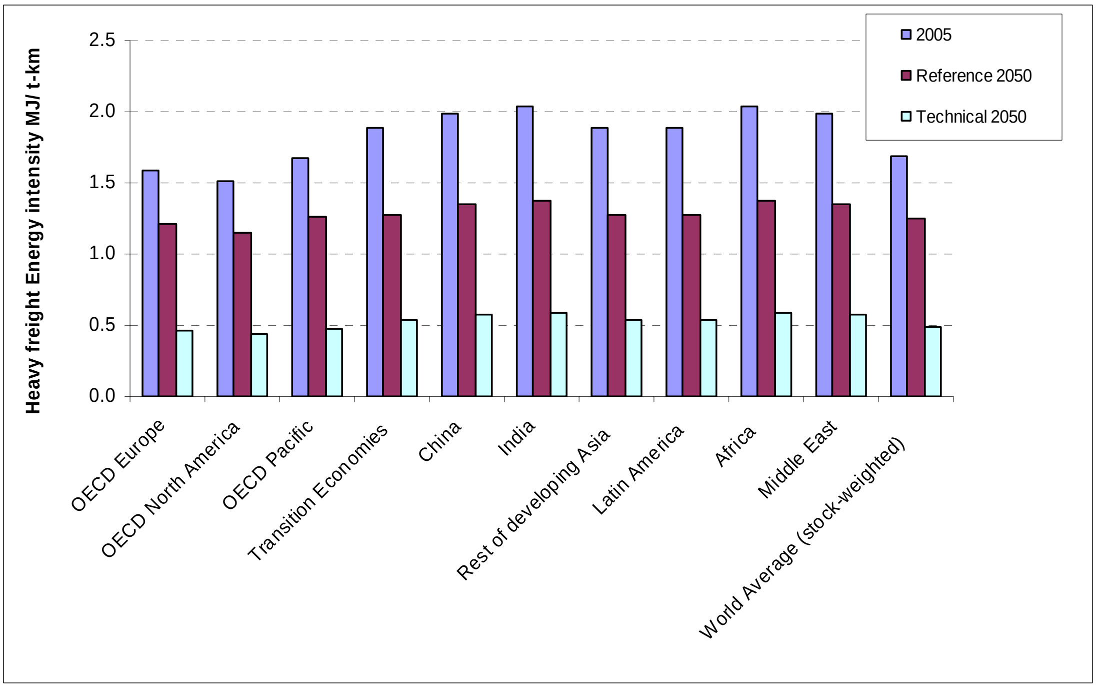


Figure 36: Reference scenario and 2050 technical potential energy intensities for different regions for heavy freight transport

Current intensities are highest in Middle East, India and Africa and lowest in OECD North America. The reference scenario predicts that future values will converge assuming past improvement percentages and assuming a higher learning rate in developing regions.

Freight rail

Savings for freight rail are taken from Fulton & Eads (2004). They report a historic improvement in fuel economy of freight rail between 2 and 3% per year. Since no other sources are available for this study we assume for the technical scenario 2.5% improvement of energy-efficiency per year for freight rail. The figure below shows the energy-intensity per region in the reference scenario and in the two low energy demand scenarios. Figure 37 shows the energy-intensity per region in 2005 and 2050.

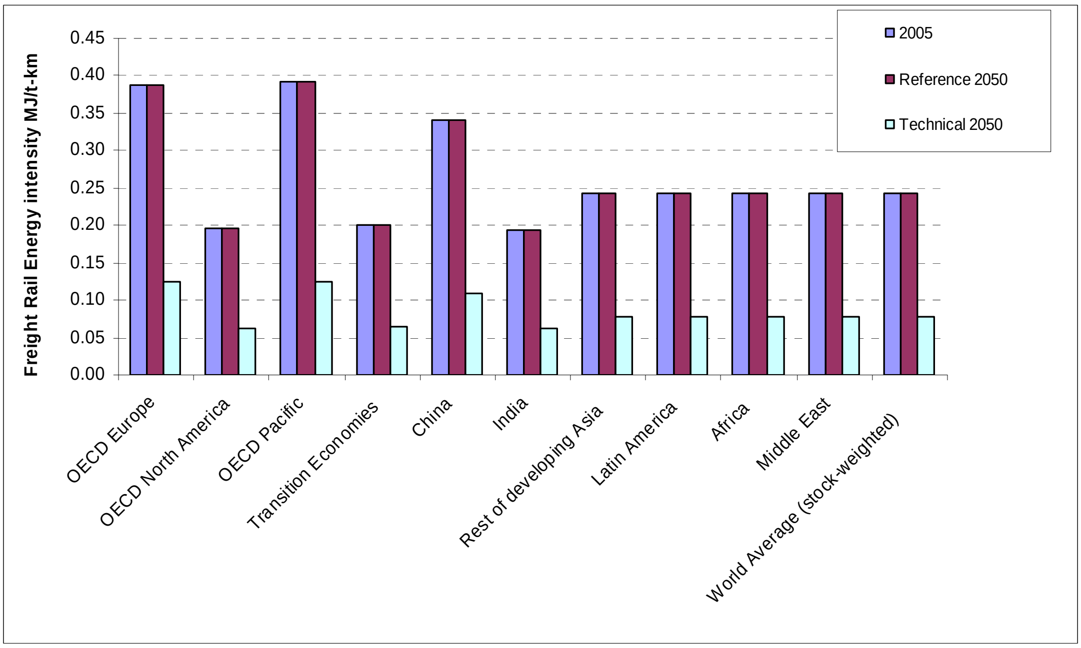


Figure 37: Reference scenario and 2050 technical potential energy intensities for different regions for freight rail

National marine

National marine savings were also taken from Lensink and De Wilde. They report 20% savings in 2030 for inland navigation as realistic potential, but with current available technology, efficiency savings up to 30% with respect to the current fleet are possible. To get to the potential in 2050, we used the same approach as described for road freight above. Figure 38 shows the energy-intensity per region in 2005 and 2050.

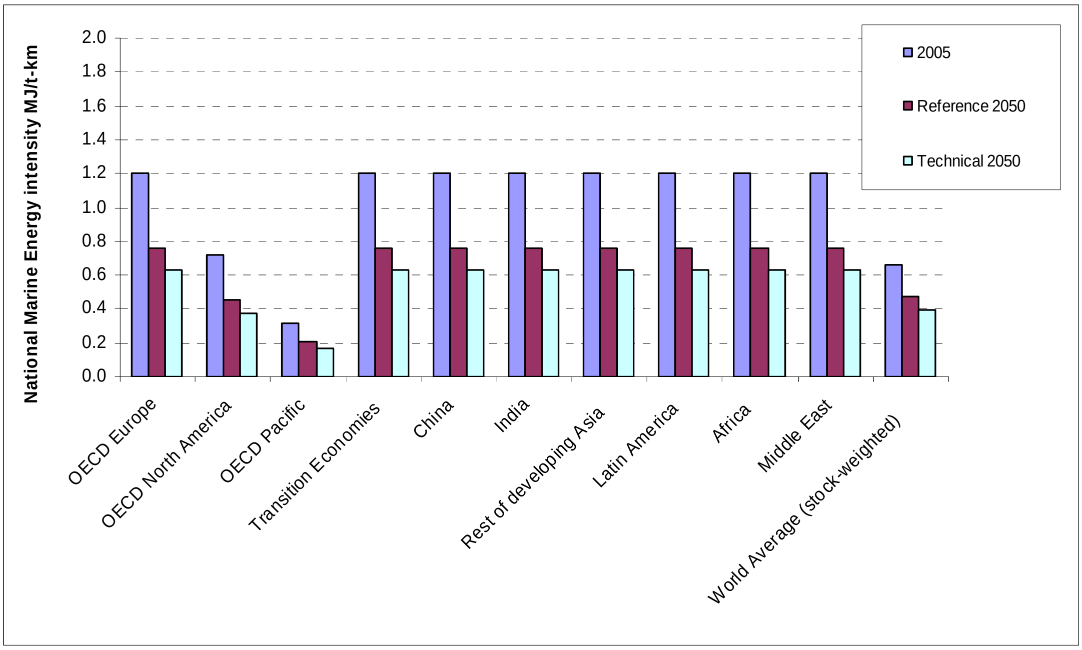


Figure 38: Reference scenario and 2050 technical potential energy intensities for different regions for national marine transport

Summary technical potentials in transport

Table 23 gives a summary of the assumptions for the technical potentials for energy-efficiency improvement for transport. The potentials are largely based on work done for the [r]evolution scenario.

Table 23: Technical potential for world passenger transport

	Reference scenario		Technical potential			Efficiency improvement 2010-2050 %/y
MJ/p-km	**2005**	**2050**	**2020**	**2030**	**2050**	
LDV (L/100 v-km)	10.4	8.5	7.5	5.4	2.8	3.2%
LDV (MJ/p-km)	2.2	2.0	1.6	1.1	0.6	3.2%
Air	2.6	1.9	2.0	1.5	0.9	2.6%
Buses	0.5	0.6	0.4	0.4	0.3	1.3%
Mini-buses	0.5	0.6	0.4	0.3	0.2	2.3%
2-wheels	0.5	0.6	0.4	0.4	0.3	1.3%
3-wheels	0.7	0.7	0.6	0.6	0.5	0.8%
Pass rail	0.3	0.3	0.3	0.2	0.2	1.0%
MJ/t-km						
Medium trucks	5.4	3.9	3.9	2.8	1.5	3.2%
Heavy trucks	1.7	1.3	1.3	0.9	0.5	3.0%
Freight rail	0.2	0.2	0.2	0.1	0.1	1.7%
National marine	0.7	0.5	0.6	0.5	0.4	1.4%
Total (index, 2005 = 100)	100		75	57	32	2.8%

The energy-efficiency improvement potential ranges from 0.8-3.2% per year for the period 2010-2050 and depends on the transport mode. The potential for passenger cars and trucks is assumed to be largest. Globally, the technical potential for energy-efficiency improvement in transport is estimated to be 2.8% per year.

Figure 39 and Figure 40 show the global average energy-intensity for passenger and freight transport in 2005 and 2050.

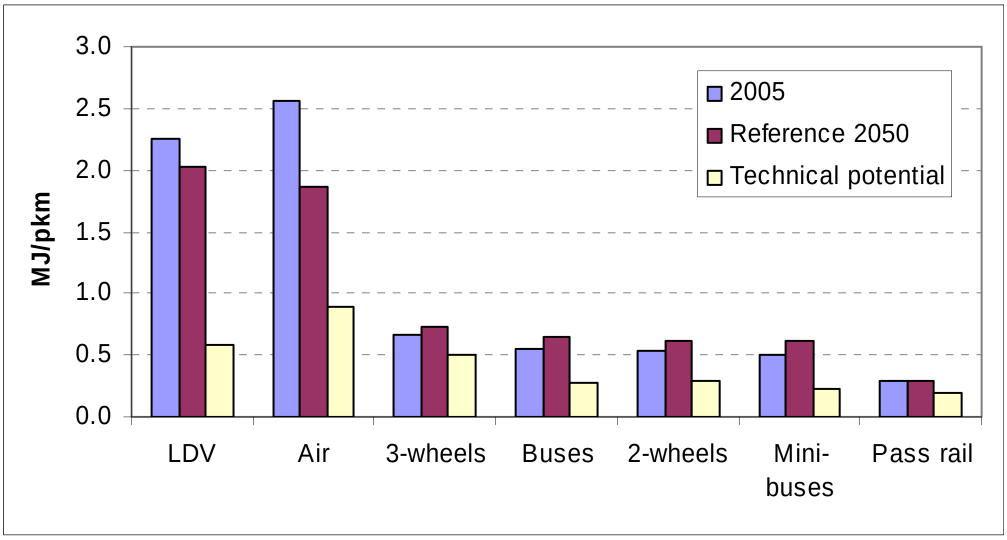


Figure 39: Reference scenario and 2050 technical potential energy intensities for the world for passenger transport

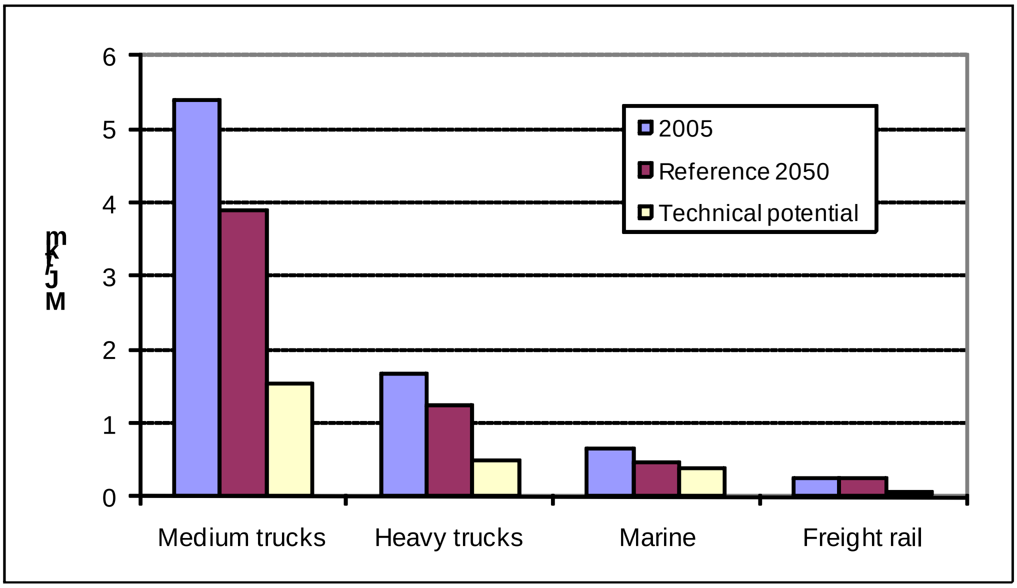


Figure 40: Reference scenario and 2050 technical potential energy intensities for the world for freight transport

3.3.4 Transformation sector

The major share of transformation losses occur in the power generation sector. In 2005 this corresponds to 90% of total transformation losses as worldwide average, including electricity transmission and distribution losses (IEA, 2007b). The remaining transformation losses occur in coal transformation (e.g. cokes production) and oil refining.

In this section we look at transformation losses in power generation in detail. For the remaining transformation losses we assume the same technical potential for energy-efficiency improvement as in industries (see section 3.3.2).

Figure 41 shows the global fuel mix for power generation, based on electricity output in 2005 and 2030. The figure shows that currently 40% of power generation is generated by coal, 7% by oil and 20% by natural gas. Together these fossil fuel sources correspond to 67% of power generation. Nuclear power and hydropower correspond to 15% and 16% of power generation in 2005, respectively. By 2030 the fuel mix is not expected to have changed much. By then, 70% of power is expected to be generated from fossil fuels, 9% by nuclear power and 21% by renewable energy sources.

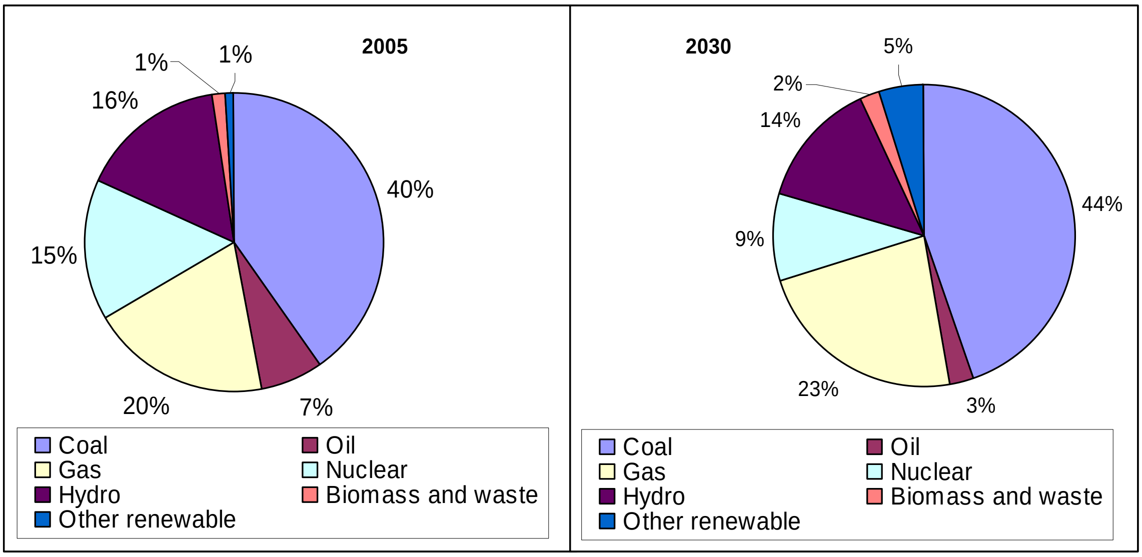


Figure 41: Global fuel mix for power generation based on electricity output (IEA, 2007)

In this section we focus on the technical potential for improving the energy-efficiency of fossil-fired power generation, since this is the largest source used for power generation and it is of most concern for causing climate change and pollution.

The efficiency of fossil-fired power generation is calculated by the following formula: $E = \frac{P}{I}$

Where:

E = Energy-efficiency of power generation

P = Power production in region (based on gross output, including auxiliary electricity consumption)

I = Total fuel input for power generation in region (in lower heating value)

Currently, the global average conversion efficiency for fossil-fired power generation is 32% for coal, 34% for gas and 34% for oil in 2005 (IEA, 2007). The current best practice efficiency[14] corresponds to 60% for gas-fired power generation, 50% for oil-fired power generation and 47% for coal-fired power generation (European Commission (2006), Hendriks et al. (2004), VGB (2004), Power Technology (2008)). Currently, a demonstration coal plant is being constructed in Europe with a steam temperature of 700 °C. The energy-efficiency of this plant is expected to be in the range of 52 to 55%. Commercial availability of the technology is expected after 2020 (Techwise A/S, 2003a). For gas-fired power plants there are already several plants built with net energy-efficiencies of 62%.

Since the typical lifetime of a fossil power plant is 30-40 years, by 2050 most power plants in operation today will have been replaced. We assume that by 2050 the average efficiency of power plants can be 50%[15] for coal plants, 50% for oil plants and 60% for gas plants. This corresponds to an average efficiency for fossil-fired power generation of 53% in 2050, based on 64% coal-fired power generation, 33% gas-fired power generation and 4% oil-fired power generation, corresponding to the expected fossil fuel mix in 2030. This is an improvement potential of 38% in the period 2010-2050 and corresponds to 1.2% energy-efficiency improvement per year. We use this improvement potential to calculate intermediate potentials for 2020 and 2030.

The energy-efficiency improvement potential differs per region and depends on the fuel mix for fossil-fired power generation and the current energy-efficiency. Figure 42 shows the fuel mix for fossil power generation per region in 2005 and 2030.

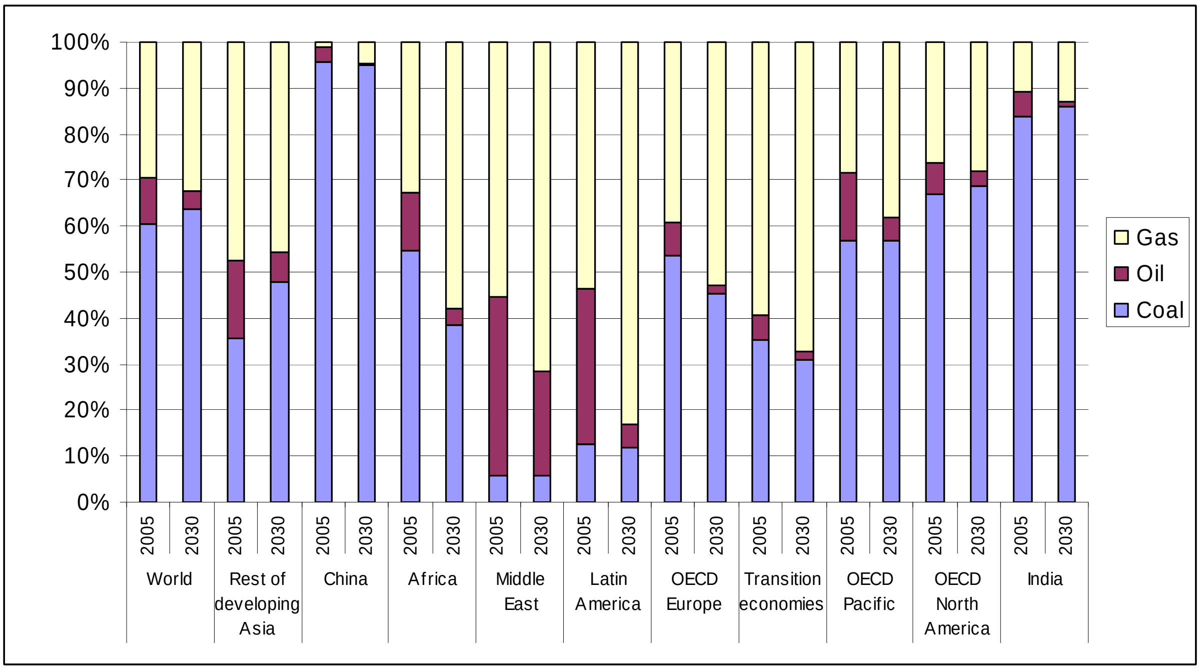


Figure 42: Fossil fuel mix per region in 2005 and 2030, based on electricity output (IEA, 2007a)

In most regions coal and gas are the predominant source for fossil power generation. In the Middle East oil is also used for power generation by (40% in 2005). For the calculation of the technical potential for energy-efficiency improvement, we assume that the fuel mix for fossil

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[14] Net design energy-efficiency, auxiliary power consumption is excluded.

[15] Assuming best practice for coal-fired power plants increases quite strongly in the next decade to 52-55%.

power generation in 2050 is the same as in 2030.

Figure 43 shows the average efficiency for fossil-fired power generation in 2005 and the technical potential for the energy-efficiency in 2050.

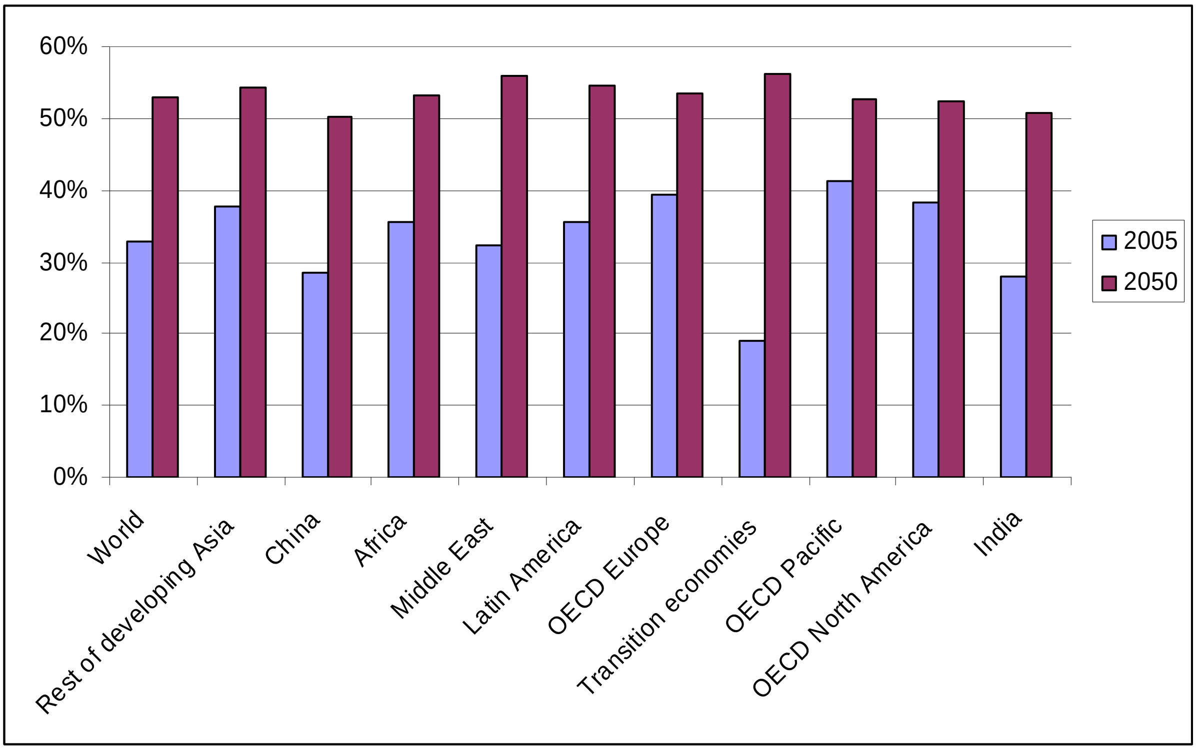

Figure 43: Average efficiency for fossil-fired power generation in 2005 and technical potential in 2050 per region

For China, where fossil-fired power generation is mainly produced from coal, the potential efficiency equals 50% in 2050. For regions with a high share of natural gas the potential efficiency equals 56% in 2050.

Table 24 shows the underlying data for Figure 43, including the energy-efficiency improvement potential as percentage per year.

Table 24: Average efficiency fossil-fired power generation in 2005 and 2050 and improvement potential per year

	2005	2050	Energy-efficiency improvement (%/y) 2010-2050
OECD Pacific	41%	53%	0.6%
OECD Europe	39%	53%	0.8%
OECD North America	38%	52%	0.8%
Rest of developing Asia	38%	54%	0.9%
Africa	36%	53%	1.0%
Latin America	36%	55%	1.1%
Middle East	32%	56%	1.4%
China	28%	50%	1.4%
India	28%	51%	1.5%
Transition economies	19%	56%	2.7%
World	**33%**	**53%**	**1.2%**

Table 25 shows the technical potentials for energy-efficiency improvement in the transformation sector per region. The potential for the other transformation industries, except power generation is based on the technical potential for industries in the region. For power generation by renewable sources and nuclear power we conservatively assume an energy-efficiency improvement potential of 0.5% per year, due to a lack of comprehensive data[16]. This corresponds to an efficiency improvement of 18% in the period 2010-2050 and concerns mainly retrofit of hydropower plants, more efficient new wind turbines and improved nuclear reactors.

Table 25: Technical potential energy-efficiency improvement transformation sector per region[17]

	Energy-efficiency improvement (%/y) 2010-2050			
	Fossil power generation	*Renewable and nuclear power generation*	*Other transformation sector*	**Total transformation sector**
OECD Europe	0.8%	0.5%	2.2%	1.1%
OECD North America	0.8%	0.5%	2.3%	0.9%
OECD Pacific	0.6%	0.5%	2.2%	1.0%
Transition economies	2.7%	0.5%	2.3%	2.3%
China	1.4%	0.5%	2.6%	1.5%
India	1.5%	0.5%	2.6%	1.6%
Rest of developing Asia	0.9%	0.5%	2.4%	0.9%
Middle East	1.4%	0.5%	2.8%	1.9%
Latin America	1.1%	0.5%	2.5%	1.7%
Africa	1.0%	0.5%	2.3%	1.7%
World	**1.2%**	**0.5%**	**2.4%**	**1.4%**

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[16] In the past years the energy-efficiency of many RES technologies has increased significantly, but aggregated learning rates for the coming decades are not available.

[17] Assuming the same fuel mix (i.e. share of renewable energy sources) of power generation as in the reference scenario.

Figure 44 shows the conversion efficiency in 2005 and the technical potential for the conversion efficiency in 2050 per region (with the same fuel mix (e.g. share of renewable energy sources) for power generation as in the reference scenario).

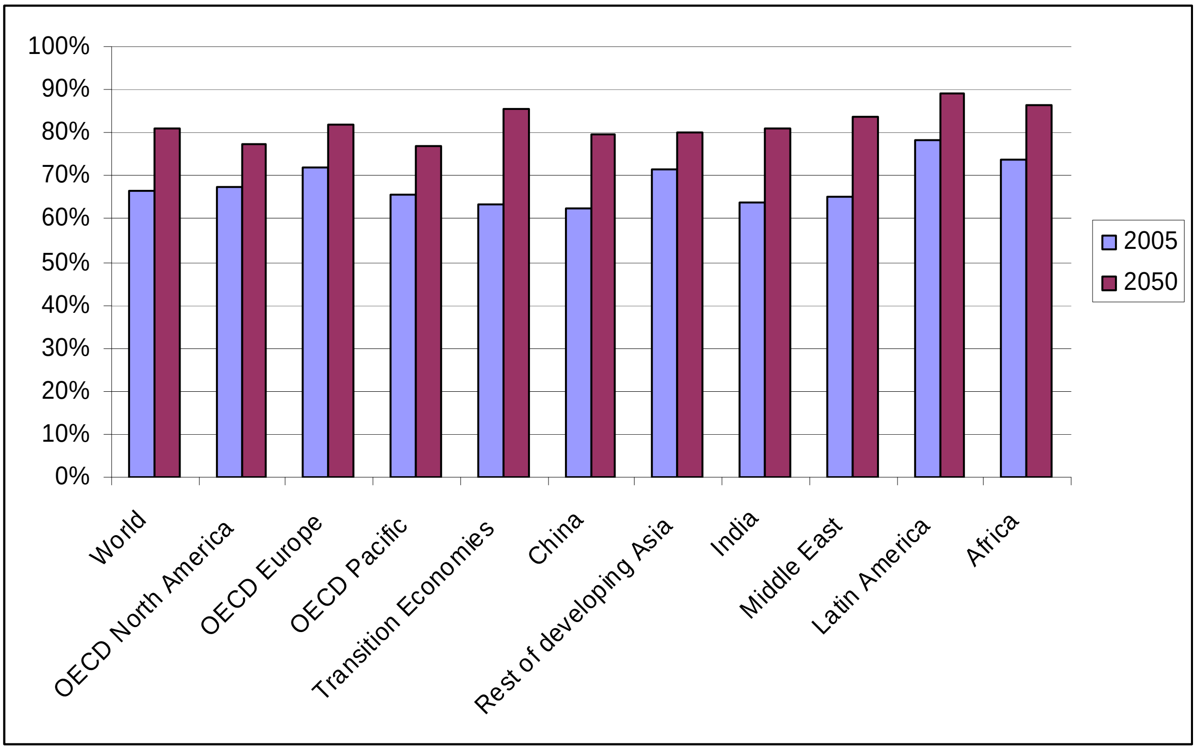

Figure 44: Conversion efficiency of transformation sector (ratio: final energy demand / primary energy demand)

Table 26 shows the underlying data of the figure with intermediate values for 2020 and 2030.

Table 26: Conversion efficiency of transformation sector (ratio: final energy demand / primary energy demand)

	2005	**2020**	**2030**	**2050**
Latin America	78%	82%	85%	89%
Africa	74%	78%	81%	86%
OECD Europe	72%	75%	78%	82%
Rest of developing Asia	72%	74%	76%	80%
OECD North America	68%	70%	73%	77%
OECD Pacific	66%	69%	72%	77%
Middle East	65%	71%	76%	84%
India	64%	69%	74%	81%
Transition Economies	63%	71%	77%	85%
China	62%	68%	72%	80%
World	**67%**	**71%**	**75%**	**81%**

Sensitivity analysis for carbon capture and storage

The use of capture and storage (CCS) at a power plant reduces the electric efficiency by 11-25% (Hendriks et al, 2004). In this sensitivity analysis we aim to see how the derived values change if all fossil-fired power plants were equipped with CCS. We assume that the best practice electric efficiency decreases by 15%.

Table 27 shows the difference in results for the technical potential for energy-efficiency improvement (with the same share of renewable energy sources for power generation as in the reference scenario).

Table 27: Technical potential energy-efficiency improvement transformation sector per region[18]

	Energy-efficiency improvement (%/y) 2010-2050			
	Fossil power generation	*Renewable and nuclear power generation*	*Other transformation sector*	**Total transformation sector**
No CCS	1.2%	0.5%	2.4%	1.4%
All fossil with CCS	0.8%	0.5%	2.4%	1.2%

The energy-efficiency improvement for fossil fired power generation decreases from 1.2% per year to 0.8% per year if all power plants are equipped with CCS in 2050. The 0.8% per year is based on the situation in 2050 where all fossil power plants have been replaced by new best practice plants with CCS (so current plants are not in operation anymore in 2050). The average energy-efficiency of fossil plants with CCS is then 45% in 2050, in comparison to 53% in the case without CCS. The average efficiency for power plants in 2005 is 32%. An increase to 45% (all plants CCS) corresponds to 0.8% per year in the period 2010-2050 and an increase to 53% (no plants CCS) corresponds to 1.2% per year.

Please note that the reason that there is energy-efficiency improvement in spite of the implementation of CCS is that new best practice power plants have a much higher efficiency than current global average. The situation per country however may be different. A country with already a high average fossil efficiency might decrease due to large scale CCS implementation.

Table 28 shows the resulting average conversion efficiency for the transformation sector in the case of maximum CCS implementation. It shows that if CCS is applied to all fossil power generation in the reference scenario, the conversion efficiency for the transformation sector changes from 81% to 79% in 2050. This means that the application of CCS has a maximum influence of 2.5% on primary energy demand.

Table 28: Conversion efficiency of transformation sector (ratio: final energy demand / primary energy demand) [19]

	2005	**2020**	**2030**	**2050**
No CCS	67%	71%	75%	81%
All fossil with CCS	67%	70%	74%	79%

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[18] Assuming the same fuel mix (i.e. share of renewable energy sources) of power generation as in the reference scenario.

[19] Assuming the same fuel mix (i.e. share of renewable energy sources) of power generation as in the reference scenario.

3.3.5 Results

Table 29 gives a summary of the technical potentials per sector and per region. The global technical potential for energy-efficiency improvement in the energy demand sectors corresponds to 2.4% per year and ranges from 2.1 to 2.6% per year depending on the region. For the transformation sector, the energy-efficiency improvement potential corresponds to 1.4% per year and ranges from 0.9 to 2.3% per year.

Table 29: Summary technical potentials per sector in energy-efficiency improvement per year for period 2010-2050

Region	Buildings and agriculture	Industry	Transport	**Total energy demand sectors**	Transformation sector
OECD Europe	2.6%	2.2%	2.9%	2.2%	1.1%
OECD North America	2.5%	2.3%	3.0%	2.6%	0.9%
OECD Pacific	2.0%	2.2%	2.8%	2.5%	1.0%
Transition economies	2.0%	2.3%	2.8%	2.2%	2.3%
China	2.0%	2.6%	2.4%	2.4%	1.5%
India	2.2%	2.6%	2.4%	2.4%	1.6%
Rest of developing Asia	2.0%	2.4%	2.6%	2.3%	0.9%
Middle East	2.2%	2.8%	2.9%	2.6%	1.9%
Latin America	2.2%	2.5%	2.9%	2.5%	1.7%
Africa	1.8%	2.3%	2.8%	2.1%	1.7%
World	**2.2%**	**2.4%**	**2.8%**	**2.4%**	**1.4%**

Figure 45 shows the global final energy demand in 2005, 2020, 2030 and 2050 in the frozen efficiency scenario, the reference scenario and the technical potential scenario. The frozen efficiency scenario is back-calculated from the reference scenario based on assumptions regarding energy-efficiency improvement in the reference scenario. For more details regarding these assumptions and the reference scenario see section 3.2.1. The technical potential scenario is based on implementing the technical potentials for energy-efficiency improvement.

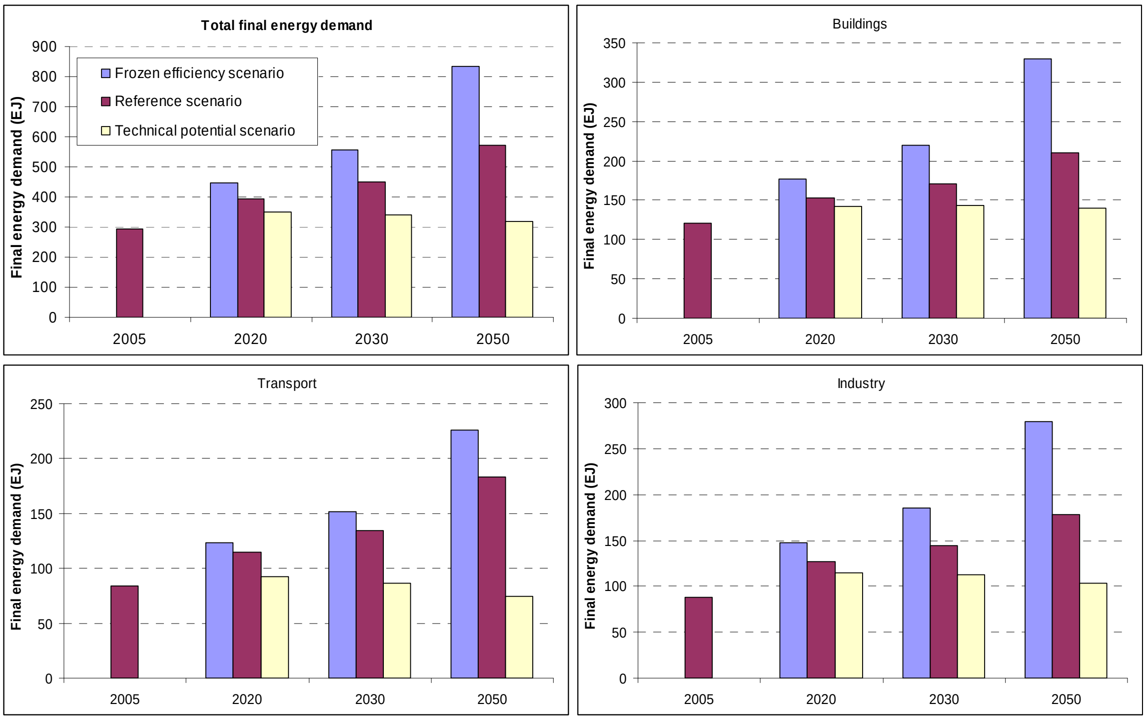

Figure 45: Global final energy demand in reference scenario, frozen efficiency scenario and technical potentials scenario for 2020, 2030 and 2050

In the technical potential scenario, global energy demand corresponds to 317 EJ in 2050. This is 8% above the current energy demand, which equals 293 EJ in 2005. In the reference scenario final energy demand is expected to increase to 570 EJ in 2050. In the technical scenario this energy demand is reduced by 45% in 2050. In 2030, the energy demand in the technical potential scenario is 25% less than in the reference scenario and in 2020 11% less. In comparison to the frozen efficiency scenario, the technical scenario shows a reduced final energy demand of 22% in 2020, 39% in 2030 and 62% in 2050.

Figure 46 shows the final energy demand in 2005, 2020, 2030 and 2050 per region, for the different scenarios.

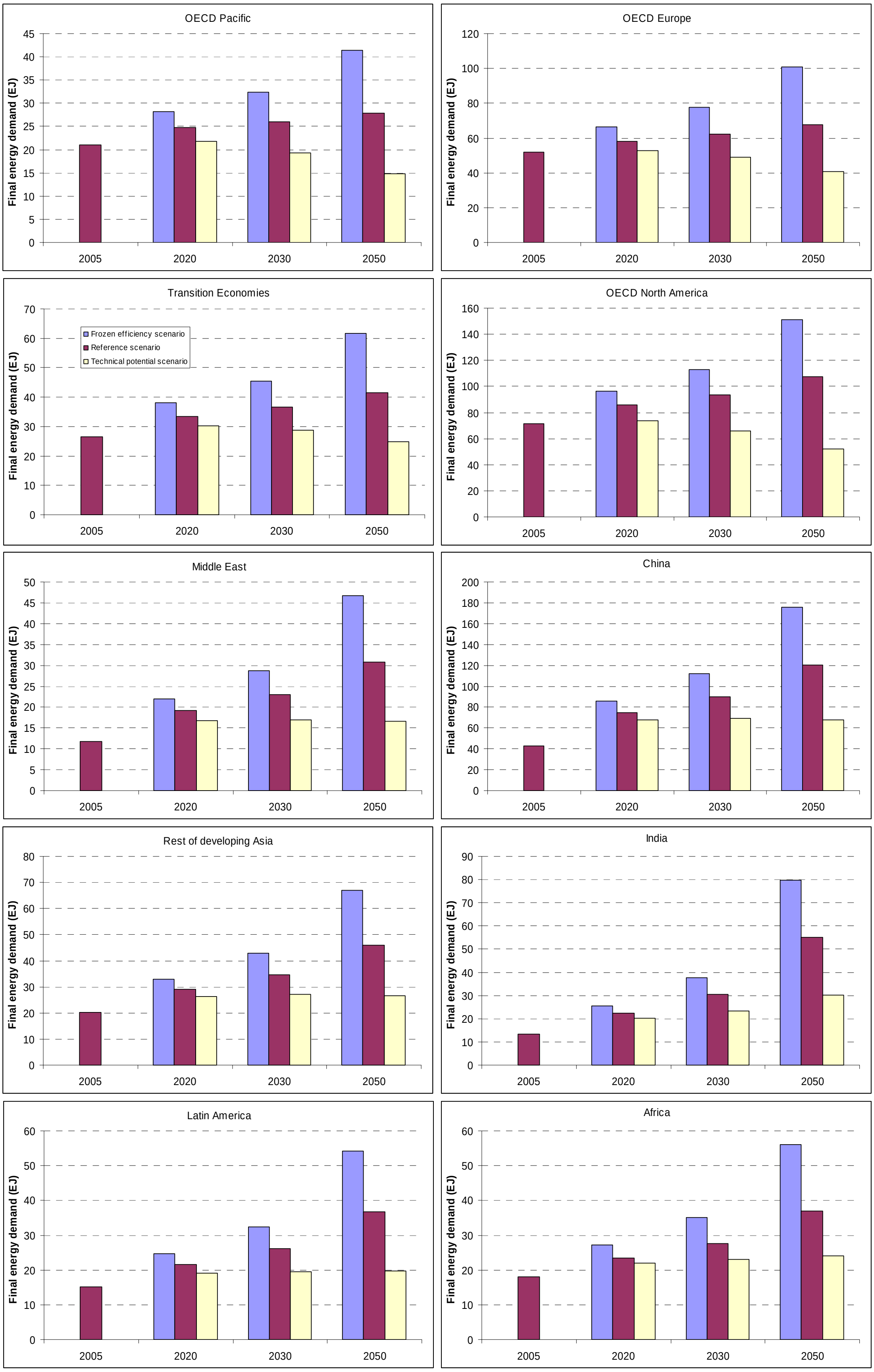

Figure 46: Final energy demand in reference scenario, frozen efficiency scenario and technical potentials scenario for 2020, 2030 and 2050 per region

Figure 47 shows the primary energy supply and final energy demand in the reference scenario and in the technical potential scenario. The primary energy supply in the technical potential scenario is based on the final energy demand in the technical scenario and the technical energy-efficiency improvement potential for the transformation sector (in terms of conversion efficiency).

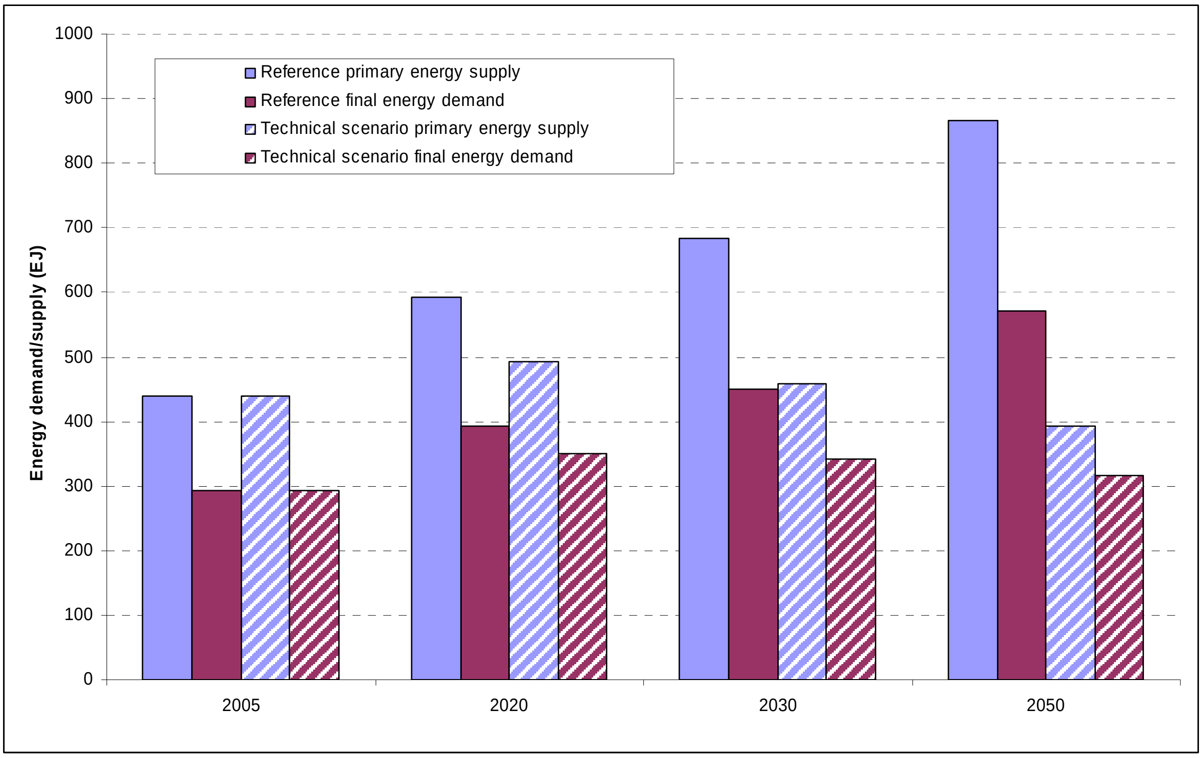

Figure 47: Global primary energy supply and final energy demand in 2005, 2020, 2030 and 2050 in the reference scenario and in the technical potential scenario

In the technical potential scenario the primary energy supply is equal to 392 EJ in 2050. This is 55% lower than the primary energy supply in the reference scenario in 2050. As a comparison, the primary energy supply in 2005 is 440 EJ. This means that in the technical scenario total primary energy supply in 2050 is 10% lower than in 2005.

Figure 48 shows the primary energy supply per region in 2005 and in 2050, for the reference scenario and the technical potential scenario.

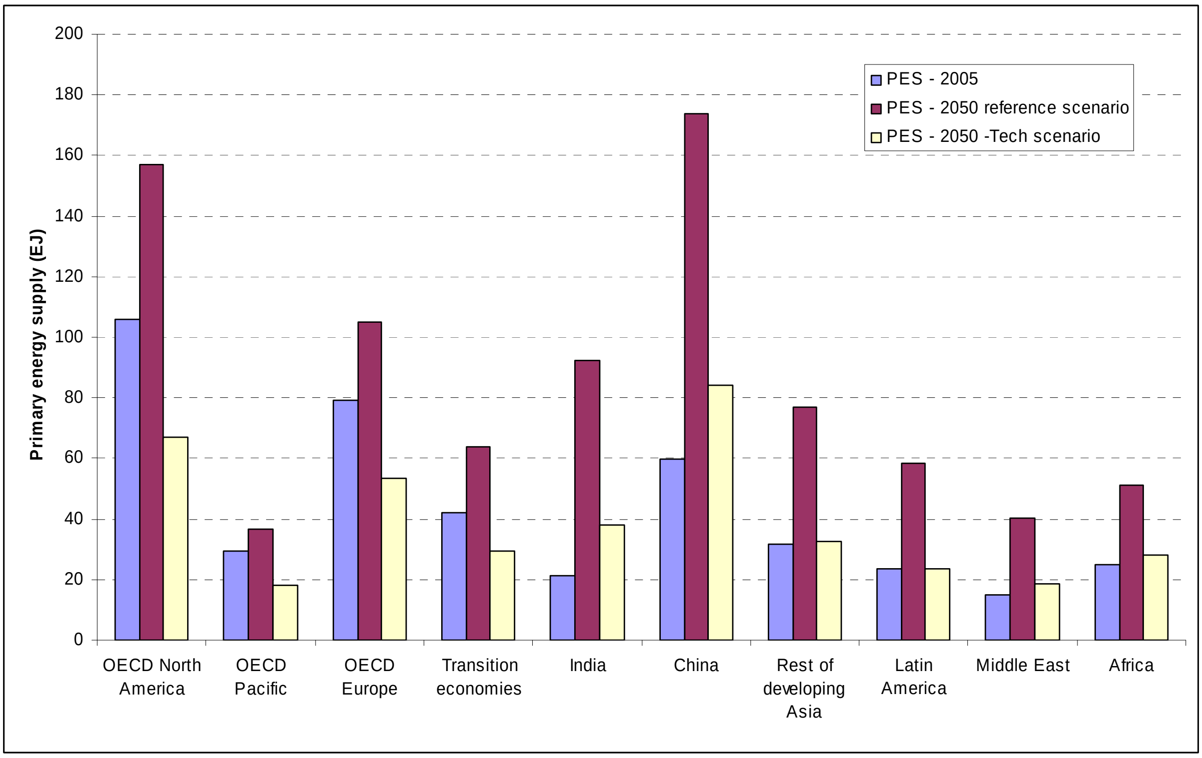

Figure 48: Primary energy supply (PES) per region in reference scenario and technical potentials scenario for 2005 and 2050

For the OECD countries and the region transition economies the primary energy supply in 2050 is lower in the technical scenario than in 2005, whereas for the developing regions the primary energy supply in 2050 is higher than in 2005.

4 Conclusions

The goal of Work Package 4 is to develop a data set with global energy-efficiency potentials on a regional level for the years 2020, 2030 and 2050. This data set is largely based on work done for the 2008 Greenpeace / EREC [r]evolution scenario.

The main conclusions of WP4 are summarized below.

Worldwide final energy demand is expected to grow by 95%, from 290 EJ in 2005 to 570 EJ in 2050, if we continue business on current footing.

The relative growth in the transport sector is largest, where energy demand is expected to grow from 84 EJ in 2005 to 183 EJ in 2050. Fuel demand in buildings and agriculture is expected to grow slowest from 91 EJ in 2005 to 124 EJ in 2050.

Growth in final energy demand can be limited to 8% in 2050 in comparison to 2005 level in by implementing the technical potential for energy-efficiency improvement.

In the Technical scenario, worldwide final energy demand is equal to 317 EJ in 2050. The table below gives the increase or decrease of energy demand in 2050 in comparison to 2005 per sector for the world.

Table 30: Change of final energy demand in 2050 in comparison to 2005 level

Sector	**Reference scenario**			**Technical scenario**	
	2005 (EJ)	2050 (EJ)	Change 2050/ 2005	2050 (EJ)	Change 2050/ 2005
Industry	88	178	+101%	103	+17%
Transport	84	183	+119%	75	-11%
Buildings and Agriculture	121	210	+74%	139	+16%
Total	292	571	+95%	317	+8%

Primary energy supply can be limited to 392 EJ in 2050 by implementing technical potentials for energy-efficiency improvement in demand and supply sectors, which is 10% below primary energy supply in 2005 (440 EJ).

In the technical potential scenario the primary energy supply is equal to 392 EJ in 2050. This is 55% lower than the primary energy supply in the reference scenario in 2050. As a comparison, the primary energy supply in 2005 is 440 EJ. This means that in the technical scenario total primary energy supply in 2050 is 10% lower than in 2005.

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Appendix I: List of abbreviations and definitions

ACEEE	American Council for an Energy Efficient Economy
BEMS	Building Energy Management Systems
BOF	Basic Oxygen Furnace
CaCO3	Limestone
CCS	Carbon Capture and Storage
CFL	Compact Fluorescent Light Bulbs
DRI	Direct Reduced Iron
DVR	Digital Video Recorder
EAF	Electric Arc Furnace
EIM	Energy Intensity after Implementation of Measure
EIR	Energy intensity in reference scenario
HDD	Heating Degree Day
HEM	High Efficiency Motors
LDV	Light-duty Vehicles
LED	Light Emitting Diode
LFL	Linear Fluorescent Lamp
NH3	Ammonia
OHF	Open Hearth Furnace
PES	Primary energy supply
STB	Set-top Boxes
TE	Transition Economies
VSD	Variable Speed Drives
WBCSD SMP	Sustainable Mobility Project
WP	Work Package

<u>Definitions</u>

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

Appendix II: Underlying tables

Reference scenario

Final energy consumption (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	292621	328741	364861	393278	421696	450114	479377	508640	539659	570678
OECD North America	71450	76894	82338	86052	89765	93479	96986	100493	103974	107454
OECD Pacific	21064	22558	24053	24684	25315	25945	26433	26920	27388	27856
OECD Europe	52038	54120	56202	58221	60239	62258	63691	65124	66394	67663
Transition economies	26636	29217	31798	33374	34951	36528	37789	39051	40323	41594
India	13356	15931	18506	22497	26488	30480	35951	41423	48250	55078
China	42705	55119	67533	75000	82466	89932	97616	105299	112990	120681
Rest of developing Asia	20191	23233	26275	29073	31871	34669	37425	40181	43007	45832
Latin America	15248	17351	19453	21694	23934	26174	28674	31173	33964	36755
Middle East	11786	14522	17259	19154	21050	22945	24890	26836	28825	30814
Africa	18147	19795	21443	23530	25618	27705	29921	32138	34544	36950

Transport (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	83595	93939	104284	114392	124501	134610	146096	157583	170333	183083
OECD North America	30839	33420	36001	37709	39417	41125	42725	44325	45898	47471
OECD Pacific	6849	7256	7663	7831	7998	8166	8289	8412	8528	8644
OECD Europe	16252	16860	17467	17983	18498	19014	19352	19689	19979	20269
Transition economies	5733	6531	7329	7716	8104	8491	8805	9118	9433	9747
India	1549	2156	2763	4103	5443	6783	8808	10833	13557	16281
China	5066	7557	10048	13119	16189	19259	23188	27118	31429	35741
Rest of developing Asia	5157	6085	7013	8131	9249	10367	11560	12753	14011	15270
Latin America	5033	5595	6156	6933	7709	8485	9351	10216	11176	12135
Middle East	4314	5226	6138	6426	6714	7001	7208	7414	7591	7769
Africa	2803	3254	3705	4442	5180	5918	6812	7705	8731	9757

Buildings and agriculture (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	120686	131817	142948	152421	161894	171367	180731	190094	200015	209936
OECD North America	24571	26566	28561	30038	31514	32991	34431	35871	37328	38785
OECD Pacific	7267	7936	8605	8917	9229	9541	9798	10055	10304	10553
OECD Europe	21798	22667	23535	24662	25789	26916	27774	28633	29408	30184
Transition economies	12367	13284	14200	14808	15417	16025	16486	16947	17408	17868
India	7662	8415	9169	10230	11290	12351	13717	15083	16784	18484
China	17626	20118	22609	24032	25456	26879	28266	29654	31095	32536
Rest of developing Asia	9014	10020	11026	11898	12769	13641	14466	15291	16141	16990
Latin America	4469	5184	5898	6602	7307	8011	8809	9607	10507	11407
Middle East	3926	4808	5691	6519	7347	8175	9080	9985	10935	11886
Africa	11986	12820	13653	14714	15776	16837	17903	18969	20106	21243

Industry (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	88340	102985	117629	126465	135301	144137	152551	160964	169311	177659
OECD North America	16040	16908	17776	18305	18834	19363	19830	20297	20748	21198
OECD Pacific	6948	7366	7785	7936	8087	8239	8346	8454	8556	8658
OECD Europe	13988	14594	15200	15576	15952	16328	16565	16802	17006	17210
Transition economies	8536	9402	10269	10850	11430	12011	12499	12986	13482	13979
India	4145	5359	6573	8164	9755	11346	13426	15507	17910	20313
China	20013	27444	34876	37849	40821	43794	46161	48528	50466	52404
Rest of developing Asia	6019	7128	8236	9044	9852	10661	11399	12138	12855	13573
Latin America	5746	6573	7399	8159	8918	9678	10514	11350	12282	13213
Middle East	3546	4488	5430	6209	6989	7768	8603	9437	10298	11160
Africa	3359	3722	4086	4374	4662	4950	5207	5464	5707	5950

Frozen efficiency scenario

Final energy consumption (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	292621	343163	397602	447240	500395	557294	618985	684899	757509	835031
OECD North America	71450	79826	88743	96307	104339	112867	121666	131004	140882	151364
OECD Pacific	21064	23565	26253	28152	30173	32324	34426	36657	38995	41476
OECD Europe	52038	56555	61381	66466	71898	77697	83122	88893	94797	101068
Transition economies	26636	30514	34675	38013	41584	45404	49080	53001	57197	61672
India	13356	16674	20257	25685	31522	37795	46361	55560	67207	79702
China	42705	57714	73996	85831	98488	112021	126581	142080	158459	175857
Rest of developing Asia	20191	24260	28645	33068	37809	42889	48259	54001	60222	66868
Latin America	15248	18112	21205	24688	28437	32469	37140	42163	47973	54220
Middle East	11786	15180	18862	21908	25209	28782	32725	36993	41677	46741
Africa	18147	20762	23584	27122	30936	35045	39624	44548	50099	56063
Transport (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	83595	96261	109475	122976	137034	151668	168423	185846	205429	225783
OECD North America	30839	34111	37506	40099	42782	45559	48311	51157	54068	57079
OECD Pacific	6849	7474	8129	8557	9002	9467	9897	10345	10803	11278
OECD Europe	16252	17375	18550	19681	20864	22100	23179	24304	25415	26571
Transition economies	5733	6659	7620	8180	8760	9359	9895	10449	11022	11613
India	1549	2190	2850	4298	5791	7329	9666	12074	15346	18717
China	5066	7701	10434	13881	17456	21161	25962	30939	36540	42342
Rest of developing Asia	5157	6228	7347	8719	10151	11646	13292	15009	16878	18827
Latin America	5033	5750	6502	7525	8600	9728	11017	12371	13908	15521
Middle East	4314	5405	6566	7109	7681	8284	8820	9383	9937	10517
Africa	2803	3368	3970	4928	5949	7035	8382	9815	11513	13318
Buildings and agriculture (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	120686	138610	158061	177221	197937	220317	244329	270232	298988	329992
OECD North America	24570.75	27935	31581	34925	38531	42415	46547	50994	55799	60965
OECD Pacific	7266.911	8345	9515	10368	11284	12266	13246	14294	15403	16588
OECD Europe	21797.79	23835	26024	28675	31531	34604	37548	40704	43960	47445
Transition economies	12367.15	13968	15701	17218	18849	20603	22288	24092	26021	28086
India	7661.844	8849	10139	11894	13804	15879	18544	21442	25089	29055
China	17626.43	21154	24999	27943	31123	34557	38213	42155	46482	51143
Rest of developing Asia	9014.01	10536	12192	13833	15612	17537	19557	21737	24127	26706
Latin America	4469.055	5451	6522	7677	8934	10300	11909	13656	15706	17930
Middle East	3925.76	5056	6293	7580	8983	10510	12275	14194	16346	18682
Africa	11986.32	13480	15096	17108	19288	21646	24203	26965	30055	33391
Industry (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
World	88339.7	108292	130066	147043	165424	185309	206233	228821	253092	279256
OECD North America	16040.14	17779	19655	21283	23027	24893	26808	28854	31014	33321
OECD Pacific	6947.729	7746	8608	9227	9888	10592	11283	12018	12790	13609
OECD Europe	13988.03	15346	16807	18110	19504	20992	22395	23886	25422	27052
Transition economies	8536.028	9887	11354	12615	13975	15442	16897	18460	20154	21973
India	4144.932	5635	7268	9493	11927	14587	18151	22044	26772	31930
China	20012.9	28859	38563	44007	49909	56303	62405	68986	75438	82372
Rest of developing Asia	6019.441	7495	9107	10516	12046	13706	15410	17255	19217	21335
Latin America	5746.103	6911	8181	9486	10904	12442	14214	16136	18359	20769
Middle East	3545.849	4719	6004	7220	8545	9987	11630	13415	15394	17542
Africa	3358.544	3914	4518	5085	5700	6364	7039	7768	8532	9353

Technical scenario

Tech 2050											Savings in comparison to reference scenario		
Final energy consumption (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2020	2030	2050
World	292621	343163	351675	350082	346821	342181	336841	330472	324242	317204	11%	24%	44%
OECD North America	71450	79826	77478	73453	69559	65808	62080	58532	55149	51944	15%	30%	52%
OECD Pacific	21064	23565	23061	21731	20475	19289	18072	16934	15858	14853	12%	26%	47%
OECD Europe	52038	56555	54676	52781	50937	49144	46971	44906	42837	40878	9%	21%	40%
Transition economies	26636	30514	30915	30229	29509	28765	27772	26798	25851	24926	9%	21%	40%
India	13356	16674	17965	20182	21934	23283	25272	26798	28683	30100	10%	24%	45%
China	42705	57714	65655	67564	68780	69405	69603	69347	68688	67715	10%	23%	44%
Rest of developing Asia	20191	24260	25521	26241	26721	26997	27053	26964	26788	26504	10%	22%	42%
Latin America	15248	18112	18649	19102	19366	19471	19621	19632	19697	19640	12%	26%	47%
Middle East	11786	15180	16504	16794	16947	16985	16972	16874	16736	16534	12%	26%	46%
Africa	18147	20762	21251	22006	22593	23034	23424	23688	23954	24110	6%	17%	35%
Transport (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2020	2030	2050
World	83595	96261	94829	92435	89500	86165	83396	80280	77536	74509	19%	36%	59%
OECD North America	30839	34111	32156	29474	26961	24615	22378	20316	18409	16662	22%	40%	65%
OECD Pacific	6849	7474	7018	6377	5792	5259	4747	4283	3861	3480	19%	36%	60%
OECD Europe	16252	17375	16115	14854	13679	12588	11470	10448	9492	8621	17%	34%	57%
Transition economies	5733	6659	6615	6165	5731	5315	4878	4472	4095	3745	20%	37%	62%
India	1549	2190	2522	3366	4012	4493	5244	5796	6519	7035	18%	34%	57%
China	5066	7701	9253	10918	12176	13090	14244	15053	15767	16204	17%	32%	55%
Rest of developing Asia	5157	6228	6436	6690	6823	6857	6856	6781	6680	6527	18%	34%	57%
Latin America	5033	5750	5605	5592	5508	5371	5244	5076	4919	4732	19%	37%	61%
Middle East	4314	5405	5664	5291	4932	4589	4216	3869	3535	3228	18%	34%	58%
Africa	2803	3368	3444	3709	3885	3986	4120	4186	4260	4275	17%	33%	56%
Buildings and agriculture (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2020	2030	2050
World	120686	138610	141823	142715	143090	143006	142415	141467	140597	139407	6%	17%	34%
OECD North America	24571	27935	27826	27114	26356	25563	24718	23859	23003	22144	10%	23%	43%
OECD Pacific	7267	8345	8341	7967	7600	7242	6856	6485	6126	5783	11%	24%	45%
OECD Europe	21798	23835	23523	23430	23287	23102	22659	22203	21676	21146	5%	14%	30%
Transition economies	12367	13968	14193	14068	13921	13754	13450	13142	12831	12518	5%	14%	30%
India	7662	8849	9071	9522	9888	10177	10634	11001	11517	11934	7%	18%	35%
China	17626	21154	22597	22831	22987	23071	23060	22995	22919	22794	5%	14%	30%
Rest of developing Asia	9014	10536	11020	11303	11531	11708	11802	11857	11897	11903	5%	14%	30%
Latin America	4469	5451	5835	6146	6399	6601	6829	7006	7210	7365	7%	18%	35%
Middle East	3926	5056	5630	6068	6434	6736	7039	7282	7504	7673	7%	18%	35%
Africa	11986	13480	13786	14267	14688	15053	15369	15637	15915	16147	3%	11%	24%
Industry (PJ)	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2020	2030	2050
World	88340	108292	115023	114932	114231	113011	111030	108724	106110	103288	9%	22%	42%
OECD North America	16040	17779	17497	16865	16242	15631	14984	14356	13736	13137	8%	19%	38%
OECD Pacific	6948	7746	7702	7387	7082	6788	6470	6166	5871	5590	7%	18%	35%
OECD Europe	13988	15346	15037	14498	13970	13454	12842	12255	11670	11111	7%	18%	35%
Transition economies	8536	9887	10107	9996	9858	9696	9444	9185	8926	8663	8%	19%	38%
India	4145	5635	6371	7294	8034	8613	9395	10001	10648	11131	11%	24%	45%
China	20013	28859	33804	33815	33618	33244	32299	31299	30002	28717	11%	24%	45%
Rest of developing Asia	6019	7495	8065	8248	8367	8431	8396	8325	8211	8074	9%	21%	41%
Latin America	5746	6911	7209	7364	7458	7499	7548	7550	7568	7544	10%	23%	43%
Middle East	3546	4719	5209	5435	5581	5660	5718	5723	5697	5633	12%	27%	50%
Africa	3359	3914	4022	4030	4020	3996	3935	3865	3779	3688	8%	19%	38%

Transformation sector

Transformation factor (primary energy demand / final energy demand)

	2005	2020	2030	2050
Latin America	78%	82%	85%	89%
Africa	74%	78%	81%	86%
OECD Europe	72%	75%	78%	82%
Rest of developing Asia	72%	74%	76%	80%
OECD North America	68%	70%	73%	77%
OECD Pacific	66%	69%	72%	77%
Middle East	65%	71%	76%	84%
India	64%	69%	74%	81%
Transition Economies	63%	71%	77%	85%
China	62%	68%	72%	80%
World	67%	71%	75%	81%

Transformation factor (primary energy demand / final energy demand)

With CCS case	2005	2020	2030	2050
Latin America	78%	82%	84%	89%
Africa	74%	77%	80%	85%
OECD Europe	72%	75%	77%	81%
Rest of developing Asia	72%	73%	75%	78%
OECD North America	68%	70%	72%	75%
OECD Pacific	66%	68%	71%	75%
Middle East	65%	70%	75%	82%
India	64%	68%	72%	78%
Transition Economies	63%	70%	76%	84%
China	62%	67%	70%	77%
World	67%	70%	74%	79%

Primary energy supply (EJ) in reference scenario

	2005	2020	2030	2050
World	439	593	684	867
OECD North America	106	127	137	157
OECD Pacific	29	33	34	37
OECD Europe	79	89	97	105
Transition economies	42	52	56	64
India	21	37	51	92
China	60	106	129	174
Rest of developing Asia	32	47	58	77
Latin America	23	34	41	58
Middle East	15	25	30	40
Africa	25	32	38	51

Primary energy supply (EJ) in technical scenario

					Reduction in comparison to reference primary energy supply		
	2005	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
World	439	493	458	392	17%	33%	55%
OECD North America	106	104	90	67	18%	34%	57%
OECD Pacific	29	29	25	18	13%	27%	51%
OECD Europe	79	77	68	53	14%	29%	49%
Transition economies	42	43	37	29	18%	33%	54%
India	21	30	32	38	19%	37%	59%
China	60	91	91	84	14%	30%	51%
Rest of developing Asia	32	38	37	33	19%	37%	57%
Latin America	23	27	26	24	21%	38%	60%
Middle East	15	21	20	19	17%	33%	54%
Africa	25	28	28	28	12%	26%	46%

Part V:

Costs and Bounds of Energy Efficiency

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Table of Contents

1 Introduction

The goal of Work Package 5 is to give an overview of costs and bounds for energy-efficiency improvement.

Chapter 2 focuses on costs of energy-efficiency measures. First, an overview is made of cost estimates for energy-efficiency measures in recent major scenario studies (see section 2.1). Second a case study is done in which costs for a number of important energy-efficiency measures are calculated for two regions (OECD Europe and China) (see section 2.2).

Chapter 3 gives an overview of market barriers that inhibit the uptake of energy-efficiency measures.

Chapter 4 gives summary and conclusions of this work package.

2 Cost estimates of energy-efficiency improvement

Assumptions regarding performance and costs of technologies are key inputs into long term energy scenarios. This section gives an overview of cost assumptions in recent major scenario studies (see section 2.1) and gives two case studies where costs for a number of important energy-efficiency measures are calculated for two regions (OECD Europe and China) (see section 2.2). Based on the results of the case studies an estimate is made of global costs for energy-efficiency improvement. For this purpose, a link is made with the technical potentials as calculated in Work Package 4.

2.1 Literature overview

In this section the analysed energy scenarios as well as relevant studies are revisited to analyse the extent of information they contain on costs for employing energy-efficiency measures. Studies considered include the IEA WEO 2007 Alternative Policy Scenario (APS), The Blue Map Scenario of IEA ETP 2008 and the Greenpeace/EREC Energy Energy [R]evolution scenario. Assessed potential and cost studies include Stern, 2007, the McKinsey, 2007, as well as a number of sector-specific bottom-up reports published by the European Commission titled “Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change” (2001).

The **WEO APS 2007** does not provide detailed quantitative data on costs for energy-efficiency measures on a global scale. For China and India a chapter on cost-effectiveness of policy measures is added, providing some cost data as well as few examples for investment cost, total cost of energy savings, and payback times.

In general, investment costs per unit of energy saved are lower in China than in OECD countries, because of the larger gap between the best available technology and the one in use. Therefore data cannot be simply transferred to other world regions. The most profitable options for China are reported to be industrial motor system blast furnaces, continuous casting in the iron and steel sector, as well as more use of waste heat in the cement sector, with payback periods of less than three years.

Table 1: Examples of cost for energy-efficiency measures in China

Sector	Measure	Incremental cost ($)	Energy-efficiency improvement (%)	Payback period (years)
Residential	Refrigerators (220l)			3 ½
Transport	Medium weight car	185	10	3 ½
	more efficient cars			< 4
	improved industrial motor systems		> 20	< 1

Source: based on WEO 2007

The **Greenpeace/EREC Energy [R]evolution Scenario** includes information on current costs as well as development of future costs for all renewable energy technologies. Information on economic effects of energy-efficiency measures is only included indirectly in the calculation of future electricity costs. In addition, some qualitative cost data is provided for single energy-efficiency measures.

In general, the scenario points out that implementation of assumed energy-efficiency measures compensates for the slight increase in electricity price in the [Revolution Scenario. Assuming an average cost of 3 cents/kWh for implementing energy-efficiency measures, the additional cost for electricity supply under the Energy [R]evolution Scenario will amount to a maximum of $10 billion/yr in 2010. These additional costs continue to decrease after 2010. By 2050 the annual costs of electricity supply will be $2,900 billion/yr below those in the Reference Scenario (business-as-usual).

The **IEA ETP Blue Map Scenario** contains an entire chapter on each sector, stating current status of assumed efficient technologies as well as energy-efficiency measures and gives details over the projected market share and percentage of efficiency improvement of different measures for the time horizon 2015-2050. Costs and potentials of cost reduction are provided for single specific energy-efficiency measures. The scenario compares improvements in energy-efficiency on a sector- and subsector level. Indications made on energy-efficiency improvements are not provided in a consistent format, but are expressed partly in a qualitative manner, as market shares or as share of efficiency improvements.

The most profitable options are projected to be industrial motor systems, blast furnaces, continuous casting in the iron and steel sector and more use of waste heat in the cement sector. It is also worth to note that very different potentials and cost assumptions are made for industrialized countries when compared to countries in transition leading to different costs. Also in the IEA ETP, the role of China is emphasised, as it represents the biggest and fastest growing economy.

The **STERN Review** (Stern, 2007) explores the economics of stabilizing greenhouse gases in the atmosphere. Overall costs are estimated at around 1% of GDP for stabilisation levels between 500 and 550ppm CO_{2eq}. The Stern report discusses how to identify the costs of mitigation, and chooses a resource-based approach for the calculation of global costs. It compares modeling approaches to calculating costs, and examines how policy choices may influence the latter.

The STERN report includes an aggregated carbon abatement cost curve for the UK, which shows carbon abatement costs in [£/tC] for several energy-efficiency technologies by 2020 relative to the BAU projections. Annexes 7.B to 7.G of the Stern report list the technologies that can be used to cut emissions in each sector, and give some information on associated costs. For each sector, historic and projected Business As Usual (BAU) trends for GHG emissions are provided for the ten IEA regions up to 2030. According to this baseline, sectoral saving potentials are derived.

The abatement cost curve established by **McKinsey** (2007) covers measures in the sectors power generation, manufacturing, industry (with a focus on steel and cement), transportation, residential and commercial buildings, forestry, agriculture and waste disposal. Costs are assessed for six regions (North America, Western Europe, Eastern Europe (incl. Russia), other developed countries, China and other developing nations) and span three time horizons – 2010, 2020, and 2030. The focus is on abatement measures that would cost 40 €/tCO_{2eq} or less in 2030.

Almost a quarter (6 Gt) of total abatement potential under 40€/tCO_{2eq} is covered by measures with zero or negative net life cycle cost. This potential appears mainly in the transportation and building sector. According to McKinsey, developing countries account for more than half of the total abatement potential at a cost of less than 40€/tCO_{2eq}.

Highest economic benefit from the employment of an energy-efficiency measure is stated for improved building insulation with net costs of approximately -160€/tCO_{2eq}.

The **European Commission** has carried out a number of sector-specific bottom-up studies in 2001, which include potentials for emission reduction options as well as specific cost data for each single measure in the EU 15. The reports are divided into the sectors agriculture, energy supply, fossil fuel extraction, transport and distribution, industry, fluorinated gases, transport sector, households and services, as well as the waste sector. Specific abatement costs are given in [€/tCO_{2eq}] for a high number of measures within the different subsectors, broken down for the different greenhouse gases. In addition, data is disaggregated to include additional investment costs, annual costs, as well as lifetime. Measures are subdivided into the four cost categories <0€/tCO_{2eq}, <20€/tCO_{2eq}, <50€/tCO_{2eq}, >50€/tCO_{2eq}. According to the report the emission reduction potential for energy-efficiency measures accounts for 340 Mt CO_{2eq} at costs < 0€/tCO_{2eq}. Highest economical benefit is achieved for the application of continuous casting in integrated iron and steel plants with abatement costs of -230€/tCO_{2eq}. Further 153 Mt CO_{2eq} may be mitigated at a cost of <20€/tCO_{2eq}, and 33 Mt CO_{2eq} at a cost of <50€/tCO_{2eq}.

***Table 2**: Examples for Emission reduction potential and cost for energy-efficiency measures*

Measure	**Emission reduction potential**	**Invest-ment**	**Annual cost**	**Life-time**	**Specific abatement costs**
	Mt CO_{2eq}	**€/tCO_{2eq}**	**€/tCO_{2eq}**	**years**	**€/tCO_{2eq}**
Residential					
Energy efficient TV and video equipment	1	0	-310	15	-194
Very energy efficient refrigerators and freezers	0.5	0	-317	15	-187
Efficient lightning best practice (fully implemented)	2	178	-326	8	-178
Wall insulation retrofit houses	28	2269	-129	50	-42
Roof insulation retrofit houses	26	1600	-169	20	-29
New energy efficient residential houses: best practice	12	1815	-200	20	-11

Measure	**Emission reduction potential**	**Invest-ment**	**Annual cost**	**Life-time**	**Specific abatement costs**
	Mt CO_{2eq}	**€/tCO_{2eq}**	**€/tCO_{2eq}**	**years**	**€/tCO_{2eq}**
Service					
Efficient space cooling	1	377	-277	15	-172
Efficient lighting	2	651	-278	8	-159
Very efficient lighting	1	1200	-277	8	-144
Building Energy Management Systems (BEMS)	42	0	-153	10	-129
Industry					
Application of continuous casting	1	557	-280	15	-230
Cement – new capacity	5	0	-41	15	-38
Pulverized coal injection up to 30% in the blast furnace (primary steel)	1	200	-48	15	-30
Transport					
Rolling resistance	11				-72
Aerodynamics – Cab roof fairing	3				-51
Aerodynamics – Cab Roof Deflector	2				-47
Lightweight structure –petrol cars	10				217
Lightweight structure – Diesel cars	2				327

Source: EU Commission 2000, EU Commission 2001

The EU studies calculate the potential GHG emission reductions per energy-efficiency measure. The technical potentials calculated in WP 2 and WP 4 calculate net costs per GJ of energy saved. Also, the cost data is average data for EU 15, a detailed assessment for the regions under concern in this study is not found in any of the literature sources and scenarios assessed.

2.2 Case study

In this section we make a cost estimate for a number of important energy-efficiency improvement measures in the regions OECD Europe and China.

2.2.1 Methodology

The costs for energy-efficiency measures are expressed as direct costs and refer to additional costs needed to implement a technological measure. Indirect cost savings from e.g. reduced environmental damage are not taken into account.

Specific costs of a measure are calculated by summing annualised investment costs, operation and maintenance costs and savings per GJ energy saved. The specific costs can be negative if the benefits associated with the measure are sufficiently large. The costs calculated this way are life-cycle costs and represent total costs, taking into account the technical life span of the equipment.

The prices used are market prices. Taxes and levies are not included (e.g. value added tax or excise duties on fuel). In this study a discount rate of 6% is used.

The *specific net costs for each measure (€/GJ)* are determined as follows: $E_s = C_s - P_s$

Where E_s = specific net costs of measure (€/GJ)
C_s = specific costs of measure (€/GJ)
P_s = specific benefit of measure (€/GJ)

The specific costs C_s is calculated by dividing the annual costs of the option by the annual energy savings: $C_s = (\alpha * C^{inv} + C^{O\&M})/R$

Where C_s = specific costs of measure (€/GJ)
C^{inv} = (additional) up front investment costs (€)
$C^{O\&M}$ = annual operation and maintenance costs (€/year)
α = annuity factor: $r/(1-(1+r)^{-n})$
r = discount rate (in %/year)
n = lifetime of the investment (i.e. depreciation period in years)
R = annual energy savings (GJ/year)

The specific benefits of a measure P_s are calculated by dividing the annual benefits by the annual energy savings: $Ps = P / R$

Where Ps = specific benefits of measure (€o/GJ)
P = annual benefits from energy savings (€o/year)
R = annual energy savings (GJ/year)

Besides the specific net costs of measures in €/GJ, also the simple payback time (years) of the measures will be calculated. This is done by the following formula:

Simple payback time (years) = $C^{inv} / (P - C^{O\&M})$

Where C^{inv} = (additional) up front investment costs (€)

$C^{O\&M}$ = annual operation and maintenance costs (€/year)

P = Benefit of measure (€/year)

The costs in this study are expressed in Euros (€) with a 2005 price level. The identified costs from literature sources are recalculated using the conversion factors from Table 3.

Table* 3: *Currency conversion rates[1]

Conversion from US$ in year to € in 2005		Conversion from € in year to € in 2005		Exchange rate
Year	**€2005 / US$**	**Year**	**€2005 / €**	**€ => US$**
1991	1.18	*1991*	1.39	1.18
1992	0.95	*1992*	1.32	1.38
1993	1.15	*1993*	1.27	1.10
1994	1.02	*1994*	1.23	1.21
1995	0.90	*1995*	1.20	1.34
1996	0.91	*1996*	1.18	1.29
1997	1.08	*1997*	1.16	1.08
1998	1.04	*1998*	1.15	1.10
1999	1.07	*1999*	1.14	1.06
2000	1.21	*2000*	1.12	0.93
2001	1.24	*2001*	1.09	0.88
2002	1.09	*2002*	1.06	0.98
2003	0.92	*2003*	1.04	1.13
2004	0.84	*2004*	1.02	1.21
2005	0.83	*2005*	1.00	1.20
2006	0.76	*2006*	0.98	1.29
2007	0.70	*2007*	0.96	1.37

For China prices are based on purchasing power parities (PPP). PPP compare costs in different currencies of a fixed basket of traded and non-traded goods and services and yield a widely-based measure of standard of living. Therefore they have a more direct link with energy use than prices based on market exchange rates. For converting from the Chinese currency Yuan (CNY) to Euro (€) we use the conversion rate of 1 CNY_{2005} = 0.4 $€_{2005}$. This is based on a PPP correction rate of 0.25 in 2005 (note: US$ = 1) (Nation Master, 2008) and the exchange rate of 1 CNY_{2005} = 0.12 $US\$_{2005}$ (X-rates, 2008).

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[1] Based on World Economic Outlook, International Monetary Fund. http://www.imf.org/external/ns/cs.aspx?id=28

2.2.1.1 Fuel prices

Table 4 shows average fuel prices for OECD Europe per sector. These are largely based on fuel prices for EU27.

Table 4: Fuel prices per sector for OECD Europe[2]

€$_{2005}$/GJ final energy	**Households**	**Services**	**Transport**	**Industry**
Natural gas	12	9		7
Diesel oil			13	
Gasoline			13	
Electricity	42	35		28
Heavy fuel oil	13			7
Coal				2
Biomass				
Kerosine			21	

Table 5 shows average fuel prices for China per sector.

Table 5: Fuel prices per sector for China[3]

€$_{2005}$/GJ final energy	**Households**	**Services**	**Transport**	**Industry**
Natural gas	12	9		7
Diesel oil			11	
Gasoline	2		11	
Electricity	30	17		14
Heavy fuel oil	13			7
Coal	5			2
Biomass	2			
LPG	36		14	

The energy prices in China and OECD Europe are quite similar as expressed in PPP. There are two main differences. In China currently a lot of biomass and coal is used for heating at low prices. Furthermore, electricity prices in China are significantly lower than in OECD Europe. According to Lam (2001) electricity prices in China are highly subsidised and well below costs for generation and transmission. This is because capital costs of state-owned power plants are often not reflected in electricity prices.

It seems likely that with the growing economy in China the use of wood stoves will take a lower share in energy demand for heating in the future and energy prices in households will become more similar to current prices in OECD Europe. We therefore use 12 €/GJ for fuel costs for heating in households (equal to current natural gas price in China).

For the electricity prices we just assume current values in China, but it may be that measures will become more profitable if electricity prices increase over time and subsidies decrease.

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[2] Based on Eurostat (2007). Prices are for the second quarter 2007 for EU27 excluding taxes in €$_{2005}$ prices (prices for natural gas GCV are converted to NCV by factor 0.9).

[3] Based on Pachauri and Jiang (2008) and IEA Energy Prices and taxes 2007, natural gas price in services and industry and heavy fuel oil price in industry is assumption

2.2.1.2 Conversion final to primary energy

Final power consumption is converted to primary energy use by the average conversion efficiency for power generation in the region considered. Table 6 shows the conversion efficiency for OECD Europe and China.

***Table* 6: *Average conversion efficiency for total power supply in region*[4]**

	2005
OECD Europe	35%
China	32%

2.2.1.3 Measures and assumptions

Table 7 shows the measures for which costs are calculated and the key assumptions regarding investments costs and energy savings. Measures are selected according to the potential to reduce energy demand on a global level. The study aims to include key measures per sector, based on available literature sources.

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[4] Based on IEA (2007). Gross power generation is converted to net power generation, by assuming 4% of gross power generation is used for own use.

Table 7: Included measures and key assumptions

Nr.	Sector	Measure	Investment costs (additional)	Energy savings	Life-time (yr)
1	Transport – passenger cars	Hybrid passenger cars	➢ 2000-2500 USD for petrol hybrid ➢ 5000-5500 USD for hybrid diesel [Frost and Sullivan, 2008 and TNO et. al, 2006] As average we take 3000 €	➢ Average mileage 12,500 km per year OECD Europe, 10,000 km per year China (IEA/SMP, 2004). ➢ Default car 13 km /litre g.e. for OECD Europe and 9 km /litre g.e. for China (IEA/SMP, 2004). ➢ Hybrid car 20 km /litre g.e. (Toyota, 2008).	10
2	Transport – passenger cars	Weight reduction of passenger cars	➢ 2185 € (diesel) – 1619 € (petrol) [TNO et. al, 2006 and JRC, 2008] As average we take 1800 €	➢ 18% savings (TNO et. al, 2006 and JRC, 2008) ➢ Average mileage 12,500 km per year OECD Europe, 10,000 km per year China (IEA/SMP, 2004). ➢ Default car 13 km /litre g.e. for OECD Europe and 9 km /litre g.e. for China (IEA/SMP, 2004).	10
3	Transport-buses	Hybrid buses	Additional investment costs: 150,000 – 200,000 US$ (EESI 2006) As average we take 175,000US$ Additional maintenance costs: 0.02 US$/mile (EESI 2006)	➢ Travel per vehicle: 60,000 km per year OECD Europe, 40,000 km per year China ➢ Improve of efficiency: 25 – 45% → as average 35% (IEA SMP, 2004) ➢ Default bus 3.03 km/l OECD Europe, 3.57 km/l China (IEA SMP, 2004)	10
4	Transport-trucks	➢ Improved aerodynamics ➢ Tyre inflation control (TPMS) ➢ Use of wide-based tires ➢ Reduce engine idling ➢ Driver training	8000 € (US EPA, 2008)	➢ 13% savings (US EPA, 2008) ➢ Average mileage 60,000 km per year OECD Europe, 50,000 km per year China (IEA/SMP, 2004). ➢ Default truck 1.6 MJ/t.km for OECD Europe and 2.0 MJ/t.km for China (IEA/SMP, 2004). ➢ Average truck load 8 tonnes for OECD Europe and 6 tonnes for China (IEA/SMP, 2004).	10

5	Transport - aviation	➢ Improved aerodynamics ➢ Advanced engines ➢ Improved Air Traffic Management (ATM) ➢ Further operational measures	1.4 mio € (IPCC, 2007 and IPTS, 2008)	➢ 30% (IPCC (2007) and IPTS (2008)) ➢ 2.6 MJ/p.km in China and OECD Europe (IEA/SMP, 2004). ➢ Number of passenger per aircraft 300 (assumption). ➢ Mileage 400,000 km per year (assumption).	10
6	Buildings-heat	Passive houses – new buildings	95 €/m^2 based on 7-12% higher price than new buildings (standard buildings costs of 1,000€ per m^2) [Passivhaus Institut, Darmstadt]	➢ Energy demand passive house: ➢ 54 MJ/m^2a space heating demand (Passivehaus Institut, Darmstadt) ➢ The energy demand for average new houses equals 270 MJ/m^2a in EU27 (Harmelink, 2008). ➢ The relative improvement potential in China is assumed to be the same as for EU27 (63% for new buildings). Average energy demand in households for heating amounted to around 200 MJ/m^2aGJ per household (Zhang, 2004) For the average dwelling size in China we assume 70 m^2.	30
7	Buildings-heat	Roof insulation - existing buildings	30 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing roofs of buildings built before 1975 in moderate climate EU-27: 1.5 W/m^2K ➢ After insulation in moderate climate: 0.17 W/m^2K ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) and 2750 Kd/a average in China (Zhang, 2004). ➢ Average roof area 43 m^2 for OECD Europe (0.5*average area dwelling; 85 m^2 in EU27 (Ecofys, 2008)) and 35 for China (based on average dwelling area of 70 m^2)	30
8	Buildings-	Wall insulation - existing	51 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing walls of buildings built before 1975 in moderate climate EU27: 1.5 W/m^2K	30

	heat	buildings		➢ After insulation in moderate climate: 0.22 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) and 2750 Kd/a average in China (Zhang, 2004). ➢ Average wall surface is 60 m^2 for OECD Europe (0.7*average area dwelling; is 85 m^2 in EU27 (Ecofys, 2008)) and 49 m^2 for China (based on average dwelling area of 70 m^2)	
9	Buildings-heat	Floor insulation - existing buildings	26 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing floors of buildings built before 1975 in moderate climate EU27: 1.2 W/m²K ➢ After insulation in moderate climate: 0.28 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) and 2750 Kd/a average in China (Zhang, 2004). ➢ Average floor area is 43 m^2 for OECD Europe (0.5*average area dwelling; is 85 m^2 in EU27 (Ecofys, 2008)) and 35 m^2 for China (based on average dwelling area of 70 m^2)	30
10	Buildings-heat	Window insulation - existing buildings	100 €/m^2 (Ecofys, 2008)	➢ Existing windows of buildings built before 1975 in moderate climate EU27: 3.5 W/m²K ➢ After insulation in moderate climate: 1.2 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) and 2750 Kd/a average in China (Zhang, 2004). ➢ Average window area is 13 m^2 for OECD Europe (0.15*average area dwelling; is 85 m^2 in EU27 (Ecofys, 2008)) and 11 m^2 for China (based on	30

				average dwelling area of 70 m^2)	
11	Buildings-heat	Water saving power heads	Additional investment costs taps per dwelling: 27.0 € (Bettgenhäuser et. al, 2008)	➢ 12.5% of energy use shower (Bettgenhäuser et. al, 2008) ➢ Fraction of hot tap water through shower taps of total hot tap water: 50% (Ecofys, 2008) ➢ Energy use for hot tap water: 4.5 GJ/dwelling EU27 (Ecofys, 2008)	10
12	Buildings-power	Substitute incandescent lamps with compact fluorescent lamps (CFL)	0.3 €/ klm for incandescent and 1.0 €/ klm CFL [ISR, 2007 and European Commission, 2008]	➢ Luminous efficacy range: 73 lm/W for CFL and 16 lm/W for incandescent (ISR, 2007 and European Commission, 2008) ➢ Lifespan incandescent lamp: 1,000 h and CFL: 13,000 h (ISR, 2007 and European Commission, 2008) ➢ Hours per year: 1,000 h (assumption)	10
13	Buildings-power	Efficient air conditioners	Average per 3.5 kW: € 578 Improved per 3.5 kW: € 1,020 [European Commission, 2007b]	➢ COP average: 3.4, COP improved: 5.0 [European Commission, 2007b] ➢ Average load hours air conditioning per year 400 and capacity air conditioner 3.5 kW (assumption) => Average electricity use air conditioner 1400 kWh/a.	15
14	Buildings-power	Substitute CRT-screens with LCD-screens in offices	210 € for LCD's instead of 73 € for CRT's [European Commission, 2007b]	➢ 32 W for LCD's instead 75W for CRT-screens ➢ 53 kWh/a for LCD's instead of 116 kWh/a for CRT-screens [European Commission, 2007b]	7
15	Buildings-power	Cold appliances	164 € for best practice refrigerator (Ecofys, 2008)	➢ 35% end us energy savings of refrigerator (ICARUS, 2001) ➢ Average energy demand refrigerator 224 kWh/a (Ecofys, 2008)	10
16	Buildings-power	Washing machines	136 € for best practice washing machine (ISR, 2007)	➢ 13% end use energy savings (ICARUS, 2001) ➢ Average energy demand washing machine 230 kWh/a (Ecofys, 2008)	10

17	Industry-iron and steel	Sinter plant heat recovery	➢ Retrofit capital costs 0.66 US$/tonne crude steel ➢ No annual operating cost change [LBNL, 1997]	➢ Fuel savings 0.12 GJ/tonne crude steel ➢ Electricity savings -0.01 GJ/tonne crude steel [LBNL, 1997]	15
18	Industry-iron and steel	Hot charging / direct rolling in hot rolling mills	➢ Retrofit capital costs 13.1 US$/tonne crude steel ➢ Annual operating cost change -1.15 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.52 GJ/tonne crude steel ➢ No electricity savings [LBNL, 1997]	20
19	Industry-iron and steel	Recuperative or regenerative burners in hot rolling mills	➢ Retrofit capital costs 2.2 US$/tonne crude steel ➢ No annual operating cost change [LBNL, 1997]	➢ Fuel savings 0.61 GJ/tonne crude steel ➢ No electricity savings [LBNL, 1997]	15
20	Industry-iron and steel	Scrap preheating in electric arc furnace	➢ Retrofit capital costs 6.0 US$/tonne crude steel ➢ Annual operating cost change -4.0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings -0.70 GJ/tonne crude steel ➢ Electricity savings 0.43 GJ/tonne crude steel [LBNL, 1997]	30
21	Industry-iron and steel	Near net shape casting (for other than flat products)	➢ Retrofit capital costs 134.3US$/tonne crude steel ➢ Annual operating cost change -31.3 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.30 GJ/tonne crude steel ➢ Electricity savings 0.19 GJ/tonne crude steel [LBNL, 1997]	20
22	Industry-iron and steel	Pulverized coal injection to 180 kg/thm in blast furnace	➢ Retrofit capital costs 6.2 US$/tonne crude steel ➢ Annual operating cost change -1.8 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.69 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	20
23	Industry-iron and steel	BOF gas + sensible heat recovery in basic oxygen furnace	➢ Retrofit capital costs 22.0 US$/tonne crude steel ➢ Annual operating cost change 0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.92 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	10
24	Industry –	Variable speed drives,	De Beer and Phylipsen (2001) estimate additional	Keulenaer et al (2004) estimate the savings potential for	10

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

2.2.2 Results

Table 8 shows the specific costs and payback times per measure for OECD Europe and China. In the Appendix the same table is given converted to costs in €/tonne CO_2.

Table 8: Specific costs and payback time per measure for OECD Europe and China

		OECD Europe			China		
Sector	**Measure**	**Net specific costs (€/GJ final)**	**Net specific costs (€/GJ primary)**	**Simple payback time**	**Net specific costs (€/GJ final)**	**Net specific costs (€/GJ primary)**	**Simple payback time**
Transport – passenger cars	Hybrid passenger cars	21	21	19	8	8	13
Transport – passenger cars	Weight reduction	27	27	22	24	24	24
Transport - buses	Hybrid buses	59	59	36	131	131	76
Transport - trucks	- Improved aerodynamics - Tyre inflation control (TPMS) - Use of wide-based tires - Reduce engine idling - Driver training	-2	-2	6	3	3	9
Transport - aviation	- Improved aerodynamics - Advanced engines - Improved Air Traffic Management (ATM) - Further operational measures	-19	-19	1	-12	-12	1
Buildings - heat	Passive house	20	20	37	36	36	56
Buildings - heat	Roof insulation - existing buildings	-5	-5	8	-5	-5	8
Buildings - heat	Wall insulation - existing buildings	0	0	13	1	1	15
Buildings - heat	Floor insulation - existing buildings	-4	-4	10	-3	-3	10
Buildings - heat	Window insulation - existing buildings	1	1	15	2	2	16
Buildings - heat	Water saving power heads	1	1	8	1	1	8
Buildings - power	Substitute incandescent lamps with compact fluorescent lamps (CFL)	-41	-14	0	-29	-9	0
Buildings - power	Efficient air conditioners	-13	-5	7	-2	-1	9
Buildings - power	Substitute CRT-screens with LCD-screens in offices	67	23	15	78	25	20
Buildings - power	Cold appliances	37	13	14	49	16	19
Buildings - power	Washing mashines	130	46	30	141	45	42
Iron and steel	Sinter plant heat recovery	-4	-5	1	-6	-7	1
Iron and steel	Hot charging / direct rolling in hot rolling mills	-7	-7	3	-7	-7	3
Iron and steel	Recuperative or regenerative burners in hot rolling mills	-7	-7	1	-7	-7	1
Iron and steel	Scrap preheating in electric arc furnace	40	-21	1	18	-8	1
Iron and steel	Near net shape casting (for other than flat products)	-58	-34	4	-53	-53	4
Iron and steel	Pulverized coal injection to 180 kg/thm in blast furnace	-9	-9	1	-9	-9	1
Iron and steel	BOF gas + sensible heat recovery in basic oxygen furnace	-4	-4	4	-4	-4	4
Electric motors	Variable speed drives, high efficiency motors and efficient pumps, compressors and fans	-24	-9	1	-11	-3	2
Cement	Application of multi-stage preheaters	-2	-2	7	-2	-2	7
Cement	Optimisation of heat recovery in clinker cooling	-7	-7	0	-7	-7	0
Glass	Improved melting technique and furnace design	-4	-4	4	-4	-4	4
Chemicals	Process integration – pinch analysis	-5	-5	3	-5	-5	3
Chemicals	Debottlenecking petrochemical plant	-6	-6	2	-6	-6	2
Chemicals	Advanced reformer for ammonia production	-1	-1	11	-1	-1	11

Figure 1 and Figure 2 show the results for both regions in a cost curve. As can be seen the majority of the energy savings are within a cost range of -20 to 20 €/GJ final energy.

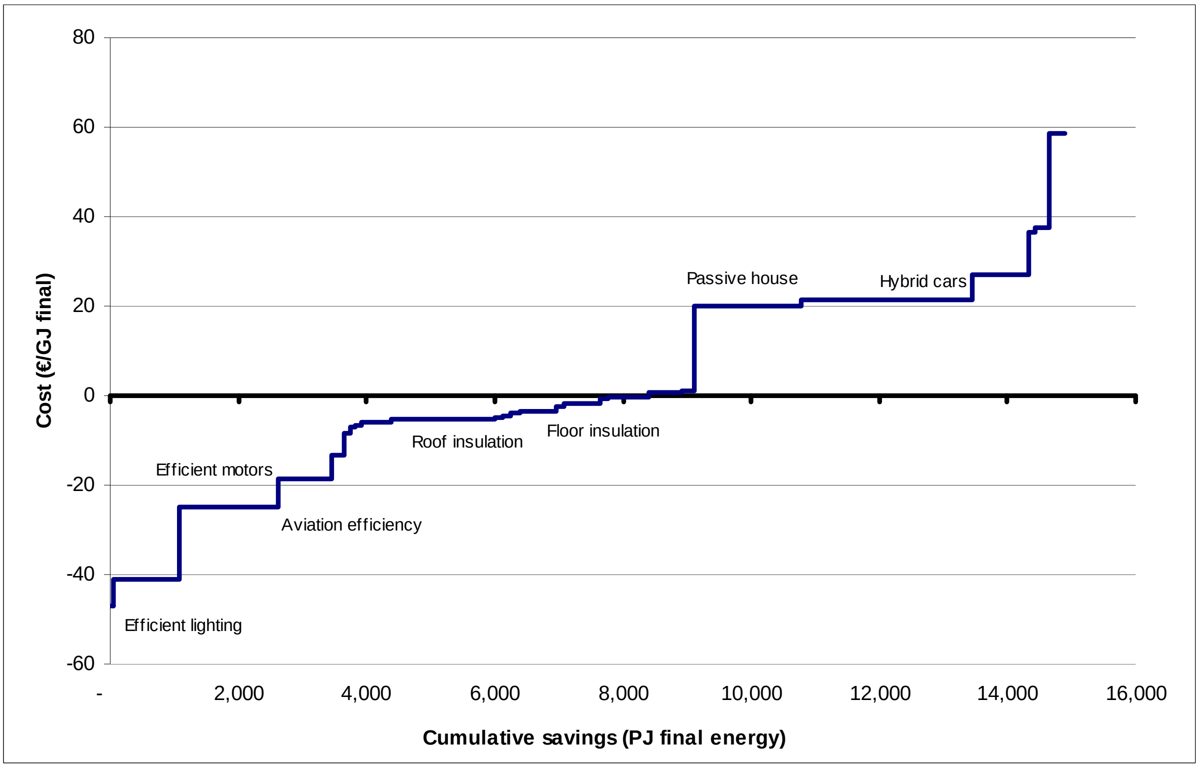

Figure 1: Cost curve OECD Europe

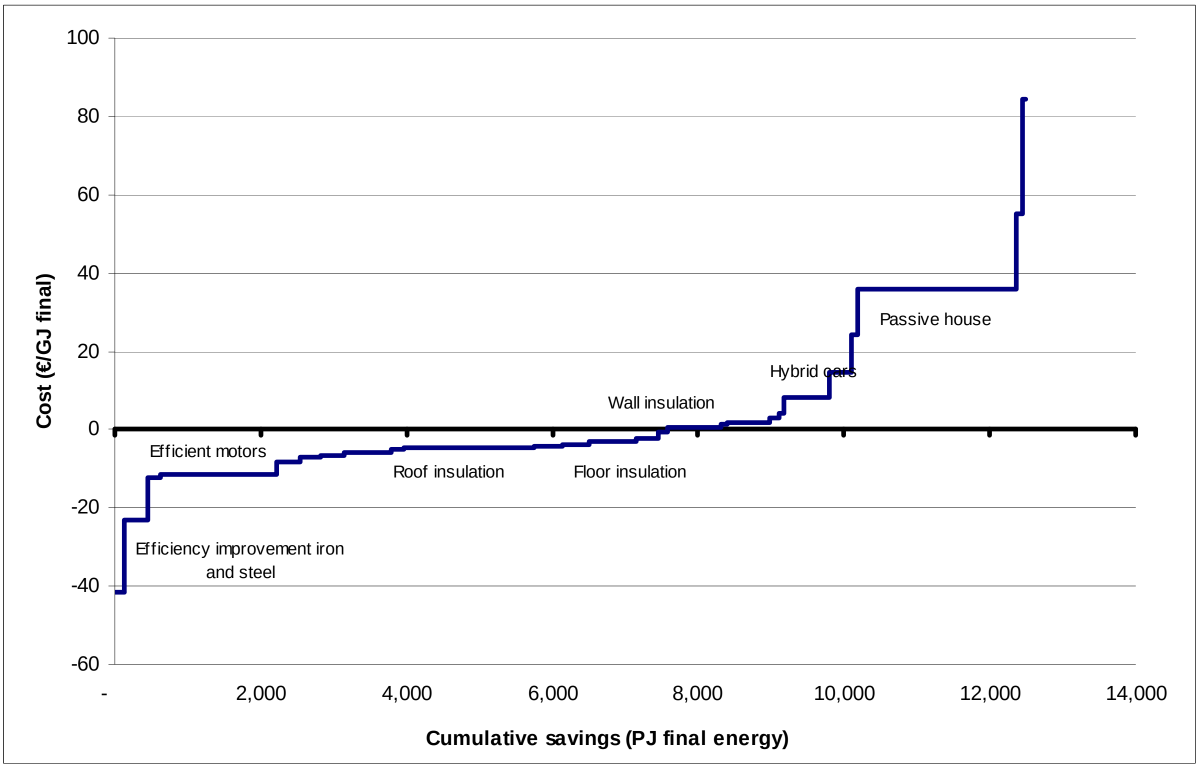

Figure 2: Cost curve for China

The selected measures apply to approximately 75-80% of final energy demand. This means that for 20% of final energy demand no measures are implemented. The included measures save about 30% of the final energy demand in OECD Europe and China. The savings per sector and region can be found in Table 9. The savings correspond to around 30% in the transport sector, 35% in the buildings sector and 25% in industry.

Table 9: Savings in total final energy demand by selected measures

Savings in final energy demand	**OECD Europe**	**China**
Total final energy demand	**29%**	**30%**
Transport	32%	25%
Buildings and agriculture	32%	37%
Industry	22%	25%

The total costs for implementing the selected measures by summing them up amount to 66 bln € for OECD Europe and 80 bln €$_{PPP}$ for China. These costs correspond to respectively 0.6% of GDP in OECD Europe and 1.0% of GDP in China in 2005, see Table 10.

Table 10: Total costs of implementing selected measures

Costs (bln €)	**OECD Europe**	**China**
Total final energy demand	**66**	**80**
Transport	80	35
Buildings and agriculture	29	79
Industry	-43	-34
Total GDP (bln €) in 2005	*12,000*	*7,800*
Share costs of measures in GDP	*0.6%*	*1.0%*

There are quite a number of cost-effective measures available for energy-efficiency improvement. Table 11 shows the share of cost-effective savings in total savings per region and sector. In total around 55-60% of the calculated savings are cost-effective.

Table 11: Share cost effective measures in total potential

Share cost effective measures	**OECD Europe**	**China**
Total final energy demand	**55%**	**59%**
Transport	27%	15%
Buildings and agriculture	57%	42%
Industry	97%	94%

The average costs for improving energy-efficiency by the selected measures amounts to 5 €/GJ, of which the transport measures on average cost 18 €/GJ, the buildings measures 8 €/GJ and the industry measures -10 €/GJ (see Table 12).

Table 12: Average specific costs

Specific costs (€/GJ final)	**OECD Europe**	**China**	**Average costs both regions**
Total final energy demand	**4**	**6**	**5**
Transport	15	28	18
Buildings and agriculture	4	12	8
Industry	-14	-7	-10

2.2.2.1 Sensitivity analysis

Discount rate

The results are quite sensitive to the discount rate used. If the discount rate is changed from 6% to 4%, the average costs for the energy-efficiency measures decreases from 5 €/GJ to 3 €/GJ. If the discount rate is changed to 8% the average costs increase to 8 €/GJ.

Fuel prices

The results are very sensitive to the energy price assumptions. If fuel prices increase by 50% the average costs decrease from 5 €/GJ to -1 €/GJ. If fuel prices decrease by 50% the average costs increase to 12 €/GJ.

2.2.2.2 Costs of energy-efficiency measures in a global perspective

The technical savings potential in 2050, as calculated in WP4, amounted to 40% for OECD Europe and 44% for China, in comparison to the reference scenario. Globally the savings amounted to 44% of reference energy demand in 2050. This would lead to only a slight increase of final energy demand from 293 EJ in 2005 to 317 EJ in 2050. We estimate that the annual costs for implementing this technical potential will be around 0.4% of global GDP in 2050.

Long term energy-efficiency improvement requires continuous innovation and therefore besides current best practices, new measures will need to be implemented in the period up to 2050 to achieve the technical potentials. The savings potential by the measures included in the cost calculation amounts to approximately 30% of current final energy demand. Since only a selection of measures is included in the calculation, the actual potential for current best practices to reduce energy demand is higher. This is also true, because no measures are included for 20% of the energy demand (mainly in agriculture and some industries).

In the scenarios, GDP and energy demand continues to increase, although to a different degree. By 2050, global GDP in the reference scenario has increased by 440% from 2005 while energy demand increases in the reference scenario by 195% in 2050. This means that in principle, implementing energy-efficiency measures becomes relatively cheaper. In order to reduce 44% of final energy demand in 2050 at the average costs as calculated here of 5 €/GJ, the total costs would amount to 0.4% of global GDP in 2050. The costs needed to implement emerging innovative technologies are unknown, however, and may be more expensive than current best practice technologies as calculated here. On the other hand, fuel prices are likely to increase in the future, which has a large impact on the profitability of energy-efficiency measures.

3 Market barriers

Although the potential for energy-efficiency is large, there are several market barriers that prevent the uptake of cost-effective energy-efficiency measures. Often energy policies aimed at improving energy-efficiency are implemented to overcome these barriers. In this section we discuss different type of market barriers that can limit the uptake of energy-efficiency measures. Many studies have demonstrated the existence of market barriers for energy-efficiency improvement (IPCC, 2001; DeCanio, 1993; DeCanio, 1994; Sorrell et al., 2004), of which some are market failures, i.e. barriers that may lead to increased (energy) costs and hence a sub-optimisation.

Brown (2001) distinguished between market failures and barriers. “Market failures” occur when there is a flaw in the way markets operate. While “market barriers” refer to obstacles that are not based on market failures but which nonetheless contribute to a slow diffusion and adoption of energy efficient technologies.

Table 13 gives examples of important market failures and market barriers.

Table 13: Market failures and barriers inhibiting energy-efficiency improvements

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

We will discuss these failures and barriers below.

3.1.1 Principal-agent problem

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

The principal-agent problem can be categorized as given in the two-by-two matrix of Table 14, which classifies the technology according to user’s ability to choose the technology and the user’s responsibility for paying associated energy costs.

Table 14: Principal agent classification of energy and end users (Graus and Worrell, 2008)

	Chooses Technology	**Does not Choose Technology**
Pays Energy Bill	Category 1: No Problem	Category 2: Efficiency Problem
Does not Pay Energy Bill	Category 3: Usage and Efficiency Problem	Category 4: Usage Problem

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

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

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

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

3.1.2 Distortionary fiscal and regulatory policies

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

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

3.1.3 Unprized costs (market externalities)

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

3.1.4 Insufficient and inaccurate information

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

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

3.1.5 Low energy costs and low price elasticity

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

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

3.1.6 Capital market barriers

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

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

4 Summary and conclusions

Few global studies on energy-efficiency costs and benefits are available. Some studies that calculate CO_2 mitigation costs for energy-efficiency show large differences in costs estimates.

From the case study that was done for OECD Europe and China in this study, it was found that the costs estimates are very sensitive to fuel price assumptions. They can change from positive to negative costs just by higher fuel price assumptions. Also the discount rate used influences costs significantly as well as assumptions regarding incremental investment costs of energy-efficiency measures and estimated fuel savings. Further research is therefore needed to estimate global and regional costs of energy-efficiency measures.

Based on the case study done for OECD Europe and China we estimate that to implement the global technical potential as calculated in WP4, annual costs equivalent to 0.5% of GDP in 2050 are needed. Globally, the estimated technical savings potential amounted to 44% of reference energy demand in 2050. This would lead to only a slight increase of final energy demand from 293 EJ in 2005 to 317 EJ in 2050.

It was found that there is a large potential for cost-effective measures, equivalent to around 55-60% of energy savings of included measures. There are however a number of market failures and barriers that inhibit the uptake of energy-efficiency measures. These are e.g. insufficient and inaccurate information, capital market barriers and low energy costs and low price elasticity. Policies aimed at removing market barriers are important to stimulate energy-efficiency improvement.

In industries, cost-effective measures often not able to meet investment criteria. Some industries have investment criteria where investments need to be paid back three times in a five or ten year period in order to be considered. Most energy-efficiency measures, although cost-effective, do not meet these criteria.

5 Abbreviations

Bln	Billion
CHP	Combined Heat and Power
CNY	Chinese Yuan
CO_{2eq}	Carbon Dioxide Equivalent
CRT	Cathode Ray Tube
EPA	Environmental Protection Agency
ETP	Energy Technology Perspectives
GDP	Gross Domestic Product
GHG	Greenhouse Gas
LCD	Liquid-Crystal Display
PPM	Parts Per Million
PPP	Purchase Power Parity
TPMS	Tyre inflation control
WETO	World Energy Technology Outlook

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Appendix

Table 15: Net costs per tonne of CO_2 per measure for OECD Europe and China

		OECD Europe			China		
Sector	**Measure**	**Net specific costs (€/GJ primary)**	**CO2 emission factor (g CO2/TJ primary)**	**EUR/tonne CO2**	**Net specific costs (€/GJ primary)**	**CO2 emission factor (g CO2/TJ primary)**	**EUR/tonne CO2**
Transport – passenger cars	Hybrid passenger cars	21	73	292	8	73	112
Transport – passenger cars	Weight reduction	27	73	372	24	73	331
Transport - buses	Hybrid buses	59	73	810	131	73	1797
Transport - trucks	- Improved aerodynamics - Tyre inflation control (TPMS) - Use of wide-based tires - Reduce engine idling - Driver training	-2	73	-22	3	73	40
Transport - aviation	- Improved aerodynamics - Advanced engines - Improved Air Traffic Management (ATM) - Further operational measures	-19	73	-254	-12	73	-168
Buildings - heat	Passive house	20	56	359	36	56	638
Buildings - heat	Roof insulation - existing buildings	-5	56	-95	-5	56	-83
Buildings - heat	Wall insulation - existing buildings	0	56	-5	1	56	11
Buildings - heat	Floor insulation - existing buildings	-4	56	-65	-3	56	-52
Buildings - heat	Window insulation - existing buildings	1	56	14	2	56	31
Buildings - heat	Water saving power heads	1	56	22	1	56	27
Buildings - power	Substitute incandescent lamps with compact fluorescent lamps (CFL)	-14	111	-129	-9	244	-38
Buildings - power	Efficient air conditioners	-5	111	-42	-1	244	-3
Buildings - power	Substitute CRT-screens with LCD-screens in offices	23	111	210	25	244	102
Buildings - power	Cold appliances	13	111	118	16	244	64
Buildings - power	Washing mashines	46	111	410	45	244	185
Iron and steel	Sinter plant heat recovery	-5	56	-96	-7	56	-126
Iron and steel	Hot charging / direct rolling in hot rolling mills	-7	56	-125	-7	56	-125
Iron and steel	Recuperative or regenerative burners in hot rolling mills	-7	56	-118	-7	56	-118
Iron and steel	Scrap preheating in electric arc furnace	-21	56	-366	-8	56	-138
Iron and steel	Near net shape casting (for other than flat products)	-34	56	-603	-53	56	-942
Iron and steel	Pulverized coal injection to 180 kg/thm in blast furnace	-9	93	-96	-9	93	-96
Iron and steel	BOF gas + sensible heat recovery in basic oxygen furnace	-4	85	-41	-4	85	-41
Electric motors	Variable speed drives, high efficiency motors and efficient pumps, compressors and fans	-9	111	-77	-3	244	-14
Cement	Application of multi-stage preheaters	-2	56	-43	-2	56	-43

Part VI:

Energy Consumption and Behavioural Changes

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Table of Contents

1 Introduction

In modern energy systems the reduction of greenhouse gas emissions can be accomplished with basically three approaches:

1) Shift in energy carriers towards less CO_2-emitting sources: introduction of renewable energies (Part II and III)

2) Introduction of technologies that are more efficient than other technologies: energy efficiency (Part IV and V)

3) Behavioural changes (of individuals and groups) to reduce energy consumption: sufficiency and alteration of life styles, including the shift of behavioural modes

This chapter focuses on the question whether behavioural changes play a significant role in the modelling of energy demand scenarios. As has been shown in previous chapters, renewable energies and energy efficiency are modelled in very different ways regarding their possible contributions to future energy systems. This could hold true for behavioural dimensions as well. The hypothesis therefore is: Behavioural dimensions of energy demand are modelled differently in different energy scenarios, and they are mostly included implicitly.

To test the hypothesis, some selected energy scenarios – covering the global as well as the German energy system – are analysed regarding the behaviour of actors and their quantitative role in the development of the future energy system.

The analysis covers different dimensions of human behaviour in modern energy systems and their role in scenarios: characterising the different actors in the scenario context as a starting point, concrete behavioural dimensions are described subsequently to get the whole picture. Two further relevant criteria are social and cultural contexts. They play roles in intraregional as well as transregional settings: in the first they address aspects like the divide between rich and poor individuals and groups within one modelling (geographical) region, in the latter they cover aspects of social and cultural mixing between different modelling regions that could become drivers for behavioural changes. The discussion of the paradigmatic orientation of the scenarios clarifies the general modelling approach and its intellectual background.

There are mainly two tangible domains that explicitly allow the integration of human behaviour in current energy scenario structures:

1) refurbishment rates of buildings

2) modal shift in the transport sector

Refurbishment: Energetic modernisation of buildings (insulation) is a parameter showing human behaviour very clearly. Usual refurbishment cycles span a time frame of about 30 to 50 years. During such a cycle the options for energy (heat) savings are limited. By refurbishing the respective up-to-date energy saving standard has to be met. It is this dynamics that make energy saving in buildings a rather inert process. Behavioural changes in this respect can be expressed as shorter refurbishment rates. To be able to identify a certain refurbishment rate as an active behavioural *change*, business-as-usual rates as a baseline have to be included in the scenarios. These business-as-usual rates can e.g. be a proliferation of historic experiences. In the following scenario analysis it is crucial to measure refurbishment rates of alternative developments versus a business as usual setting.

Modal shift: Changing the mode of transport is a significant aspect of behavioural change. The decision to either keep historic/traditional modes or to choose other modes involves active decisions of individual consumers. Motivation is irrelevant in this context, a shift could be economically driven or encouraged by or compulsorily introduced by a policy maker. Modal shifts often involve deeper behavioural changes of individuals, as a shift in the means of transportation often comes together with other behavioural aspects (e.g. style and location of living – inner city versus rural area).

2 Analysis of Global and National Energy Scenarios

2.1 IEA World Energy Outlook 2007 and 2008

In the following, emphasis is put on World Energy Outlook 2007 due to two reasons:

1) It analyses two countries – China and India – in detail. This allows some insight into the approach towards final consumer structures

2) In comparison to World Energy Outlook 2007 the current WEO 2008 can be compared in the light of these two countries

The World Energy Outlook 2007 tries to identify and quantify the factors that will drive on the one hand global energy demand and on the other hand the energy demand of China and India (with large rates of economic growth) to answer the question: how will China’s and India’s energy choices affect the world as a whole? It approaches the answer by means of detailed sets of projections and scenarios of energy markets in these countries, fuel by fuel and sector by sector.

The study defines a *Reference Scenario* (if nothing is done by governments to change historic energy trends), an *Alternative Policy Scenario* (if additional government actions are done to rein in the growth of energy demand) and a *High Growth Scenario* (where GDP growth doesn’t slow down as assumed in the Reference and Alternative Policy Scenarios). But not even in the Alternative Policy Scenario long-term CO_2 emissions can be halved – like G8 leaders “agreed to consider” in 2007. Therefore the authors of the study developed a more ambitious “450 Stabilisation Case”.

The World Energy Outlook 2008 includes China and India in the conventional modelling approach. Beyond the regular projections the Outlook 2008 concentrates on production structures of fossil fuels, mainly crude oil.

2.1.1 Reference to actors and deduced measures

Political actors as decision makers are addressed strongly in WEO 2007. Individual actors on the consumption side, however are not explicit elements in the modelling structure. Therefore major changes are happening only on the side of technical structures.

One shortcoming of the study is it does not include solutions beyond mainstream policy – even in the 450 Stabilisation Case: “In principle, there are many ways in which energy-related CO_2 emissions could be reduced to 23 Gt in 2030. In response to requests from policy makers, we describe here one possible pathway … to achieving this very ambitious target in order to illustrate the magnitude and urgency of challenge of transforming the global energy system.”

The terms “policy” and “measure” are used quasi synonymous. The study has analysed more than 1400 policies from OECD and non-OECD countries. Criteria for analysis have been the energy efficiency of specific technologies, the activities that drive energy demand and the rates of turnover of the physical capital stock of energy-using equipment. Logical energy and climate policy has a strong technological bias. It has to support and to subsidise energy efficiency and substitution of CO_2-intensive fuels, and it has to regulate the forces of energy demand.

There are two main appeals to political actors: 1) Contemporary policies are far from being sufficient. 2) Collective action is needed to address global energy challenges. IEA countries and China and India need enhanced policy co-operation, more co-operative activities and other multilateral and bilateral agreements.

On the national level, government action must focus energy efficiency and conservation. Also nuclear power, renewables and CCS can make a contribution. Furthermore regulatory measures such as standards and mandates will be needed, together with government support for long-term research, development and demonstration of new technologies.

The relevant actors – individuals, enterprises etc. – are driving forces of growing energy demand. Rising household incomes and the improvement in quality of life leads to more energy consumption and a growing vehicle stock. Nevertheless residential demand grows slower than in other sectors. This is largely a result of switching from traditional biomass to modern fuels. This transition can be interpreted as a modal shift in heat generation.

Two questions remain for the analysis of WEO: What is the understanding of development and what is the understanding of policy?

In WEO 2008 there is less direct reference to actors than in WEO 2007. This may derive from the mentioned different focus of WEO 2008. However, the modelling details of WEO 2007 regarding China and India are probably included in the general structure of WEO 2008.

2.1.2 Behavioural Dimensions

No quality and no behavioural dimensions are explicitly mentioned in WEO 2007. But there are some hints that point to such a dimension: First the World Energy Model ECO (WEM-ECO), developed for the purposes of the High Growth Scenario. Savings behaviours are interlinked to economic and population growth, but it remains unclear, which type of behaviour and of whom (actor).

A second trail is integrated in the 450 Stabilisation Case and a “Spotlight” on the question: “Can China and India Ever Mirror Western Lifestyles?” Western lifestyles are interlinked with an economic growth on traditional lines – including reducing poverty, modernising lifestyles and raising comfort levels. This may be called an energy-intensive path of development, growth and the corresponding lifestyles. But there are some signs of a radically different development path – leapfrogging to new technologies and involving different lifestyles.

In this Spotlight analysis neither actors nor policy measures nor any explicit social and cultural change is mentioned. Even in this approach the IEA chooses a traditional policy line:

Efficiency, technological progress and substitution as well as market-based instruments are favoured. According to the IEA, policies in these fields bear economic benefits and lower energy costs in many cases – with this “triple-win” (quote) outcome the question of a different distribution does not seem to be important.

Another trail which may imply behavioural quality and dimension is the residential sector, analysed in the demand projection of the Reference Scenario and the Alternative Policy Scenario. In China, per-capita energy consumption in the residential sector is expected to rise by 1.1% per year over 2005-2030 in the Reference Scenario, residential (and also commercial) energy consumption grows by nearly 40% by 2030. Urban residential living space increases from 26 m^2 per capita to 38 m^2 for urban residents and to 41 m^2 for rural residents. The energy-related residential and services CO_2 emissions have an annual growth rate of 1,7% from 2005 to 2030 – nonetheless this is much less compared to the other sectors (3,7% power generation, 2,0% industry, 5,4% Transport and 3,7% other). With this background, one aspect for behavioural change could be a positive reaction to technical energy-efficiency: Appliance efficiency improvements could also encourage more rational and efficient use of appliances.

In the Alternative Policy Scenario China’s main drivers for rising energy demand are greater wealth and higher urbanisation. Energy demand in the coastal region of China grows faster – by 2% per year in 2005-2030 than midland consumption. Behavioural change could result as a reaction on political measures. The policy Assumption in China’s Residential Sector in the Alternative Policy Scenario mentions “Minimum efficiency performance standards – reach standards” (for refrigerators, air conditioners and colour TVs) , “Energy efficiency labelling” (also for washing machines) , “Building codes and stands” (to reduce energy consumption in new buildings by 50% by 2010 compared to 2008) and “Solar thermal” (promotion of building-integrated solar thermal systems in urban areas).

An explicit behavioural change is “modal shift” in the transport sector. The Alternative Policy Scenario assumes modal shift and reduced fuel consumption in other modes to reduce oil demand by 10%.

In India, residential energy consumption is expected to rise by 1,6 % per year over 2005-2030 in the Reference Scenario. Energy demand for transport is expected to see rapid growth by 6.1% per year as the vehicle stock expands rapidly with rising economic activity and household incomes. Actually the use of traditional biomass is very inefficient in India and will be replaced by more efficient fuels (like liquefied petroleum gas, kerosene, gas and electricity). In rural households biomass use will remain the primary fuel. Nonetheless rural households make up over 70% of the population but account for only 42% of the residential demand for oil, gas and electricity.

In the Alternative Policy Scenario households are assumed to be able to afford more efficient, cleaner fuels for cooking and heating because they have higher incomes compared to the reference case.

Key policies in India’s residential and service sectors describe five measures: Building codes & standards (eco efficient design); energy efficient labelling (for refrigerators, lamps and other products); improved cooking stoves (chuldhas in rural and semi urban households);

further introduction of biogas and solar devices (water heating systems). Energy saving options in the residential sector includes space heating, water heating, cooking, lighting and appliance use.

Modal shift to public transport is also mentioned for India and contributes to oil savings. However, the quantitative value attributed to this remains unclear.

World Energy Outlook 2008 correlates changes in energy prices to behavioural changes: rising oil prices lead to the purchase of more efficient vehicles. However, this is not an explicit behavioural change as defined in this report. In alternative scenarios in WEO 2008 buildings get better insulation, but it’s unclear whether this includes refurbishment of existing buildings or just new buildings. Refurbishment rates are not discussed in the report.

Behavioural changes as results of changing preferences or value orientation of consumers are not discussed.

2.1.3 Social and cultural context

The WEO 2007 focuses the political, economic and demographic context of China and India. The reference scenarios include the existing policies and measures, the alternative policy scenarios also policies and measures under discussion (some 80 policies and measures for India, covering all energy sectors, have been analysed. Nonetheless there is no differentiated social and cultural context corresponding to the strong political and economic context. There is only some discrimination between coastal (more energy intensive growth because investment for construction, infrastructure and industry has centred in the coastal regions and midland consumption in China and between rural (much more use of firewood and dung) and urban (electricity use grows more rapidly) consumption in India.

For India another social and cultural context is mentioned: The inefficient traditional energy-use. The lower the income, the higher the use of firewood for cooking. Therefore the installation of improved chuldhas in the alternative policy scenario may include a social (low income) und cultural (traditional use of biomass) context.

One social aspect includes the divide between poor and rich households: Indian households with a higher income can afford more efficient, cleaner fuels for cooking and heating.

WEO 2008 omits the discussion of social and cultural contexts, too.

2.1.4 Paradigmatic orientation

The IEA scenarios and projections (both WEO 2007 and WEO 2008) are basically growth oriented, arguing in the traditional thread of “development and improvement in quality of life requires economic growth, economic growth requires more energy”. Solutions to accompanying problems are energy efficiency and less CO_2-intensive fuels (nuclear and renewables).

The IEA does not model sufficiency paths. A radically different development path compared to the path of the western industrialised countries is mentioned in the spotlight “Can China and India Ever Mirror Western Lifestyles?” in WEO 2007 (see above). This traditional approach can be interpreted as judging individual actors as not willing or not able to change their behaviour.

2.1.5 Conclusions

Technical innovations are the main drivers of emissions reductions in the IEA approach. The understanding of policy is instrumental (people have to be governed) and mechanical (incentives evoke reactions). The behavioural dimension of the study is neglected – actors are reacting, hardly showing any proactive behaviours. Some implicit aspects of behavioural change are mentioned like improvements in appliance efficiency which will also encourage more rational and efficient use. One explicit aspect is mentioned for the transport sector: modal shift to public transport contributes to oil savings.

The overarching driver of emissions reduction in the World Energy Outlooks is structural change. But this change is accomplished mainly with technological change.

2.2 IEA Energy Technology Perspectives 2008

ACT and BLUE scenarios reach significantly lower CO_2 emissions than IEA's baseline projection. In both cases the formulation of new policies and measures is a prerequisite to be able to follow the modelled emissions and consumption paths. But according to the IEA, both scenarios „contain relatively optimistic assumptions for all key technology areas" (p. 58).

In the ACT scenario CO_2 emissions reach an emissions level by 2050 in the vicinity of today's emissions level with maximum emissions between 2020 and 2030. BLUE scenario fulfills more ambitious emissions targets, as demanded by the IPCC to limit long-term global mean temperature increase to 2.0 to 2.4 °C: emissions are to be brought down to at least 50 percent of the year 2000 level. To reach this level, technology development needs to increase pace in BLUE compared to ACT (cf. Figure 2-1).

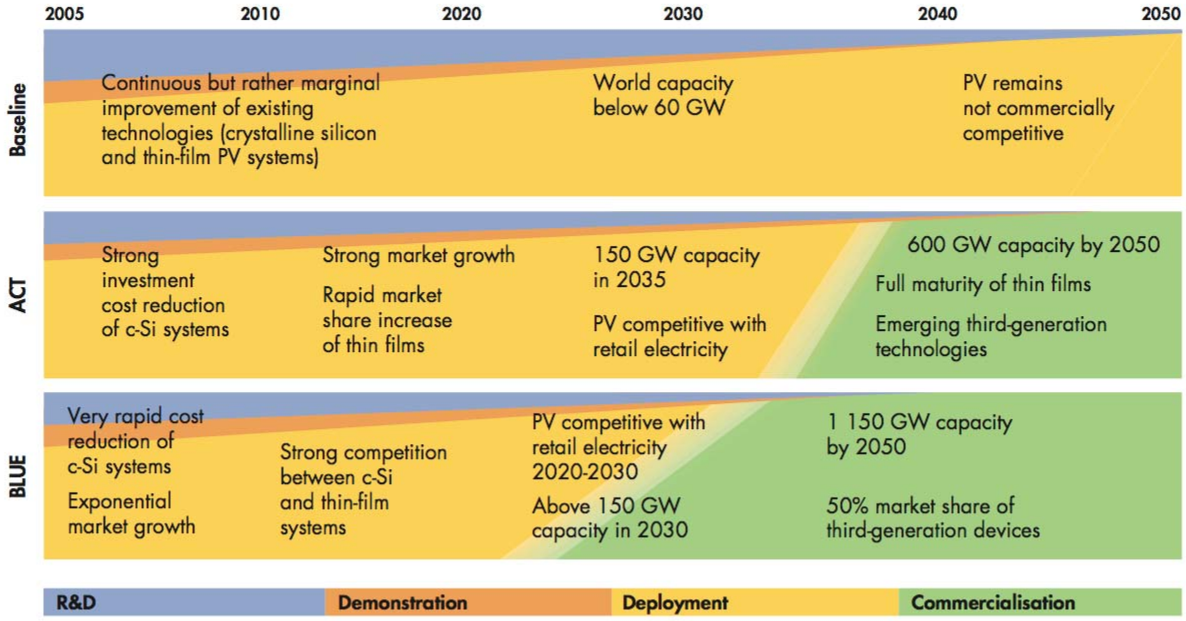


Figure 2-1. Technology lines (here showing photovoltaic) according to different scenarios and the baseline projection. In scenario BLUE technology development needs to progress at higher rate than in scenario ACT. (IEA 2008)

In the following the analysis will concentrate on BLUE scenario. However, most of the characteristics described are also valid for ACT.

2.2.1 Reference to actors and deduced measures

In BLUE scenario the policy maker is the central actor. As the IEA calculates technology oriented scenarios, non-technological aspects find only cursory reference. However, the IEA states that "governments will need to give a lead to public opinion … Neither the ACT nor the BLUE scenarios can be achieved without a major shift in priorities, and in the BLUE scenarios, **this needs to be radical and urgent** (sic)" (p. 45).

There is a close interlinkage between technologies to be developed and the behaving actors. As a key finding the IEA points to the necessity of identifying policies and measures to advance consumer awareness. This is accompanied by expressing the need for identification of "future actions to alter consumer behaviour and preferences" (p. 127). In the roadmap chapter the IEA focuses on recommendations to enhance RD&D on technological side, but also to increase acceptance of technologies by the public/consumers. Introduction of policies is mentioned as another element of technology deployment (mandatory minimum efficiency performance standards for energy efficiency in buildings and for appliances, standards in the transport sector), but not analysed in detail.

2.2.2 Behavioural Dimensions

Three basic fields involve behavioural aspects in the IEA scenarios:

- Modal shift in the transport sector
- Rate of retrofit in the building sector
- Generally introduction of technologies that can be *negatively* influenced by the behavioural dimension

Modal shift. In BLUE scenario modal shift in the transport sector leads to an emission reduction of 15 percent in car, truck and air travel by 2050 compared to emissions in the baseline development. This is identical to the ACT scenario. Hence emissions reductions beyond the ACT level do not involve additional behavioural changes according to the IEA scenario modellers. This points to the fact that the IEA does not assume that consumer behaviour will play an additional role when it comes to far-reaching emissions reductions in the long-term. Behavioural changes in transport are mentioned in the scenario documentation within the broader framework of dynamics of city growth. This being a complex and not yet fully understood task, the IEA finally states: "... some elements appear critical: strong urban planning, major investments in public transit and non-motorised transport infrastructure, and policies to discourage car use. These clearly go well beyond technology considerations, and so are not covered here in any detail." (p. 449) Despite this statement, to show possible impacts of energy efficient transport planning on CO_2 emissions, the BLUE scenario models public and non-motorised transport to reach a share of around 60 percent by 2050 in 1000 cities (for comparison: in the baseline projection this share is in the range of 30 percent). Average transport energy consumption and resulting CO_2 emissions are then about 40 percent lower than in the baseline development. It has to be taken into consideration, though, that in BLUE scenario vehicles are far more efficient than in baseline projection, offsetting the contribution of modal shift to overall emissions reduction.

Another assumption is the shift from air travel to high speed rail travel: 25 percent of all air travels shorter than 750 km will have shifted to rail by 2050 in the BLUE scenario (representing about 5 percent of all air travel at that time). Further assumption: A small share of car travel will have shifted to rail, too. This is supposed to lead to emissions 3 percent lower than in the baseline projection.

Building stock turnover. Turnover rate of the building stock is considerably higher in developing countries than in industrialised countries. Another structural difference lies in residential and service sector buildings, the latter being retired earlier than the first. Long turnover rates are a serious obstacle for the reduction of heating and cooling demand. To reach the energy savings according to BLUE scenario, about 200 million dwellings have to be refurbished in OECD countries to comply with new energy standards. This is indirectly linked to the alteration of urban development.

The BLUE scenario addresses some specific technologies and technology lines in this respect, e.g. zero-energy buildings.

Influence of behaviour on technology deployment. The behavioural dimension can become an obstacle for the dissemination of technologies. The IEA lists the following aspects:

- new technologies are often perceived as having higher risks
- lack of information to consumers prevents them from making valid comparisons of investment options

Therefore various barriers were “influenced by behaviour and psychology” (p. 245), according to the IEA.

2.2.3 Social and cultural context

The modal share is often closely linked with general developmental issues and hence with social contexts: The higher the share of cars in city transport systems (and hence the higher the share of individual vs. public transport), the higher the annual energy consumption gets. This is displayed in Figure 2-2.

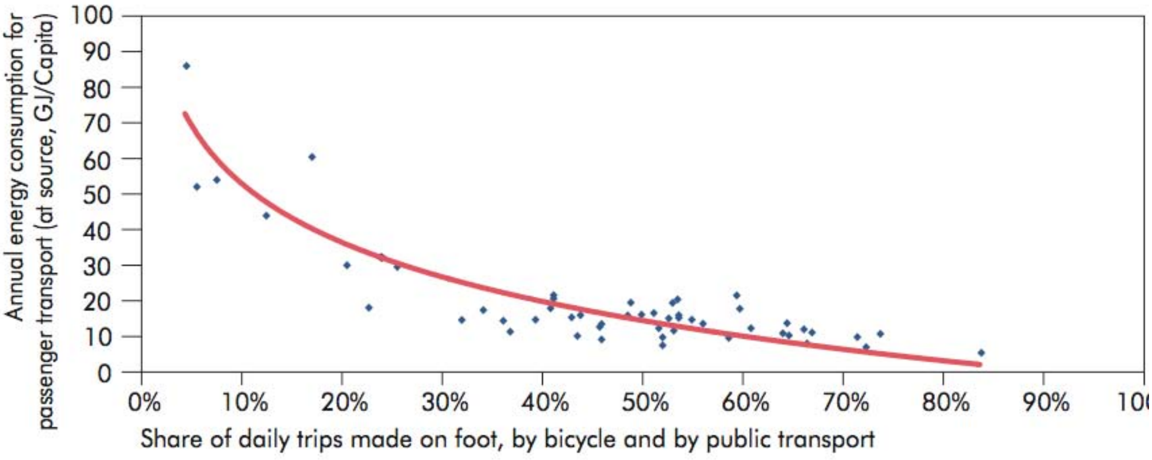


Figure 2-2. Energy consumption for passenger transport vs. Modal share. IEA 2008.

This is partially linked to the general development standard: typically the share of car transport is smaller in developing countries. As many examples show, an increase in the share of cars in city transport systems is not necessarily corresponding to GDP growth, but depends on the investment patterns in developing countries whether cars will reach a high or a low share. It can be concluded, and this is what IEA did, that for an emission path as modelled in BLUE scenario, shares of passenger cars will have to be rather low (see above).

2.2.4 Paradigmatic orientation

The scenarios are technology oriented. However, the IEA admits that technologies are critically depending on soft factors, e. g. consumer behaviour.

2.2.5 Conclusions

The current IEA scenarios consider behavioural changes of consumers, mainly in the transport sector via modal shift. Modal shift is as a first approximation independent from technologies. Comparing the BLUE scenario to the ACT scenario reveals IEA’s basic assumption/view that behavioural changes are limited in range: although BLUE scenario models ambitious climate protection targets, behavioural aspects reach just the same size as in scenario ACT.

2.3 IPCC - Special Report on Emission Scenarios (2000)

The IPCC global SRES scenarios consist of four scenario families. These families have many members that describe different emission paths. In general the four families can be discriminated by rate of economic growth, population growth and inter-regional development and transfer. Another criterion is the pace of technology development. The analysis of behavioural dimensions has to concentrate on the general storylines of the scenario families, as the multitude of specific scenarios would be too confusing.

2.3.1 Reference to actors and deduced measures

Actors are described as essential elements of the different scenario families. This is expressed in the storylines. However, differentiation hardly goes deeper than this basic storyline level or is at least not presented in the scenario report.

The B1 Scenario Family includes structural changes that can be traced back to the assumption of behavioural changes of individuals.

The A1 scenario family is shaped by rapid economic growth and technology introduction, among other parameters. Different regions converge in social, cultural as well as in economic terms. On the contrary, scenario family A2 keeps regional differences. Technological change progresses at slower pace than in A1.

Economic structures change very quickly in the B1 scenario family. The rapid change towards service and information societies leads to a considerable reduction of material intensity and to the introduction of clean technologies. Global solutions in regard to sustainability are favoured over regional and local approaches. This includes stronger equity among other aspects. B2 scenario family favours local and regional solutions oriented towards social equity and environmental protection. Economic and population growth rates are moderate and are in between the A1 and B1 scenario families.

2.3.2 Behavioural Dimensions and social and cultural context

The analysis shows that behavioural dimensions play a relevant role in the B1 scenario family. This can be derived from the general assumption that structural change happens quickly in B1. The transition from a material intensive to an information and service society requires a certain change in human behaviour.

As the B2 family emphasises local and regional solutions, this could be interpreted as an approach that requires stronger individual behavioural aspects. These behavioural changes have partly been discussed in the scenario report. B2 scenarios are characterised by the narrowing of international income differences – being an indicator of a certain alteration of social differences between world regions. Within regions the local inequity is reduced through “stronger community-support networks” (p. 183) An explicit behavioural aspect is reflected in the assumption that meat consumption in the B2 family is lower than in the A1 family.

Cultural contexts within each geographical region are not included in the scenarios. The same holds true for social aspects. However, relative distribution of wealth between different regions is a criterion in different scenario families.

In A1 “high economic growth leads to shifts of economic power from traditional core countries to the current economic ’periphery‘ …” (p. 180) Economic reallocation of this type can be interpreted as a prerequisite for behavioural changes, which does not necessarily mean that these behavioural changes affect scenario results. Indeed, such influences cannot be detected in the scenarios. The IPCC publication does not include information on this topic. Due to a certain degree of convergence, cultural and social mixing happens.

In scenario family A2 social and cultural interactions between different regions are not emphasised. Regarding equity of regions and countries: The income gap between the currently rich and poor countries/regions does not narrow. This is a structural difference between A2 on the one hand and A1 and B1 on the other hand.

Equitable income distribution is one facet of the B1 family. In contrast to A1, in B1 the gains from increased productivity are invested in improved efficiency (resulting in progressing dematerialisation), in equity and environmental protection. One hint to the behavioural dimension is given with the statement on future living conditions: “Cities are compact and designed for public and non-motorised transport, with suburban developments tightly controlled.” (p. 182) This explicitly affords an active change in individual behaviour and in the definition of individual lifestyles.

2.3.3 Paradigmatic orientation

The scenarios present a wide range of different paradigms. These are mentioned in the subchapters above and span a range from economy and technology oriented approaches – high economic growth and rapid technological development – to more locally focussed and low-growth development paths.

2.3.4 Conclusions

The IPCC scenarios are modelling global emission and energy demand paths. Behavioural changes are in parts explicitly included in the modelling structure, they are a prerequisite of some scenarios (B1 family), being mentioned in the general storyline as a necessary element in future energy consumption patterns.

2.4 EC WETO H_2 (2006)

World Energy Technology Outlook WETO is a technology focussed set of scenarios, consisting of a *Reference* development, a *Carbon Constrained Case* (CCC) and as further development of CCC the scenario towards a hydrogen economy *WETO-*H_2.

The paradigm of WETO can be characterised as a “classical” technology oriented growth path. The WETO H_2 case is modelling a hydrogen future, not an explicit highly efficient system. Therefore primary energy demand of the H_2 scenario is only 8 percent less than in the reference case.

WETO is using POLES as modelling data set, hence it represents the seven POLES geographical regions. Other regions that can be discriminated are: EU 25, OECD, OPEC, OPEC Middle East, Persian Gulf.

2.4.1 Reference to actors and deduced measures

WETO-H_2 addresses different political actors as decision makers. Individual consumers are not included in the model as explicitly acting entities which could trigger structural changes.

2.4.2 Behavioural Dimensions, social and cultural context and paradigmatic orientation

One of the characteristics of the CCC scenario is that “… behavioural changes in energy demand are important elements in emission reductions.” (p. 57) However, the size of these explicit behavioural changes are not quantified in the scenario report.

There is neither a social nor cultural context included in the model. Due to the regional discrimination (geographical regions) some points can be derived in terms of converging developments: energy consumption will strongly increase in developing countries, and so will GDP growth. Both will grow stronger than in industrialised countries, which can already be observed currently.

Paradigmatic orientation can be characterised as technology oriented, and although explicit behavioural change seems to play a role in the scenario context, its quantitative role is undefined.

2.5 Lead Study 2007 and 2008, “Leitstudie 2007 und 2008”, for the German energy system

The study “Leitstudie 2007” shows that CO_2 reduction targets pursued by the German federal government are technically and economically achievable. The study’s author explains the necessity of political measures and mentions shortcomings of the recent past, like the weak progress in realising efficiency potentials.

The study undertakes a quantitative assessment of renewable energy and technical energy efficiency measures and is not a qualitative assessment of the behavioural dimension.

Similarly “Lead Study 2008” has a quantitative focus and stresses the importance of initiating a structural change of energy supply that needs to be realised within the whole European Union.

2.5.1 Reference to actors and deduced measures

The author first addresses *political actors,* as the increased utilisation of renewable energy to 2020 was to be politically supported until self-supporting markets are established. In the scenario only policy makers in the form of necessary policies and measures to reach certain renewable and efficiency goals are addressed. Several instruments and measures are assumed to be introduced because actually there are not enough efforts to mobilise technical and structural efficiency options. Apart from that general structural change and punctual shifting to sustainable power supply are explicitly mentioned. For the transport sector the following measures are discussed: decreasing growth of traffic and possibilities of other modes of transportation are suggested, which would mean different infrastructural planning (compared to current approaches). The necessity of combining measures to reinforce efficiency and to increase renewable energy shares is discussed as a guiding principle. Reduction targets can only be reached if partial strategies lump together that may mobilise the potentials in all consumption and transformation sectors.

Lead Study 2008 adds that municipal activities, in particular those of municipal energy suppliers, are necessary to accelerate structural change of the heat supply.

Associations and business representatives of the branch of renewable energies are mentioned as *economic actors*. Orientation of the study towards more communicational approaches seems to include only these associations and business representatives. Not explicitly mentioned is the automobile industry, but it is implicitly included in the context of oil- and fuel-saving and smaller vehicles (e. g. down-sizing).

Lead Study 2008 points out that some economic actors are opposed to political strategies and targets aimed at reducing CO_2 emissions, e.g. the German automobile industry is speaking out against emission reduction targets for their vehicles.

Private households are on the one hand conceptualised as central actors for the heat sector but on the other hand they are not included with regard to measures and structural conditions. Private households are regarded as essential for the decrease of final energy demand – about 37% to 2050, as shows Tab. 2-1.

Tab. 2-1. Decrease of final energy demand by about 37% in all sectors from 2005 to 2050: strategies, actors and measures (own schedule on the basis of the information of the study):

		Actor	Absolute and percent	Measure
Decrease of demand, absolute	3.345 PJ/a			
Decrease of demand, percent	37%			
By the strategy of further efficiency measures for the end-user	1.535 PJ/a bzw. ca. 46%	Private households	715 PJ/a 46.6%	in particular by help of extensive refurbishment of old buildings
		Transport sector	320 PJ/a 20.8%	No information
		Trade and service, Handel,	290 PJ/a 18.9%	No information
		Industry	210 PJ/a 13.7%	No information

The contribution of households to the decrease of energy demand is therefore more than twice as high as the contribution of other actors. Main measure is the refurbishment of old buildings, addressed are above all others house-owners, whereas architects are qualitatively classified as slowing down the process because they are not orientated to energy efficiency and renewable energies. Measures of or for other actors remain scarce.

In Lead Study 2008 final energy demand of households decreases by about 48%, in the transport sector by 27%, and in industry by 32%.

The fuzzy structure of actors within the heat sector is mentioned as problematic in Lead Study 2007 and 2008: there are millions of actors because nearly *every owner* of a building belongs to this group. The reference to actors in the study is more orientated to objects (buildings) than to the individuals (owners and users) and it remains unclear whether the expected reduction within the heat sector is realistic.

Finally the study presents an ambitious type of scenario with strong targets of emissions reduction: Decrease of energy demand for space heating (80PJ/a), decrease of energy for process heat (70PJ/a) and decrease of electricity demand (22 PJ/a) are mentioned as preconditions for a further decrease of final energy demand for about 2.7% – however without mentioning any actor.

Lead Study 2008 mentions that the recent unambiguous scientific findings on climate change and its implications as well as the high level of energy prices might lead to more and more social actors supporting the necessary transformation of energy supply.

2.5.2 Behavioural Dimensions

Within Lead Study 2007 and 2008 individual behaviour is first stated in terms of building owners and is seen as problematic within the investment context: Investment decisions do usually not consider energy efficiency or alternative energies. Even the economic optimum is not as important as the given structural networks and private preferences and recommendations of architects are prioritised.

Furthermore within both studies *individual behaviour* is seen as a problem within the transport sector: The decrease of fuel consumption is compensated by the trend to larger cars, more comfort and higher technical security standards – this can also be seen as a rebound effect. This dimension of behaviour includes producers and consumers. The expectation in the transport sector is moving towards higher emissions because the trend to “more” and “bigger” is opposed to the reduction targets.

In the modelling there is almost no behavioural dimension and there are no acting and learning subjects. Merely section 3.3 is relevant and table 3-1 shows the development of prices for import and consumption from 1995 to 2005, but only two consumer-groups are mentioned: wholesale trade and private households. Here it could be interesting to show the relation between the development of income and of energy prices on the one hand and the share of energy costs of the household budget on the other side. This could be combined with the time factor: Actually renewable energies are more expensive. It takes them as long as 2025 to reach the break even point with fossil fuels. Therefore the political and social breakthrough of another energy path may be difficult because of the long period between investment and economic benefit.

The *quality of behaviour* is formulated very generally and includes only efficiency (no sufficiency path and no consistency path like for example modal shift). Named are additional measures of efficiency for and from the end-user who may contribute about half to the decrease of final energy demand (37% from 2005 to 2050). Further mentioned is the considerable more efficient use of fuels – but the link to behaviour is weak because the decrease is caused by the adoption of more efficient vehicles. Finally the study discusses the necessity of higher end-use-efficiency and about the failures regarding the efficient use of electricity. Lead Study 2008 sees the biggest potential for energy savings in private households. The private sector is therefore mainly contributing to the decrease of electricity use. This assumption is also very generally based on higher efficiency and does not include any behavioural change.

2.5.3 Social and cultural context

Lead study 2007 and 2008 argue nearly without any social and cultural context. Thus for example the social situation of two as essential conceptualised actors – the building owner and the building user – is not at all subject of the Lead Study 2007. The cultural dimension is reduced to the ecological and economic optimisation and architects are named as obstacles towards more efficient building structures. Symbolic denotations of buildings and cars are ignored by the study. Private households are acting within a social and cultural no-man's-land and the expected efficient behaviour is not embedded in any context. There is no social or cultural context within the development of the heat market/sector until 2050 either. Reduction potentials are evidently large – but these potentials have to be mobilised. There is no reflection about cultural patterns that are inconsistent with common forms of use or with a transformation from consumer to prosumer who takes care for the production of energy for example as building owner.

2.5.4 Paradigmatic orientation

Population will decrease but will nevertheless use more energy per capita. This shows the paradigm of growth as basis of the studies. A sufficiency path is missing, therefore CO_2 emissions of growing energy consumption per capita can only be controlled by efficiency measures and renewable energies (corresponding with markets which need political support before they become self-supporting). At the same time both studies plead strongly for efficiency and so criticise “progress” (but it does not become clear if this progress is exclusively technical or also social): Long term sustainable energy supply can only be provided if an increase of efficiency is combined with renewable energies. This leads also to reduced energy import dependence and to enhanced security of energy supply. However the progress of energy- and environmental policies is smaller regarding the reduction of primary energy demand compared to the extension of renewable energies. Finally lead study 2007 refers to a dilemma regarding the alternative scenarios with higher reduction targets and criticises the pressure of growth: A stronger decrease of electricity production is not compatible with the actually planned fossil fuelled and renewable energy power plants. The reason for the planned new builds is that neglected efforts for efficiency naturally provoke the planning of higher production capacity. Neglecting efficiency cannot be compensated by a stronger extension of renewable energies. This would be too expensive and would strengthen the dynamics of growth. Lead study 2008 suspects that electricity use may decrease by 20% in the long term if the efficiency of electricity use rises by about a factor of two until 2050.

2.5.5 Conclusions

The trust in the actors of private households and especially building owners is high – but their readiness to behave different and their social and cultural context remain vague. An obvious consideration regarding the social context is that there is a growing willingness for efficiency and energy-saving because of rising energy prices and correspondingly strongly burdened residential budgets – but no increasing willingness regarding investments for efficiency or paying a higher price for renewable energies. Willingness for efficiency may decrease if this is combined with high initial costs (like a new heating system or a new car). A problematic situation regarding aspects of fairness and equity: purchasing smaller amounts of power leads to less possibilities for investment and therefore groups with low income are affected strongest by rising energy prices.

The plausibility and persuasive power of both studies strongly results from economic criteria and is fixed to prices: The more expensive conventional or fossil energies, the more attractive renewable energies will become. Therefore renewables are obviously weakened by a lower rise of prices as long as external costs are not included.

Also the intervention of climate politics is conceptualised economically as prices for CO_2-emissions. But in this case it is different: the more effective climate politics become, the more relevant become renewable energies. Would the behavioural dimension be included here, it would have to be orientated obviously to the “homo oeconomicus” who is concerned about maximizing his own (cost) benefit – but it can be doubted that this social construct is suitable as an actor of sustainability.

2.6 Klimaschutz und Stromwirtschaft 2020/2030, Eco Institute/Arrhenius Institute

Behavioural dimensions are in some ways outlined in this scenario and the analysis shows that regarding problems were taken into account as well as possibilities for solution. The scenario also illustrates that the design of scenarios has to be changed to include behavioural dimensions.

2.6.1 Reference to actors and deduced measures

There is reference to actors in this scenario. From the very beginning the study emphasises with regard to the methodical approach that the actual dominating expectations of the actors of the power market have to be taken into account. However, this is more an intention than actual modelling criterion of the study. In addition and beyond the modelling the political actors have a high rank in the scenario description because realisation of energy savings depends on them as can be seen in Tab. 2-2.

Tab. 2-2. Behavioural complex of problems and deduced strategies.

Energy demand type	Strategy approach	Change via … towards …	Saved TWh absolute	Share in %
a) Electric heating, in particular night-storage heater. 6.5% of the whole final energy consumption of electricity	Energy saving fund and realization of well-aimed information campaigns. Promotion program for the substitution of electric heating	Via politically organised incentives towards substitution (modal shift)	See below	See below
b) Electric water heating	See above as well as dynamic standards of maximal consumption within the framework of the EU directive of eco design for the most important electric appliances	Via political set standards towards change of appliance or heating system (efficiency and modal shift)	a) + b): 35 TWh Furthermore 6 ThW because the substitution of electric heating provokes also a substitution of installations for process heating and of electric cooker	50,0% 8.6 % total 58.6%
c) efficiency improvements for a multiplicity of electric appliances (one third of residential	Dynamic standards of maximal consumption within the framework of the EU directive of eco design	Via political set standards towards change or optimisation of appli-	22 TWh (regarding to additional generated emissions by this	31.4%

power consumption) allow nonetheless future optimum value that underlies today's average about 30-40%	for the most important giant electric appliances	ances (efficiency)	measures if electric appliances are substituted	
d) raising need for information and communication device as well as residential consumer electronics losses due to standby	Dynamic standards of maximal consumption within the framework of the EU directive of eco design Other regulatory measures	Via political set standards towards simple technical change /efficiency, no sufficiency on losses due to standby)	No information	-
e) lighting	Standards of maximal consumption Optimisation of useful properties New technologies	Via political set standards towards technical optimisation below autonomous efficiency improvements and towards substitution of classic resistor lamps	7 TWh	10.0%

Source: own configuration on the basis of information at p. 16-18 in the scenario report.

As stated in the report, well defined targets are important, for example with regard to the extension of renewable energies and a close amendment of the European emission-trading-system beginning in 2013 (p. 51 u. 52). Political measures – like setting standards (maximum specific consumption), support programs for cogeneration or the substitution of energy-intensive appliances, the creation of institutions like a national energy-saving-fund or the realisation of well directed information campaigns – are further held to be prerequisites for the realisation of saving potentials (p 17, 18). Economic and market actors in principle are rather responsive to political guidelines than to behave in a CO_2-decreasing manner voluntarily. This applies also to investors (who react for example to the price signal of a revised emission-trading system or to lower costs in the course of large-scale production of renewable energies) and to individual consumers. They react to political guidelines or technical innovations, but in principle they do not act voluntarily.

For this reason the scenario has a weak point that on the one hand the expectations to the residential and commercial consumption sectors are high, but on the other hand possibilities and bounds are not analysed with regard to both sectors or actor-groups. And after all the study does not cover their active behaviour but just their reaction to political measures and technical changes. However the demand sectors *industry* and *transport* are considered to be much more opposed to change and behavioural change.

According to the authors of the scenario further potentials to decrease electricity consumption may be developed for the sectors industry and transport, but much broader and more measures and combinations of measures would be essential to develop further potentials for lowering electricity consumption. Such an analysis was beyond the scope of the study. It follows firstly that business, trade and services are considered by the scenario authors as those areas in which changes may be introduced easiest and with the smallest structural efforts. Secondly scenarios and quantitative designs depend obviously also on assigned questions.

The study makes stronger reference to actors than e.g. the Lead Study. Both are however designed in such a general way (in terms of individual behaviours, not in terms of modelling accuracy) that concrete indications for the behavioural dimension can hardly be found.

2.6.2 Behavioural Dimensions

Not explicitly named but implicitly assumed are in principal three different behavioural dimensions which are assigned to actor-groups:

- Governance behaviour of political actors (clear setting of objectives, credible energy and climate policies, consequent and supporting measures)
- Investment behaviour of electricity producers (modernisation of power stations, choice of low-CO_2 energy sources) which is following the behaviour of political actors
- Demand behaviour of electricity consumers that also depends on the behaviour of political actors and technical developments. These consumers can be discriminated between industry (which is mentioned as consumer of electricity, not as producers of energy efficient appliances) and households. For the latter buying behaviour is implicitly assumed and substitution of energy intensive appliances (e. g. electric heating) is explicitly mentioned. This contains at the same time an element of modal shift.

However, a further behavioural dimension does not appear in the scenario: general efficient behaviour. So for instance solutions for standby losses are politically set standards and technically possible efficiency – not the prudent care of users and consumers.

2.6.3 Social and cultural context

The scenario is “free” from contexts (see also the analysis matrix in appendix 6), if any, there is an economic context, particularly the liberalised electricity market. The scenario covers groups of actors very broadly. However behaviour happens within social and cultural contexts. The absence of the social dimension attracts attention notably at the point where additional costs for a standard household are calculated as per CO_2-certificates. The financial status of many households unable to pay high energy prices currently is not put into perspective.

2.6.2 Paradigmatic orientation

Paradigmatic orientations of the scenario are located at different levels: Primacy of politics that affects and forms other domains, an almost mechanistic concept of political incentives that automatically causes changed behaviour (oriented to investment behaviour as well as to buying behaviour). The decrease of electricity demand is a result of substitution and enhanced energy efficiency – consequently there does not exist an orientation towards specific sufficiency paths.

2.6.3 Conclusions

Deeco-s as model of the electricity market maps processes of need and can be used to test a set of conceivable improvements, and identifies thereby potential synergies and conflicts (for technological improvements as well as for enhanced effectiveness, for operative improvements and modified demand behaviour). This model could be adapted to include behavioural dimensions.

3 Résumé

3.1 Verification of initial hypothesis

The basic hypothesis to test was: Behavioural dimensions of energy demand are modelled differently in different energy scenarios, and they are mostly included implicitly.

The results of the analysis show that behavioural dimensions are not sufficiently included in energy scenarios. Some scenarios completely omit this dimension, other scenarios indicate that explicit behavioural changes play a role, but the scenario modellers do not make explicit behaviour a guiding principle in their modelling. Two explanations for these approaches (or omittances) are possible: 1) explicit behavioural changes (of individual actors and groups) are not considered to play a role in future energy systems 2) explicit behaviour is considered to be too complex to be modelled in energy scenarios.

3.2 General characterisation of scenario architecture

It has to be questioned if the architecture and the rationality of scenarios allows for integration of a behavioural dimension. The language and character of scenarios is mechanical: A measure evokes a certain reaction or set of reactions. Scenarios are conceptualised more technical and hardly include society and its subjects. However, without subjects (acting individuals or social actors) the behavioural dimension cannot be included.

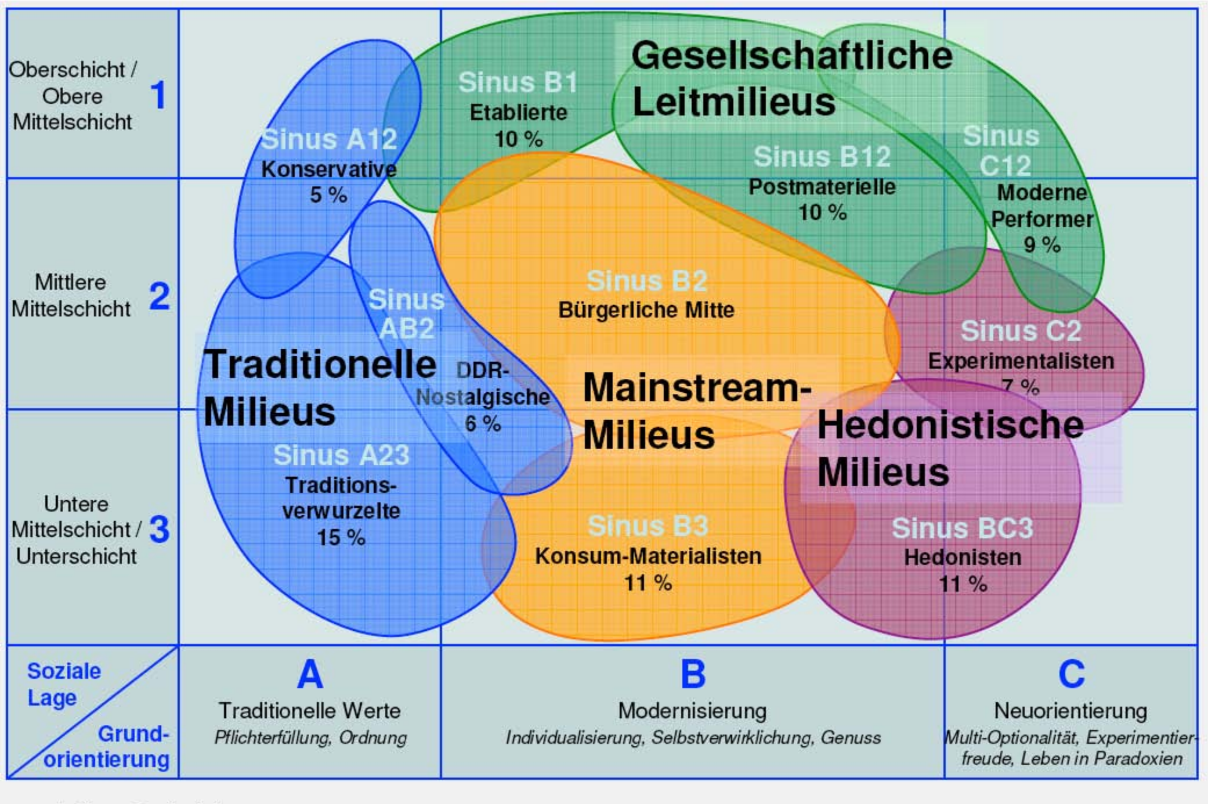
Above all it has still to be discussed whether behavioural dimensions can be explicitly integrated into the existing architecture and logic of scenarios at all, or the scenario structures themselves have to be changed. Up to date it is also an open question to what extent explicit behavioural dimensions can be quantified at all or to what extent they have to remain a parameter that can only be analysed qualitatively.

Can behavioural changes (BC) be included into existing scenario architecture?

Seen from an analytical and methodical perspective, behavioural changes are but a parameter/category (or set of parameters) comparable to other parameters/categories. Nonetheless, their degree of complexity is higher. Econometric and other models that resemble “black boxes” (complex interdependencies of a multitude of equations without the possibility of the modeller to directly interfere at any stage, as the level of automatisation is high) are insensitive to BC dynamics, as BC cannot be directly translated to econometric equations and models.

BC could be integrated into more open and transparent scenarios that allow the constant alteration of assumptions. Typical bottom-up scenarios are such an example: they allow for fixed assumptions for each sector and each technology separately, the level of automation of the scenario process as such is low. The choice of basic assumptions on modal shift or refurbishment rates can be transferred to different technology choices (or to the choice not to use technologies) and increases in building efficiency.

However, there is a basic methodical problem: current energy scenarios concentrate on economic sectors, energy structures and patterns, and on the processing of energy carriers. But BC regard individual consumers (persons, companies). Therefore, to integrate BC into scenarios, the scenario structure would have to be changed significantly: The starting point could be the disaggregation of a whole society into different consumer types / social milieus (hedonist, traditionalist etc.). One approach to such a disaggregation is displayed in Figure 3-1. In general it would have to be discussed in detail how certain consumption patterns can be attached to social milieus at all, as some milieus probably show comparable energy consumption behaviour. However, there are other models and approaches that would have to be taken into consideration as general starting points. The subsequent step would be to peg certain energy consumption values/patterns to these milieus to be able to calculate absolute energy demands. This step would be extremely labour intensive, as assumptions for all economic sectors would have to be made. The last step would be to model a change of the relative shares of social milieus. This would allow scenarios like “the share of all consumption intensive milieus increases” or “ecologically aware milieus become dominant”.



nach Sinus Sociovision 2005

Figure 3-1. Example of social milieus that could be taken into consideration for modelling behavioural change. Sinus Sociovision 2005

If sustainability aspects are to be included in energy scenarios, this will have to be represented in the choice of consumer types as well. However, there is no strong correlation between social milieus and sustainability (Kleinhückelkotten 2002, 2005) which has to be taken into consideration. Furthermore diffusion of sustainable behaviour depends e.g. on an orientation towards sufficiency (which is, as was shown, missing in the scenarios).

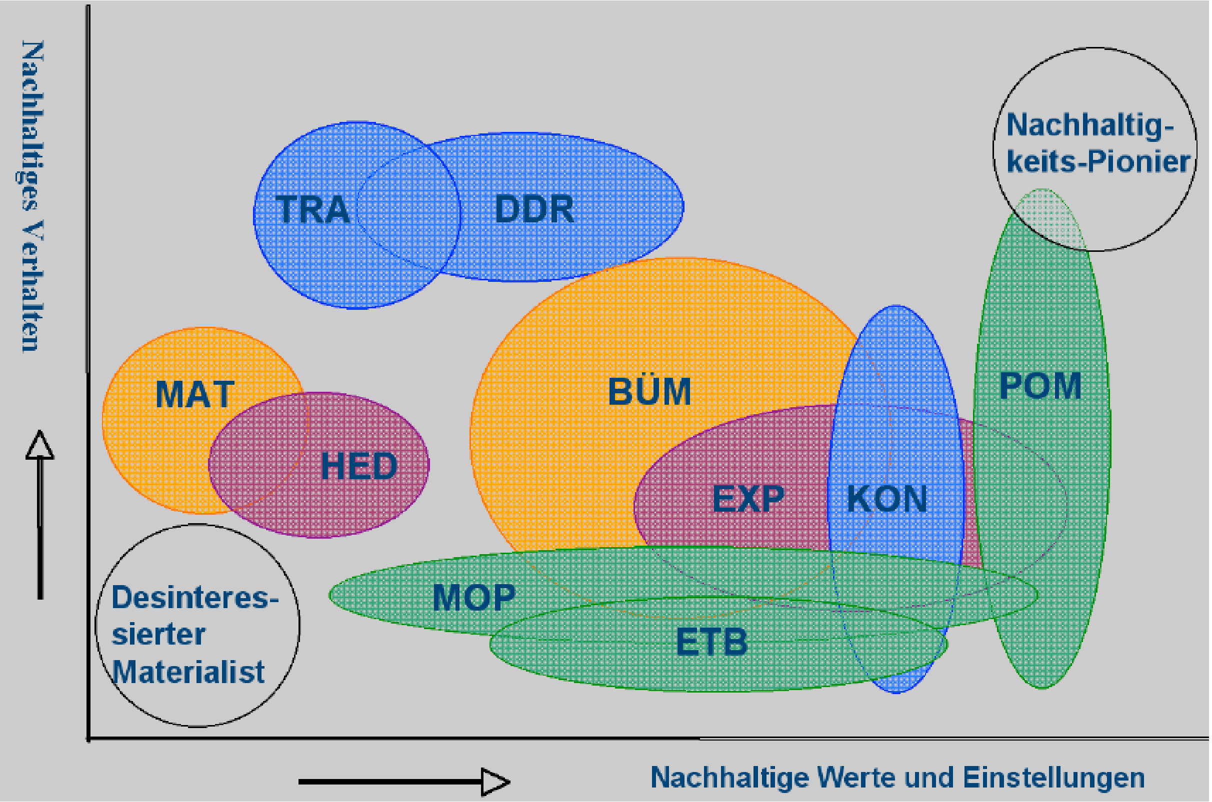


Figure 3-2. Social milieus and sustainable values and orientations. Abbreviations refer to the social mileus in Figure 3-1. Kleinhückelkotten 2005

To what extent can BC be quantified at all?

In a first approximation BC are more a qualitative category. However, their influence on energy consumption structures and patterns can be measured. The basic analytical problem is that BC are a complex mixture of modal shifts, technology choices and to some extent the general shift and/or abandonment of certain consumption patterns (sufficiency). Approaching BC from a purely technological perspective will not produce satisfactory results.

The integration of BC into current scenarios remains a great and in many parts unsatisfactory challenge. As a first approximation to integrate some aspects of BC in scenario modelling, the focus should be put on the following aspects:

- Thorough development of a reference to actors
- Integration of social, cultural and contexts of “Lebenswelt”
- Stronger reflection of the normative orientations of the scenarios themselves and development of means to methodically deal with norms

3.3 Open research topics

The major research challenges are twofold:

1) Find ways to integrate BC into current scenario structures
2) Develop different scenario approaches to focus on BC as major parameter

As discussed above, current scenario structures can only integrate BC to some extent, but they will never be able to incorporate them totally. The different options, how BC can enrich traditional scenario structures, remain to be analysed. Another field for analyses is a contradiction within scenarios: Private households are expected to contribute large shares of energy saving – but their readiness to behave differently (compared to a “trend behaviour”) and their social and cultural contexts remain vague. They sometimes seem to be “invisible contributors”.

Developing a different scenario approach is a strategy to fully take BC into consideration. However, this new type of scenario would not be comparable to current scenario structures. Therefore open research questions in this context are: what could this new scenario structure look like? The second question would be: how could this new structure produce results that are comparable to traditional scenario structures?

Behavioural changes represent the whole complexity of societal systems. Due to this complexity it is an important and worthwhile challenge to develop scenario structures to investigate the influence of behavioural changes on future energy systems.

4 Abbreviations

CCS	Carbon Capture and Storage
BC	behavioural changes
CCC	Carbon Constraint Case
OPEC	Organisation of the Petroleum Exporting Countries
OECD	Organisation for Economic Co-operation and Development
GDP	gross domestic product
RD&D	research, development and dissemination

Social Milieus (Sinus):

BÜM	Mainstream
DDR	DDR-nostalgics
ETB	established people
EXP	experimentalists
HED	Hedonists
KON	Conservatives
MAT	consumption-oriented materialists
MOP	modern performers
POM	postmaterialists
TRA	Traditionalists

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