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[COMMENTS ON TEXT BY TSU TO REVIEWER: This chapter has been allocated 45 template pages, currently it counts 67 pages (excluding this page and the bibliography), so it is 22 pages over target. Reviewers are kindly asked to indicate where the chapter could be shortened.]

Turquoise highlights are inserted comments from Authors or TSU i.e. [AUTHORS/TSU: ….]

Chapter 10: Industry

Contents

Executive Summary

1. One third of the world's GHG emissions from fuel combustion and processes arise in industry. 56% of these emissions arise in producing five key materials: steel, cement, plastic, paper and aluminium, with steel and cement dominating.

2. Industrial production involves two main sources of direct GHG emissions: process emissions from chemical reactions and combustion emissions from the burning of fossil fuels. Indirect emissions associated with use by industry of purchased electricity and steam are also relevant. Global energy-related CO_2 emissions grew from 0.83 $GtCO_2$ in 1990 and 10 $GtCO_2$ in 2005 to 11 $GtCO_2$ /yr (3 GtC/yr) in 2009 for manufacturing industry.

3. Manufacturing production has been growing steadily at annual rates that range from 6.2% for iron and steel to 11.4% for cement, over past two decades. Manufacturing activities are increasing rapidly in developing countries, in many cases to meet increased domestic demand. The overall proportion of global trade has also increased. Trade is an important factor that influences CO_2 emissions at the country level. Emission inventories based on consumption rather than production reflect this new trend.

4. Increases in the demand for industrial products (e.g. cars) and services (e.g. mobility) typically drive up the production of industrial commodities (e.g. steel). In the future further growth in demand for industrial output is expected, but will vary for different sub-sectors as well as from region to region. For some materials (e.g. cement) is likely to double or even more than triple by 2050 in some regions (e.g. in India) while in other regions only modest demand increases are expected (e.g. OECD) or even a decline is possible (e.g. cement in China). *High agreement, medium evidence.*

5. There has been a strong improvement in the energy-intensive materials processing industries in the last 2-3 decades, particularly in energy and process efficiency. This is driven by their relatively high share of energy costs. As a result, energy intensities in best practice are approaching technical limits, with at most 25%-30% improvement left across all industries. The potential varies regionally. *High agreement, robust evidence.*

6. As a consequence of growing material demand, absolute CO_2 emissions from manufacturing industry are still increasing. Depending on growth rates assumed, the increase expected ranges between 45% to 60% under Business as Usual (BAU) conditions. Therefore, besides still unexploited energy saving potentials and further improvement in energy productivity, achieving an absolute reduction in emissions from the industry sector will require options beyond energy efficiency. These include fuel and feedstock switching, waste recycling and energy recovery. *High agreement, medium evidence.*

7. Material efficiency - using less new material to provide the same final service - is an additional promising and largely unexplored option to achieve GHG reductions. Alternative product design (e.g. more durable products), consumption behaviour (e.g. more intensive use and longer life of products) and service demand reduction (such as per capita mobility, floor space etc.) through lifestyle changes are important means to reduce GHG emissions. Product and lifestyle changes are associated with low investment needs, but assessments of the full macro-economic impacts are still lacking. *High agreement, medium evidence.*

8. There are long-term step-change options under development - *mostly* connected with CCS, which could contribute to GHG mitigation in the future, but currently implies high technological risks and low public acceptance. *Medium agreement, medium evidence:*

9. Emissions of non-CO_2 GHGs for the manufacturing industry increased from 0.476 $GtCO_{2\text{-eq}}$ in 1990 and 0.548 $GtCO_{2\text{-eq}}$ in 2005 to 0.678 $GtCO_{2eq}$ in 2010. For non-CO_2 gases, process optimisation,

alternative refrigerants, thermal destruction, and secondary catalysts are options for mitigation. Rising demand for products such as flat panel TVs and solar PV will lead to higher emissions.

10. Extractive industry is growing at faster rate to meet materials demand in manufacturing sector. Particularly many emerging economies typically produce more than they consume. *Medium agreement, medium evidence.*
11. The service sector's share of world GDP increased from 50% in 1970 to 72% in 2009.
12. Tourism, which serve here as an illustrative example, is one of the most dynamic service sectors. It is estimated to contribute from 3.9% to 6% of global anthropogenic CO_2 emissions, with a best estimate of 4.9%. Over the past decades, tourism has experienced continued expansion and diversification, owing to increased wealth and leisure time, freedom to travel and technological progress in means of transport. Given projected growth in demand, significant mitigation measures for the tourism sector can come through change in demand and lifestyle.
13. Cooperation schemes and cross-sectoral collaboration at different levels – e.g. sharing of infrastructure, information, waste, heat, etc. - may provide further mitigation potential in certain regions/company types (e.g. SMEs in developing and emerging economies). Industrial clusters, industrial parks, and industrial symbiosis are emerging trends. *High agreement, high evidence.*
14. There is scarce knowledge on the potential impacts of climate change on mitigation potentials of manufacturing, extractive industries and services. Adaptation measures such as flood defence are likely to increase demand for industrial materials. *High agreement, medium evidence.*
15. Mitigation measures which generate co-benefits through enhanced environmental compliance, health benefits through better local air and water quality and which generates public acceptance and reduced waste disposal costs, liability, training needs, etc. are adopted faster. *High agreement, high evidence.*
16. Unless barriers to mitigation in industry are resolved, the pace and extent of mitigation in industry will be limited. Barriers include, but are not limited to: access to capital for energy efficiency improvements and feedstock/fuel change, fair market value for cogenerated electricity to the grid, availability of cost competitive technology for CO_2 capture and public acceptance of storage, cost of HFC recycling and incineration and PFC emission reduction from aluminium plants, and lifestyle choices that result in strong demand for materials and product choice. *High agreement, high evidence.*
17. Given the barriers and limited product alternatives, additional sector-specific policies (standards, voluntary actions by industries, R&D) are required in order to ensure the implementation of mitigation strategies in industry and services, to complement overarching economic instruments and policy measures such as carbon pricing. *High agreement, high evidence.*
18. Complementary policies are even more important for the trade-exposed sectors and trade across boundaries (e.g. embodied emissions). *High agreement, medium evidence.*
19. The majority of existing scenarios expect a further increase in final energy demand in industry. While there is no strong correlation between mitigation ambitions and decrease of final energy intensity in the sector (amongst others due to different model assumptions about parameters such as price elasticity), integrated assessment models indicate a positive correlation between mitigation ambitions and share of electricity in industrial final energy. H*igh agreement, robust evidence*.
20. Technology oriented scenarios show possible future pathways describing that CO_2 emissions in industry can fall significantly from 2009 levels by 2050 (IEA Energy Technology Perspective scenario 2DS for instance expects a reduction of 20% if all relevant mitigation measures are combined, including significant contributions of CCS).

21. For a selected set of materials (steel, cement, plastic, paper and aluminium) although global demand is expected to double GHG emissions can be reduced by 50% compared to BAU. More can be achieved if there is a proactive strategy to reduce primary material demand by users (e.g. through efficient product design).
22. Waste from various sectors is replacing natural raw materials and fossil fuels in industries thereby reducing emission intensity. This also results in direct emission reduction from waste disposal as a co-benefit.

10.1 Introduction

[Author Note to reviewers: this section currently includes a box on the risk of double counting which the chapter team agreed was crucial for framing the analysis of the industry sector. Discussions are underway with the Technical Support Unit on whether this box should be inserted in one of the framing chapters of AR5 and where]

This chapter covers industry and the service sector. It discusses trends in activity levels and emissions, options for mitigation (technology, practices and behavioural aspects), mitigation potentials of these options and co-benefits, co-benefits, risks and barriers to their deployment, as well as industry-specific policy instruments, among other things. This chapter complements with bottom up view the Chapter 6's analysis of long term mitigation pathways and transformation opportunities from a system and sector specific perspective.

Industrial emissions alone represent around one third of overall global GHG emissions. Emissions from industry are dominated by material processing, i.e. conversion of natural resources (ores, oil, biomass) into products through manufacturing. Industrial production involves two main sources of direct GHG emissions: process emissions from chemical reactions and combustion emissions from the burning of fossil fuels. Indirect emissions associated with purchased electricity and steam are relevant in both areas. Another indirect source are emissions from product use (e.g. CO_2 from buildings and vehicles, F-gases from refrigerator use), which are considered in other chapters, e.g. Chapter 8 (Buildings) or chapter 9 (Transport).

Steel and cement are accounting for nearly one half of all emissions from manufacturing. The other most intensive sectors are chemicals and fertilisers (chlorine, chloralkali, F-gases, petrochemicals), pulp and paper, non-ferrous metals (in particular aluminium), food processing (note food growing itself is covered in chapter 11), and textiles.

This chapter also includes discussion of extractive industries for metallic minerals such as copper, rare earth and others (the extraction of energy carriers such as coal and oil is considered in Chapter 7). The service sector is very heterogeneous and cannot be addressed in detail in this chapter. To give an insight into the sector, tourism has been selected as illustrative example throughout the chapter. Lastly, the chapter includes a section analysing the opportunities for mitigation in the waste industry. The section on waste is a summary of the waste related discussion appearing across all chapters in this report.

In comparison to AR 4, this chapter adopts a more holistic approach (Figure 10.1) and analyses industrial activity over the whole supply chain, from extraction of ore and inclusion of waste through downstream products to the provision of services (e.g. mobility). Emissions arise from energy and processes both in the production and use of goods (e.g. as owners of a car or as user of mobility service of a car), trade of emission-intensive materials and goods across borders.

Approach shown in Figure 10.1 allows analysis of options for GHG emission mitigation in the industry sector along six entry points: (1) Reducing energy requirements of processes; (2) reducing emissions from energy use and processes; (3) Reducing material requirements for products and in processes; (4) Reducing demand for final manufactured products (e.g. through car sharing); and (5) Reducing demand for the use of manufactured products (e.g. through reduction of mobility demand). Furthermore, (6) GHG emissions from material extraction offer further opportunities for reductions through prudent use of waste as resource. .

This chapter finds, just as was concluded in AR4, that in comparison with other sectors, analysis of mitigation opportunities in the industry and services sectors is still inhibited by a lack of detailed reliable data: energy consumption in industry is often only monitored at a highly aggregated level by national agencies, so analysis of mitigation opportunities relies heavily on data reported by industries themselves, which might have commercial sensitivities.

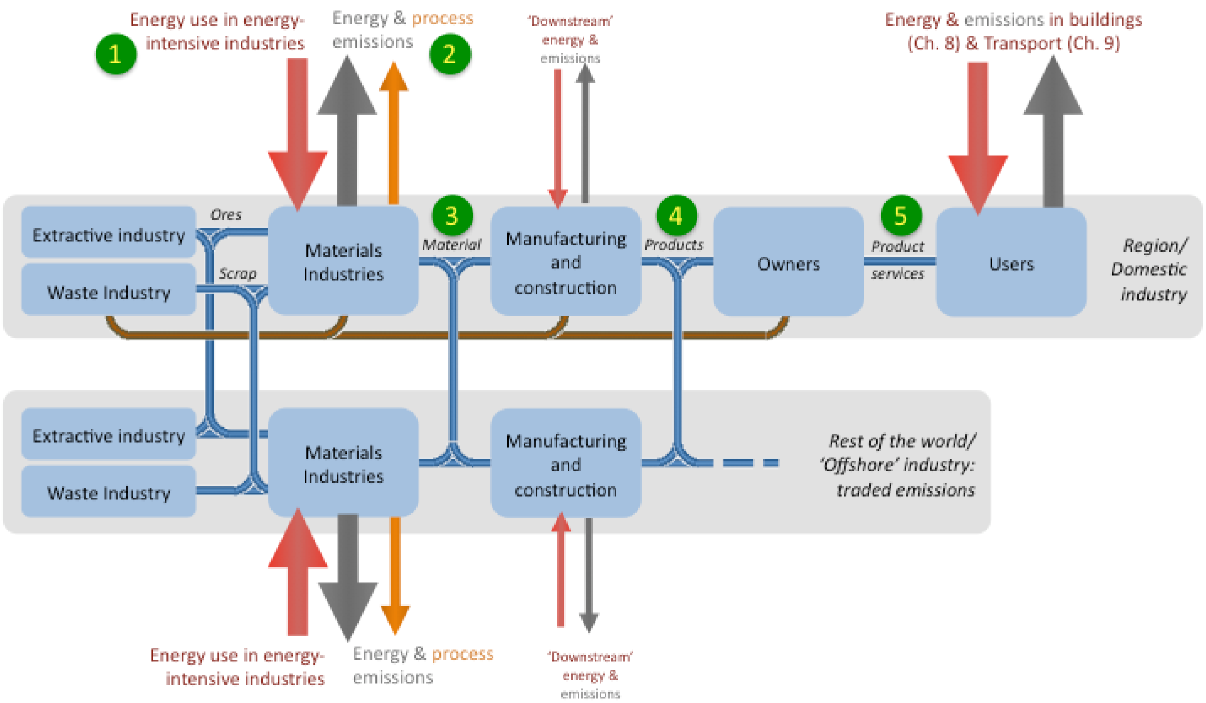

Figure 10.1. A schematic illustration of industrial activity over the whole supply chain. Options for GHG emission mitigation in the industry sector are indicated by the circled numbers: (1) Reducing energy requirements of processes; (2) reducing emissions from energy use and processes; (3) Reducing material requirements for products and in processes; (4) Reducing demand for final manufactured products; and (5) Reducing demand for the use of manufactured products. (6) By using waste to substitute resources from extractive industries.

Moreover it has to be considered that while examining options for mitigation by different sectors there is a significant danger of double-counting because of the many different ways in which emissions can be attributed. Box 1 shows a Sankey diagram clearly delineating different sources of anthropogenic emissions aims to resolve this confusion.

Box 1.1 How to avoid double counting

While examining options for mitigation by different sectors and reflecting the system complexity there is a significant danger of confusion and double-counting because of the many different ways that emissions can be attributed. Using a Sankey diagram (Figure 10.2) provides a representation of anthropogenic emissions which aims to resolve this confusion.

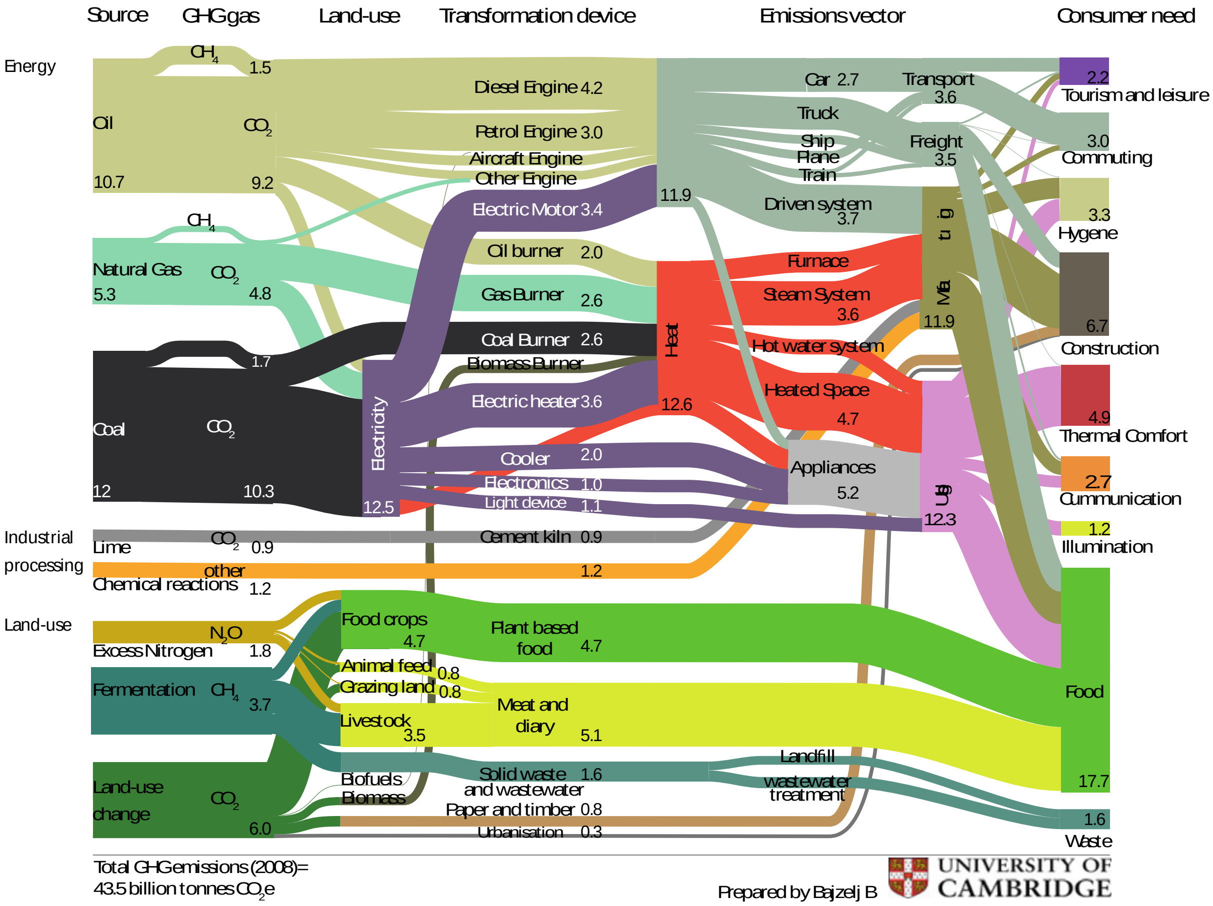

Figure 10.2. A Sankey diagram showing the sources and attribution of all anthropogenic greenhouse gas emissions. (This figure is in development and will be submitted for publication during 2012, as Bajzelj, Kopec, Allwood et al., (2012).)

The Sankey diagram in Figure 10.2 reflects the complexity of GHG emissions origins and potential anchor points for mitigation. It shows the sources of GHG emissions to the left, and a sequence of attributions from left to right leading to the final provision of human services. Some key messages from this diagram are:

The figure shows the sources of GHG emissions to the left, and a sequence of attributions from left to right leading to the final provision of services to meet human demand. Some key messages from this diagram are:

- Summing line widths cut by any vertical slice through the diagram leads to the full 43.5 billion tonnes CO_2e. Therefore emissions abatement opportunities that occur in the same vertical slice can correctly be added – if all were applied, their total effect would equal their sum. However, abatement opportunities occurring along a horizontal chain are multiplicative not additive, so cannot be compared independently. The separation of transport, manufacturing and building use illustrated in the same vertical slice to the right of the diagram is therefore logically consistent. However, the separation of the energy sector (primarily electricity generation) from end-use sectors has potential for confusion, as does the provision of food (due to a mix of agriculture and energy related emissions). The right hand side of the diagram attributes emissions finally to services – one of which is 'tourism and leisure' – and any emissions attributed to this service have already been attributed to both end-use sectors and either energy or agriculture chapters.
- Two thirds of all emissions arise from combustion of fossil fuels. The calcination reaction in cement production, emissions of CO2 from steel making, and use of GHGs in processing account

for the remaining industrial emissions. Non-energy and process emissions arise from the use of fertilisers, fermentation within animal digestion and of wastes, and land-use change mainly related to deforestation.

- The provision of food is the dominant final service, accounting for 40% of all emissions, roughly equally from agriculture and the energy of cooking and processing.

The final services to the right side of Figure 10.2 can be re-attributed in many ways: to service industries, to final consumption, or to the human motivations which drive consumption. As one illustration of the different insights gained from this re-attribution, tourism has been selected as illustrative example. The discussion attempts to illustrate the specific opportunities for abatement that can be driven by service providers (in this case, the tourism industry) and the barriers that constrain their deployment.

10.2 New developments in mineral extractive industries, manufacturing and services (especially tourism)

The level of world production of mineral extractive industries, manufacturing and services has been steadily growing. From 1970 to 2011, global annual production of metallic minerals such as iron ore increased by 264%, copper 168%, silver 154%, and gold 82% (USGS 2011); in the same period, world cement production grew by 495%; aluminium 357%; ammonia 251% (USGS 2011); steel 153% (WSA 2012); and from 1970 to 2010 paper production increased by 296% (FAO 2012). Service sector share in the world GDP increased from 50% in 1970 to 72% in 2009; while industry decrease from 38.2 to 25.4% (WB 2012).

Concerning the extractive industries for metallic minerals, most of the countries in Africa, Latin America, and the transition economies produce more than they consume; whereas consumption of metals is being driven mainly by developed countries and the countries of developing Asia (UNCTAD 2008). South Africa dominates the world's production of platinum, China leads in production of gold and iron ore, Peru is the world's leading producer of silver, and Chile produces nearly one third of the world's supply of copper (USGS 2011). Between 2005 and 2011 annual per capita production of iron ore increased for the main producers except Russia, while world per capita production of copper decreased by 1%, gold stayed constant and silver increased by 2%. China´s per capita production increase is more than 6% while in all cases for Australia there is decline and US per capita production of copper decreased by 31% (Table 10.1).

Rare earth elements are mostly associated with the hi-tech industry because of their various uses in high strength permanent magnets, lasers, automotive catalytic converters, fiber optics/superconductors, and electronic devices (Moldoveanu and Papangelakis 2012). The world production of rare earths (130 Mt in 2010) is dominated by production in China, accounting for 97% of global rare earths extraction (USGS 2011). New technologies, such as electric vehicles (EVs) or renewable technologies, increase demand for certain minerals, such as lithium, gallium and phosphates (Bebbington and Bury 2009, 2009). An important research on extraction methods and increasing recycling rates reveal increase reserves of these materials (Eckelman et al. 2012; Graedel et al. 2011; Moldoveanu and Papangelakis 2012; Resnick Institute 2011).

Regarding manufacturing production, the annual production growth rate of steel, cement, ammonia, and aluminium, ranged from 4% to 7% between 2005 and 2011 (Table 10.1). China is the largest producer of these industrial outputs. Production of these commodities was either stagnant or saw negative average annual growth in the U.S., Canada, Russia, and Japan during this period. In fact most of OECD member countries experienced a major downturn in industrial production due to the economic recession, which started in 2008 and deepened in 2010 (USGS 2011). Over the last decades the world has witnessed decreasing industrial activity in developed countries and significant increases in industrial activity in some developing countries. The increase in industrial production has been concentrated in Asia, and in particular China, which has experienced explosive industrial growth. For example in 2010, nearly 50% of steel was produced and consumed in mainland China, whereas in many middle-income countries industrialization has stagnated and Africa has remained marginalized (WSA, 2012; UNIDO, 2009). In 2011, developing countries accounted for 76% of global cement manufacture (USGS 2011), 75% of global nitrogen fertilizer production, about 78% of global primary aluminium production (USGS 2011), and 73% of global steel production (USGS 2011). Particularly in the first decade of this century, demand increased disproportionately. From 1980 to 2000, worldwide steel production grew by 18% and from 2000 to 2011 by 67% (WSA 2011). In 2011, 1.4 billion tons of steel (210 kg/cap) were manufactured; nearly 50% was produced and consumed in mainland China (China exported only 5.3% of the rolled steel it produced in 2010 (NBS 2011). China also dominates global cement production, producing 2,000 million metric tons – Mt - (1463 kg/cap) in 2011,[1] followed by India with 210 Mt (168 kg/cap) (USGS 2011). Production in the U.S., which is the third largest cement producer globally, dropped from a high of 101 Mt in 2005 to 61 Mt in 2011 due to the economic crisis. Total global cement production grew from 2,310 Mt in 2005 to 3,400 Mt in 2011 (USGS 2011). Under business-as-usual conditions, the strong growth in the volume of steel produced is expected to continue, particularly in developing areas where more than 60% of steel consumption will be used to create new infrastructure (WSA 2011).

An important change in the world industrial output in the last decades has been the rise in the proportion of trade. Not only are manufactured products traded, but the process of production is increasingly broken down into tasks that are themselves outsourced/traded. Production is becoming less vertically integrated. Rise in the proportion of trade has been driving production increase and relocation through process outsourcing besides population growth, urbanization led activity growth (Fisher-Vanden et al. 2004; Liu and Ang 2007; OECD 2011; Reddy and Ray 2010). In contrast, the economic recession of 2009 reduced industrial production worldwide because of consumption reduction, credit crunch, and fall in world trade (Nissanke 2009). Though large-scale production dominates these energy-intensive industries, globally small- and medium-sized enterprises have significant shares in many developing countries, which creates special challenges for mitigation efforts (Ghosh and Roy 2011; Roy 2010; Worrell et al. 2009).

Similar to industry, the services sector is heterogeneous. The service sector is reported usually to cover heterogeneous economic activities such as public administration, finance, education, trade, hotels, restaurants and health. Activity growth in developing countries and structural shift with rising income is driving service sector growth (Fisher-Vanden et al. 2004; Liu and Ang 2007; OECD 2011; Reddy and Ray 2010). OECD countries are shifting from manufacturing towards service-oriented economies (Schäfer 2005; Sun 1998; US EIA 2010), but this is also true for some Non-OECD countries. India has almost 64%-66% (WB 2012) of GDP contribution from service sector.

Tourism, over the past decades, has experienced continued expansion and diversification, owing to increased wealth and leisure time, freedom to travel and technological progress in means of transport. It has become one of the largest and fastest growing economic sectors in the world: from 25 million of tourists in 1950 (UNWTO 2011) to the current 984 million (UNWTO 2012). Total tourism demand (international and domestic) has accounted for about 9.8 billion arrivals in 2005 (UNWTO and UNEP 2008). Tourism has steadily developed for some decades in high-income countries, recovering fast from the various political or economic crises. It is currently taking off in emerging economies. As growth has been particularly fast in the world's emerging regions, the share in international tourist arrivals received by emerging and developing economies has risen from 31% in 1990 to 47% in 2010 (UNWTO 2011). Domestic tourism, which represents over four times more than international tourism (UNWTO and UNEP 2008), develops currently in emerging economies at rates that can exceed 10% per year (ITOPC 2009; NBS 2011). The World Travel and Tourism Council

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[1] The China Cement Association reports that the 2010 production value is 1,868 million tons.

estimates that in 2008 the travel and tourism sector accounted for 10.9% of global GDP, 12.2% of world exports, and 9.4% of word investment, from direct and indirect activities (WTTC 2009).

Table 10.1: Total and per capita production of energy-intensive industrial goods and minerals for the World Top-5 Producers of Each Commodity: 2005, 2011, and Average Annual Growth Rate (AAGR) (BGS 2011; USGS 2011)

Commodity	Region/ Country	2005	2011	AAGR	2005	2011	AAGR	Commodity	Region/ Country	2005	2011	AAGR	2005	2011	AAGR
		(Mt)	(Mt)		kg/cap	kg/cap				(Mt)	(Mt)		kg/cap	kg/cap	
Steel	World	1146.6	1490.1	4%	176.2	210.3	3%	**Ammonia**	World	121.0	136.0	2%	18.6	19.2	1%
	China	355.8	683.3	11%	272.1	499.8	11%		China	37.8	41.0	1%	28.9	30.0	1%
	Japan	112.5	107.6	-1%	889.9	797.7	-2%		India	10.8	12.0	2%	9.5	9.6	0%
	U.S.	94.9	86.2	-2%	2,830.0	265.3	-33%		Russia	10.0	11.0	2%	69.5	74.8	1%
	India	45.8	72.2	8%	40.2	57.7	6%		U.S.	8.0	8.1	0%	239.8	24.9	-31%
	Russia	66.1	68.7	1%	459.8	467.3	0%		Trinidad & Tobago	4.2	5.6	5%	3193.0	4106.0	4%
Cement	World	2310.0	3400.0	7%	355.0	479.9	5%	**Aluminium**	World	31.9	44.1	6%	4.9	6.2	4%
	China	1040.0	2000.0	12%	795.4	1,463.1	11%		China	7.8	18.0	15%	6.0	13.2	14%
	India	145.0	210.0	6%	127.2	168.0	5%		Russia	3.7	4.0	2%	25.4	27.2	1%
	U.S.	101.0	68.4	-6%	3,012.0	210.4	-36%		Canada	2.9	3.0	0%	89.5	83.1	-1%
	Brazil	36.7	62.1	9%	197.3	311.0	8%		Australia	1.9	1.9	0%	93.1	82.2	-2%
	Japan	69.6	47.0	-6%	550.7	348.4	-7%		U.S.	2.5	2.0	-4%	74.0	6.1	-34%
Iron ore	World	1540.0	2800.0	10%	236.7	395.2	9%	**Gold**	World	2.5	2.7	1%	0.4	0.4	0%
	China	420.0	1200.0	19%	321.2	877.9	18%		China	0.2	0.4	8%	0.2	0.3	7%
	Australia	262.0	480.0	11%	12,840.9	20,449.5	8%		Australia	0.3	0.3	1%	12.8	11.5	-2%
	Brazil	280.0	390.0	6%	1,505.5	1,953.1	4%		Russia	0.2	0.2	3%	1.2	1.4	2%
	India	140.0	240.0	9%	122.8	192.0	8%		S. Africa	0.3	0.2	-7%	6.2	3.7	-8%
	Russia	97.0	100.0	1%	674.3	679.8	0%		Peru	0.2	0.2	-5%	7.4	5.0	-6%
Copper	World	15.0	15.8	1%	2.3	2.2	-1%	**Silver**	World	19.3	23.8	4%	3.0	3.4	2%
	Chile	5.3	5.4	0%	326.3	306.0	-1%		Mexico	2.9	4.5	8%	27.1	38.7	6%
	U.S.	1.1	1.2	1%	34.0	3.7	-31%		Peru	3.2	4.0	4%	115.8	134.5	3%
	Peru	1.0	1.2	3%	36.6	41.0	2%		China	2.5	4.0	8%	1.9	2.9	7%
	China	0.8	1.1	7%	0.6	0.8	6%		Australia	2.1	1.9	-1%	100.5	80.9	-4%
	Australia	0.9	0.9	0%	45.7	40.0	-2%		Russia	1.4	1.4	0%	9.7	9.5	0%

10.3 New developments in emission trends and drivers

10.3.1 Extractive industries

Mining involves diverse range of energy-intensive processes such as excavation, mine operation, material transfer, mineral preparation, and separation. Energy consumption for mining[2] and quarrying represents about 2.7% of worldwide industrial energy use, varying regionally (26% in Canada, 20.4% in South Africa, 6.2% in Ireland, 5.6% in Mexico, and 4.2% in Brazil in 2009 (IEA 2010a, 2010b). Energy costs are estimated to represent more than 15% of the total cost of production in the mining industry in the US (SWEEP 2011).

10.3.2 Manufacturing

GHG emissions from manufacturing can be grouped into: (1) energy-related CO2 emissions, (2) CO2 emissions from non-energy uses of fossil fuels and from non-fossil fuel sources, and (3) non-CO2 GHGs. Energy-related CO2 emissions can be further distinguished between those based on final or site energy and those based on primary or source energy, which account for electricity generation, transmission, and distribution losses. Some studies, notably the IEA, refer to “direct” CO2 emissions as emissions from fuel combustion and process-related emissions and “indirect” CO2 emissions as emissions from the power generation sector due to electricity use in industry (IEA 2009a).

Global energy-related CO2 emissions in 2009 were 11 GtCO2-eq/yr (3 GtC eq/yr) for manufacturing. Global and regional data on final energy use, primary energy use[3], and energy-related CO2 emissions including indirect emissions related to electricity use and non-energy uses (IEA 2010a, 2010b, 2011a) for manufacturing are shown in Table 10.2.

Manufacturing primary energy use grew from 129 EJ in 1990 to 177 EJ in 2009. In 2009, energy-related CO2 emissions from manufacturing were 42% of global CO2 emissions. The largest emissions were from the developing Asia region, followed by OECD North America and OECD Europe. The share of non-energy use of fossil fuels (e.g. the use of fossil fuels as a chemical industry feedstock, of refinery and coke oven products, and of solid carbon for the production of metals and inorganic chemicals) in total manufacturing final energy use has grown from 20% in 2000 to 24% in 2009 (IEA 2010a, 2010b). While only a small portion of the carbon contained in the fossil fuels used for these non-energy uses is emitted, this is a growing source of emissions, especially from the chemical industry (Patel et al. 2005). Emissions from non-fossil fuel sources (e.g. cement manufacturing) were estimated to be 1.415 GtCO2 in 2008 (Boden et al. 2010).

The emissions of non-CO_2 GHGs increased from 0.548 $GtCO_2e$ to 0.678 $GtCO_2e$ between 2005 and 2010 (Table 10.3). The increase is dominated by almost doubling of production of HFC-23 from HCFC-22 production, and ODS substitutes. In the period 1990-2005, fluorinated gases (F-gases) were the most important non-CO_2 GHG source in manufacturing industry. Most of the F-gases arise from the emissions from different processes including the production of aluminium and HCFC-22 and the manufacturing of flat panel displays, magnesium, photovoltaics and semiconductors. The rest of the F-gases correspond mostly to HFCs that are used in refrigeration equipment used in industrial

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[2] Discussion on extraction of energy carriers takes place in Chapter 7.

[3] Primary energy associated with electricity and heat consumption was calculated by multiplying the amount of electricity and heat consumed by each end-use sector by electricity and heat primary factors. Primary factors were derived as the ratio of fuel inputs at power plants to electricity or heat delivered. Fuel inputs for electricity production were separated from inputs to heat production, with fuel inputs in combined heat and power plants being separated into fuel inputs for electricity and heat production according to the shares of electricity and heat produced in these plants. In order to calculate primary energy for non-fossil fuel (hydro, nuclear, renewable), we followed the direct equivalent method (SRES method); the primary energy of the non-fossil fuel energy is accounted for at the level of secondary energy; that is, the first usable energy form or “currency” available to the energy system (IPCC 2000).

processes. Most of the N_2O emissions are contributed by the chemical industry, particularly from the production of nitric and adipic acids (EPA 2011).

Table 10.2: Manufacturing final energy, primary energy and energy-related CO2 emissions for nine world regions (IEA 2010a, 2010b, 2011a) [This table might be converted into a world map in SOD, for stronger visual impact. If possible it might show trade flows of major materials across regions]

	Final Energy (EJ)				Primary Energy (EJ)			Carbon Dioxide (MtCO2)		
	1990	**2005**	**2009**		**1990**	**2005**	**2009**	**1990**	**2005**	**2009**
Latin America and Caribbean (LAM)	5.87	8.69	8.98	**Latin America**	4.83	7.81	8.30	195	329	344
North America (USA, Canada) (NAM)	19.22	21.92	19.17	**OECD North America**	29.26	32.71	28.29	1,555	1,587	1,397
Japan, Aus, NZ, (JPAUNZ)	6.87	7.25	6.55	**OECD Pacific**	11.08	14.51	13.68	646	782	726
Western Europe (WEU)	14.85	16.63	14.23	**OECD Europe**	24.86	26.12	22.37	1,382	1,261	1,055
East Asia (China, Taiwan, Korea, Mongolia (EAS)	14.60	28.58	38.79	**Developing Asia**	25.43	56.27	73.95	1,955	4,409	5,769
South-East Asia and Pacific (PSA)	2.16	5.18	5.87							
South Asia (SAS)	3.99	6.91	8.62							
Sub Saharan Africa (SSA)	1.28	2.10	2.34	**Africa**	4.00	5.53	6.01	250	306	315
Middle East and North Africa (MNA)	4.37	7.24	9.25	**Middle East**	2.91	6.25	8.53	177	353	457
Economies in Transition (EIT)	21.92	13.44	12.62	**Transition Economies**	26.74	16.94	15.84	1,778	996	975
World	95.12	117.93	126.42	**World**	129.11	166.14	176.97	7,938	10,022	11,040

Note: includes industry and non-energy industry. Non-energy use covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Table 10.3: Emissions of non-CO_2 GHGs (EPA 2011)

	Emissions (MtCO2e)		
Source	1990	2005	2010
HFC-23 from HCFC-22 production	91	177	309
ODS substitutes[4]	0	73	93
PFCs, SF_6 and NF_3 from flat planel display manufacturing	0	4	3
N2O from adipic acid and nitric acid production	199	131	118
PFCs and NF_3 from photovoltaic manufacturing	0	1	4
PFC from aluminium production	84	51	47
SF_6 from manufacturing of electrical equipment[5]		7	7
HFCs, PFCs, SF_6 and NF_3 from semiconductor manufacturing	13	20	17
SF_6 from magnesium manufacturing	12	10	5
CH_4 and N_2O from other industrial processes	77	74	75
Total	476	548	678

Note: does not include N_2O emissions from caprolactam.

Most of these CO2 emissions arise from fossil fuel combustion largely used to provide the intense heat that is often required to bring about the physical and chemical transformations that convert raw materials into industrial products (see Figure 10.3 and Figure 10.4 below). These industries, which include production of chemicals and petrochemicals, iron and steel, cement, pulp and paper, and aluminium, usually account for most of the sector’s energy consumption in many countries. In India, the share of energy use by energy-intensive manufacturing industries in total manufacturing energy consumption is 62% (INCCA 2010), while it is about 80% in China (NBS 2012).

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[4] EPA confirmed that in the final EPA report, they will include the tables for the breakout information of the refrigeration and air conditioning sector by end use groupings, which we need to allocate this source. The values included now in this Table are the ones included in Table 7.4 of AR4. The value for 2005 is the average of the AR4 values for 2000 and 2010.

[5] Table 7.4 of AR4 includes information for SF6 emissions from use of electrical equipment. Now, the information is about emissions from manufacturing electrical equipment. According with the Table from X-Cut (IPCC source category allocation) emissions from use should be handled in the Energy Chapter. The reference for the information included is (Rhiemeier et al. 2010).

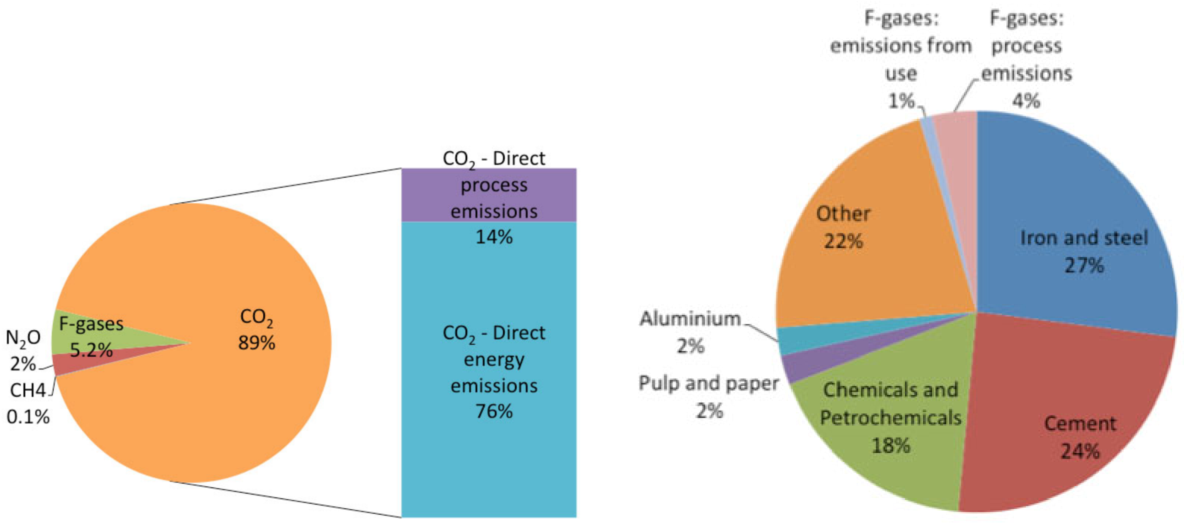


Figure 10.3. Global share of GHG emissions in industry, 2006 (EPA 2011; IEA 2009b).
Notes: Emissions from the use of F-gases in refrigeration equipment used in industrial processes included; emission from all other use of F-gases excluded

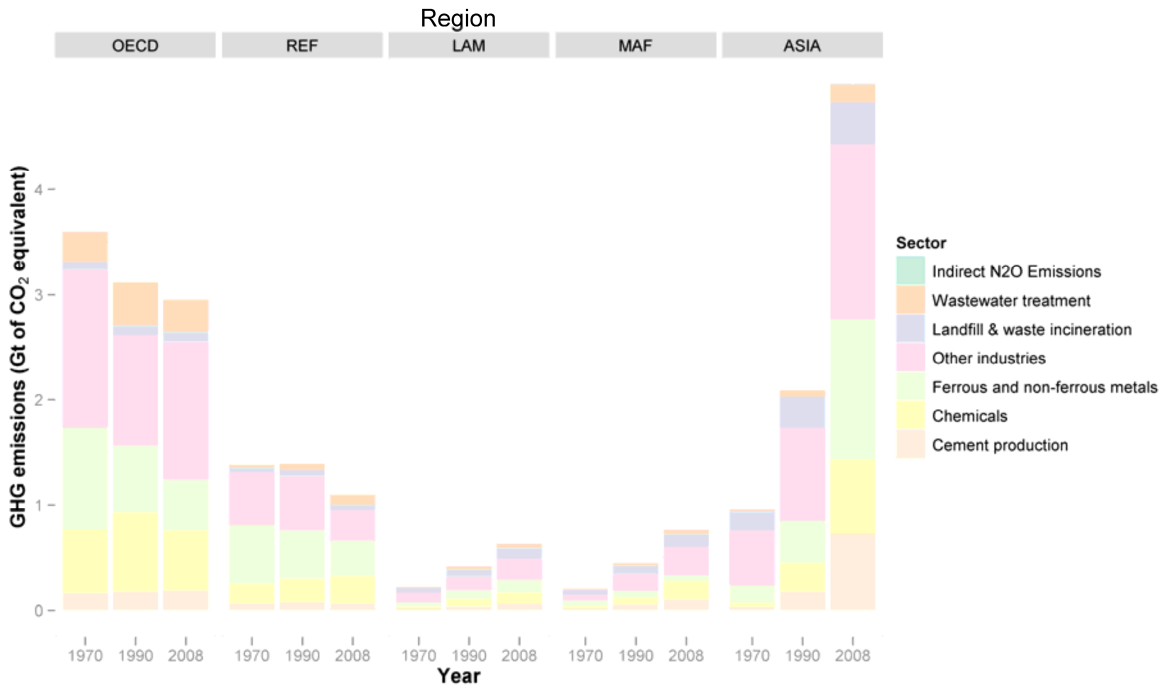


Figure 10.4. Industry and waste/wastewater GHG emissions by sub-sectors by world regions, 1970, 1990, 2010 (in Gt of CO2 equivalent per year) (EPA 2011; IEA 2009b).

Trade is an important factor that influences CO$_2$ emissions at the country level. Phasing out of some carbon-intensive manufacturing sectors in developed countries has resulted in reduced carbon emissions intensities (Jackson et al. 2007). Emission inventories based on consumption rather than production reflect this new trend. Some authors (Ahmad and Wyckoff 2003; Peters and Hertwich 2008; Wang and Watson 2007; Weber et al. 2008) argue that products produced and exported for consumption in developed countries are an important contributing factor of the emission increase for certain countries such as China, particularly since 2000. In 2004, 23% of global CO$_2$ emissions, or 6.2 Gt CO$_2$, were embodied in manufactured products that were traded internationally, primarily as exports from China and other emerging markets to consumers in developed countries (Davis and

Caldeira 2010). In large economies of Western Europe net imported emissions account for 20-50%, and nearly 18% and 11% in Japan and the United States, respectively (Davis and Caldeira 2010). In Switzerland, Sweden, Austria, the United Kingdom, and France, more than 30% of consumption-based emissions were imported, with net imports to many Europeans of over 4 tons CO_2 per capita in 2004. Net import of emissions to the United States in the same year was somewhat less: 10.8% of total consumption-based emissions and 2.4 tons CO_2 per capita (Davis and Caldeira 2010). A recent study reveals that consumption-based CO_2 emissions of OECD countries were, on average about 16% higher in 2005 than conventional measures of production based emissions.

The IEA Energy Technology Perspectives (ETP) study (IEA 2012) assumes that industrial production will double or triple to satisfy growing demand in the next 40 years, particularly in Non-OECD regions (excluding China, were material demand is expected to flatten). In its baseline scenario 6DS (6 degree scenario) CO2 emissions to grow in comparison to the current situation by between 45 and 65%, depending on the assumptions on material demand.

10.3.3 Service Sector with special reference to tourism

With regard to GHG emissions, service sector is less diverse, as it comprises only energy-related emissions. Of these, 23% were direct emissions (fuel combustion) and 77% indirect (electricity and heat use) in 2010 (Enerdata 2011). Direct GHG emissions mainly result from the provision of space heating and hot water in buildings, while main sources of indirect GHG emissions are indoor lighting, ventilation and space and water heating via electric boilers (Bertoldi and Atanasiu 2011a; Gruber and Schlomann 2009) are included in other chapters. Other energy services are more specific to the different specific service subsectors. For example, refrigeration has a great importance in trade, IT appliances are intensively used in the finance and administration subsectors and cooking and laundry are relevant in hotels, restaurants and the health sector (Fleiter et al. 2010).

From 1990 to 2010, worldwide GHG emissions from the service sector increased by 93% to reach 3.8 $GtCO_2$ in 2010, which is equivalent to 14% of all energy-related CO_2 emissions (Enerdata 2011) due to an expanded use of electricity-based energy services Worldwide, electricity demand in the service sector even increased by 128 % between 1990 and 2010, making it the fastest growing demand sector in relative terms (Enerdata 2011). This translates into an increase of annual electricity demand of about 2,700 TWh, which is at the same level as the industry and residential sectors' increase over the same period (Enerdata 2011).

With an increase of 240% from 1990 to 2010, growth of service sector emissions was particularly high in Asia (Enerdata 2011). As a consequence, total Asian GHG emissions in the service sector reached the same level as American emissions at about 1.3 GtCO2 in 2010 (Enerdata 2011). Together, both regions account for two thirds of global GHG emissions in the service sector in 2010.

Compared to industry, however, the service sector shows substantially lower carbon intensity in terms of CO_2 emissions per value added generated. In 2010, the service sector had emissions of 100 $kgCO_2$ on average per 1 000 $05ppp value added, whereas this figure was more than six times higher in the industry sector - counting only energy-related emissions (Enerdata 2011). Consequently, a shift to a service-based economy also implies a decrease of a country's overall emission intensity. Examples of countries with a relatively high service sector contribution in GDP are India (Deb Pal et al. 2012; Roy et al. 2011), the United States, France and the UK (Enerdata 2011).

However, the definition of the service sector as used for energy and CO_2 balances does not take into account indirect emissions embodied in the products consumed by this sector (despite electricity use). Whether a shift from manufacturing towards service-oriented economies leads total energy use reduction is contested (Henriques and Kander 2010; Suh 2006), as transition to a service-oriented economy also lifts demand for manufacturing outputs. For example, for Spain (Butnar and Llop 2011) and Japan (Nansai et al. 2009), it is shown that increases in the service sector's emissions mainly result from emission increases in its supply chain, i.e. in the manufacturing of products.

Tourism is estimated to contribute from 3.9% to 6% of global anthropogenic CO_2 emissions, with a best estimate of4.9% (UNWTO, UNEP et al. 2008). In affluent countries this share is more important: e.g. the Netherlands (9.1%)(De Bruijn, Dirven et al. 2010), France (IFEN 2000), Switzerland (Perch-Nielsen, Sesartic et al. 2010), and Sweden (11% in 2001) (Gössling and Hall 2008).

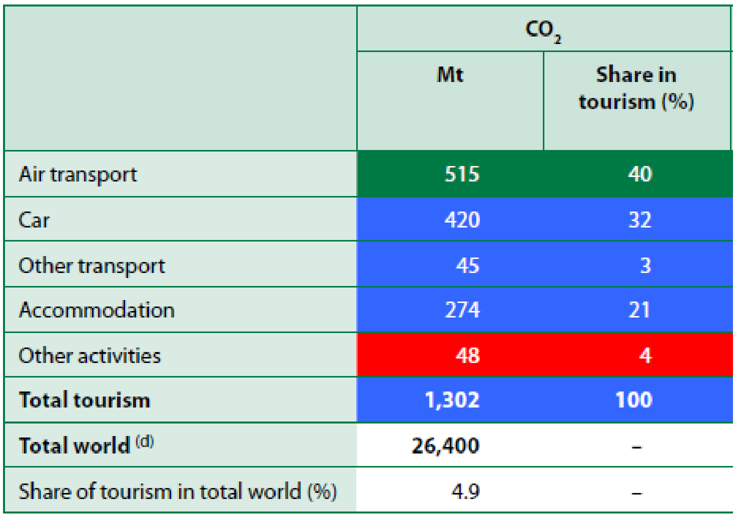
When expressed in terms of radiative forcing, both the share of tourism in global emissions (from 5.2% to 12.5% in 2005) and that of tourism related aviation (5.4% to 8.3% of global emissions) quite significantly increase (Scott et al. 2010).

The volume of cruise travel (highly intensive in emissions (Amelung and Lamers 2007; Eijgelaar, Thaper et al. 2010) and included in “other transport”) has grown at an average annual rate of 7.4% since 1990 (CLIA 2009). The emissions from accommodation represent 3.5% of global emissions from building (World Economic Forum 2009). North America generates 40% of these (with a particularly high energy intensity), Europe 21% and Asia and Pacific 29% (for more general information about transport and building cf. chapter 8 and 9).

These figures represent direct emissions: taking into account indirect emissions or considering a life cycle perspective would naturally increase the volume of emissions: no such assessment has to date been done (OECD and UNEP 2011).

The origins of emissions in tourism by subsector are displayed in Table 10.4 showing the dominance of air transport.

Table 10.4: Estimated emissions from global tourism (including same-day visitors) 2005



	CO_2	
	Mt	**Share in tourism (%)**
Air transport	515	40
Car	420	32
Other transport	45	3
Accommodation	274	21
Other activities	48	4
Total tourism	**1,302**	**100**
Total world [(d)]	**26,400**	–
Share of tourism in total world (%)	4.9	–

Note. Colours illustrate the margins of error with respect to the data and underlying assumptions: Green represents a degree of margin of error of +/-10%, blue +/- 25% and red +100%/-50%. Source: (UNWTO and UNEP 2008)

Out of a world total of 981 Mt of CO2 in 2005 (UNWTO and UNEP 2008):

- Overnight stays represent 844 Mt and same day visitors hundred and 133 Mt
- the emissions within regions account for 630 million and are dominated by domestic travel (478 Mt)
- International tourism between regions (almost exclusively by air) accounts for 218 Mt, more than two thirds of which relate to travel between high-income countries and from trips originating in high-income countries with destinations in developing countries
- Aviation accounts for 515 MT out of the global figure of 981M t

The greater part of emissions is generated (Gössling, Peeters et al. 2005; TEC and Direction des études et de l'évaluation Environnementale 2008; De Bruijn, Dirven et al. 2009) by a minority of travellers (frequent travellers using the plane over long distances) (Gössling et al. 2009), e.g. 5% percent of the French are responsible for 50% percent of the emissions from tourism travel (TEC and DEEE 2008). The Netherlands survey shows that more than 90% of the growth of emissions between 2002 and 2008 is caused by holidays taken outside of Europe (de Bruijn et al. 2010). These studies also point to the large variety in the emissions intensity of various tourism segments.

Several studies show that an unrestricted growth of tourism would by 2050 consume the whole carbon budget compatible with the +2°C guardrail (Bows et al. 2009; Scott et al. 2010). A business as usual scenario (UNWTO and UNEP 2008) projects emissions to grow by 130% from 2005 to 2035, notably the emissions of air transport and accommodation triple.

10.4 Mitigation technology options, practices and behavioural aspects (including efficiency improvements, household and industry waste)

Limits to energy efficiency are progressively being approached by many energy intensive industries, although some options for efficiency improvement still remain. In contrary, for the service sector significant unexploited potentials can be observed. A raft of less-explored measures related to material efficiency could also be deployed, but as yet have had little attention. This section deals with the changing technology, practices and behavioural options which are the full constituents of feasible mitigation portfolio. To proceed in a structured way we re-state the Kaya identity (Kaya 1990) with reference to Figure 10.1

$$\begin{aligned}\begin{matrix}\text{Industrial}\\ \text{emissions}\end{matrix} &= \left(\begin{matrix}\text{Energy per}\\ \text{unit material}\end{matrix} \times \begin{matrix}\text{Emissions per}\\ \text{per unit energy}\end{matrix} + \begin{matrix}\text{Process emissions}\\ \text{per unit material}\end{matrix}\right)\\ &\times \begin{matrix}\text{Material input}\\ \text{per product}\end{matrix} \times \begin{matrix}\text{Products per}\\ \text{unit service}\end{matrix} \times \begin{matrix}\text{Total demand}\\ \text{for service}\end{matrix}\end{aligned} \qquad (1)$$

The terms in equation (1) relate to the numbers in Figure 10.1, where the mitigation options can be translated as: Energy efficiency, Emissions efficiency (including fuel switching and CCS), Materials use efficiency, and Reduction of demand for products (e.g. emerging from owners of cars or a meat based diet) and services (e.g., mobility service by motorized individual transport).

10.4.1 Sector-wide mitigation approaches

This section considers sector-wide opportunities arising from equation (1) subheadings corresponding with the numbers in Figure 10.1.

10.4.1.1 Energy efficiency-reducing energy requirements

Improvements in the energy intensity[6] of industries arise from increasing adoption of new technologies (Dasgupta et al. 2012) and from structural change (Roy et al. 2010). On average, Japan and the Republic of Korea have the highest levels of industrial energy efficiency, followed by Europe and North America. Energy efficiency levels are generally lower than in Non-OECD countries but, where there has been a recent, rapid expansion using the latest plant design, efficiencies can be high (IEA 2008). In all OECD countries since 1990 there has been a structural shift towards manufacturing lower energy-intensive products such as information technologies on-shore, while relying on an increased dependence on imports of energy-intensive products produced off-shire (Liu and Ang 2007).

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[6] Energy use per unit of output produced

Practice change helps in mitigation. In industry, the two main devices used to create useful energy are electric motors and furnaces. The major remaining opportunities for efficiency are in the design and operation of systems using motors: turning off motors when not in use, avoiding over-specification and redesigning couplings to reduce total load requirements. There are still opportunities to improve the overall efficiency of furnaces through management of heat flows: heat exchange between hot exhaust gases and cool incoming fuel and air; improved insulation; capture and use of heat in hot products; use of exhaust heat for electricity generation or as an input to lower temperature processes. Industrial processes have an estimated technical efficiency potential of 25–30% (UNIDO 2012).

Best practice in the steel and aluminium sectors is already within a factor of two of the absolute theoretical limit defined by Gibbs (Allwood et al. 2010a) (Allwood et al. 2010a) manufacturing facilities use best practice technologies or operating procedures. Studies show that the potential annual energy savings from adopting best available technologies is about 33 EJ which is approximately 30% of current global industrial energy consumption and 6% of total energy use worldwide (Saygin et al. 2011) and 19% to 32% of current CO_2 emissions in the industrial sector (IEA 2009c). Additional savings can be realized in the future through adoption of emerging technologies currently under development or that have not yet been fully commercialized. For example, the U.S. Department of Energy's Industrial Technologies Program supported more than 600 research and development projects that produced over 250 commercialized energy-saving technologies during the past 30 years; in 2009, 95 of these technologies saved 54 PJ in measured savings in the U.S. (US DOE 2010). Similar limits estimated by Schäfer et al. (2005) for the cement, plastics and paper industries show that average performance is approaching an asymptote. Typical estimates suggest that around 25% of current energy per unit output is the limit to likely future energy efficiency opportunities (Allwood et al. 2010a).

10.4.1.2 Emissions efficiency, fuel switching and carbon capture and storage

In 2008, 40% of industrial energy supply was from coal and oil while gas provided 20%. These shares are forecast to change to 30% and 24% respectively by 2035 (IEA 2011b). Natural gas is useful in industries such as in food, beverage and paint manufacture, which require clean burning fuels. The use of wastes and biomass in industry is currently limited, but forecast to grow three to four times from 2007 to 2050 (IEA 2009c). Municipal solid waste can be used as an energy source or feedstock in the chemical and petrochemical, iron and steel and cement industry (IEA 2009c). Due to the expected competition with other sectors, (IEA 2009c) predicts that the price of waste will be 30 to 35% of that of coal by 2030 and 75% in 2050. If power generation is decarbonised while also providing an increased total power output, there could be an opportunity to reduce CO_2 emissions in industry through greater electrification, for example through the wider use of heat pumps instead of boilers (HPTCJ 2010; IEA 2009c). Solar thermal energy for drying, washing and evaporation in the chemical (IEA 2009b) food and beverages, textiles, and pulp and paper sectors may also be developed further – although to date fewer than 100 such systems worldwide have been deployed in washing processes (Edenhofer et al. 2011).

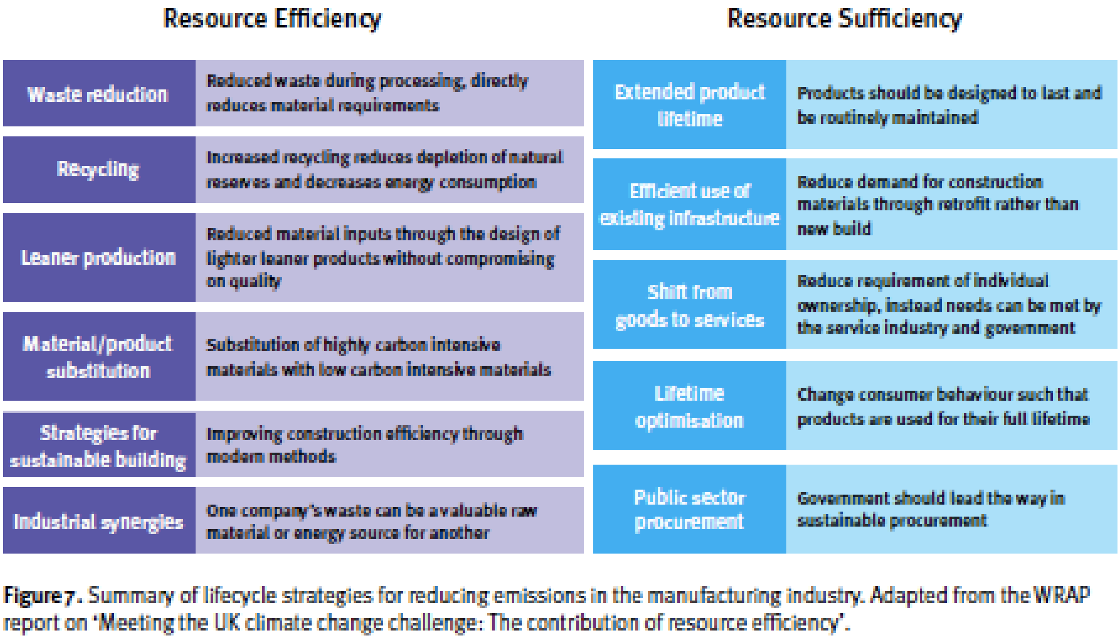
Five sources representing 83% of non-CO_2 emissions from the industrial sector can be managed by changing practices (EPA 2011): ozone depleting substances (e.g Hydrofluorocarbons) can be retained by leak repair, refrigerant recovery and recycling, proper disposal or replaced by alternative refrigerants (ammonia, HC, CO_2); emissions of HFC-23 which arises in HCFC-22 production can be reduced by process optimization and by thermal destruction. In non-Annex I countries, destruction of HFC-23 is the major source of credits in the CDM (82 MtCO2e/year); emissions of PFCs, SF6 and NF3 are growing rapidly due to flat panel display manufacturing. 98% of them arise in China (EPA 2011) and can be countered by fuelled combustion, plasma and catalytic technologies; N_2O emissions from adipic and nitric acid production have decreased from 199 to 131 $MtCO_2eq$ between 1990 and 2005 in OECD countries due to the implementation of thermal destruction and secondary catalysts; emissions of PFCs and NF3 from Photovoltaic (PV) manufacturing are expected to increase with annual growth rates ranging between 10 and more than 50% (Edenhofer et al. 2011), accordingly corresponding mitigation options have to be developed.

Industrial utilization of CO_2 was assessed in the IPCC SRCCS (Mazzotti et al. 2005) and it was found that the scope of future potential industrial uses of CO_2 was too small, the storage time of CO_2 in industrial products was too short, and the energy balance too unfavourable for industrial uses of CO_2 to become a significant means of mitigating climate change. Nonetheless, a growing number of pilot and demonstration projects (e.g. CO_2 for urea production or as building blocks for polymers) are taking place. A recent analysis (Global CCS Institute 2011) projects the cumulative demand of CO_2 for utilization out to 2020 in the industry sector to be less than 125 Mt CO_2 compared to over 500 Mt CO_2 for EOR. Given differences in the potentials and locations for capture, utilization and storage in the industry and energy sectors, integrated CCS projects may involve both the energy and industry sectors as does the Enid fertilizer plant (Global CCS Institute 2012).

In its mitigation scenarios, forecasts are that a large part of emission reduction in industry will occur by CO_2 sequestration (up to 30% in 2050) (IEA 2009b) however this forecast is far ahead of commercial reality: in the EU a small number of large-scale industrial CCS facilities are planned but have not been implemented. CCS in gas processing (Kuramochi et al. 2012) and parts of chemical industry (ammonia production) might be early opportunities as the CO_2 in flue gas is already highly concentrated up to 85% (lower costs and less energy needed). Emission-intensive industrial sectors like cement or iron and steel have less pure CO_2 concentrations in flue gas (up to 30%). These are nonetheless higher than from power plants (Cheng et al. 2010). CCS potential in the cement sector has been studied by (IEAGHG 2008) (Barker et al. 2009) (Croezen and Korteland 2010) (Bosoaga et al. 2009). The apparent attraction of CCS is that it does not require changes to production processes, where other mitigation options might require a considerable changes or retro-fitting (Croezen and Korteland 2010). However, a challenge for all CCS applications is the uncertainties associated with the assessment of the geological storage potential, their high costs, uncertainty about public acceptance, and the lack of any large-scale proof of concept (Viebahn et al. 2012).

10.4.1.3 Material substitution, material reuse and waste (material efficiency)

In comparison to energy efficiency and emissions efficiency strategies to reduce emissions in the manufacturing sector via material substitution, material re-use and demand management are so far less known. (Brown et al. 2012) provide a useful categorisation of material efficiency strategies:



Resource Efficiency	
Waste reduction	Reduced waste during processing, directly reduces material requirements
Recycling	Increased recycling reduces depletion of natural reserves and decreases energy consumption
Leaner production	Reduced material inputs through the design of lighter leaner products without compromising on quality
Material/product substitution	Substitution of highly carbon intensive materials with low carbon intensive materials
Strategies for sustainable building	Improving construction efficiency through modern methods
Industrial synergies	One company's waste can be a valuable raw material or energy source for another

Resource Sufficiency	
Extended product lifetime	Products should be designed to last and be routinely maintained
Efficient use of existing infrastructure	Reduce demand for construction materials through retrofit rather than new build
Shift from goods to services	Reduce requirement of individual ownership, instead needs can be met by the service industry and government
Lifetime optimisation	Change consumer behaviour such that products are used for their full lifetime
Public sector procurement	Government should lead the way in sustainable procurement

Figure 7. Summary of lifecycle strategies for reducing emissions in the manufacturing industry. Adapted from the WRAP report on 'Meeting the UK climate change challenge: The contribution of resource efficiency'.

Figure 10.5. Summary of lifecycle strategies for reducing emissions in the manufacturing sector. (Brown et al. 2012)

Reducing materials requirements in the production process/product

Material substitution can lead to reduction in total energy requirements and hence emissions: using alternative feedstock for producing existing materials, material selection in product design, designing lighter products and improving manufacturing yields. For plastics, a possible feedstock substitution is of vegetable oil for oil. Some of the substitutes in cement production are blast furnace slag, fly ash from coal-fired power stations for clinker, magnesium oxide, which may be used in place of limestone. For metals, by definition there are no substitutes for the required chemical elements, so metal must be made from ore or recycled. However, re-use potentially provides an alternative supply of metal feedstock, if large components are undamaged in first use. A detailed study (Allwood et al. 2012) on re-use of structural steel in construction concluded that there are no technical barriers to re-use, that there is a profit opportunity and that the potential supply is growing. (Ashby 2009) shows that options for material substitution in design are limited: epoxy based composite materials and magnesium alloys have higher embodied energy than steel or aluminium; wood could be substituted for metal in some applications, but is still energy intensive due to kiln drying. Many products could be one third lighter without loss of performance in use (Carruth et al. 2011). At present, asymmetric risks, the additional costs of producing optimised products, additional loads applied before use and uncertainty over future requirements act as barriers to this approach. Materials which are initially produced as stock products and then reshaped – metals and paper for example – are subject to high losses in production: approximately one tenth of all paper, a quarter of all steel, and 40% of all aluminium produced each year never makes it into products but is scrapped and internally recycled. This could be avoided by process innovations (Milford et al. 2011).

Recycling of materials

Recycling which is widely applied for metals as a means to use less energy is an additional GHG mitigation option. An more in depth discussion of could be find in the excursus section about waste There is no recycling possible for cement, plastic recycling is greatly inhibited by the wide variety of incompatible compositions in use, and while paper recycling may save energy, it does not always reduce emissions due to the high use of biomass to power primary paper making. Recycling rates for metals vary widely (Graedel et al. 2011), and are inhibited for rarer metals by the high cost of collection of small quantities, and by their use as alloying elements or as thin closely bonded layers in electronics. For steel and aluminium, typical product life span is 20-40 years, so the availability of material for recycling lags global demand, and even with high recycling rates, it is unlikely that production from scrap will exceed that from ore within the next 30-40 years. Most recycling of steel and aluminium is actually of scrap generated in production – post-consumer scrap for example makes up only 20% of total aluminium recycling. The quality of liquid metal made from recycled scrap depends on control of alloy composition, and despite the closed-loop of aluminium can recycling, almost all other aluminium recycling is from higher value ductile wrought alloys with a low silicon content, to lower value, casting alloys with high silicon content.

10.4.1.4 Reducing demand for products and demand management

Most products are owned in order to deliver a 'product service' rather than for their own sake, so potentially the same level of service could be delivered with fewer products. Using products for longer could reduce demand for replacement goods, and hence reduce industrial emissions (Allwood et al. 2012). New business models could foster the use of such products. Alternative delivery of services can help implementing "dematerialisation" although the widely discussed 'paperless office' has proved elusive. More intense use of products can also reduce GHG emission, e.g. the more intense use of cars via car sharing models. Eventually, a solution to reduce industrial emissions is to reduce overall demand for products without reducing services provided by the products made in industry. The ambition of the 'sustainable consumption' notion and policies (see 10.11) is in this direction.

10.4.1.5 Reducing demand for product services

A final option for mitigation in industry is to reduce the overall demand for product services – travel less, heat/cool less and buy less is a second pillar of 'sustainable consumption' and nowadays backed a growing academic literature in the area Clear evidence that, beyond some threshold of development, populations do not become 'happier' (as reflected in a wide range of socio-economic measures) with increasing wealth, suggests that reduced overall consumption might not be harmful in developed economies (Layard 2006; Roy and Pal 2009)), and a literature questioning the ultimate policy target of GDP growth is growing, albeit without clear prescriptions about implementation (Jackson 2011),. The strategy of service reduction, one of the material efficiency strategies (Allwood et al. 2010a) has not received much attention to date, but may be an important "last resort".

10.4.2 Sector specific mitigation opportunities

This section examines literature reporting the application of the principles of section 10.4.1 to the highest emitting industrial sectors:

10.4.2.1 Iron and steel

Steel continues to dominate global metal production with total crude steel production of around 1400 Mt in 2010. In 2010, China led steel production, producing 44% of the world's steel. Other significant producers include EU-27 (12%), Japan (8%), USA (8%), India (5%) and Russia (5%) (WSA 2011). 70% of all steel is made from Pig iron produced by reducing iron oxide in a blast furnace using coke or coal before reduction in an oxygen blown converter (WSA 2011). Steel is also made from scrap (23%) or iron oxide reduced in solid state (direct reduced iron. 7%) melted in electric-arc furnaces before refining. Global steel sector emissions are estimated to be 2.6 Gt CO_2 in 2006, including direct and indirect emissions (IEA 2009b).

Energy efficiency. The steel industry is pursuing: improved heat and energy recovery from process gases, products and waste streams; improved fuel delivery through pulverized coal injection; improved furnace designs and process controls; reducing the number of temperature cycles through better process coupling such as in Endless Strip Production (Arvedi et al. 2008) and use of various energy efficiency technologies (Worrell, E et al. 2010) (APP 2010). Energy efficiency measures could reduce specific energy consumption for ore-based steelmaking by up to 15%, with a further 15% saving from breakthrough technologies, subject to further R&D. Energy efficiency measures could reduce specific energy consumption for scrap-based steelmaking by up to 32%, with a further 15% saving from breakthrough technologies (Energetics Inc. 2005). The IEA estimate that a global transition to the energy efficiency levels of best available technology could reduce CO_2 emissions by an average of 0.3 t CO_2/t crude steel (IEA 2009b)- this is approximately a 15% saving. Efforts to promote energy efficiency and to reduce the production of hazardous wastes are the subject of both international guidelines on environmental monitoring (International Finance Corporation 2007) and regional benchmarks on best practice techniques (European Commission 2012). With China's dominance in steel production increased share of electric arc furnace in production can enhance energy efficiency, also coke dry quenching would be important in short-term emissions reduction (Wang et al. 2007). The Ultra-Low CO_2 Steelmaking (ULCOS) programme, run by a consortium of 48 European companies and organizations, aims to reduce CO_2 emissions by 50% or more, but has not written any peer-reviewed literature. They have identified four production routes for further development: top-gas recycling applied to blast furnaces, HIsarna (a smelt reduction technology), advanced direct reduction and electrolysis. The first three of these routes would require CCS to achieve emissions reductions, and the fourth would reduce emissions only if powered by low carbon electricity.

Emissions efficiency and fuel switching: The coal and coke used in conventional iron-making is emissions intensive; switching to gas-based DRI and oil and natural gas injection has been used, where economic and practicable. Charcoal, another coke substitute, is currently used for iron-making, notably in Brazil (Taibi et al. n.d.), and processing to improve charcoal's mechanical properties is another substitute under development, although extensive land area is required to produce wood for charcoal. Other alternative fuels include ferro-coke (Takeda et al. 2011), biomass and waste plastics; examples of waste plastic injection can be found in Japan, Germany and Austria (IEA 2009b). Hydrogen fuel might reduce emissions if an emissions free source of hydrogen were available, but at present this is not the case. Hydrogen reduction is being investigated in the US (Pinegar et al. 2011) and Japan (Matsumiya 2011). Molten oxide electrolysis (Wang et al. 2011) could reduce emissions if a low or CO_2-free electricity source was available. However this technology is only at the very early stages of development and identifying a suitable anode material has proved difficult.

Material efficiency: Material efficiency offers the potential for large emissions reductions in the iron and steel sector (Allwood et al. 2010a) and cost reduction as well (Roy et. al 2012 forth coming). Milford et al. (2011) examined the impact of yield losses along the steel supply chain and found that 26% of global liquid steel produced does not make it into final products as it is lost as process scrap. Eliminating this process scrap would have reduced total CO_2 emissions by 16% in 2008. Cooper et al. (2012) explore reuse of end-of-life steel components; rather than sending old steel for recycling by melting, products or components can be disassembled, refurbished and sent back into use, avoiding the energy of re-melting. Cooper et al. estimate that nearly 30% of all steel produced in 2008 could be re-used.

Reduced product and service demand: Case studies show by applying a set of general principles for lightweight product design, demand for global steel could be reduced by up to 30% (Carruth et al. (2011). The relationship between product life, more intense use, and embodied and in-use emissions is explored by (Skelton, A.C.H. and Allwood, J.M. 2012) and demonstrates that for four case study products, the optimal product life will vary with the share of embodied and in-use emissions and the actual (rather than the design) life. Cooper et al. (2012) also explore product life proposing an "onion-skin model" to demonstrate how replacement strategies at the component level can be used to maximise product life and minimize steel demand.

10.4.2.2 Cement

CO2 emissions from cement production in 2006 totalled 1.9 Gt CO_2: 1.1 Gt CO_2 from process emissions (calcination) and 0.8 Gt CO_2 from fuel emissions (IEA 2009b), and a small contribution from grinding and transport (Bosoaga et al. 2009).

Energy efficiency. Estimates of theoretical minimum primary energy consumption[7] for thermal (fuel) energy use ranges between 1.6 and 1.85 GJ/t (Locher 2006). For large new dry kilns, the "best possible" energy efficiency is 2.7 GJ/t clinker with electricity consumption of 80 kWh/t clinker or lower (Muller and Harnish 2008). "International best practice" final energy ranges from 1.8 to 2.1 to 2.9 GJ/t cement and primary energy ranges from 2.15 to 2.5 to 3.4 GJ/t cement for production of blast furnace slag, fly ash, and Portland cement, respectively (Worrell et al. 2008b). **Figure 10.6** illustrates how these process emissions intensities have declined in various regions of the world (Klee et al. 2011).

Many options still exist to improve the energy efficiency of cement manufacturing (APP 2010; Muller and Harnish 2008; Worrell and Galitsky 2008; Worrell et al. 2008a). Oda et al. (2012) found large differences in regional thermal energy consumption for cement manufacture, with the least efficient region consuming 1.77 times as much energy as the most efficient region in 2005. The IEA and WBCSD forecast that global weighted average thermal energy intensity will drop to 3.2 - 3.3 GJ/t clinker and electric energy intensity will decline to 90 to 100 kWh/t cement by 2050 (IEA/WBCSD 2009). It is estimated that 510 Mt CO2 would be saved if all current cement kilns used best available technology and increased use of clinker substitutes (IEA 2009b).

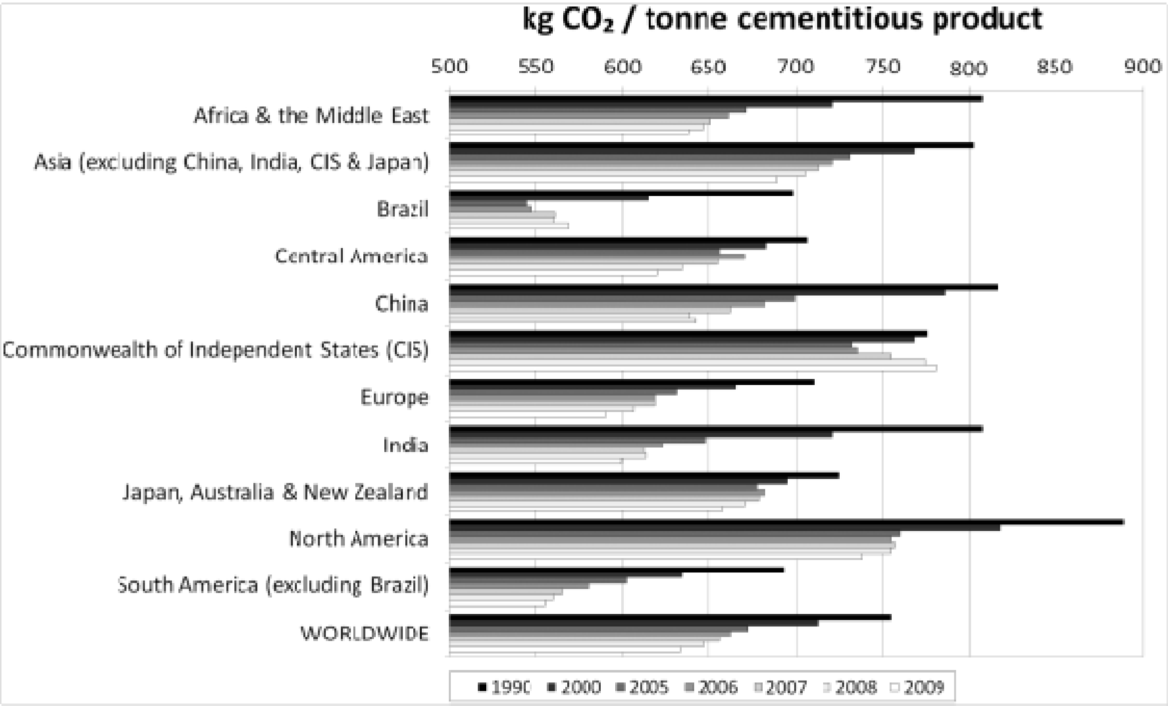


Figure 10.6. Trend in emission intensity for cementitious product (Klee et al. 2011).

Emissions efficiency and fuel switching: The majority of cement kilns burn coal (IEA/WBCSD 2009), but waste material derived from either fossil or biomass, could be used as an alternative fuel. These fuels have a lower CO_2 intensity, depending on their exact composition, particularly the proportion of biomass in them. Alternative fuels are used in cement production in many countries (The

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[7] Final energy is defined as the energy used at the production facility. Primary energy is defined as the energy used at the production facility as well as the energy used to produce the electricity consumed at the facility. For primary energy values, the losses associated with conversion of fuels into electricity along with the losses associated with electricity transmission and distribution are included. It is assumed that these losses are 67%.

Netherlands (92%), Belgium (56%), Germany (50%), Switzerland (48%), and Austria (47%) (Wang 2008) but potential exists in many countries (e.g. China, (Murray and Price 2008). **Figure 10.7** illustrates the share of alternative fuels and biomass used status in 2005 for clinker production in a number of countries (Oda et al. 2012). This trend is rising. In India one company could use 54 thousand tonnes of waste materials in 2009-10 to reduce fossil fuel use (UltraTech 2010). Using alternative fuels could reduce cement sector emissions by 0.16 Gt CO_2e per year by 2030 (Vattenfall 2007) while the cement industry could use up to 70% alternative fuels by 2050 (IEA/WBCSD 2009).

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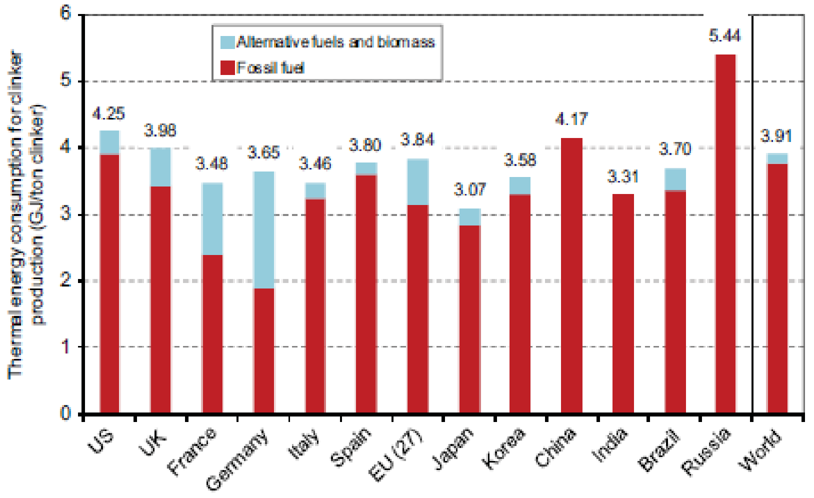


Fig. 8. Final estimates of thermal energy consumption in clinker production in 2005. *Note*: Total thermal energy consumption consists of values for fossil fuels, alternative fuels, and biomass. Thermal energy is measured in terms of low heat value (LHV) base. There is no correction for waste heat recovery power generation.

Figure 10.7. Estimates of thermal energy consumption in clinker production in 2005, from Oda et al. (2012).

Cement kilns can be fitted to harvest carbon dioxide, which could then be stored, but this has yet to be piloted and “commercial-scale CCS in the cement industry is still far from deployment” (Naranjo et al. 2011). Implementing this technology would increase cement production costs by 40-90% (IEAGHG 2008).

Material efficiency: Cement is the main ingredient in concrete. For concrete, two applicable material efficiency strategies are: using less cement initially and reusing concrete components at end of first product life (distinct from down-cycling of concrete into aggregate which is widely applied). Less cement can be used by placing concrete only where necessary, for example Orr et al. (2010) use curved fabric moulds to reduce concrete mass by 40% compared with a standard, prismatic shape. By using higher-strength concrete, less material is needed; CO_2 savings of 40% have been reported on specific projects using ‘ultra-high-strength’ concretes (Muller and Harnish 2008). Reusing continuous concrete elements is difficult because it requires elements to be broken up but remain undamaged. Concrete blocks can be reused, as masonry blocks and bricks are reused already, but to date there is little published in this area. Fast growing readymix concrete production in India in computer controlled batching plants is optimising proportion of cement (Task Force 2007).

Reduced product and service demand: Demand for cement can be reduced by improving the quality of cement (which leads to longer building and infrastructure lifetimes) and using other construction materials. Demand for clinker can be reduced by reducing the clinker-to-cement ratio. Portland cement is comprised of 95% clinker and 5% gypsum. Cement can be produced with lower ratios of clinker use additives such as blast furnace slag from steel mills, fly ash from power plants, limestone, and natural or artificial pozzolans. The weighted average clinker-to-cement ratio for the companies participating in the WBCSD GNR project was 76% in 2009 (WBCSD 2011). In China, this ratio was 63% in 2010 (China Cement 2011; NDRC 2011a). In India ratio is 0.8 (Sathaye et al. 2005).

Cement, in concrete, is used in the construction of buildings and infrastructure. Reducing demand for these products can be achieved by extending their lifespans or using them more intensely. Buildings and infrastructure have lifetimes less than 80 years (less than 40 years in East Asia) (Hatayama et al. 2010) however their core structural elements (those which drive demand for concrete) could last over 200 years if well maintained. Reduced demand for building and infrastructure services could be achieved by reducing journey requirements, increasing the number of people living and working in each building, or decreasing per-capita demand for utilities (water, electricity, waste) but has as yet had little attention.

10.4.2.3 Chemicals (plastics/fertilisers/others)

The chemicals industry produces a wide range of different products on scales ranging over several orders of magnitude. However, emissions in this sector are dominated by a relatively small number of key outputs: ethylene, used primarily in producing plastics; fertilizer; and adipic acid, nitric acid and caprolactam, used in the production of plastics and other synthetic polymers and fertilizer. Emissions arise both from the use of energy in production, and from the venting of byproducts from the chemical processes. Fertilizer is also responsible for further emissions of GHGs after application.

Energy Efficiency in Production: The majority of energy use in the production of ethylene is in the steam cracking process, which produces ethylene from a variety of hydrocarbon feedstocks. Steam cracking processes were responsible for emissions of around 180MtCO_2/year (Ren et al. 2006), and consumed about 65% of the total energy used in ethylene production. The worldwide potential for energy saving in steam cracking can be 23% (Saygin et al. 2011) by upgrading all plants to best practice technology, and a further saving of around 12% was possible with best available technology. Switching to a biomass-based route as an alternative to steam cracking could reduce total CO_2 emissions per ton of output (Ren and Patel 2009) but with significantly higher energy use (avoided CO_2 emissions are due to “electricity co-generation”). Fertilizer production accounts for around 1.2% of world energy consumption (Swaminathan and Sukalac 2004), the majority of which is used to produce ammonia (NH_3). 22% energy savings are (Saygin et al. 2011) possible in ammonia production by upgrading all plants to best practice technology, and 43% savings are possible by applying best available technology. Nitrous oxide (N_2O) is emitted during production of adipic and nitric acids, which have a variety of industrial uses. Adipic acid is used primarily in the production of plastics and synthetic fibres, and nitric acid is used to produce synthetic fertilizer. By 2020 annual emissions from these industries will grow to 177 MtCO_2eq (EPA 2006). These emissions could be reduced by up to 99% depending on plant operating conditions (Reimer et al. 2000).

Efficiency in Use: Many of the material efficiency measures identified in section 10.4.1.3 can be applied to the use of plastics as a means of demand reduction. To produce a high value recycled material with favourable properties, a pure waste stream is required, as impurities in inputs to the recycling process greatly degrade the properties of the recycled material. More efficient use of fertilizer gives benefits both in reduced direct emissions of N_2O from the fertilizer itself and from reduced fertilizer production (Smith et al. 2008).

Technological innovation in nitrogen fertilizer production is limited within the current process of ammonia production (which accounts for 87% of the industry’s total energy consumption (IFA 2009) via the Haber-Bosch process (Erisman et al. 2008). Possible improvements relate to the introduction of new nitrous oxide (N_2O) emission reduction technologies in nitric acid production such as high-temperature catalytic N_2O decomposition (Melián-Cabrera et al. 2004) which has been shown to reduce N_2O emissions by up to 70-90% (BIS Production Partner 2012; Yara 2012). N_2O emissions from nitric acid production which currently accounts for 15.7% of emissions in the sector has the potential to reduce GHG emissions by 73 Mio. t CO_2-eq/year through Best Practice technologies (IFA 2009). Greater energy efficiency in ammonia production plants can also lead to significant energy-savings; for example, Natural gas-based ammonia production results in 25% energy savings compared to Naphtha, 36% compared to Fuel Oil and 50% compared to Coal and 27 Mio. t CO_2-eq/year GHG emissions savings in the industry (IFA 2009).

10.4.2.4 Pulp and paper

Figure 10.8 shows that energy inputs in the European pulp and paper industry were reduced from 16.07 to 13.55 GJ per tonne of paper between 1990 and 2008. However, the graph also suggests that energy intensity has now stabilised, and no significant future efficiencies are forecast. A list of emerging technologies listed by (Kramer et al. 2009) include more efficient motor drives, more efficient steam cycle washers, use of microwaves to reduce log pulping energy, biotreatment of wood chips and electrohydraulic contaminant removal techniques all offer small potential improvements to sub-components of the overall process.

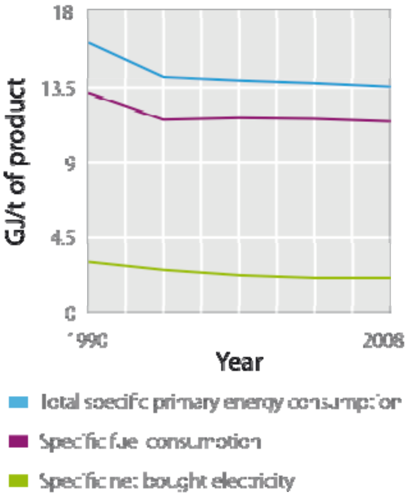


Figure 10.8. Energy intensity associated to the production of market pulp and paper in Europe (the data represents best practice across the Confederation of European Paper Industries [CEPI] member countries for all types of market pulp and paper products. Pulp types include wood pulp, recovered paper, non-fibrous materials and pulp other than wood. Paper types include newsprint, graphic paper, case materials, carton board, packaging paper, and household and sanitary paper, among others. The y axis is expressed in terms of primary energy (source) per tonne of market pulp and paper produced, considering the full mix of products.) (Figure extracted from (Allwood et al. 2012 p. 318), elaborated with data from (CEPI 2011).

Emissions efficiency and fuel switching: Direct CO_2 emissions from European pulp and paper production were reduced from 0.57 to 0.35 $ktCO_2$ per kt of paper between 1990 and 2009, whereas indirect emissions were reduced from 0.2 to 0.11 $ktCO_2$ per kt of paper during the same time period (CEPI 2011). Combined heat and power (CHP) accounted for 94.8% of total on-site electricity produced by EU paper makers in 2009, compared to 88.1% in 1990 (CEPI 2011), leaving little room for improvement. The global pulp and paper industry usually has ready access to biomass resources and it generates from biomass approximately a third of its own energy needs (IEA 2009b) (53% in the EU, (CEPI 2011).

Energy savings could be obtained from the development of emerging technologies such as black liquor gasification, which could result in significant energy reductions due to large amounts of excess power production (Jacobs and IPST 2006; Worrell et al. 2008a).

Black Liquor Gasification which uses the by-product of the chemical pulping process has the potential to replace the commonly used Tomlinson recovery boiler as an alternative technology to increase safety, flexibility and energy efficiency of pulp and paper mills (Naqvi et al. 2010). With commercial maturity expected in 10-15 years (Eriksson and Harvey 2004), Black Liquor Gasification can be utilized as a waste-to-energy method with the potential to achieve higher overall energy efficiency (38% for electricity generation) than the conventional recovery boiler (9-14% efficiency) while generating an energy-rich syngas from the liquor (Naqvi et al. 2010). The syngas can also be utilized as a feedstock for chemical production or to produce dimethyl ether, which can be used as a diesel substitute in road transport (Pettersson and Harvey 2012; Takeishi 2010).

Material efficiency, material substitution, material reuse and waste: Methane emissions from paper decomposition in landfills can be significantly reduced by recycling (Miner 2010). Recycling rates in Europe and North America reached 72% and 63% in 2009, respectively (AF & PA 2011; CEPI 2011), leaving a small range for improvement when considering the maximum theoretical limit of 81% estimated by (CEPI 2006). In Europe, the share of recovered paper used in paper manufacturing has increased from roughly 33% in 1991 to around 44% in 2009 (CEPI 2011). Higher material efficiency could be achieved through the improvement of recycling yields and the manufacturing of lighter paper. The former could be obtained by promoting the design of easy to remove inks and adhesives and less harmful de-inking chemicals, while the latter could be achieved by reducing the average weight of newspapers and office paper from 45 and 80 g/m^2 to 42 and 70 g/m^2 respectively (Hekkert et al. 2002; Van den Reek, J 1999).

Reduced demand for products and reduced demand for material services: Alternative opportunities to reduce demand for paper products in the future include printing on demand, removing print to allow paper re-use (Leal-Ayala et al. 2012), and substituting e-readers for paper. More research is required in these areas to establish their true demand reduction potential.

10.4.2.5 Non-ferrous (aluminium/others)

Table 10.5 shows emissions intensities for a range of non-ferrous metals (Sjardin 2003). Annual production is dominated by aluminium, with 56Mte of aluminium produced globally in 2009, of which 18Mte was secondary production. Production is expected to rise to 97Mte by 2020 (IAI 2009). Magnesium is another significant non-ferrous metal, but with global primary production of only 653Kte in 2009 (IMA (International Magnesium Association) 2009) it is dwarfed by aluminium production. In addition to CO_2 emissions resulting from electrode and reductant use, the production of non-ferrous metals can result in the emission of high-GWP GHGs, for example PFCs in aluminium or SF6 in magnesium which can add significantly to CO_2-eq emissions. Aluminium production is particularly associated with high electricity demand. The sector accounts for 3.5% of global electricity consumption; more than half of the energy used in non-ferrous metals (IEA 2008) and energy accounts for nearly 40% of Aluminium production costs.

Table 10.5: Emission factors from electrode and reductant use for various non-ferrous metals (Sjardin 2003)

	CO_2 emissions (te CO_2/te product)
Primary Aluminium	1.55
Ferrosilicon	2.92
Ferrochromium	1.63
Silicomanganese	1.66
Calcium carbide	1.10
Magnesium	0.05
Silicon Metal	4.85
Lead	0.64
Zinc	0.43

Energy efficiency: Few improvements are forecast, mainly focusing on the need to maintain a constant alumina concentration in the electrolysis cell (point feeding), removing gases from the cell (transverse slots cut in the anodes) and optimal control. The IEA forecast a maximum possible 12% future saving in energy requirements by future efficiencies. The current best practice primary energy intensity value is 174GJ/te for primary production (85% of this being the energy requirement for electrolysis) and 7.6GJ/te for secondary production (Worrell et al. 2008b). The theoretical minimum energy requirement just for chemically transforming alumina to aluminium is 32.5 GJ/te of aluminium produced (BCS, Inc. 2007). This value is not a practical target as it represents the thermodynamic ideal with an infinitely slow reaction. The 'Aluminium Industry Vision', however, has a 2020 final average energy target for smelting in the US of 40GJ/te of aluminium produced (compared to a 1995 value of 55.5GJ/te). The options for new process development in aluminium production – multipolar electrolysis cells, inert anodes and carbothermic reactions – have been pursued for decades and remain elusive. However, there are significant carbon abatement opportunities in the area of material efficiency and demand reduction.

Material efficiency: From liquid aluminium to final product, the yield in forming and fabrication is only 59% which could be improved by near-net shape casting and blanking and stamping process innovation (Milford et al. 2011). For chip scrap produced from machining operations (in aluminium for example (Tekkaya et al. 2009) or magnesium (Wu et al. n.d.)) extrusion processes are being developed to bond scrap in the solid state to form a relatively high quality product potentially offering energy savings of up to 95% compared to re-melting.

Aluminium building components (window frames, curtain walls and cladding) could be reused when a building is demolished (Cooper and Allwood n.d.) and more modular product designs would facilitate repair and upgrade, giving longer product lives and an overall reduction in demand for new materials (Cooper et al. 2012).

10.4.2.6 Food processing

The food industry as discussed in this chapter includes all processing beyond the farm gate, while everything before is in the agriculture industry, and discussed in chapter 11. In the developed world, the emissions released beyond the farm gate are approximately equal to those released before (Garnett 2011) and Figure 10.2 suggests that in total provision of human food drives around 17.7 GtCO2e.

The three largest uses of energy in the food industry in the US are animal slaughtering and processing, wet corn milling, fruit and vegetable preservation, accounting for 19%, 15% and 14% respectively (US EIA 2009). Reductions of between 5 and 35% of total CO_2 emissions can be made by investing in increased heat exchanger networks or heat pumps (Fritzson and Berntsson 2006). However, the most cost effective reduction in CO_2 emissions would be achieved by switching from heavy fuel oil to natural gas. 83% of the energy used in wet corn milling is for dewatering, drying, and evaporation processes (Galitsky et al. 2003) and 60% of that used in fruit and vegetable processing is in boilers (Masanet et al. 2008). Combined heat and power can save energy by 20-30%; mechanical dewatering, potentially reducing the energy intensity of drying by 99% compared to rotary drying (Masanet et al. 2008); pinch technology in drying, with estimated 8-40% energy cost savings (Galitsky et al. 2003); direct use of turbine gas for drying, with estimated 35-45% reductions in primary fuel consumption compared to steam-based heating methods (Masanet et al. 2008); and thermal and mechanical vapour recompression in drying, with estimated 15-20% total energy savings, which could be increased further by use of reverse osmosis (Galitsky et al. 2003). Many of these technologies could also be used in cooking and drying in other sectors of the food industry. Cullen et al. (2011) suggest that 88% savings in energy for refrigeration could be made with better insulation, and reduced ventilation in fridges and freezers. Other ways of improving emissions efficiency using lower-emission modes of transport (Garnett 2011). In transporting food, there is a trade-off between local sourcing, and producing the food in areas where there are other environmental benefits (Edwards-Jones et al. 2008; Sim et al. 2007).

Up to one third of food produced for human consumption is wasted in either in production/retailing stage, or by consumers. Gustavsonn et al. (2011) suggest that, in developed countries, consumer behaviour could be changed, and 'best-before-dates' reviewed, while in developing countries small farmers should be encouraged to organize, diversify and upscale their production and marketing, and investments should be made in infrastructure and transportation. Landfill emissions associated with this food waste could be reduced by use of anaerobic digestion processes (Woods et al. 2010). In addition, overall demand for food could be reduced without sacrificing wellbeing. Globally, approximately 1.5 billion out of 5 billion people over the age of 20 are overweight and 500 million are obese (Beddington et al. 2011). Demand for high-emission food such as meat and dairy products could therefore be replaced by demand for other, lower-emission foods. Meat and dairy products contribute to half of the emissions from food (when the emissions from the up-stream processes are included) according to Garnet (2009), while Stehfest et al. (2009) puts the figure at 18% of global GHG emissions. Furthermore, demand is set to double by 2050, as developing nations grow wealthier and eat more meat and dairy foods (Garnett 2009; Stehfest et al. 2009). In order to maintain a constant total demand for meat and dairy, Garnet (2009) calculated that those in the developed world would have to reduce the amount of meat and milk they consume by half.

10.4.2.7 Textiles

In 2009, textiles and leather manufacturing consumed 2.15 EJ final energy globally. Global consumption is dominated by Asia, which was responsible for 65% of total world energy use for textiles and leather manufacturing (56% of global energy use was from China) in 2009. In the U.S., about 45% of the final energy used for textile mills is natural gas, about 35% is net site electricity, and 14% coal (US EIA 2009). In China, final energy consumption for textiles production is dominated by coal (39%) and site electricity (38%) (NBS 2010).

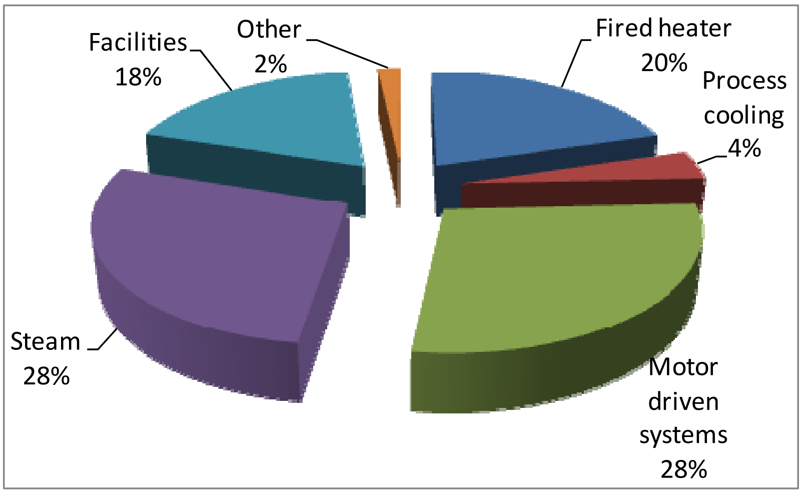


Figure 10.9. Final energy end-use in the US textile industry.

Figure 10.9 provides a breakdown of final energy use by end use in the U.S. textile industry, showing that motor driven systems and steam systems dominate the energy end uses. Around 36% of the energy input to the U.S. textile industry is lost onsite, with motor driven systems responsible for 13%, followed by energy distribution and boiler losses of 8% and 7%, respectively (US DoE 2004).

Numerous energy efficiency technologies and measures exist that are applicable to the textile industry (CIPEC 2007; ECCJ 2007; Hasanbeigi and Price 2012). Hong et al. (2010) reports CO2 emissions reductions of 140 kt/CO2 following the adoption of energy-saving measures in 303 firms in Taiwan. In India, CO2 emissions reductions of at least 13% were calculated based on implementation of operations and maintenance improvements, fuel switching, and adoption of five energy-efficient technologies (Velavan et al. 2009).

10.4.2.8 Other industry sectors

If requested by expert review and space constraints allow more industrial sectors could be added (e.g. glass).

10.4.2.9 Mining

Underground mining requires more energy than surface mining due to greater requirements for hauling, ventilation, water pumping, and other operations (US DoE 2007). In general, there is very little data available on energy use by specific mining process, equipment type or fuel type utilized. Analysis of energy use in the US mining industry reveals that investments in state-of-the-art equipment and further research could reduce energy consumption by almost 50% (US DoE 2007), and that energy costs are estimated to represent more than 15% of the total cost of production in the mining industry (SWEEP 2011).

In the extraction of metal ores, one of the greatest challenges for energy efficiency enhancement is that of recovery ratio, that refers to the percentage of valualble ore within the total mine material. Lower grades inevitably require greater amounts of material to be moved per unit of product. The recovery ratio for metals averages about 4.5% (US DoE 2007). The ‘grade’ of recyclable materials is often greater than the ores currently being mined, for this reason advancing recycling for mineral commodities would bring improvements in overall energy efficieny (IIED 2002). In the excavation and processing material processes, energy can be saved with efficient motors, and by cooling air at the surface then blowing it rather than cooling underground (SWEEP 2011). Loading, hauling, crushing and grinding in mining also have potential for efficiency improvements (Norgate and Haque (2010).

10.4.2.10 Summary matrix

Table 10.6: Summary table of all mitigation options for manufacturing (not for mining and services)

"Pure" Kaya	**ACTIVITY**			**ENERGY INTENSITY**	**GHG INTENSITY**	
Industry Kaya	**Total demand for product service**	**Products/service**	**Material input/product**	**Energy/material**	**Emissions/energy**	**Non-energy emissions/material**
Sector wide	Reduce demand as general strategy, lifestyle change as specific option	More durable products, Alternative delivery of service, More intense use of products	Biomass-based feedstock use of waste, Material efficiency in product design, (Light-weight), Reduce material losses/improve manufacturing yield, Recycling of materials	Electric motors (variable speed control system, system design and operation; furnaces (heat flow management); co-generation	Fuel switching and feedstock substitution (coal to gas, biomass, municipal solid waste, electrification, hydrogen), Renewable energies, CCS	Alternative refrigerants, novel processes, process optimisation), thermal destruction of strong GHGs
Iron & Steel	Service reduction	More durable steel products, including component replacement strategy; More intense use of steel products	Reuse of structural steel/steel components, recycling of scrap, material substitution (wood and stone or magnesium alloys), reduction of material losses (precise casting)	Improved heat and energy recovery; better process coupling (less temperature cycles); pulverized coal injection), ULCOS	Fuel switching and Feedstock substitution (biomass, waste, electrolysis, gas-based DRI, charcoal, ferro-coke), CCS	
Cement	Reduced demand for services: journey requirements, per capita demand for utilities	Longer building and infrastructure lifetimes, higher strength concrete, intense use of buildings/infrastructure	Clinker substitutes (blast furnace slag, fly ash), recycling of materials (reusing concrete), alternative construction materials, less cement in concrete, reduce concrete mass	Improve thermal and electric efficiency	Fuel switching (waste, biomass, scrap tires; alternative fossil fuels (solvents, waste oils, tires)), CCS	
Chemicals		More intense use (more efficient use of fertiliser)	Alternative feedstock: bio-based materials (vegetable oil) for plastics, Recycling of materials	BPT/BAT for steam cracking (ethylene), ammonia; improve plant operation conditions for nitric and adipic acid production	Renewable energy, fuel switch to biomass, waste, feedstock substitution to gas or biomass, CCS/CCU in ammonia/urea production and polymer synthesis	Secondary catalysts, Thermal destruction for N_2O from adipic/nitric acid production
Pulp and paper	Reduced demand for services (printing on demand)	More intense use (removing print to allow reuse)	Process innovation, material recycling (easy to remove inks and adhesive and less harmful de-inking chemicals)	Energy efficiency improvement	Renewable energy (solar thermal, biomass), CCS	
Non-ferrous metals		Modularity to improve repair and upgrade of long lasting products, Less Al in one-way packaging)	Reuse by disassembly, recycling, reduce material losses/improve manufacturing yield: near-net shape casting, blanking and stamping process innovation	Aluminium processes (multipolar electrolysis, inert anodes, carbothermic reactions)		
Food and beverages	Reduce demand for services: e.g. meat and milk consumption	Consumer behaviour (review of "best before" dates), organise and upscale production		CHP, mechanical dewatering, various drying technologies; more efficient refrigeration	Renewables: solar thermal, fuel switching (heat pumps), CO_2 use	Reducing landfill emissions from food waste via anaerobic digestion
Textiles				motor driven and steam systems, operation and maintenance	Renewables: solar thermal, fuel switching	

10.4.2.11 Services (with special reference to tourism)

Data and studies on global mitigation potentials in the service sector are scarce. Many studies do not report the service sector individually, but aggregate it with the residential sector (Hoogwijk et al. 2010) or include it in the buildings sector (Akashi and Hanaoka 2012; IEA 2011c; Ürge-Vorsatz and Novikova 2008). Some service-sector specific analyses are available for Europe (Bertoldi and Atanasiu 2011b; Jakob et al. 2012). Electricity use accounts for 66% of GHG emissions in the service sector in Europe (Enerdata 2011). While official EU projections expect continuously increasing electricity demand in the EU service sector (including agriculture) from about 760 TWh in 2007 to about 1090 TWh in 2030 (Capros et al. 2010), other studies show that only by applying cost-effective technologies (i.e. technologies available at negative abatement costs) the demand could be more than 100 TWh lower in 2030 and by applying best available technology without taking costs into account it could be about 400 TWh lower (Jakob et al. 2012). Implementation of the EU legislation on minimum standards and labelling are is estimated to save about 90 TWh by 2020 (Bertoldi and Atanasiu 2011b).

An overview of the important mitigation options, related to space heating, lighting, ICT equipment, air-conditioning and water/air conveying systems, is given in the buildings chapter.

Mitigation options for tourism include technical, behavioural and organisational aspects. Many mitigation options and potentials are the same as those identified in the transport, buildings (accommodation), food (catering) etc. The corresponding chapters contain much information relevant to the services and tourism. Approaches to mitigation in tourism vary across regions (OECD and UNEP 2011). Some reduction targets have been put forward by the WTTC: -25% to -30% by 2020, -50% in 2035 compared to 2005. Such targets are supported by ETC and UNWTO “as a minimum requirement for progress on effective emissions reductions (Scott et al. 2010). These targets contrast with the trends in emissions growth and reveal a gap of more than 100% between the projected emissions for 2035 and the target (Scott et al. 2010). Such targets thus place an additional burden of reduction in other sectors.

10.5 Infrastructure and systemic perspectives

Collaborative Interactions among industries, and between industry and other economic sectors have significant implications for GHG mitigation through economies-of-scale and to overcome technological and infrastructure barriers. Strategies adopted in other sectors may lead to increased emissions in industry for example higher production of solar PV, flat screen TV manufacturing etc. There is hence a need to take a system-wide view, although setting the system boundaries often poses a challenge. Systemic approach can be at different levels, namely, at micro-level (within a single company, such as process integration, heat cascading, and cleaner production), meso-level (between two or more companies, such as inter-sectoral cooperation in industrial clusters in a specific district and eco-industrial parks) and macro-level (cross-sectoral cooperation, such as urban symbiosis, regional eco-industrial network or reuse of waste or by-products). The following sections show that these systemic approaches can reduce the total consumption of materials and energy and contribute to the reduction of GHG emission. The section focuses on the meso- and macro-levels of cooperation and provides selected examples. Moreover, a consideration is made of the implications that mitigation efforts in other sectors can have on the industry sector.

10.5.1 Industrial clusters and parks (meso-level)

In order to encourage process integration between individual companies and industrial symbiosis at industrial cluster level, different kind of infrastructures such as information exchange platform or pipelines are necessary so that both material and energy use can be optimized (Côté and Hall 1995).

Small and medium enterprises (SMEs) often suffer not only from difficulties arising due to their size, lack of access to information but also from being isolated (Sengenberger and Pyke 1992). Clustering of SMEs can facilitate growth and competitiveness (Schmitz 1995). In terms of implementation of GHG mitigation options, SMEs can benefit in various forms from clustering via the exchange of information and experience, as well as via the use of common purchase or supply structures (e.g. cogeneration). SME clusters are emerging mostly in Asian countries like Bangladesh, China, India, Indonesia, Some such well-studied clusters are furniture manufacturing clusters in Indonesia (Chaminade and Vang 2008), roof tile clusters in Central Java (Sandee and Rietveld 2001), hardware production, food, printing and packing, tea, porcelain, electrical machinery, farming and planting, aquatic products in China (Chen and Cao 2006), cotton hosiery, woollen knitwear, sewing machines, bicycle and bicycle parts, leather, IT in Bangladesh and India (UNIDO 2009b). There are however, some SME clusters emerging in European countries as well, especially in bio-chemical and software area (Villa and Antonelli 2008).

Related to GHG mitigation most SMEs cannot afford the costs or time involved in identification and implementing mitigation options on their own (Ghosh and Roy 2011). It is the same situation as for the identification and implementation of more synergy opportunities to reduce industrial water provision and waste water treatment, use of waste materials and waste management. In order to overcome such barriers, eco- industrial parks (EIPs) have been created both in developed and developing countries. The objective of EIPs is to reduce the cumulative environmental impact of the whole industrial park in a manner which encourages byproducts exchange among different companies so that ideally a closed loop cycle can be set up (Geng and Doberstein 2008). Such an initiative can reduce the total consumption of virgin materials and final waste, and improve the efficiency of companies and their competitiveness. Since the extraction and transformation of virgin materials is usually energy intensive, EIP efforts can abate greenhouse gas emissions of industry.

In order to encourage the development of EIPs, many countries support and initiate EIPs. For instance, Chinese eco- industrial park standards contain quantitative indicators for material reduction and recycling, as well as pollution control (Geng et al. 2009). Two pioneering eco-industrial parks in China have achieved over 80% solid waste reuse ratio and over 82% industrial water reuse ratio (Geng et al. 2008). The Japanese eco-town project in Kawasaki achieved substitution of at least 513, 000 tons of raw material, resulting in about the avoidance of 1% of the current total landfill in Japan (van Berkel et al. 2009).

10.5.2 Cross-sectoral cooperation (macro level)

Opportunities arise from the geographic proximity of urban and industrial areas, resulting in the potential to transfer urban refuse as a resource to industrial applications, and vice versa (Geng 2010). For instance, the cement industry can accept both virgin materials (such as limestone and coal) and various wastes/industrial by-products as their inputs, as explained in section 10.4. The examples from Japan (Hashimoto et al. 2010), Hidaka city (Morimoto et al. 2006), have shown that CO_2 emissions can be reduced to 15%-20% by use of municipal solid waste in cement kilns. In Sweden, both exhaust heat from industries and heat generated from burning municipal wastes are supplied to local municipal users through district heating (Holmgren and Gebremedhin 2004). As examples for instance from India and Europe show, cement industry also co-processes industrial waste and agricultural waste as fossil fuel substitutes so that strategically locating industries between urban centres and agricultural land can make waste-based energy sources cost effective. Industrial waste can also be used to reduce conventional fuel demand in other sectors. For example, the European bio-DME project aims to supply heavy-duty trucks and industry with dimethyl-ether fuel made from black liquor produced by the pulp industry in Sweden (BioDME, 2012). In India 30% fly ash building blocks use is mandatory for buildings construction sector, cement and power plants are entering into long term contracts to reduce supply as well as price uncertainty through spot market fly ash price which is facing competing demand from domestic and international markets and multiple sectors like road and embankment construction, agriculture. Some power plants are entering into long-term contracts with brick manufacturers to locate their facility with power plant’s boundary to reduce ash transport cost.

The reuse of materials captured in urban infrastructures (urban mining) can reduce the demand for primary products (e.g. ore) and thus contribute to GHG mitigation in extractive industries. For example, urban stock of steel is estimated 1.32 billion tonnes in Japan where the total annual crude steel production was 0.11 billion tonnes in FY2010 (JISF 2012). Currently, particularly in buildings besides already established re-use structures urban stock of steel increases and leads to a growing potential for future urban mining. While in 2003 in Japan only 7.45 Mt of steel scrap comes from the building sector, 19.4 Mt are going into the building sector.

An additional example for cross-sectoral cooperation is that of CCS. If CO_2 from major sources like cement and iron/steel industry is to be captured, expensive and large capture units and in particular transport and storage facilities are needed. So-called CO_2 clusters could help to gain critical mass to trigger investment in storage and pipeline infrastructure to transport the CO_2 from source to sink. (van den Broek et al. 2009; McKinsey 2008) estimate that a European pipeline network would be economically viable under a scenario where sources and sinks are clustered. This would not only include the industry sector but would comprise cooperation with the energy sector (CO_2 from power plants or refineries) as well.

10.5.3 Cross-sectoral implications of mitigation efforts

There are many implications of the mitigation strategies of other sectors for industrial emissions. Examples relate chiefly to material substitution (e.g. potential lightweight materials, high-strength steel and aluminium: cf. chapter 8), growing demand for rechargeable batteries for vehicles (cf. chapter 8) and the demand for new materials (e.g. innovative building structures or thermal insulation for buildings: cf. chapter 9; high-temperature steel for power plants: cf. chapter 7). These materials consume energy at the time of manufacturing, but the potential energy-saving effect is observed over a long period of time (ICCA 2009). As the emissions from the use of these materials are not reflected in industry's emissions, incentive schemes that do not take the whole product life-cycle into account can be counterproductive. For vehicle weight reduction, the increase in GHG emissions from increased aluminium production could be larger than the GHG savings from vehicle weight reduction (Geyer 2008). Kim et al. (2010) have however indicated that in about two decades, closed-loop recycling can significantly reduce the impacts of aluminium-intensive vehicles.

Nowadays much attention is focused on improving the energy efficiency on the user side (e.g. efficiency of building operation and maintenance (Yeo and Gabbai 2011). With continuous implementation of mitigation options for the overall balance embodied emissions become more and more important. This is especially so for low energy buildings where the ratio of embodied energy to total lifecycle energy increases significantly (Thormark 2006; Yohanis and Norton 2002). So far policymakers traditionally focus on regulating operational energy use in buildings, ignoring other life cycle components such as embodied energy (Acquaye et al. 2011). For example, between 2% and 38% of a traditional building lifetime energy demand is associated with all the material used in the construction, rehabilitation and maintenance phases, while this range may increase to 9-46% for a low-energy building (Sartori and Hestnes 2007).

A further example of an interaction between mitigation strategies in industry and other sectors is the increased extraction of raw materials for low-carbon energy technologies. Moss et al. (2011) examine market and political risks for supply-chain bottlenecks for each of the 14 metals that are used in significant quantities in the technologies of the EU's Strategic Energy Technology Plan (SET-Plan). For instance metal requirements and associated bottlenecks in green technologies, such as electric vehicles, low-carbon lighting, electricity storage and fuel cells and hydrogen, have been assessed.

Often the overall approaches for mitigation in products (recycling, material substitution and dematerialisation) can be conflicting. For example, the quality of many recycled metals is maintained solely through the addition of pure primary materials (Verhoef et al. 2004), thus perpetuating the use of these materials and creating a challenge for the set up of closed loop recycling (e.g.

automotive aluminium, (Kim et al. 2011)). Additionally, due to product retention (the period of use) and growing demand, secondary materials needed for recycling are limited.

10.6 Climate change feedback and interaction with adaptation

This section focuses on the potential impacts of climate change and adaptation measures on the emissions, the mitigation measures and associated potential of industry and services (in particular on tourism); climate change impacts on industry are dealt with in more detail in WG 2 of AR 5.

Insights into potential synergy effects (how adaptation options could reduce emissions in industry) or trade offs (how adaptation options could lead to additional emissions in industry) are currently lacking. However, it can be expected that many adaptation options can generate additional industrial demand and will lead to additional emissions in the sector. Improving flood defence, for example, as a reaction of sea level rise may lead to a growing demand for cement for embankment, which would induce manufactured materials and mechanical energy to build them. Climate change and corresponding adaptation measures may affect the demand for products and services. The changes in use of certain products may affect retail. Manufacturers of textile products, machinery for agriculture or construction, and heating/cooling equipment may be affected. There is as yet no comprehensive assessment of these effects, nor any estimate on market effects resulting from changes in demand for products. There is as yet no comprehensive assessment of these effects, nor any estimate on market effects resulting from changes in demand for services, products and their trade.

With respect to tourism taken here as illustrative example for the service sector specific feedbacks from adaptation needs can be identified. The decrease in rainfall and water shortages in many coastal resorts will lead to an increase of desalination which is known to be energy intensive (Lattemann and Höpner 2008; Stokes and Horvath 2009) and induces a growing material demand. Another example is the call for a larger use of snowmaking to maintain tourism activities, winter sports activities, pilgrimage etc. Lastly tourism, unlike other activities, will have to cope up particularly in some parts of the world with various impacts of climate change (Handmer et al. 2012) and the reconstruction that follows (e.g. accommodation or facilities such as golf courses).

10.7 Costs and potentials

Acknowledging that particularly the high energy intensive industrial branches have high incentives to optimize energy consumption and accordingly many efforts have been done in this direction GHG, mitigation potential of the manufacturing sector is still significant and multiple mitigation options exist (cf. section 10.4): energy use per unit of production(can be reduced through enhanced material use efficiency and energy efficiency per se), GHG intensity per unit of fuel use or deployment of CCS technology, and process optimisation.

In general there is little comprehensive information on costs associated with mitigation options in the industry sector and in the service sector (including tourism). The assessment of CO_2 emission reduction potential in this section for the industrial sector is therefore mainly based on the concepts used in the ETP IEA reports and some of the marginal abatement cost studies. The Marginal Abatement Curves (MACs) even though have limitations (e.g. missing system perspectives and coverage of system interdependencies) provide information to undertand the different perspectives of sectors or regions (e.g. developed and developing countries). Sector specific global abatement cost curves for the year 2030 and for three industrial sectors are available in (McKinsey Company 2009). The latest study (IEA 2012) projects three scenarios related with temperature increase by 2050: 6DS (business as usual), 4DS (all policies and measures currently planned are implemented) and 2DS (2°C pathway). The 2DS scenario describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C. Discussion in this chapter is more about a deployment potential (resulting from complex scenario analysis with a set of underlying assumptions) rather than actual estimates of observed technical or economic potentials.

Following this approach the mitigation potential of CO_2 for the overall Industry sector is in the order of 5.5 to 7.5 Gt CO_2 for the year 2050 (comparing the 2DS and the 6 DS scenario for this year) and the additional investments required to achieve this potential are estimated to be 2 trillion USD (IEA 2012).The estimation for potential for reduction in energy intensity is in the order of 25% (IEA 2012). Comparing the 2DS scenario for 2050 and the 2010 emissions, the reduction is 1 Gt CO_2 (12% reduction).

Information on how different options contribute to mitigation potential is available in the former IEA ETP report. A CO_2 emissions reduction of 50% in 2050 (compared with 2007 values) is reported as achievable by the implementation of: end use fuel efficiency (40%), fuel and feedstock switching (21%), recycling and energy recovery (9%) and CCS (30%) (IEA 2012). Table 10.7 provides a general view of mitigation potential for different sectors. All industrial sectors have potentials for energy savings. Two sectors (Iron and steel and Chemical and petrochemical) have major 50% mitigation potential within the Industrial sector. From a regional perspective China and India has 44% of that potential (IEA 2012). Akashi, Hanaoka et al. 2011 also indicate that the largest potential for CO_2 emissions savings for some energy intensive industries comes from China and. With associated costs under 100US$/t$CO_2$ in 2030 the use of efficient blast furnaces in the steel industry in China and India can respectively reduce total emissions by 186 MtCO_2 and 165 MtCO_2. This represents a combined total of 75% of the global CO_2 emissions reduction potential for this technology.

MAC studies also show the highest potential is in chemicals, followed by iron and steel and cement: 2, 1.5 and 0.9 GtCO_2/year respectively. 60% of this potential can be achieved at negative costs or at a cost less than 20 euro/tCO_2 (McKinsey Company 2009). MACs are very country specific. Regional variation in options, potentials and cost are shown in MAC studies too. Two country MACs examples provide a regional perspective. In Germany mitigation potential is estimated as 20% for 2020 emissions with options with cost less than 20 euro/tCO_2 representing 80% of this potential. Main options are: energy efficiency (e.g. variable speed drives in diverse motor speed applications, heat recovery, mechanical optimizations of drive systems) efficiency of catalytic converters (chemicals) and N_2O decomposition in adipic acid production (McKinsey Germany 2007).

In Brazil, mitigation potential is estimated as 43% for the year 2030, with options with cost less than 20 US$/t$CO_2$ representing 80% of the potential. Main options are: substitution of non renewable biomass and energy efficiency (e.g. heat recovery in oven/kilns and cogeneration and optimization of combustion) (Henriques Jr. et al. 2010). MACs are also available for other countries (Turner et al. 2010)(AEA 2010). .

(UNIDO 2012) analyzed the potential of energy savings based on universal application of best available technologies. All the values are higher in developing countries (30 to 35%) compared with developed countries (15%). Other industrial sectors not included in Table 10.7 have significant potential for energy savings: 10 to 15% in developed countries and 25 to 30% in developing countries (UNIDO 2012).

Mitigation options could also be analyzed from the perspective of some industry wide technologies. Around two thirds of electricity consumption in the industrial sector is used to drive motors. Steam generation consumes 30% of global final industrial energy use. Efficiency of motor systems and steam systems can be improved by 20–25% and 10% respectively (Brown et al. 2012).

Another study assesses different strategies to achieve a 50% cut in the emissions of five sectors (cement, steel, paper, aluminium and plastics) and reports stronger limitations for the industry sector (Allwood et al. 2010b). Because these sectors have already been subject to significant energy efficiency improvements further enhancement of potentials in the same direction may be expensive.

Demand for these industries is expected to rise and consequently substantial mitigation potential lies outside the manufacturing sector through behavioral and social practice changes. The conclusion is that this can only be achieved by implementing strategies at least partly going beyond the sectors boundaries: non destructive recycling, reducing demand trough light weighting, life extension or substitution for other materials, and radical process innovations. The scenario of extensive implementation of CCS is also assessed, but is concluded that only for the Cement sector this technology is required.

[Non-CO_2 gases: The USA EPA 2011 study, published in draft form August 2011, does not include the estimate of costs and potentials. This paragraph will be updated once the information from the US EPA is made available.]

Table 10.7: Mitigation options: costs and potentials (IEA 2012)

		Energy intensity	**CO2 intensity**		**Total**
Industry	**Indicators**	*Energy/material*	*Emissions/energy*	*Non energy emissions/material*	
	Strategy	New technologies that deliver improved energy efficiency. Promoting of more recycling	Enable fuel and feedstock switching	CCS	Deploying of Best Available technologies (BAT)
	Concrete options	Energy efficiency: smelting reduction, advanced cogeneration. Greatest level of recycling	Black liquor gasification	New separation membranes	
	Potential	Energy intensity 25% lower (difference 2DS to 6DS scenario)			45 to 55% (difference 2DS to 6DS scenario)
	Costs				Total additional investment 2010 - 2050 = 1.5 to 2 trillion USD (2DS vs 6DS)
Steel	**Indicators**	*GJ/tonne of crude steel*			*tCO2/tonne of crude steel*
	Concrete options	Increased recycling and use of scrap, Smelting reduction, Top gas recycling blast furnace, Hydrogen smelting, Production of iron by molten oxide electrolysis	Switch from coal to natural gas, Use of highly reactive materials to lower reducing agents in blast furnaces, Use of charcoal and waste plastic	CCS for blast furnaces, CCS for DRI, CCS for smelting reduction	
	Potential	Energy intensity 35% lower than current level, Energy savings potential based on currently BAT = 4.4 GJ/t steel			50% (difference 2DS to 6DS scenario)
	Costs				Total additional investment 2010 - 2050= 0.2 to 0.4 trillion (2DS vs 6DS)
Cement	**Indicators**	*Gj/tonne of cement*			*tCO2/tonne of cement*
	Concrete options	Shift to best available technologies: long dry process with pre-heaters and pre-calciners, Fluidised bed technology, Further improvements in BAT	Fuel switching, Use of alternative fuels	Clinker to cement ratio decrease, CCS post-combustion, CCS oxyfuelling.	
	Potential	Energy intensity 30% lower than current level (mainly influenced by the reduction in clinker to cement ratio), Energy savings potential based on currently BAT = 1.1 GJ/t cement	Increase proportion of alternative fuels (biomass, waste and other renewables) from 4% to 28% (comparing 2DS and 6 DS scenarios)	8% reduction in clinker to cement ratio (comparing 2DS and 6DS scenarios), CCS is a key option, accounting for 50% of emission reductions, 50 to 70% of all new large plans and 30 to 45% of retrofitted plants to be equipped with CCS by 2050	43% (difference 2DS to 6DS scenario)

	Costs			In Europe CCS double the capital cost of a cement plant. Marginal abatement costs for the cement industry are critically sensitive to future costs of CCS.	Total additional investment 2010 - 2050= 0.4 to 0.5 trillion (2DS vs 6DS)
Chemical and Petrochemicals	**Strategy**	Energy efficiency, Recycling	Process integration		
	Concrete options	Thermal energy efficiency improvements, New development in catalysts, membranes and other separation process, Process intensification	Energy recovery, Replacement of coal and oil by natural gas, Use of biomass and waste, Combined heat and power,	Bio-based chemicals and plastics CCS for ammonia plants	55% (difference 2DS to 6DS scenario)
	Potential	Energy intensity reduction of 22% comparing 4DS and 2DS scenario	4 to 5% of total energy use from biomass and waste by 2050		
	Costs				Total additional investment 2010 - 2050= 0.3 to 0.4 trillion
Pulp and paper	**Concrete options**	Heat and electricity savings, Recycling, Advanced water removal technologies	Cogeneration, Waste heat recovery, Fuel switching, Black liquor and biomass gasification, Biomass conversion to chemicals and liquid fuels	CCS	
	Potential	Recovered paper increase 4%, Energy savings potential based on currently BAT = 3.0 GJ/tonne	Biomass and waste share could be increased from 27% to 50%.		55 to 70% (difference 2DS to 6DS scenario)
	Costs				Total additional investment 2010 - 2050= 0.1 to 0.2 trillion (2DS vs 6DS)
Aluminium	**Concrete options**	Increased use of scrap, Process change, Energy efficiency in both refining and smelting, Replacing old smelter technologies with modern pre-bake cells	Use of low carbon electricity	New process controls to optimize cell-operation conditions	Wetted drained cathodes, Inert anodes, Carbothermic reduction,Kaoline reduction
	Potential	12 to 37% reduction in energy intensity compared with current level,5% increase in the proportion of production from recycled aluminium (2DS vs 6DS), Energy savings potential based on currently BAT = 9.8 GJ/tonne of primary aluminium production			14 to 25% (difference 2DS to 6DS scenario)
	Costs				Total additional investment 2010 - 2050= 0.03 to 0.04 trillion (2DS vs 6DS)

10.8 Co-benefits, risks, spill overs

Besides cost aspects, several other aspects have implications on the final deployment of mitigation technologies. Perception of additional benefits, risks associated with technological strategies and, uncertainties on the potential reliability of mitigation technologies amongst others can affect investment decisions of companies, priority setting of governments and also public acceptance. The public as users have a central role in the implementation of mitigation options via the uptake of consumption behaviour and their acceptance of or opposition to newer options. Since Chapter 2 deals with the general aspects of risk and uncertainty, including those related to carbon price volatility, risk perception and socially-acceptable risk etc., this section discusses illustrative examples that relate directly to mitigation in industry rather than presenting an exhaustive analysis of all aspects. Against that background, Table 10.8 summarizes a more qualitative assessment of risk including behavioural aspects associated with mitigation options. The following text will give some background for the elements in the table.

Table 10.8: Qualitative assessment of risk factors involved in industry mitigation options

	Degree of Risk
Technological risks	Low - High
> Energy efficiency	Low
> Material efficiency e.g., supply chain risks	Medium
>Fuel switch	Low
>CCS	High
Behavioural risks (e.g. product /service demand change)	Very high
Environmental risks	Low-high
Public acceptance	High

10.8.1 Socio-economic, environmental and health effects

The implementation of industrial GHG mitigation options can lead to positive and negative effects on the framework of industrial activity (e.g. competiveness) or on the whole economy and society (e.g. air quality). In general, quantifying the corresponding benefits and costs that a mitigation technology or practice produces is challenging, and moreover different stakeholders may have different perspectives of what the corresponding losses and gains are. Identifying mitigation technology options that positively results in emissions reduction and energy efficiency improvements as well as minimizing negative outcomes on socio-economic and environmental and health issues are therefore critical

At the company or sector level, a typical example of a co-benefit from GHG mitigation in the industry sector is an increase in productivity via reduced use of energy or raw materials inputs and resultant production cost reduction. A study of the impact of energy saving technologies and innovation investments on the productivity of Chinese iron and steel enterprises found that productive efficiency growth can be attributed among other factors to the adoption and amelioration of energy saving measures and the investments in improved techniques associated with energy saving (Zhang and Wang 2008). Other benefits to companies can include reduced costs of environmental compliance and waste disposal or decreased liability. It is important to note that co-benefits need to be assessed in the light of the costs of implementation of the mitigation options (e.g. training requirements, losses during technology installation) (Worrell et al. 2003), which may be larger for SMEs or isolated enterprises (Zhang and Wang 2008).

At the economy-wide level, mitigation policies in industry and services can have a positive effect on other policy objectives such as local pollution and therefore health. Quantification of these benefits is often done on a case-by-case basis. For example, Mestl et al. (2005) find that the environmental health benefits of using electrical arc furnaces for steel production in the city of Tiyuan (China) could potentially lead to higher benefits than other options, despite being the most costly option.

In industry, possible spill-over effects may be related to trade, carbon leakage, technology and knowledge transfer, among other things. Since Chapter 13 covers the issues in details here only an example of the issue of carbon leakage is presented which strongly relates to industry. There are concerns that industry's competiveness would be lower in those countries where industries need to comply with specific mitigation policies, as carbon-intensive industries would get relocated in countries with less stringent carbon abatement policies. On the contrary public perception is in favour of differentiated responsibility in historically low emitting and industrially less developed regions who envisage mitigation actions as counter developmental. Empirical evidence suggests that in reality only a small number of industries could suffer significant impacts (HM Treasury 2006). Only a small share of the high GHG emitting industries have internationally mobile plants and processes and varied distribution options for their products enabling them effectively to go for trade diversion and relocation. For example, cement is bulky and hard to transport over long distances. Creating right public perception through knowledge dissemination can reduce risks as well as supporting the threatened industry sector with other factors relevant for decision of industrial facility site (e.g. access to suitable infrastructure, qualification level of worker).

Trade-offs often arise from the limitation of resources, and must be understood in order to decide what is the best option to allocate funds to. A typical example is the trade-off between investing in mitigation *vs*. adaptation. In the industry context an illustrative example is the potential competition between biomass applications for energy supply (heat, electricity) and biomass as a feedstock for the industry sector (e.g. biorefineries, automobile production). A clear conflict between economic development and mitigation policies is usually also found in the tourism sector. At the company level, companies may need to trade off between the investments in e.g. health and safety *vs.* those aimed at reducing their climate impact. Potential conflicts must be studied and opportunities where the co-benefits are more significant than the conflicts must be identified.

10.8.2 Technological risks and uncertainties

While there is a wealth of literature on the environmental impacts of energy-related mitigation technologies (e.g. biofuels, battery-electric vehicles), knowledge on environmental risks for industrial mitigation options is so far lacking. A particular set of potential health and safety and environmental risks could arise from additional mining activities as some mitigation technologies could substantially increase the need for specific materials (e.g. rare earths) and the exploitation of new extraction locations or methods accordingly. Also in the opposite case, if demand on particular materials were to be reduced, environmental risks could occur. For example, seventeen mines have recently closed in the Philippines, many of which did not have the resources to implement post-closure measures. In 1999, 5.7 million cubic meters of acidic waste were discharged from the abandoned Atlas mine on the island of Cebu (DENR-PAB 2000). The resulting impact to the marine environment, including an extensive fish kill, was considered one of the country's top ten recent environmental disasters.

Carbon Capture and Sequestration (CCS) is another example of a technological option subject to several risks and uncertainties. First, it is unclear when CCS will be commercially available for industrial applications. Experience shows that the projected decreases in learning curves have not always been realised for complex and risky technologies (Rai et al. 2009). Additionally, the assessment of the potential storage capacity and its quality in terms of long-term stability is uncertain (Bradshaw et al. 2007). The geology is complex and detailed investigations are lacking. If sequestration of CO_2 takes place, the corresponding underground space is occupied in the long-term and other forms of utilization are impeded (e.g. geothermal energy production, storage of natural gas). Some potential environmental risks of CCS include CO_2 leakage due to corrosion of materials or to unknown geology, and damage of ground water resources. Lastly, CCS acceptance by the public is a further uncertainty, discussed below.

10.8.3 Social acceptability

The asymmetric impacts that a particular industrial activity has on society can lead to different responses to its implementation. From a socio-constructivist perspective social response to industrial activity depends on three sets of factors related to 1) the dynamics of regional development and the historical place of industry in the community, 2) the relationship between residents and the industry and local governance capacities, and 3) the social or socio-economic impacts experienced (Fortin and Gagnon 2006). Public hearing and stakeholder participation - especially on environmental and social impact assessment- prior to issuance of permission to operate has become mandatory in almost all countries now, and industries' budget on social corporate responsibility is now disclosed as a good practice. Mitigation measures in the industry sector might be socially acceptable if they come along with co-benefits for instance reducing not only GHG emission, but improving local environmental standards as a whole (e.g. energy efficiency measures that reduce local emission). Regional variation in commitment to mitigation activity through international negotiation creates public perception leading to public acceptance of mitigation action and investment.

Industrial CCS does not provide environmental co-benefits, moreover for many people the technology is connected with safety risks. Given the halting of several research projects for CCS due to local opposition, public concerns for safety are often seen as a future barrier to this technology. Most research on the issue points towards a distinct lack of public awareness and specific knowledge with regard to CCS. Accordingly, communication and information channels play a major role for an evaluation of the technology by the public (Fischedick et al. 2009; Pietzner et al. 2011), There is no particular evidence on what the acceptance would be for the case of industrial applications of CCS. A number of studies approach the question of the potential drivers of social acceptance of this technology, and how the perceptions change when expert information is given. Using survey results from six European countries, (de Best-Waldhober et al. 2009) show that giving information about CCS together with information on other alternatives for mitigation can lead to a less favourable evaluation of the technology by the public. In line with this approach a number of initiatives are aiming to engage the public in a dialogue about the potential use of the technology within the context of other alternatives.

Few industries have as profound an influence on community development as mining. Mining activities have generated social conflicts in different parts of the world (Martinez-Alier 2001). The Latin American Observatory of Mining Conflicts reported more than 150 active mining conflicts in the region, most of which started in the 2000s (OCMAL 2010). Besides this general experience, the potential for interactions of social tensions and greenhouse gas reduction mitigation initiatives in this sector are unknown.

10.9 Barriers and opportunities

Options to reduce greenhouse gas emissions in industry face a complex set of barriers and opportunities. These can influence when, where and how these options are deployed. In general they are not readily captured in model studies and scenarios.

Typically, the following categories of barriers and opportunities can be distinguished:

- Technological aspects

    - Technology: includes maturity, reliability, safety, performance, cost of technology options and systems, and gaps in information
    - Physical: includes availability of infrastructure, geography, and space available
- Institutional, legal and cultural aspects
    - Institutional and legal: includes regulatory frameworks, and institutions that may enable investment
    - Cultural: includes public acceptance, workforce capacity (e.g. education, training, and knowledge), and cultural norms
- Financial aspects: includes investment risk, value proposition, competitiveness, and access to capital

Barriers and opportunities combine to influence investment and operational decisions: all barriers must be addressed to allow implementation (see (Flannery and Kheshgi 2005)). For example, due to an intensive use of GHG mitigation technologies in the IEA's Blue Scenarios (IEA 2009a) global investments in industry are 2-2.5 trillion USD higher than in the reference case; successfully deploying these technologies would require not only consideration of the barriers and opportunities to investment listed above, but also the other types of barriers and opportunities that may both factor into an investment decision and affect the success on an investment. Intensity of barriers may differ from region to region. For instance, many developing country players, in particular SMEs, face uncertainty and in particular lack of information to access mitigation technologies.

Table 10.9 summarizes barriers and opportunities of these types for some of the major greenhouse gas emission reduction options for industry discussed in this chapter.

10.9.1 Manufacturing and extractive industries

10.9.1.1 Energy efficiency for reducing energy requirements

Even though energy costs often form a significant fraction of overall costs in industry, a number of issues limit the extent to which the industrial sector takes steps to minimize its energy use via energy efficiency measures. These barriers include: failure to recognize the positive impact of energy efficiency on profitability; short investment payback thresholds; limited access to capital; impact of non-energy policies on energy efficiency; public acceptance of unconventional manufacturing processes; and a wide range of market failures (IEA 2009a). Schleich and Gruber (2008), however, find that energy-intensive industries - such as iron and steel, and mineral processing – are quite aware of potential cost savings from investing in energy efficiency, which is automatically considered in investment decisions. In contrast, they find that in the commercial and service sectors, the energy cost share is usually low and for smaller companies overhead costs for energy management and training personnel can be prohibitive. In many cases the importance of barriers depend on specific circumstances. By surveying the Swedish foundry industry, (Rohdin et al. 2007) compiled barriers reported access to capital as the largest barrier, followed by technical risk and other barriers. Foundries that were group-owned were found to have strict investment criteria – e.g. 1-3 year pay-off for investments – whereas private companies reported that they do not use any formal investment criteria. Cogeneration or combined heat and power (CHP) systems is a specific form of energy efficiency option and has found success in heavy industry not only as a mean for the reduction of GHG emissions by improving system energy efficiency but in reducing system cost and enhanced independence (accounting for decreased power demand from the grid) in many cases. For industry, however, the IEA (IEA 2009a) finds that CHP faces a complex set of economic, regulatory, social and political barriers that restrain its wider use including: market restriction securing a fair market value for electricity exported to the grid; high upfront costs compared to large power plants; difficulty concentrating suitable heat loads and lack of integrated planning; grid access; non-transparent and technically demanding interconnection procedures; lack of consumer and policymaker knowledge about CHP energy, cost and emission savings; and industry perceptions that CHP is an investment outside their core business. Examples of severe barriers include emission limits beyond those of GHG emissions (e.g. the US Clean Air Act), unfavourable tax rates and feed-in tariffs, and utility law and regulatory provisions that limit competition affecting permitting to build a CHP facility. For a cogeneration project (often applied to an existing facility), the resulting electricity price paid to a cogeneration facility is the most important variable in determining the project's success – more so than capital costs, operating and maintenance cost and even fuel costs (Meidel, 2005). Prices are affected by rules for electricity markets, which differ from region to region, can form either incentives or barriers for cogeneration. A fair predictable price for cogeneration electricity can be a key enabler of cogeneration projects (Meidel 2005).

10.9.1.2 Emissions efficiency, fuel switching and carbon capture and storage

Emissions efficiency can be improved by changing fuels and feedstocks to industry. The Fourth Assessment Report (Bernstein et al. 2007) focused its consideration of industrial fuel switching to switches within fossil fuels, and concluded that such switches remain applicable today, even if the motivation for fuel switching is not always only related to GHG reduction rationales (Burtraw et al 2011). Cost-related co-benefits relating to fuel switching and changes in feedstock use patterns have become increasingly important.

There are a number of challenges associated with feedstock and energy substitution in industry. Waste materials and biomass as fuel and feedstock substitutes are limited by their availability, hence competition could drive up prices and make industrial applications less attractive (IEA 2009c). Moreover, while a decarbonised power sector will offer new opportunities to reduce CO_2 intensity of some industrial processes, the lack of a stable carbon price and effective global emissions system remains a barrier for making this transition (Bassi et al. 2009; IEA 2009c).

The application of CO_2 capture and storage to the industries covered in this chapter share many of the barriers to its application to power generation. These barriers (IEA 2009c) include the lack of technology development and maturity (GAO 2010), public acceptance (Johnsson et al. 2009), lack of CO_2 pipeline infrastructure, regulatory and permitting uncertainties (IEA 2007), space constraints when applied in retrofit situations (CONCAWE 2011), high capital costs and long project development times, investment risk associated with poorly defined liability, and generally the current lack of financial incentives to offset the additional cost of CCS (Kheshgi et al. 2012): see table 10.9. These barriers are further aggravated because of limited technology research on CO_2 capture from cement production, iron and steel industries, and the petrochemical industry, and the trade-exposed nature of these industries which can limit viable CCS business models.

10.9.1.3 Material efficiency

Material efficiency entails providing material services with less material throughput in production and processing. Improvements can either be made by reducing the amount of the material contained in the final product or by reducing the amount of material that enters the production process. A waste hierarchy of "reduce, re-use, recycle" is a growing model across various countries including the UK, and has now been adopted in China under the banner of 'Circular Economy' (Yuan et al., 2006). There are a wide range of opportunities to be harnessed from implementing material efficiency options, including the reduction in production costs, reduction in the demands for raw materials, and decreased amount of waste material going into the landfill, and emergence of new business opportunities related to material efficiency (Allwood et al., 2011; Clift, 2006, Clift and Wright, 2000). Research has demonstrated that aluminium can be recycled as often as necessary with minimal loss in quality whereby about 96% of the original material of aluminium can be recycled after use, requiring only 5% of the energy of primary aluminium production (Warsen, 2009; Frees, 2008). While there are clear opportunities in the technical feasibility of material efficiency options, their commercial deployment so far remains at a small scale. Barriers to a circular economy which is a growing model across various countries and aims systematically for the fulfilment of the hierarchy principles of material efficiency "reduce, re-use, recycle", however, include lack of human and institutional capacities to encourage management decisions and public participation (Geng and Doberstein 2008), and fragmented and weak institutions (Geng et al. 2010).

10.9.1.4 Product demand reduction

Three main categories of barriers (Allwood et al. 2011) specific for demand reduction for products and demand management are relevant: economic, regulatory and social barriers. Business models in production companies are locked into maintaining or growing sales volumes, and therefore motivated to increase product replacement rates rather than engaging in material efficiency improvements which require upfront cost and potentially longer payback period. In connection with this, existing regulatory and legal instruments do not take into sufficient account of externalities and therefore not captured by prices. Social barriers also pose an obstacle in that the social logic of consumerism locks people into status symbols, materialistic lifestyles (creating a growing energy intensive product demand) as the basis for participating in the life of society, and national accounting systems based on GDP indicator also support the pursuit of actions and policies that aim to increase demand spending for more products (Roy and Pal 2009, Jackson 2011) and use and throw lifestyle has grown into a social norm. Eventually, uncertainty aspects related to the overall balance of specific material demand reduction measures play a role. From a system efficiency point of view, extending lifetimes of products where technologies are improving would imply the extended use of products of poorer performance and potentially poorer energy efficiency which may offset advantages of avoiding replacement.

10.9.1.5 Non-CO_2 greenhouse gases

Barriers to preventing or avoiding the release of HFCs, CFCs, HCFCs, PFC, SF6 in industry and from its products (IPCC/TEAP 2005) include for instance: lack of certification and control of leakage of HFCs from refrigeration (Heijnes et al. 1999); cost of recycled HFCs in markets where there is direct competition from newly produced HFCs (Heijnes et al. 1999); lack of awareness (e.g., that Production of PV, Flat screen TV can increase NON CO2 emissions), lack of information and communication and education about solvent replacements (Heijnes et al. 1999); (IPCC/TEAP 2005); cost of adaptation of existing aluminium production for PFC emission reduction and the absence of lower cost technologies in such situations (Heijnes et al. 1999); cost incineration of HFCs emitted in HCFC production (Heijnes et al. 1999); regulatory barriers to alternatives to some HFC use in aerosols (IPCC/TEAP 2005).

10.9.2 Services (with special reference to tourism)

[Author Note: A short paragraph dealing more in general with barriers with regard to service sector will be included here in SOD]

In the field of tourism which serves as an illustrative example for the services sector mitigation first faces a general lack of sensitivity and awareness of

- stakeholders for whom it is far from being an important concern (Becken and Hay 2007);
- tourists who generally are not aware of the emissions neither for transport nor for accommodation and activities, and are attracted by the behaviour of a minority of hypermobile tourists (Gössling et al. 2009) ;
- governments who pursue contradicting objectives, developing aviation and long haul tourism markets while they seek to reduce emissions (OECD and UNEP 2011).

These factors tend to increase the lock-in of tourism to the most emitting modes of transport at the expense of the development of rail infrastructure (Peeters et al. 2006). Should large-scale mitigation emerge, it would surely be confronted with financial barriers (high investment in infrastructure and facilities) particularly in developing countries (Becken 2005).

Table 10.9: Barriers (-) and opportunities (+) for greenhouse gas emission reduction options in industry. References and discussion appear in respective sub-sections of 10.9.1.

	Energy Efficiency	Cogeneration	Emissions Efficiency	Material Efficiency	Product Demand Reduction	Non-CO_2 GHGs	CO_2 Capture, Utilization and Storage
Technological Aspects: Technology	+ many options available - technical risk	+ mature in heavy industry - non-transparent and technically demanding interconnection procedures	+ fuels and technologies readily available - retrofit challenges	+ several options available - technology 'lock-in' in conventional supply side technologies	- slower technology turnover can slow technology performance improvement	+ approaches and technologies available - lower cost technology for PFC emission reduction in existing aluminium production plants	+ large potential scope for cement production, iron and steel, and petrochemicals - lack of technology development, demonstration and maturity for industry applications
Technological Aspects: Physical	+ less energy and fuel use, lower cooling needs, smaller size	- concentrating suitable heat loads - retrofit constraints	- lack of sufficient feedstock to meet demand	- retrofit constraints + reduction in waste materials	+ reduction in disposed products		- retrofit constraints - lack of CO_2 pipeline infrastructure - limited scope and lifetime for industrial CO_2 utilization
Institutional and Legal	- lack of trained personnel - impact of non-energy policies - market barriers	- regulatory (e.g. US Clean Air Act) - taxes and feed-in tariffs - permitting +/- grid access	- regulatory constraints in fuel and carbon prices	- fragmented and weak institutions	- regulatory and legal instruments do not take into sufficient account of externalities	- certification and control of leakage in refrigeration systems - regulatory barriers to HFC alternatives in aerosols	- regulatory and permitting uncertainty
Cultural	+/- attention to energy efficiency - lack of acceptance of unconventional manufacturing processes	- outside core business - lack of consumer and policymaker knowledge	- social acceptability of incineration	+/- public participation	- materialist lifestyles that limit behaviour change	- lack of information/education about solvent replacements	- public acceptance
Financial	- access to capital - high overhead costs for small or less energy intensive industries +/- factoring in efficiency into investment decisions (e.g. energy management) - short investment payback	+ economic in many cases +/- fair market value for grid power? - higher upfront cost than large power plant	- access to capital investment	- upfront cost and potentially longer payback period	- business models locked in increasing volume sales	- recycled HFCs not cost competitive with new HFCs - cost of HFC incineration - cost of PFC emission reduction for existing aluminium plants	- lack of financial incentive - liability risk - high capital cost and long project development times

10.10 Sectoral policies

This section discusses the range of policies available to foster the widespread implementation of the mitigation options in industry sector and to overcome sector specific barriers. It concentrates on sector specific policies while chapter 15 in particular, but also chapters 14 and 16, additionally analyze the impact of policies relevant to industry, such as voluntary agreements and emissions trading. The discussion in this section follows the elements of figure 10.1 to describe and evaluate policy options towards mitigation in industry. National circumstances are varied and diverse combination of market mechanisms, regulatory approaches, voluntary schemes and information dissemination are in practice.

10.10.1 Energy efficiency

The use of energy efficiency policy in industry has increased appreciably since the late 1990s as (Tanaka 2011) showed for IEA countries and five major developing countries (cf. Figure 10.10).

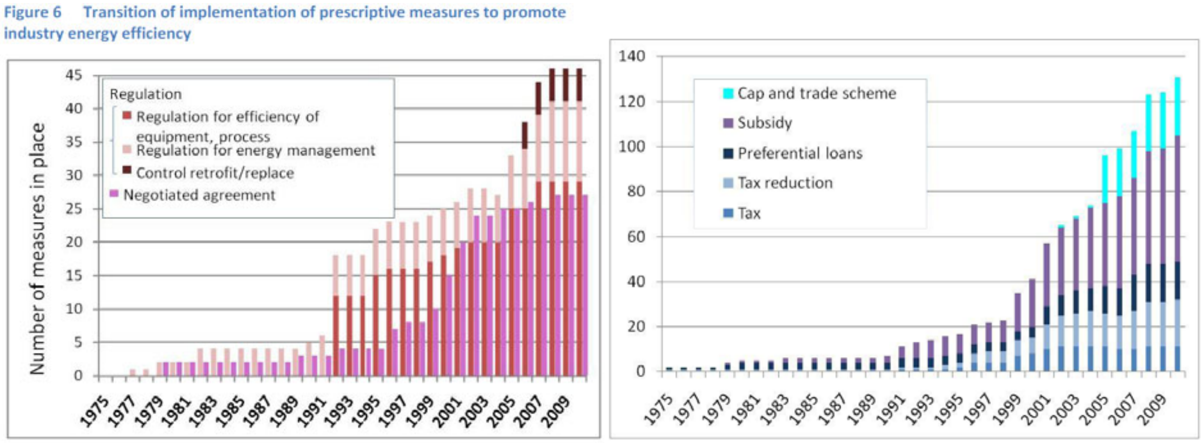


Figure 10.10. Trend in growth of implemented economic and prescriptive measures to promote energy efficiency.

So far only a few national governments evaluated their industry-specific policy mixes (Reinaud and Goldberg 2011). For the UK (Barker et al. 2007) estimate that from 2000 to 2010 the UK Climate Change Agreements would have resulted in a reduction of total final demand for energy of 2.6%.

Voluntary agreements (VA) have been found in various assessments to be effective and cost-efficient (Barker et al. 2007). VA programs (Ireland, France, The Netherlands, Denmark, and the UK), were often responsible for increasing the adoption of energy-efficiency and GHG mitigation technologies by industries beyond what would have been otherwise adopted without the programs (Rezessy and Bertoldi 2011). Some key factors contributing to successful VAs appear to be a strong institutional framework; a robust and independent monitoring and evaluation system; credible mechanisms for dealing with non-compliance; capacity-building and, very importantly, accompanying measures such as free or subsidized energy audits, mandatory energy management plans, technical assistance, information and financing for implementation (Price et al. 2010) as well as dialogue between industry and government (Yamaguchi 2012).

As an example of a voluntary programme, the learning networks in Germany are an instrument designed to lower transaction costs of investment decisions for energy efficiency for industry. The programme sees the companies of each network agreeing on a common target for energy-efficiency improvements, and meeting regularly for exchange of experiences. Each company receives an initial consultation from an experienced engineer, regular follow-ups and monitoring of energy consumption and CO_2 emissions, among other things. Companies in Germany's Bundesland Baden-Württemberg participating in such networks could realize significant net energy cost reductions and a carbon intensity reduction of 2.5% per year, brought about mainly by increases in electrical efficiency (Rezessy and Bertoldi 2011).

Cap-and-trade schemes to reduce GHG emissions and enhance energy efficiency in energy-intensive industry have been in place in the last decade. The largest scheme by far is the European Emissions Trading Scheme (ETS). The impact that the first phase of the EU's trading scheme has had on abatement within the EU reflecting the more experimental status of the regime must be evaluated with caution. An estimate by (Jochem and Gruber 2007) for a highly industrial country such as Germany is of 6.3 % of emissions reduced in the three years of the trial period (2005-2008).

With regard to carbon leakage which was expected to emerge after implementing a regional ETS two ex post studies on the competitiveness impact of the EU ETS find no impact of the spot CO_2 price on net imports (i.e. import-export balance) of cement, steel and aluminium ((Ellerman et al. 2010 p. 174) and (Reinaud 2008)). Despite this, in the revised EU ETS directive, for the majority of the industries (accounting for three fourths of emissions) (Ellerman et al. 2010) special provisions have been taken to mitigate carbon leakage concerns, such as free allowances. A simulation of two main solutions put forward (border tax adjustments and output-based allocation) (Clò 2010) indicate that even without specific policies the leakage effect could be minor, although there are important variations among sectors.

Some assessment of the future efficiency of carbon pricing in the field of tourism (air travel) which serves here as an illustrative example for the service sector has been made, based either on current carbon prices (e.g.(Monjon and Quirion 2011)) or projected future prices (Peeters and Dubois 2010; Veryard 2009). The conclusion is that carbon prices are not sufficient to have a significant effect on tourism flows and related emissions (Gössling et al. 2008; Pentelow and Scott 2009; Tol 2007), and that even with much higher prices the effect would be limited (Dubois et al. 2010; Peeters and Dubois 2010). Thus, institutions like OECD and UNEP consequently are calling for other instruments to limit emissions (e.g. regulations) (Dubois et al. 2010; Peeters and Dubois 2010).

With regards to target-driven policies, one of the key initiatives for realizing the energy intensity goals in China was the Top-1000 Energy-Consuming Enterprises program. It required the establishment of energy use reporting systems and energy conservation plans, adoption of incentives and investments, and conduction of audits and training, among others. The program surpassed its programmatic savings goal of saving 100 million tons of coal equivalent (Mtce) by 50%, resulting in avoided CO_2 emissions of approximately 400 $MtCO_2$ (Dubois et al. 2010; Peeters and Dubois 2010).

The adoption of Energy Management Systems in industry may be mandatory, as in the UK, Netherlands, Japan, Italy, Canada, Turkey, Portugal and France, or voluntary in such countries like Denmark, Germany, Ireland (Lin et al. 2011; NDRC 2011b; Price et al. 2011). Often just the identification of energy saving potential is enough to bring about change within a company. The effectiveness and cost of 22 audit programmes in 15 countries has been reviewed by (Lin et al. 2011; NDRC 2011b; Price et al. 2011), who give recommendations on the success factors (e.g. use of public databases for additional benchmarking, use of incentives for participation in audits).

In addition to dedicated GHG mitigation policies co-benefits of other policies should be considered. Local air quality standards have an indirect effect on GHG mitigation. Given the priorities of many governments these indirect policies have played a relatively more effective role than climate policies (e.g. in India (Price and Lu 2011a)).

10.10.2 Emissions efficiency

The policies directed at increasing energy efficiency (see section above) most often result in reduction of greenhouse gas emissions intensity as well, in particular when part of a wider policy mix addressing multiple policy objectives. Examples for emissions efficiency policy strategies include support schemes and fiscal incentives for fuel switching, inclusion of reduction of non-CO_2 gases in voluntary agreements (e.g. Japanese voluntary action plan Keidanren, cf. Chapter 15, p. 18) or market mechanism (Bureau of energy Efficiency led REC, EsCert market for Indian industries, (Roy 2010).

At the moment none of the existing cap-and-trade systems include gases with relatively high Global Warming Potential (GWP) such as HFCs, PFCs, and SF_6. Including them within the same cap and trade programme (and therefore prices) as energy-related emissions may draw opposition from the industries concerned, but having a special programme for these gases could result in a more costly policy (Roy 2010). Another option would be to charge an upfront fee that would then be refunded when the gases are later captured and destroyed (Hall 2007). The CDM has been a major driver for abatement of the industrial gases HFC-23 and N_2O in developing countries; these abatement options had been ignored before the CDM provided monetary incentives (Michaelowa and Buen 2012).

Mining represents the largest share of GHG emissions in Australia. For this reason the country's low carbon policy includes provisions to support the coal mining industry to implement technologies for capture of fugitive emissions (Hall 2007). Specific measures to capture coal bed methane for power generation in India is another example. In its exploration of potential policy options for the US, (Höhne et al. 2012) describes and evaluates following mechanism: a) including all emissions from mining in the cap and trade system, (b) setting up a programme by which mine operators could offset emissions on a project basis and (c) a hybrid approach, in which emissions from underground mines are directly included in the cap, while emissions from surface, or abandoned mines, or from fugitive sources, would be addressed through and offsets programme.

For Carbon Capture and Sequestration (CCS) besides the general lack of a suitable legal framework in most world regions (von Hirschhausen et al. 2012) and an ongoing discussion of the inclusion of CCS in the CDM in particular RD&D policies are of specific importance for industrial applications.

10.10.3 Material efficiency and reducing demand for products

A number of policy packages are directly and indirectly aimed at reducing demand for products and services, products needed per unit of service, or material input per unit of product. Examples are: European Action Plan on Sustainable Consumption and Production (SCP) and Sustainable Industry (Hall 2007), EU's resource efficiency strategy and roadmap (EC 2008) and Germany's resource efficiency programme, ProgRess (EC 2011a, 2012). SCP policies include both voluntary and regulatory instruments, such as the Eco-design directive, as well as the Green Public Procurement policies. Aside from setting a framework and long-term goals for future legislation and setting up networks and knowledge bases, these packages include few specific policies and, most importantly, do neither set quantitative targets nor explicitly address the link between material efficiency and greenhouse gas emission reductions. Australia's Low Carbon Policy Package does address material efficiency specifically by setting an objective of 0.5 % additional material efficiency improvement per year, although according to (EC 2011a, 2012) it has no specific policies in place to do so yet.

In Asia and the Pacific there are a number of region-specific policy instruments for climate change mitigation through SCP, such as the China Refrigerator Project which realized savings of about 11 million tonnes of CO2 emissions between 1999 and 2005 by combining several practices including sustainable product design, technological innovation, eco-labelling, and awareness raising of consumers and retailers (SWITCH-Asia Network Facility 2009). However, there is still a lack of solid ex-post assessments on SCP policy impacts.

Policy instruments for resource use efficiency are increasingly being promoted for mitigation of GHG emissions in industry (GTZ et al. 2006) but there is a need to communicate effectively to industry on the need and potential for an integrated approach (Höhne et al. 2012). Possible examples are taxes on non-renewable materials or incentives to product-service systems, such as chemical leasing.

Besides industry-specific policies there are policies with a different sector focus that influence industrial activity indirectly, by reducing need for products (e.g. car pooling incentive schemes can lead to the production of less cars) or industrial materials (e.g. vehicle fuel economy targets can incentivize the design of lighter vehicles).

10.10.4 Specific policies for the services sector

Compared to manufacturing firms, most firms in the service sector face substantially lower energy costs as a share of their revenue and many firms are SMEs. Such firms allocate fewer resources to improving energy efficiency, resulting – among others – in a low level of information about the availability of energy-efficiency improvements and fewer staff dedicated to energy efficiency (Lettenmeier et al. 2009). Energy audits help to overcome such barriers (Gruber and Brand 1991) and have been established in a number of countries worldwide (Schleich 2004). The audits induce highly cost-efficient measures with an average payback period ranging from one to six years (Price and Lu 2011b). External energy audits are also regularly combined with voluntary agreements or energy management schemes and can also be useful in energy-intensive manufacturing firms (Fleiter et al. 2012). Audits, are, however, only one example for the possible policies. There are not many policies particular dedicated to the service sector. Most policies are overlapping either with buildings (e.g. efficiency standards for office buildings or electrical appliances), households or manufacturing industry and will be discussed in the specific chapters (cf. chapters 8 and 9).

As an example for the services sector for tourism an OECD review of national tourism-related policies (Anderson and Newell 2004; Price and Lu 2011b; Stenqvist and Nilsson 2012) found that only one third of countries have identified tourism-related mitigation options. Policies may vary according the forms of tourism (reduction in long haul travel (OECD and UNEP 2011)), the place of tourism, or the uses of leisure time (Dubois and Ceron 2006; Dubois et al. 2010).

10.11 Sectoral implications of transformation pathways and sustainable development

Technology specific discussion of mitigation options in industry and services sector in section 10.4 has shown the variety of options for future actions. This section provides a long term vision of how the whole sector or specific industrial branches are expected to emerge under various assumptions on system transition. The analysis is based on results of the integrated assessment models used in chapter 6 and complemented by the discussion of more bottom-up technology-focused projections of industry's long-term mitigation. Scenarios describing potential long-term future pathways are also systematically discussed in terms of implications for sustainable development, corresponding investment needs, the role of different technologies and strategies and other aspects.

10.11.1 Long-term Transformation Pathways for industry from the perspective of integrated assessment models

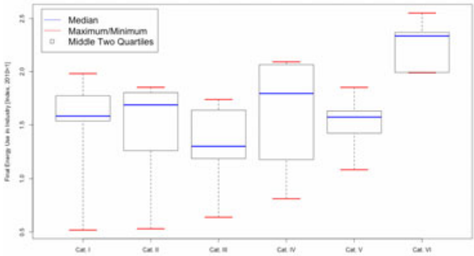
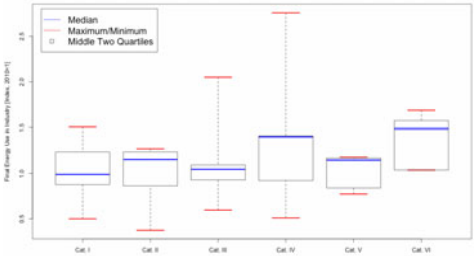
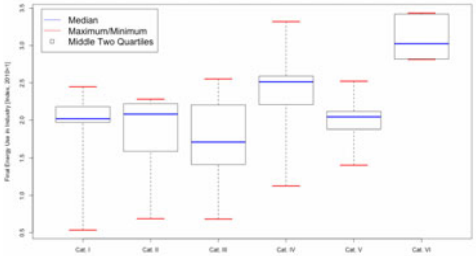
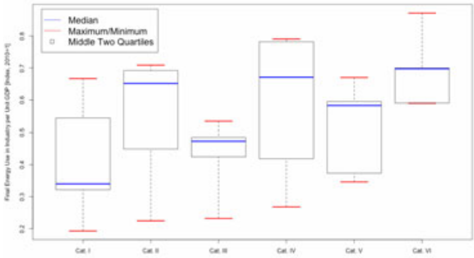
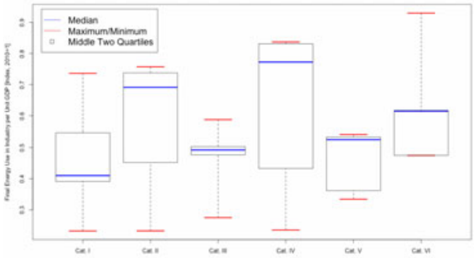
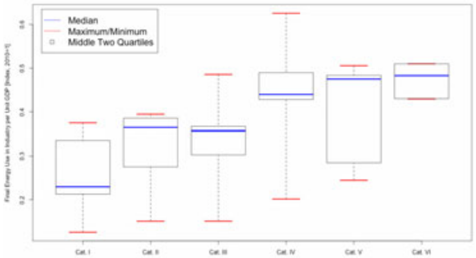
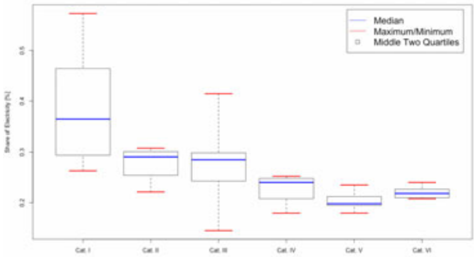
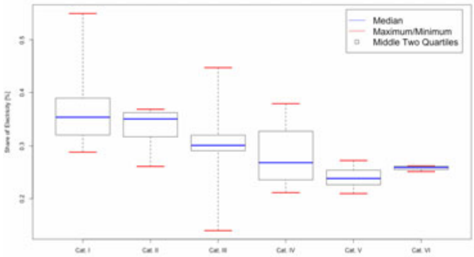
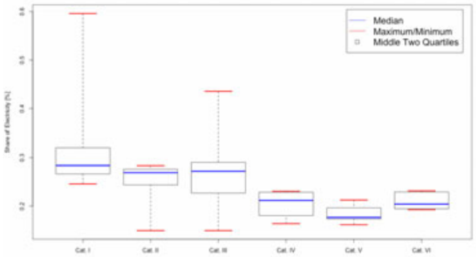
[Results available for the industry sector by the time of FOD submission are on a relatively aggregate level, showing ranges for three indicators, for two reference years (2030 and 2050), of which only 2050 is shown here. Subsequent versions are expected to provide more detailed indicators as well as additional information such as contribution of industry sector to overall mitigation target]

(Dubois and Ceron 2006; Dubois et al. 2010) shows results for the year 2050 for different climate stabilization categories based on long-term transformation pathways analysis based on a large number of possible scenarios for the industry sector on three key indicators of industry activity: final energy use in industry (105 scenarios), energy intensity (52 scenarios) and share of electricity (63 scenarios). Due to a diverging disaggregation level for the industry sector of the models surveyed in chapter 6 results in the table derived from a different number of scenarios.

While detailed analysis is pending some important aspects can already been derived for the scenario survey. [In terms of industry specific data the integrated scenario model results are on a relatively aggregated level. From FOD to SOD a stronger iteration process between chapter 6 and the sector chapter will help to further elaborate the scenario comparison, additionally more scenarios will be used in SOD.] The majority of existing scenarios expect an further increase in final energy demand in industry. In the longer run electricity share in industrial final energy is expected to increase with higher mitigation ambitions. While there is in general a trend for more intensive use of electrical appliances already under Business as Usual conditions, as often associated with energy efficiency gains substitution of fossil fuel use in industry by electricity applications play a even greater role if ambitious mitigation targets are pursued. In the case of final energy and particularly energy intensity the relationship is less clear. As there is a general trend of decreasing final energy demand and energy intensity with growing mitigation ambitions, ranges of the scenario results are significantly overlapping. The degree to which energy intensity will vary with mitigation effort will depend on the effect that climate policy has on energy prices and the price elasticity of final energy demand. Different models show different price responses to climate policy. The effect of climate policy on energy prices is very dependent on the model assumptions about technology cost and availability (including the relative competitiveness of energy efficient technologies and production routes). And models differ in the effect that changing prices has on both energy service demand. [There are models that would show stronger reductions in energy use and energy intensity, but these are not included in the database so far, discussion of those models will be added in SOD.]

[Caveats: It is important to note that scenario results and the specific role of a sector heavily depends on scenario assumptions and model architecture. No results for services or tourism sector are currently available. Moreover from FOD to SOD the number of scenarios examined in chapter 6 will be increased to display the full set of possible future pathways for the industry sector.]

Table 10.10: Key indicators for Industry, from Chapter 6 Transformation Pathways scenarios, in 2050 *[Reference year 2030 also available but not shown]*

	World	Group A	Group B
Final Energy Use in Industry			
Energy intensity (final energy per unit of GDP)			
Share of electricity in Industrial final energy			

Categories I to VI denote mitigation scenario categories consistent with RCPs (I most ambitious, VI least ambitious)
For FE and energy intensity, results are relative to 2010.
Group A = OECD90 + REF
Group B = ASIA + MAF + LAM

10.11.2 In-depth analysis for industry sector from a bottom up scenario perspective

[The aim of this sub-section for the SOD is to give a more detailed view of the long-term transformation pathways by means of a number of scenario “deep dives”, as well as to provide where possible an additional bottom-up perspective to the IAM. In the FOD with IEA Energy Technology Perspective 2012 chiefly one additional study could be covered in more detail as discussions with Chapter 6 on deep-dive are still underway. The models that contain industry-specific information and are hence being considered for the deep-dive in SOD are GCAM, MESSAGE, and IMACLIM]

The aim of this sub-section is to complement the above top-down IAM assessment based perspective with the insights from studies that provide more detailed information on long-term future for industry. For this purpose in SOD from the sample of scenarios described before a set of illustrative examples will be selected and complemented by additional more technology focussed projections not being dealt with in chapter 6. For FOD, due to so far limited data availability, focus is currently limited to IEA’s latest projections for the sector (IEA 2012) and a few selected other studies. [For the SOD this sub-section would consider a wider range of studies.]

The IEA Energy technology Perspective (ETP) study (IEA 2012) assumes that industrial production will significantly increase in many regions of the world to satisfy growing demand in the next 40 years, particularly in Non-OECD regions (excluding China, were material demand is expected to flatten). For some materials demand is likely to double by 2050 or in some regions even to triple (e.g. cement in India) while in other regions only modest demand increase can be expected (e.g. OECD) or even demand on specific materials is expected to flatten (e.g. cement in China). In its baseline scenario 6DS (6 degree scenario) describing a development which can be expected if only energy and climate policies and measures are taken into account that have been already implemented IEA foresees CO_2 emissions to grow in comparison to the current situation by between 45 and 65% (the range is a result of different demand scenarios reflecting the uncertainty about the projection of long-term growth in consumption). Besides autonomous energy efficiency increases, in the 6DS no major shifts in technology or energy consumption behaviour is expected. In contrast, in the 2DS (2-degree scenario) exploring a potential pathway to halve global CO2 emissions by 2050 . Based on the assumptions and driven by the mitigation target in the 2DS final energy demand in the industry sector is significantly lower than in the 6DS, but still exceeds the current level clearly (42 to 48%). CO2 emissions in industry in 2DS fall by 20% from 2009 levels, mainly by deploying existing Best Available Technologies (BAT), by improving production techniques, increasing energy efficiency, fuel and feedstock switching for almost all direct sources of emissions, material recycling, energy recovery and CCS. In particular CCS is considered a critical option in the 2DS, responsible for 24-30% of the abatement potential, China alone accounting for 21% of the global CO_2 captured. Importantly, in the 2DS industrial applications of CCS are equally important as application of CCS to power generation at the global level and, in some regions (e.g. India), industrial applications of CCS are far more important than those in power generation.

In the 2DS scenario industrial emissions peak in the coming decade. Moreover the report highlights an urgent need to avoid lock-in: plants that will be built or refurbished over the next ten years will account for 30% of the overall industrial production in 2020, and 10% in 2050.

Selected industry specific results of the IEA ETP study (IEA 2012) are shown in Table 10.11 (global), Table 10.12 (OECD Europe, low demand growth)) and Table 10.13 (India, high demand growth). Here, a systematic comparison of three ETP scenarios takes place, including the 4DS (4-degree scenario) describing a pathway which tries to limit the rise in global average temperature to 4°C by 2050. Note: For industry IEA ETP only covers CO_2 emissions, other GHG gases are not discussed.

Table 10.11: Global final energy demand in industry by energy carrier, industry emissions and additional investment needs (IEA 2012)

World	**2010**	**2050 low demand**			**2050 high demand**		
		6DS	4DS	2DS	6DS	4DS	2DS
CO2 emissions for industry [$GtCO_2$]	7.9	12.2	10	6.7	13.7	10.9	6.8
Additional investment needs[1] [trillion USD]				2			2.5
Final energy demand [EJ]							
Coal	41	56	49	38	64	56	42
Oil	29	52	49	40	60	51	34
Natural Gas	25	53	47	38	57	49	40
Electricity	26	62	54	46	67	57	50
Heat	5	6	5	6	6	5	5
Biomass, waste & other renewables	8	16	18	23	18	21	29
Total	134	245	222	191	272	239	200

[1] only for 5 sectors: steel, cement, Chemicals and Petrochemicals, Aluminium and pulp and paper (in comparison to 6DS scenario)

Table 10.12: Final energy demand in industry in OECD Europe by energy carrier [EJ] (IEA 2012)

OECD Europe	**2010**	**2050 low demand**			**2050 high demand**		
		6DS	4DS	2DS	6DS	4DS	2DS
Final energy demand [EJ]							
Coal	2.6	2.3	2.1	1.6	2.4	2.2	1.6
Oil	4.0	3.5	3.2	2.7	3.7	3.0	2.1
Natural Gas	4.3	4.9	4.6	3.3	5.1	4.7	2.9
Electricity	4.3	5.5	5.1	4.4	5.8	5.4	4.1
Heat	0.7	0.8	0.7	0.8	0.7	0.7	0.5
Biomass, waste & other renewables	1.0	1.8	2.0	2.4	2.0	2.2	2.4
Total	16,9	18,8	17,7	15,2	19,7	18,2	13,6

Table 10.13: Final energy demand in industry in India by energy carrier [EJ] (IEA 2012)

India	**2010**	**2050 low demand**			**2050 high demand**		
		6DS	4DS	2DS	6DS	4DS	2DS
Final energy demand [EJ]							
Coal	2.5	9.7	8.7	6.8	12.0	11.0	8.7
Oil	1.6	3.8	3.6	3.0	5.5	4.9	3.1
Natural Gas	0.5	1.3	1.3	1.4	1.5	1.5	1.9
Electricity	1.2	5.3	5.2	4.6	6.1	5.8	4.7
Heat	0.0	0.0	0.0	0.2	0.0	0.0	0.2
Biomass, waste & other renewables	1.2	1.9	2.1	2.6	2.4	2.6	3.3
Total	7	22	20,9	18,6	27,5	25,8	21,9

Based on the assumptions and driven by the mitigation target in the 2DS final energy demand in the industry sector is significantly lower than in the 6DS, but still exceeds the current level clearly (42 to 48%). Nonetheless, the 2DS shows an ongoing decoupling of energy consumption and materials production. Electricity, natural gas and biomass in absolute and relative terms increase their contributions to final energy sector demand, while oil and coal demand stay at the current level. CO2 emissions in industry sector result in 2050 at a between 6.7 and 6.8 Gt CO_2 (cf. 7.9 Gt CO2 in 2010) which is by 45% to 50% lower in the 2DS than the corresponding level in the 6DS, with all sub-sectors and world regions contributing to the reduction. Many new technologies have to support such a future pathway, even those which are currently being developed, demonstrated and adopted (IEA 2012). As a consequence energy intensity and CO_2-intensity significantly decreases in all sub-sectors. For instance in the steel sector (cement sector) in the 2DS energy intensity in 2050 is about 35% (22 to 29%) lower and CO_2-intensity is 61% to 65% (47% to 52%) lower than the current levels. In the cement sector for instance the comparative higher reduction of CO_2-intensity is a result of alternative fuel use (e.g. waste) and application of CCS, with the latter one driven by the energy penalty of the CCS process even at least partly offsetting energy efficiency gains.

Besides the IEA's ETP a broad range of technology triggered possible futures for the industry sector are also projected by various studies. For example:

- Given that demand for a set of materials (production of goods in steel, cement, plastic, paper and aluminium) doubles as expected, GHG emissions can only be reduced by 50% compared to a selected baseline assuming that no additional climate policy measures will be implemented if there is a proactive strategy to reduce primary material demand (Allwood et al. 2010a). The mitigation is expected to come through efficient design, non-destructive use of components or materials or material substitution.
- For the steel industry an expected reduction of 80% CO2 in comparison to a reference case seems to be possible with CCS but not before 2025 (Allwood et al. 2010a). For the paper and pulp production over 90% of CO2 reduction is outlined in context with black liquor gasification with CCS (2015-2020: market deployment).
- The EU Low Carbon Economy Road Map (Croezen and Korteland 2010) of the EU Commission discusses a scenario for the European industry achieving a more than 80% GHG reduction by 2050 in Europe. This scenario comprises amongst others the following results:
    - Application of more advanced resource (material) and energy efficient industrial processes and equipment (incl. recycling) could make a major contribution and allow industry sectors to reduce GHG by half or more
    - In addition to efficiency increase, Carbon Capture and Storage (CCS) is used as an option in some areas (e.g. cement and steel sector)
    - Selected measures have to be seen and judged in the line of the global competitiveness of the branches, carbon leakage should be avoided (impacts of measures have to be systematically monitored)

[For SOD when including more illustrative scenarios further discussion will focus on the questions how do the long term mitigation potentials compare and what are the corresponding strategies and under what conditions could these pathways be realised.]

For the services sector integrated assessment models in general do not deliver specific scenario data. Thus, the following discussion related to the service sector mainly focuses on bottom up studies and as done before on the illustrative example of tourism. Tourism is an example of a service sector where the discussion of transformation pathways is not only technological driven, but strongly correlated with the question of how certain levels of mitigation goals would imply for the activity level.

Several studies show that an unrestricted growth of tourism would by 2050 consume the whole carbon budget compatible with the +2°C guardrail (EC 2011b). A business as usual scenario (Bows et al. 2009; Scott et al. 2010) projects emissions to grow by 130% from 2005 to 2035, notably the emissions of air transport and accommodation triple. At world level compared to the business as usual projection, two scenarios, one reflecting technological potentials and the other behavioural potentials, have been built (UNWTO and UNEP 2008), as shown in (UNWTO and UNEP 2008)(UNWTO and UNEP 2008):

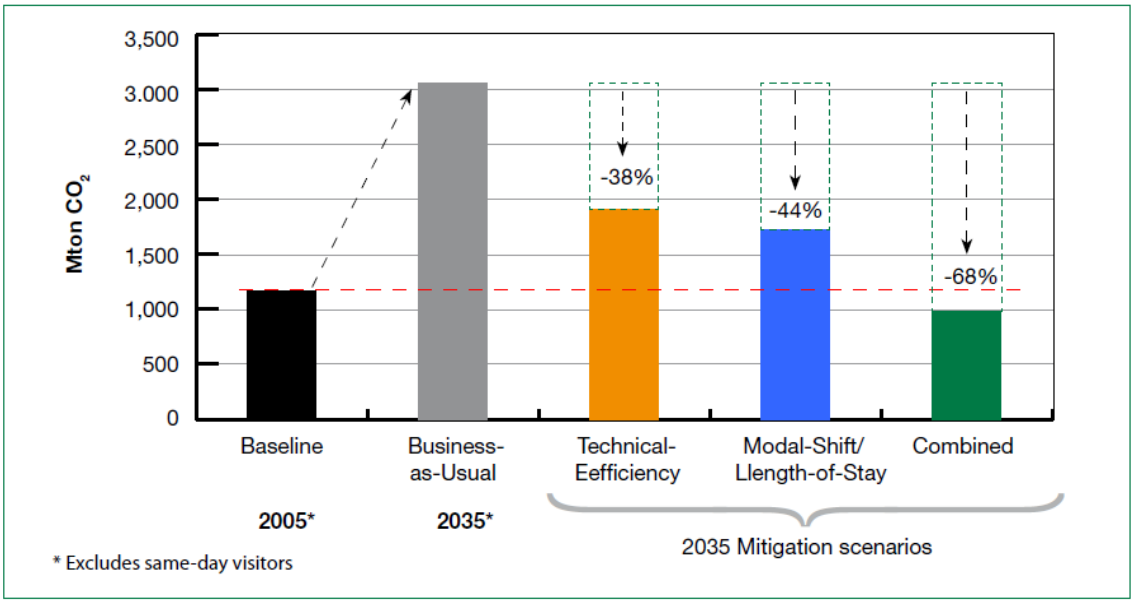


Figure 10.11. Scenarios of CO_2 mitigation potential from global tourism in 2035 (UNWTO and UNEP 2008)

These scenarios show both that the contribution of technology is limited in terms of achievable mitigation potentials and that even when combining technological and behavioural potentials CO2 emissions no significant reduction in 2035 compared to 2005 can be reached. Insufficient technological mitigation potential and the need for drastic changes in the forms of tourism (reduction in long haul travel (UNWTO and UNEP 2008)) and in the place of tourism and uses of leisure time, implying changes in lifestyles (Dubois and Ceron 2006; Dubois et al. 2010) are the limiting factors.

10.11.3 Discussion

This section combines the discussion on industry futures in terms of implications for a few sustainable development indicators: social aspects and employment, investment needs, the role of different strategies etc.. This discussion will help to get a better understanding about the implementation probability of the different future pathways from a industry specific perspective. [For SOD a more in depth discussion will take place.]

Sustainable development: Employment impulses (quantitative and qualitative) are an important example for sustainable development indicators. Climate change mitigation options for energy intensive industries vary widely depending on the choices of technologies and sectorial mitigation strategies that are employed. These options in turn may positively or negatively affect growth and jobs within these sectors. Identifying mitigation options that enhance positive effects (that is, on emissions reduction and on energy efficiency improvements) and minimize the negative outcomes (on jobs for example) is therefore critical.

Given that employment in high carbon intensive sectors including energy-intensive manufacturing industries such as metals, coke, mechanical wood and paper accounts for 38% or *circa* 600 million workers across the world (Dubois and Ceron 2006; Dubois et al. 2010), any changes in the energy supply structure is challenging. However, implementation of mitigation options in the sector can be done simultaneously by creating new employment opportunities if development and deployment of low carbon technologies as part of the so called green economy will be fostered.

Table 10.14 below is an overview of the potential of green jobs across different industries (UNEP 2008). The following representation is used: Yellow (Fair); Light Green (Good); Deep Green

(Excellent). It can be deduced from Table 10.14 that growing demand on green technologies could serve as a driver for job creation in several energy intensive industries.

Table 10.14: Green potential across industries

Industry	Greening Potential	Green Jobs: progress to date	Long term green jobs potential
Steel	🟩	🟧	🟧
Aluminium	🟩	🟧	🟧
Cement	🟧	🟧	🟧
Pulp and Paper	🟩	🟧	🟩
Recycling	■	🟩	■

[Author Note: discussion of employment effects will be extended if space constraints allow in SOD.]

The impact of climate change mitigation policies on employment in high carbon intensive sectors, was estimated by ILO (2009) for two different climate mitigation policies approaches and different scenarios based on a study in 9 countries (Australia, France, Germany, Hungary, Japan, Korea, Sweden, the United Kingdom and the US) after five years of implementation. Given that climate change mitigation policies in the form of energy or carbon taxes applied to high carbon intensive sectors are agued to have regressive effects on the economy (Timilsina 2009) and on employment (Chateau, Saint-Martin et al. 2011; Rahman 2011), the ILO study concluded that climate change mitigation policies can be a driver for job creation when the policies are combined with job support. Potentially, this can raise employment in developed countries by 2.6 million and 14.3 million for the whole world.

[Author Note: For SOD a broader set of SD indicators will be discussed.]

Investment needs: In the IEA's 2DS scenario (IEA 2012), the investment needs in the five most intensive sectors are estimated to be between USD 10.7 trillion and USD 12.5 trillion between 2010 and 2050. This represents USD 1.5 trillion to USD 2.0 trillion above the investments required by the 6DS and 4DS. Reflecting the demand growth relations the major part of the additional investments will be needed in the Non-OECD countries, from a sector perspective particularly steel industry and the chemical and petrochemical sector cause high investment needs. Despite additional investment needs for the application of for instance more efficient technologies those technologies lead on the time axis to significant cost savings (e.g. due to less fossil fuel consumption). Overall, the cumulative fuel savings in the 2DS compared to 6DS are estimated at 7.8 USD trillion for the 2010-2050 period (undiscounted; dependent from the selected discount rate this corresponds with a net saving of 5 to 6 USD trillion for the 2010-2050) and so far exceed the additional investment burden. However, additional investments are confronted with various barriers (cf. section 10.9).

Role of different strategies: Often the less technology-oriented options discussed in this chapter (cf. section 10.4) are not considered in integrated assessment models or bottom-up studies such as behaviour changes/sustainable consumption patterns (e.g. reduced activity due to extended product lifetime or more intensive use of products). The same holds true for not direct energy and GHG related options such as material efficiency. These options can come at low or even negative investment cost, although they face particularly high information barriers and transaction costs. Moreover there is uncertainty as to the possible macro-economic consequences of activity changes.

To continue GHG emissions reduction after 2050 considering further demand increase at least in some parts of the world besides technological and behavioural measures which are already necessary by the middle of the century additional promising technologies and strategies might be required that currently are in the R&D phase (e.g. low-carbon cements) and yet far away from commercialisation (IEA 2012). Following the ETP long-term projections notably the more intensive use of hydrogen could play an important role if an sufficient amount of low-cost and CO2-free hydrogen and electricity is available (e.g. crude steel production from electrolysis using hydrogen as reduction agent, production of iron via molten oxide electrolysis, hydrogen as feedstock for production of ammonia, methanol, ethylene and propylene) (IEA 2012).

10.12 Gaps in knowledge and data

The key challenge regarding the mitigation potential for the industry sector is the uncertainty, low quality and incompleteness of data on energy use that can serve as a basis for assessing performance and potential with high confidence. Sector data are generally collected by trade associations (international or national), highly aggregated, and generally gives little information about individual processes.

In addition to the shortage of data, a lack of clarity in its presentation leads to widely differing interpretations. In particular reported numbers may refer to final or primary energy, average or best practice, and if stated as emissions rather than energy figures, may fail to state the assumptions on which emissions were calculated. The emissions factors of different electricity sources cause particular confusion, as does the fact that the reported numbers will vary widely as the boundaries of their coverage may be quite different but unstated. Without government mandated release of data in standardised formats, this lack of clarity will persist.

Attribution of environmental impacts from the activities of industry where they occur to the products that the user use is an extremely difficult problem. Due to the variety in levels of integration: horizontal, vertical, cross border in industrial processes and the complexity of industrial processes as such (e.g. by-products), the use of familiar methodologies like LCA is also extremely limited. One possible solution might come from use of input-output analysis to avoid double counting but input-output data is absent/infrequent, highly aggregated.

Due to complex system boundary issues comparative assessments for industry processes are difficult. Process configuration and the degree of integration varies widely in a given industrial sector, so the comparison of monitoring data across companies or plants (Siitonen et al. 2010; Tanaka 2011), across nations. On the other hand, evaluation by process may not fully account for energy saving efforts over the whole mill (JISF 2012)"

Other gaps in knowledge identified to date during the creation of the specific sections include *(For SOD, list will continue to be updated and elaborated)*:

- in general data and information on developing countries are limited (across all sections)
- data on services sector and use of products (sections 10.2 and 10.3)
- embodied emissions in imports/exports: Understanding the complexities of the carbon flows from sector-to-sector and region-to-region, adopting standardized methodologies and protocols to account for these emissions (Wiedmann 2009) (10.3)
- gaining insight into to how trade can be used as a climate change mitigation option (UNEP and WTO 2009) and the impacts any adjustments in embodied emissions particularly in commodities of energy intensive industries have on national and international policies (IEA 2008) (10.3)
- additional research needed to allow for heat pump use at higher temperatures (10.4)
- mitigation options regarding material efficiency (10.4.1) and the mitigation potential of a link between resource efficiency/energy efficiency measures,
- specific data for SME related acitivities, corresponding energy consumption and mitigation potential (particularly for developing countries; including cooperation opportunities) (10.3, 10.4, 10.5)

- impact of climate change on industry, industry specific mitigation options and options for adaptation (10.6)
- systematic assessments of mitigation potential and corresponding costs on global and regional level (10.7)
- quantitative data on trade offs and co-benefits (10.8)
- impacts of climate change mitigation options on sustainability criteria including employment effects on a country basis (developed and developing countries) (10.11)
- better understanding of the net impacts of different types of mitigation options (industry sector specific and those of other sectors) on competitiveness and jobs in energy intensive industries (10.11) as well as related to carbon leakage effects (10.8). Carbon leakage causes an imbalance between countries in the emissions associated with production and those associated with consumption. Accounting for national or sectorial emissions can be undertaken from a consumption or production-based perspective (Peters 2008), as a result global demands for products from energy intensive industries for example are allocated to one region although driven by demand from other regions (IEA 2008).

Other authors have also synthesised knowledge gaps in the area. Worrell et al (2009) highlight the following with regards to industrial energy efficiency: “baseline energy intensity for specific industries, especially in transition economies, the potential energy-efficiency improvement potential in non-energy-intensive industries, quantification of co-benefits, sustainable development implications of mitigation options, and the impact of consumer preferences”.

10.13 Frequently Asked Questions

[TSU note: FAQs will be presented in box format throughout text in subsequent drafts]

FAQ 10.1 How much did the industry sector contribute to global GHG emissions and how could emissions be reduced most efficiently?

For manufacturing sector, global energy-related CO_2 emissions (including the emissions from the production and distribution of primary energy sources, such as coal used for electricity, consumed by the manufacturing sector) in 2009 were 11 GtCO2. Emissions from non-fossil fuel sources (e.g. cement manufacturing) were estimated to be 1.415 $GtCO_2$ in 2008, and emissions of non-CO_2 GHGs were 678 $MtCO_2eq$ in 2010. Worldwide GHG emissions from the service sector reached 3.8 GtCO2 in 2010; tourism, as a key component of the service sector, is estimated to contribute around 5% of global anthropogenic CO_2 emissions.

Options for mitigation of GHG emissions from industry fall into the following categories: energy efficiency, emissions efficiency (including fuel switching and CCS), materials efficiency (e.g. through reuse of waste), specific product characteristics (e.g. products with longer lifetime), and reduction of demand for products (e.g. through more intensive use of cars) and services (e.g., less mobility service by motorized individual transport).

FAQ 10.2 How will mitigation actions in other sectors affect industry? For example, will these require new and innovative products?

Collaborative Interactions between industry and other economic sectors have significant implications for GHG mitigation. Mitigation strategies, however, in other sectors may lead to increased emissions in industry, for example higher production of solar PV, Consumer preference for flat screen TV, use and throw product choice. On the other hand consumer choice for light weight car, consumer durables with longer life, materials, building insulation, low meat diet choice can reduce emissions from industry sector. Cross-sectoral cooperation, such as urban symbiosis and regional eco-industrial network can reduce the total consumption of materials and energy and contribute to the reduction of GHG emission, e.g. use of agricultural and municipal waste use in industry sector, heat cascading use.

10.14 Waste

[Author Note: In the preparation process of the First Order Draft (FOD) there was a late decision to provide such a section as an excursus section of the industry chapter. As such, the status of this specific section is different from the others above. Due to time constraints mainly an introduction has to be prepared and the structure of the section has been fixed. Various placeholders in the text show that between FOD and Second Order Draft (SOD), iteration between the chapter teams is necessary. Overlaps will be reduced and gaps will be filled.]

10.14.1 Introduction

Waste is generated in the production process of any product as well as at the consumption stage. Waste generation is an integral part of human activity and related to per capita energy consumption, GDP and material consumption (Ausubel and Herman 1988). Several mitigation options exist at the pre-consumer stage. These include reduction of waste generation during production processes, recycling and reuse. Waste is also generated post consumption of products. At the post-consumption stage mitigation options comprise reduction at source, recycling, reuse, alternative waste treatment techniques, and capture of methane at disposal sites (cf. Figure 10.12). However, waste to wealth is a new approach that is leading to many new innovations: technological and behavioural with resultant new industrial activity to handle wastes productively.

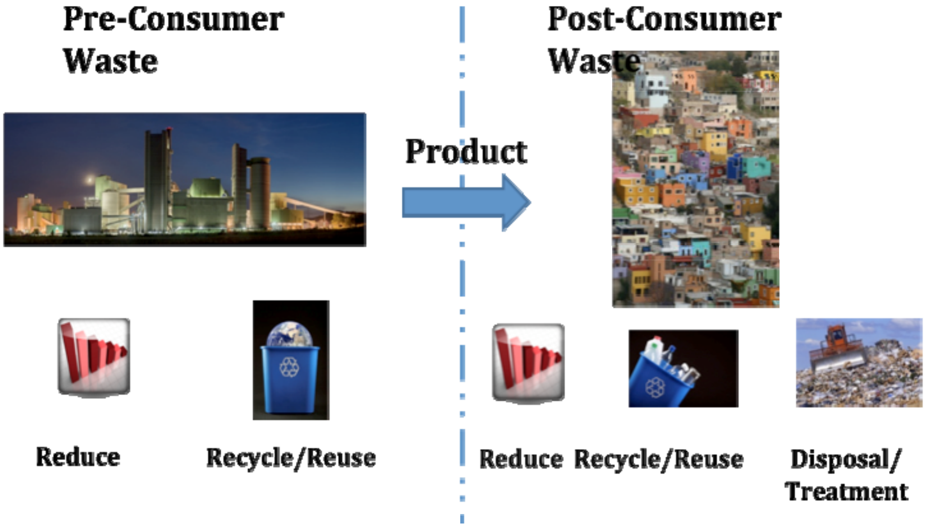


Figure 10.12. Illustration of waste mitigation options at pre-consumer and post-consumer stages

This section provides for AR 5 a summary of knowledge on current emission status from wastes generated from various economic activities, discusses the various mitigation options that are being adopted to directly reduce emissions from wastes and indirectly through reduction of waste generation and use of waste as resource within the mainstream economic activities. For AR 5 it serves as a section where waste related aspects from the different sectors will be summarized and set into context. Due to the preliminary status of the section at the end of this section the key messages from AR 4 are listed as an orientation mark and starting point for further discussion.

There is uncertainty and variability in estimates of waste quantities which are attributable to differences in the definitions of waste streams, GHG accounting convention (Gentil et al. 2009), exclusion or inclusion of minor generators and waste collection (Friedrich and Trois 2011), availability of quality data, and assumptions in estimation models (Eriksson and Bisaillon 2011). Complexity further increases while considering waste mix (urban, industrial, and agricultural) (Lacoste and Chalmin 2007).

It is very well understood that cities are a major origin of waste. However, the contributions of municipal solid waste in cities' GHG emission are typically small in big cities but GHG from waste is also linked to many other aspects such as waste handling infrastructure, type of waste treatment technology, energy recovery from landfills and others.

Table 10.15 presents predominant sources and estimates of GHG emissions from waste sector as well as illustrative examples for GHG mitigation measures.

Table 10.15: Sources for GHG emissions from waste management activities

Activity	GHG implications
Waste handling	With regard to storage, collection and transport from waste, emissions vary from 9.4 to 368 kg CO_2e/tonne of waste as it depends on method of collection, capacity and choice of transport equipment, travel distances, etc. (Eisted et al. 2009). GHG emissions can be reduced by avoiding long transportation distances and by avoiding the use of small vehicles (Arribas et al. 2010).
Material recovery and recycling	Material recovery and recycling offers maximum benefit to GHG savings. Savings are higher in countries where coal is the predominant source of energy used for material extraction and manufacturing (such as India, China and South Africa) and involvement of informal sector in waste recycling. Savings are offset when there is long distance transport of recycled material is involved.
Composting	Sustainable development co-benefit is nutrient balance in soil on a regional scale. Net GHG emission and savings depend on composting technology, waste composition and application of compost; and estimates can vary between -900 (net saving) to 300 (net load) kg CO_2e/tonne of wet waste composted. GHG savings from avoided primary production comes from substitution of fertilizer (22.4 to 46.1 kg CO_2e/tonne of wet waste), and substitution of peat (169 kg CO_2e/tonne of wet waste) (Boldrin et al. 2009).
Anaerobic digestion	GHG emissions (or savings) depends on biogas yield (i.e. performance of technology), the nature of energy that biogas substitute, nitrous oxide emissions from digestate in soil etc. GHG emissions are found to vary between a saving of 375 to a burden of 111 kg of CO_2e/tonne of wet waste for developed countries (Møller et al. 2009) and burden of 210 kg of CO_2 e/tonne of wet waste for developing countries (Barton et al. 2008).
Landfill	CH_4 is the main GHG gas associated with landfill activities. According to (Manfredi et al. 2009) and (Barton et al. 2008), open dumping account for 0.74 to 1.0 t CO_2e/tonne of wet waste, sanitary landfills with no gas capture emit 1.2 t CO_2e/tonne of wet waste, and 0.19 t CO_2e/tonne of wet waste with gas collection and flaring. Electricity generation from landfill gas further lower down the GHG emission to 0.09 t CO_2e/tonne of wet waste. A stored biogenic carbon in landfills further saves 132-185 kg CO_2e/tonne of wet waste.
Incineration	GHG emissions come from combustion of waste and the reduction from offsets from energy generation and fuel replacement. Operational GHG emissions from incineration are small (roughly one tenth of the emission from landfills), but potential for GHG reduction target is substantial (-480 to -1373 kg CO_2e/tonne of waste with energy recovery and -181 to -2607 kg CO_2e/tonne for co-combustion from municipal solid waste (Astrup et al. 2009). In some countries, waste is used for electricity generation. In 2009, 1.3% of the total electricity generated worldwide was from combustible renewables and

	waste. Biomass and waste, including traditional and modern uses, are expected to grow by 1.2-3.1% per annum or about as fast as in the last decade. Moreover, biofuels and waste contributed to approximately 5% in the fuel balance of heat generation in 2009. In the industry sector fossil fuels currently constitute 70% of the total final energy and use of wastes and biomass use will be three to four times higher in 2050 than in 2007 (IEA 2009c).
Wastewater	[Author note: To be completed for the SOD]

10.14.2 Emissions trends

10.14.2.1 Solid waste disposal

Figure 10.13 presents CH_4 emissions from solid waste disposal starting from 1970 until 2008 based on EDGAR version 4.2. Methane emissions from solid waste disposal almost doubled between 1970 and 2008.

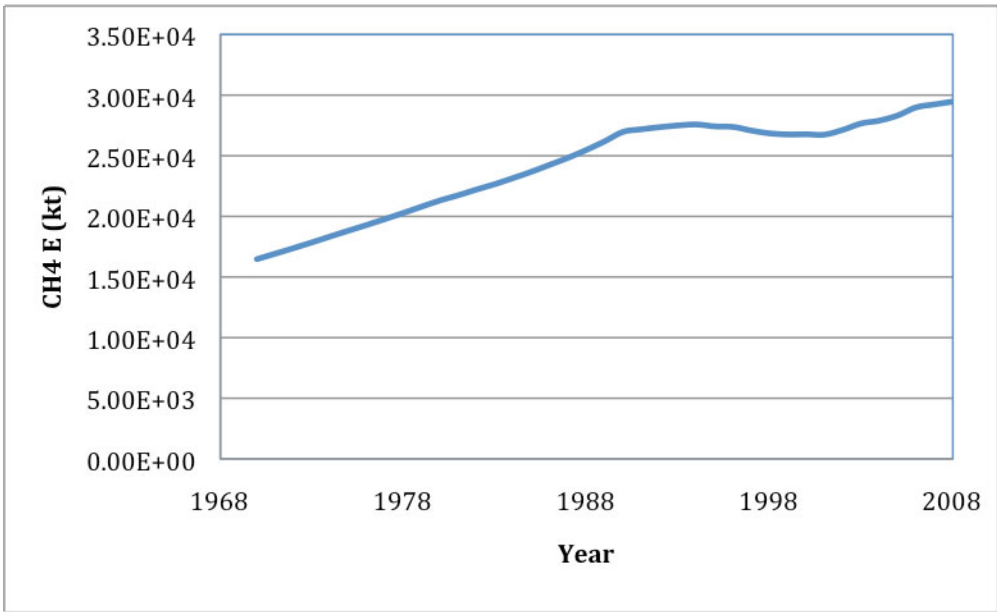


Figure 10.13. Methane Emissions from Solid Waste Disposal (EDGAR V 4.2)

10.14.2.2 Wastewater treatment

Figure 10.14 presents CH_4 emissions from wastewater treatment starting from 1970 until 2008 based on EDGAR version 4.2. Similar to emissions from solid waste disposal, emissions from wastewater treatment doubled between 1970 and 2008.

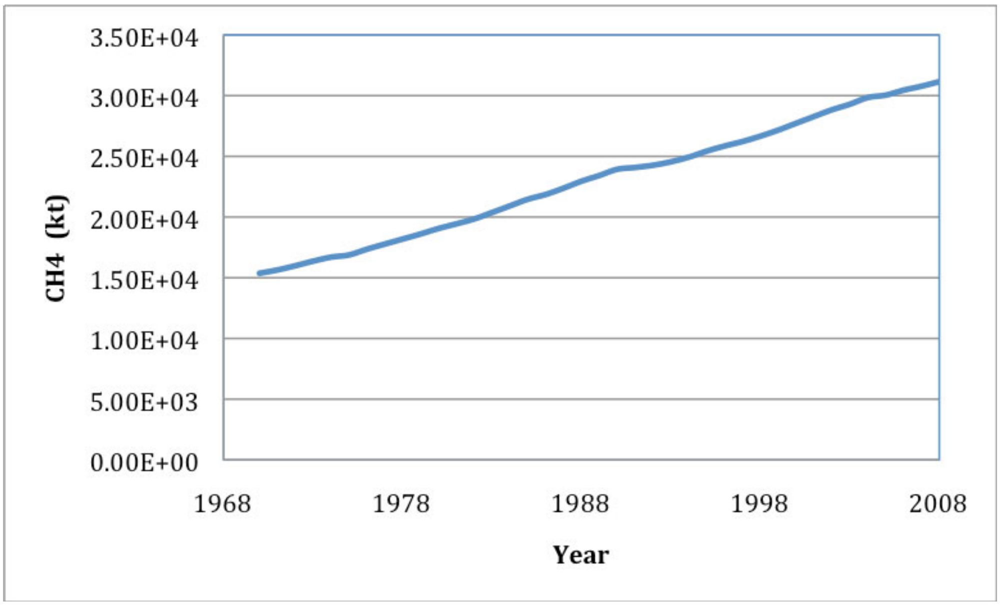


Figure 10.14 Methane Emissions from Wastewater Treatment (EDGAR V 4.2)

10.14.3 Technological options for mitigation of emissions from waste

10.14.3.1 Post-consumer waste

Waste reduction

[Author note: Section to be completed for SOD – Ch 12]

Recycling/reuse

An interesting option is the utilization of wastes in buildings. (Kinuthia and Nidzam 2011) highlights the potential utilisation of brick dust (BD), a waste material from the cutting of fired clay bricks, in construction. Other materials have been developed in (Asaad and Tawfik 2011), (Malaiškienė et al. 2011), (Devant et al. 2011), (Souza et al. 2011). Wastes have also been used in insulation materials (Benkreira et al. 2011) or in green roofs (Vila et al. 2012).

Methane capture from landfills

[Author note: Section to be completed for SOD – Ch 12]

Landfill aeration

[Author note: Section to be completed for SOD – Ch 12]

Alternative waste treatment techniques (composting, incineration, bio-digestion, gasification, RDF production)

[Author note: Section to be completed for SOD – Ch 12]

10.14.3.2 Pre-consumer waste

Waste reduction

[Author note: Section to be completed for SOD – Ch 12]

Recycling and reuse

Material substitution can lead to reduction in total energy requirements and hence emissions. For metals, by definition there are no substitutes for the required chemical elements, so metal must be made from ore or recycled. However, re-use potentially provides an alternative supply of metal feedstock, if large components are undamaged in first use. A detailed study (Allwood et al. 2012) on re-use of structural steel in construction concluded that there are no technical barriers to re-use, that there is a profit opportunity and that the potential supply is growing.

There is no recycling possible for cement, plastic recycling is greatly inhibited by the wide variety of incompatible compositions in use, and while paper recycling may save energy, it does not always reduce emissions due to the high use of biomass to power primary paper making. Recycling rates for metals vary widely (Graedel et al. 2011), and are inhibited for rarer metals by the high cost of collection of small quantities, and by their use as alloying elements or as thin closely bonded layers in electronics. For steel and aluminium, typical product lives span 20-40 years, so the availability of material for recycling lags global demand, and even with high recycling rates, it is unlikely that production from scrap will exceed that from ore within the next 30-40 years. Most recycling of steel and aluminium is actually of scrap generated in production – post-consumer aluminium for example makes up only 20% of total recycling. The quality of liquid metal made from recycled scrap depends on control of alloy composition, and despite the closed-loop of aluminium can recycling, almost all other aluminium recycling is from higher value ductile wrought alloys with a low silicon content, to lower value, casting alloys with high silicon content.

Plastics recycling may occur by four routes:

- Primary recycling – with direct re-extrusion of scrap, can occur within the factory, where a ‘pure’ waste stream of a single plastic is collected and re-fed
- Secondary recycling – used plastic is ground into chips or powder and converted to resin, but this typically gives a low quality product due to composition mixing
- Tertiary recycling – plastics are broken down chemically to produce new feedstock
- Quaternary recycling – energy recovery, in which the plastics are incinerated and the heat recovered.

Recent efforts in paper making have focused on waste paper recycling, capturing energy from the waste biomass created in pulping trees, but also aimed at improved drying technologies and the adoption of combined heat and power generation (de Beer et al. 1998; CEPI 2009; EIPPCB 2010; Hekkert and Worrell 1997; Miner and Lucier 2004; Nilsson et al. 1996).

Municipal solid waste can be used as an energy source or feedstock in the chemical and petrochemical, iron and steel and cement industry (IEA 2009c). Used tyres, wood, plastics, chemicals and other types of waste are already used in large quantities. It is important to pre-treat some types of municipal wastes before combustion if high substitution rates are to be achieved. Due to the expected competition with other sectors, (IEA 2009c) predicts that the price of waste will be 30 to 35% of that of coal by 2030 and 75% in 2050.

Industrial waste may also be used for mineralization approaches for carbon capture and storage such as coal fly ash (Montes-Hernandez et al., 2009), cement kiln dust (Huntzinger et al., 2009) and slag from steel mills (Sun et al., 2011). This approach might be more commercially viable compared to natural occurring mineralization pathways. The ultimate scale of deployment of such approaches would be constrained by the supply of these industrial wastes.

Waste treatment (disposal)

[Author note: Section to be completed for SOD – Ch 10]

10.14.3.3 Wastewater

Methane capture and flaring

[Author note: Section to be completed for SOD – Ch 12]

Methane capture and reuse

[Author note: Section to be completed for SOD – Ch 12]

10.14.4 Non-technological options for mitigation of emissions from waste

Other than technologies as short-term mitigation measure, long-term strategies could be centered firstly on avoiding or reducing waste, for instance by decoupling waste generation from economic factors such as GDP (Mazzanti and Zoboli 2008). Secondly, on the use of materials and products with the lowest embodied energy content and easy to recycle, reuse and recover in close proximity facilities.

In buildings sectors, maintaining the building stock and retrofitting existing urban settlements by using materials designed for disassembly, reuse and/or recycling is a illustrative example in that context.

Buildings designed for adaptability are more easily modified to suit changes in space planning and function over their life-span and can increasing the service-life of materials and building components through strategies such as design for deconstruction (Graham 2006). A Canadian study (Trusty and Meil 1999) of commercial retrofitting estimated complete interior retrofit, found that where a building's structural system and envelope could be reused it would avoid the generation of approximately 120 kg/m2 of solid waste.

In Europe, the Action Plan on Sustainable Consumption and Production and Sustainable Industrial Policy takes a two-pronged approach: supporting the supply of sustainable products and services and stimulating the demand for these. It includes both voluntary and regulatory instruments, such as the Eco-design, Eco-label and Energy Label Directives, as well as the Green Public Procurement policies. The Action Plan also emphasizes the role of retailers for sustainable consumption by setting up a retail forum. An example of a successful SCP initiative in North America is the 2009 Executive Order on Federal Leadership in Environment, Energy and Economic Performance or the Extended Producer Responsibility (EPR) programmes in Canada, which give industry the responsibility for managing, collecting and funding recycling (DFAIT 2010).

The existence of a shared location and infrastructure can also facilitate the identification and implementation of more synergy opportunities to reduce industrial water provision and waste water treatment, use of materials and waste management, therefore abating greenhouse gas emissions of industry. So-called eco- industrial parks have been set up both in developed and developing countries. Chinese eco industrial park standards contain quantitative indicators for material reduction and recycling, as well as pollution control. Two pioneering eco-industrial parks in China have achieved over 80% solid waste reuse ratio and over 82% industrial water reuse ratio (Geng 2010). The Japanese eco-town project in Kawasaki achieved substitution of at least 513, 000 tons of raw material, resulting in about the avoidance of 1% of the current total landfill in Japan (van Berkel et al. 2009).

10.14.5 Summary of key messages from AR4

In AR4 the following key messages could be generated displaying the meaning of waste for GHG emissions and the meaning of the sector (*Note: for FOD the messages serve as an intermediate step and will be updated or even integrated in the text after further iteration with the other chapters and elaboration of the section as such)*:

1. Post-consumer waste is a relatively small contributor to global GHG emissions (<5%).

2. There are large uncertainties with respect to direct emissions, indirect emissions and mitigation potentials for the waste sector. These uncertainties could be reduced by consistent national definitions, coordinated local and international data collection, etc.

3. Technological options available can either:

   3.1. directly reduce GHG emissions through landfill gas recovery, improved landfill practices, engineered wastewater management, etc., or

   3.2. avoid significant GHG generation through controlled composting of organic waste, state-of-the-art incineration and expanded sanitation coverage, conservation of raw materials (by minimising waste, recycling and reusing)

4. The main mitigation option - landfill gas recovery - together with complementary measures to reduce landfilling have shown to be able to stabilise CH4 emissions in developed countries. However landfilling emissions from developing countries are increasing.

5. Incineration and industrial co-combustion for waste-to-energy are proven technologies but more costly than controlled landfilling with landfill gas recovery. However, thermal processes may become more viable as energy prices increase.

6. Composting and other strategies that reduce landfilled waste are complementary mitigation measures to landfill gas recovery in the short- to medium-term

7. The global mitigation potential for reducing landfill CH_4 emissions in 2030 is estimated to be 70% of estimated emissions at costs below 100 USD/tCO2-eq/yr. Most of this potential is achievable at negative or low costs. This assumes aid from mechanisms such as CDM.

8. No solid data are available for wastewater emissions. Infrastructure for wastewater management in developing countries can provide multiple benefits. Key constraints include local availability of capital as well as the selection of locally appropriate technology.

9. Because waste management decisions are often made locally and do not consider mitigation aspects, the importance of the waste sector for reducing global GHG emissions has been underestimated. Mitigation is not the main target benefit of waste policies but the co-benefit.

Policies and measures for the waste management sector include regulatory and economic instruments, such as standards for landfill performance, extended producer responsibility schemes, landfill tax, pay-as-you-thrown (PAYT) schemes, and a variety of incentive schemes, subsidies and communication tools to promote technologies and practices.

References

ADB. (2009). *Improving energy security and reducing carbon intensity in Asia and Pacific*. Asian Development Bank, Manila, Philippines. Available at: http://www.adb.org/sites/default/files/pub/2009/Improving-Energy-Security-Reducing-Carbon-Intensity.pdf.

Agah S.M.M., and H.A. Abyaneh. (2011). Quantification of the Distribution Transformer Life Extension Value of Distributed Generation. *IEEE Transactions on Power Delivery* **26**, 1820–1828.

AGECC. (2010). *Energy for a Sustainable Future.* United Nations Secretary General's Advisory Group on Energy and Climate (AGECC), New York, NY, USA. Available at: http://www.un.org/millenniumgoals/pdf/AGECCsummaryreport%5B1%5D.pdf.

Ahearne J.F. (2011). Prospects for nuclear energy. *Energy Economics* **33**, 572–580.

Akpinar-Ferrand E., and A. Singh. (2010). Modeling increased demand of energy for air conditioners and consequent CO2 emissions to minimize health risks due to climate change in India. *Environmental Science & Policy* **13**, 702–712.

Aksoy N., C. Şimşe, and O. Gunduz. (2009). Groundwater contamination mechanism in a geothermal field: A case study of Balcova, Turkey. *Journal of Contaminant Hydrology* **103**, 13–28.

Ale B.J.M., H. Baksteen, L.J. Bellamy, A. Bloemhof, L. Goossens, A. Hale, M.L. Mude, J.I.H. Oh, I.A. Papazoglou, J. Post, and J.Y. Whiston. (2008). Quantifying occupational risk: The development of an occupational risk model. *Safesty Science* **46**, 176–185.

Allan R.N., and R. Billinton. (1988). Concepts of power system reliability evaluation. *International Journal of Electrical Power & Energy Systems* **10**, 139–141.

Alsalam J., and S. Ragnauth. (2011). *Draft Global Antropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2030*. US EPA, Washington. Available at: http://www.epa.gov/climatechange/economics.

Alvarez R., S. Pacala, J. Winebrake, W. Chameides, and S. Hamburg. (2012). Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure. *Proceedings of the National Academy of Sciences* **109**, 6435–6440.

Anderson-Teixeira K.J., P.K. Snyder, T.E. Twine, S.V. Cuadra, M.H. Costa, and E.H. DeLucia. (2012). Climate-regulation services of natural and agricultural ecoregions of the Americas. *Nature Clim. Change* **2**, 177–181.

Ang B.W., A.R. Mu, and P. Zhou. (2010). Accounting framework for tracking energy efficiency trends. *Energy Economics*, 1209–1219.

Angelis-Dimakis A., M. Biberacher, J. Dominguez, G. Fiorese, S. Gadocha, E. Gnansounou, G. Guariso, A. Kartalidis, L. Panichelli, I. Pinedo, and M. Robba. (2011). Methods and tools to evaluate the availability of renewable energy sources. *Renewable and Sustainable Energy Reviews* **15**, 1182–1200.

ARE. (2011). *Rural electrification with renewable energy: Technologies, quality standards and business models*. Alliance for Rural Electrification, Brussels, Belgium.

Arent D., and R. Tol. (Forthcoming). Chapter 10. Key Economic Sectors and Services. In: *IPCC WGII Report. CITATION DETAILS TO FOLLOW LATER.*

Arent D.J., A. Wise, and R. Gelman. (2011). The status and prospects of renewable energy for combating global warming. *Energy Economics* **33**, 584–593.

Arima E.Y., P. Richards, R. Walker, and M.M. Caldas. (2011). Statistical confirmation of indirect land use change in the Brazilian Amazon. *Environmental Research Letters* **6**, 024010.

Armaroli N., and V. Balzani. (2011). Towards an electricity-powered world. *Energy Environ. Sci.* **4**, 3193–3222.

Arndt C., S. Msangi, and J. Thurlow. (2011). Are biofuels good for African development? An analytical framework with evidence from Mozambique and Tanzania. *Biofuels* **2**, 221–234.

Arvesen A., and E.G. Hertwich. (in review). Assessing the life cycle environmental impacts of wind power: A review of present knowledge and research needs. *Renewable and Sustainable Energy Reviews*.

Arvesen A., and E.G. Hertwich. (2011). Environmental implications of large-scale adoption of wind power: a scenario-based life cycle assessment. *Environmental Research Letters* **6**, 045102.

Arvizu D., P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, and R. Zilles. (2011). Direct Solar Energy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Ashworth P., N. Boughen, M. Mayhew, and F. Millar. (2010). From research to action: Now we have to move on CCS communication. *International Journal of Greenhouse Gas Control* **4**, 426–433.

Asif M. (2009). Sustainable energy options for Pakistan. *Renewable and Sustainable Energy Reviews* **13**, 903–909.

Aspelund A., M.J. Mølnvik, and G. De Koeijer. (2006). Ship Transport of CO2: Technical Solutions and Analysis of Costs, Energy Utilization, Exergy Efficiency and CO2 Emissions. *Chemical Engineering Research and Design* **84**, 847–855.

Aunan K., J. Fang, H. Vennemo, K. Oye, and H.M. Seip. (2004). Co-benefits of climate policy--lessons learned from a study in Shanxi, China. *Energy Policy* **32**, 567–581.

Azar C., K. Lindgren, M. Obersteiner, M. Riahi, D. Vuuren, K. Elzen, K. Möllersten, and E. Larson. (2010). The feasibility of low CO2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS). *Climate Change* **100**, 195–202.

Bachu S. (2008). CO2 storage in geological media: Role, means, status and barriers to deployment. *Progress in Energy and Combustion Science* **34**, 254–273.

Bachu Stefan, D. Bonijoly, John Bradshaw, R. Burruss, Sam Holloway, N.P. Christensen, and O.M. Mathiassen. (2007). CO2 storage capacity estimation: Methodology and gaps. *International Journal of Greenhouse Gas Control* **1**, 430–443.

Bakker S., H. de Coninck, and Heleen Groenenberg. (2010). Progress on including CCS projects in the CDM: Insights on increased awareness, market potential and baseline methodologies. *International Journal of Greenhouse Gas Control* **4**, 321–326.

Bala G., K. Caldeira, M. Wickett, T.J. Phillips, D. B. Lobell, C. Delire, and A. Mirin. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences* **104**, 6550–6555.

Banse M., H. Van Meijl, A. Tabeau, and G. Woltjer. (2008). Will EU Biofuel Policies Affect Global Agricultural Markets? *European Review of Agricultural Economics* **35**, 117–141.

Barker T., L. Bernstein, J. E. Bogner, I. Bashmakov, P. R. Bosch, R. Dave,, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnæs, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M.D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla,, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, and D. Zhou. (2007). *Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R.*

Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 35–37 pp.

Barlas S. (2011). Green Completions for Shale Gas Come to Fore as Methane Emissions Reduction Tool. *Pipeline and Gas Journal* **238**. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84856189359&partnerID=40&md5=1f262679bef24e2d935db76b469a757f.

Barros N., J. Cole J., L.J. Tranvik, Y.T. Prairie, D. Bastviken, V.L.M. Huszar, P. del Giorgio, and F. Roland. (2011). Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geoscience* **4**, 593–596.

Bashmakov I. (2007). Three Laws of Energy Transitions. *Energy Policy* **35**, 3583–3594.

Bashmakov I. (2009). Resource of energy efficiency in Russia: scale, costs, and benefits. *Energy Efficiency* **2**, 369–386.

Bates B.C., Z.W. Kundewicz, S. Wu, and J.P. Palutikof. (2008). *Climate Change and Water*. IPCC Secretariat, Geneva, Switzerland.

Bazilian M., P. Nussbaumer, C. Eibs-Singer, A. Brew-Hammond, V. Modi, B. Sovacool, V. Ramana, and P.K. Aqrawi. (2012). Improving Access to Modern Energy Services: Insights from Case Studies. *The Electricity Journal* **25**, 93–114.

Behrens A., G. Lahn, E. Dreblow, J. Núñez Ferrer, M. Carraro, and S. Veit. (2012). *Escaping the Vicious Cycle of Poverty: Towards Universal Access to Energy in Developing Countries*. Centre for European Policy Studies, Brussels, Belgium.

Benato R., R. Fellin, A. Lorenzoni, and A. Paolucci. (2001). Elettrodotti blindati nel territorio: connessioni dei nuovi impianti di generazione alla RTN. *Associazione Elettrotecnica ed Elettronica Italiana* **Vol. 88**, 28–37.

Benson S., P. Cook, J. Anderson, S. Bachu, H. Nimir, B. Basu, J. Bradshaw, G. Deguchi, J. Gale, G. von Goerne, W. Heidug, S. Holloway, R. Kamal, D. Keith, P. Lloyd, P. Rocha, B. Senior, J. Thomson, T. Torp, T. Wildenborg, M. Wilson, F. Zarlenga, and D. Zhou. (2005). Underground Geological Storage. In: *IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]*.Cambridge, UK and New York, NY, USA, pp.442, .Available at: http://www.ipcc.ch/publications_and_data/_reports_carbon_dioxide.htm.

Bento A.M., R. Klotz, and J.R. Landry. (In review). Are there carbon savings from US biofuel policies? The Critical Importance of Accounting for Leakage in Land and Fuel Markets. *Journal of Environmental Economics and Management*. Available at: file://localhost/Users/rjp/literature/b/Bento%20-%20Carbon%20savings%20for%20US%20biofuel%20policies%202012.pdf.

Berndes G., N. Bird, and A. Cowie. (2011). *Bioenergy, Land Use Change and Climate Change Mitigation. Technical Report*. International Energy Agency. Available at: http://www.ieabioenergy.com/LibItem.aspx?id=6927.

Berndes Göran. (2012). Bioenergy's contribution to climate change mitigation – a matter of perspectives. *Biofuels, Bioproducts and Biorefining* **6**, 233–235.

de Best-Waldhober M., D. Daamen, and André Faaij. (2009). Informed and uninformed public opinions on CO2 capture and storage technologies in the Netherlands. *International Journal of Greenhouse Gas Control* **3**, 322–332.

Betts R.A. (2000). Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. *Nature* **408**, 187–190.

Betts R.A. (2001). Biogeophysical impacts of land use on present-day climate: near-surface temperature change and radiative forcing. *Atmospheric Science Letters* **2**, 39–51.

Betts R.A. (2011). Mitigation: A sweetener for biofuels. *Nature Clim. Change* **1**, 99–101.

Betts R.A., P.D. Falloon, K.K. Goldewijk, and N. Ramankutty. (2007). Biogeophysical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change. *Agricultural and Forest Meteorology* **142**, 216–233.

Bhuiyan M.M.., M.A. Asgar, R.. Mazumder, and M. Hussain. (2000). Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh. *Renewable Energy* **21**, 403–410.

Bickerstaff K., I. Lorenzoni, N.F. Pidgeon, W. Poortinga, and P. Simmons. (2008). Reframing nuclear power in the UK energy debate: nuclear power, climate change mitigation and radioactive waste. *Public Understanding of Science* **17**, 145 –169.

Bloomberg New Energy Finance. (2012). *Global Trends in Renewable Energy Investment*. Frankfurt School of Finance and Management gGmbH, Frankfurt. Available at: http://fs-unep-centre.org/sites/default/files/media/globaltrendsreport2012_3.pdf.

Bode S. (2006). On the impact of renewable energy support schemes on power prices. *HWWI Research Paper* **4**.

Bode Sven, and H.M. Groscurth. (2009). On the Re-regulation of the Liberalized Power Market in Europe. *Carbon and Climate Law Review* **2**, 188–197.

Bonan G.B. (2008). Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. *Science* **320**, 1444–1449.

Borenstein S. (2005). The long-run efficiency of real-time electricity pricing. *Energy Journal* **26**, 93–116.

Bosetti V., C. Carraro, and M. Tavoni. (2009). Climate change mitigation strategies in fast-growing countries: The benefits of early action. *Energy Economics* **31, Supplement 2**, S144–S151.

Bouzarovski S., S. Petrova, and R. Sarlamanov. (forthcoming). Energy Poverty Policies in the EU: A critical Perspective. *Energy Policy*.

BP. (2011a). *BP Statistical Review of World Energy*. Available at: http://www.bp.com/statisticalreview.

BP. (2011b). *BP Energy Outlook 2030*. London.

BP. (2012). *BP Statistical Review of World Energy*. Available at: http://www.bp.com/statisticalreview.

Bradshaw John, Stefan Bachu, D. Bonijoly, R. Burruss, Sam Holloway, N.P. Christensen, and O.M. Mathiassen. (2007). CO2 storage capacity estimation: Issues and development of standards. *International Journal of Greenhouse Gas Control* **1**, 62–68.

Branker K., M.J.M. Pathaka, and Paercea. (2011). *A review of solar photovoltaic levelized cost of electricity*.

Bratland O. (2010). *Pipe flow 2 - Multi-phase flow assurance*. Available at: http://drbratland.com/PipeFlow2/PipeFlow2Multi-phaseFlowAssurance.pdf.

Brennecke J.F., and B.E. Gurkan. (2010). Ionic Liquids for CO2 Capture and Emission Reduction. *The Journal of Physical Chemistry Letters* **1**, 3459–3464.

Brew-Hammond A. (2010). Energy Access in Africa: Challenges Ahead. *Energy Policy* **38**, 2291–2301.

Bright R.M., F. Cherubini, and A.H. Strømman. (2012). Climate impacts of bioenergy: Inclusion of carbon cycle and albedo dynamics in life cycle impact assessment. *Environmental Impact Assessment*

Review. Available at: file://localhost/Users/rjp/literature/b/Bright%20-%20Climate%20impacts%20of%20bioenergy%20-%20C%20cycle%20and%20albedo%202012.pdf.

Bright R.M., A.H. Strömman, and G.P. Peters. (2011). Radiative Forcing Impacts of Boreal Forest Biofuels: A Scenario Study for Norway in Light of Albedo. *Environmental Science & Technology* **45**, 7570–7580.

van den Broek M., R. Hoefnagels, E. Rubin, Wim Turkenburg, and AndrV© Faaij. (2009). Effects of technological learning on future cost and performance of power plants with CO2 capture. *Progress in Energy and Combustion Science* **35**, 457–480.

Bruckner T., G. Petschel-Held, G. Toth, F.L. Fussel, C. Helm, M. Leimbach, and H.J. Schnellnhuber. (1999). Climate change decision-support and the tolerable windows approach. *Environmental Modeling and Assessment* **4**, 217–234.

Bruvoll A., S.J. Magne, and Haakon Vennemo. (2011). *Reforming environmentally harmful subsidies. How to counteract distributional impacts*. TemaNord, Nordic Council of Ministers, Copenhagen.

Bunn M., S. Fetter, J. Holdren, and B. van der Zwaan. (2003). *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel. Project on Managing the Atom*. Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, Cambridge, MA.

Burgherr P., and S. Hirschberg. (2007). Assessment of severe accident risks in the Chinese coal chain. . *International Journal of Risk Assessment and Management* **7**, 1157–1175.

Burgherr P., S. Hirschberg, and E. Cazzoli. (2008). *Final Report on Quantifi cation of Risk Indicators for Sustainability Assessment of Future Electricity Supply Options*. New Energy Externalities Developments for Sustainability, Brussels, Belgium.

Burkhardt John J., Garvin Heath, and E. Cohen. (2012). Life Cycle Greenhouse Gas Emissions of Trough and Tower Concentrating Solar Power Electricity Generation. *Journal of Industrial Ecology* **16**, S93–S109.

Burkhardt J.J., G.A. Heath, and C.S. Turchi. (2011). Life Cycle Assessment of a Parabolic Trough Concentrating Solar Power Plant and the Impacts of Key Design Alternatives. *Environmental Science & Technology* **45**, 2457–2464.

Calvin K., James Edmonds, Ben Bond-Lamberty, Leon Clarke, Son H Kim, P. Kyle, Steven J Smith, A. Thomson, and Marshall Wise. (2009). 2.6: Limiting climate change to 450 ppm CO2 equivalent in the 21st century. *Energy Economics* **31**. Available at: http://www.sciencedirect.com/science/article/B6V7G-4WHFD6P-1/2/f1cf35774f38ef95e30797310db37533.

Campbell J.E., D. B. Lobell, and C. B. Field. (2009). Greater Transportation Energy and GHG Offsets from Bioelectricity Than Ethanol. *Science* **324**, 1055–1057.

Carbo M.C., R. Smit, B. van der Drift, and D. Jansen. (2011). Bio Energy with CCS (BECCS): Large Potential for BioSNG at Low CO2 Avoidance Cost. *Energy Procedia* **4**, 2950–2954.

Carey J. William, M. Wigand, S.J. Chipera, G. WoldeGabriel, R. Pawar, P.C. Lichtner, S.C. Wehner, M.A. Raines, and J.G.D. Guthrie. (2007). Analysis and performance of oil well cement with 30 years of CO2 exposure from the SACROC Unit, West Texas, USA. *International Journal of Greenhouse Gas Control* **1**, 75–85.

Carey W.J., R. Svec, R. Grigg, J. Zhang, and Walter Crow. (2010). Experimental investigation of wellbore integrity and CO2,Äìbrine flow along the casing,Äìcement microannulus. *International Journal of Greenhouse Gas Control* **4**, 272–282.

Carraro C., and E. Massetti. (2011). Beyond Copenhagen: a realistic climate policy in a fragmented world. *Climatic Change* **In press**.

Casillas C.E., and D.M. Kammen. (2010). Environment and development. The energy-poverty-climate nexus. *Science* **330**, 1181–1182.

de Castro C., M. Mediavilla, L.J. Miguel, and F. Frechoso. (2011). Global wind power potential: Physical and technological limits. *Energy Policy* **39**, 6677–6682.

Cathles I., L. Brown, M. Taak, and A. Hunter. (2012). A Commentary on "The Greenhouse-gas Footprint of Natural Gas in Shale Formations" by R.W. Howarth, R. Santoro, and Anthony Ingraffea. *Climate Change* **113**, 525–535.

Centolella P. (2010). The integration of Price Responsive Demand into Regional Transmission Organization (RTO) wholesale power markets and system operations. *Energy* **35**, 1568–1574.

Central Intelligence Agency. (2011). *The World Factbook*. Available at: https://www.cia.gov/library/publications/the-world-factbook/fields/2117.html#as.

Chalmers Hannah, and Jon Gibbins. (2007). Initial evaluation of the impact of post-combustion capture of carbon dioxide on supercritical pulverised coal power plant part load performance. *Fuel* **86**, 2109–2123.

Chalmers, M. Lucquiaud, J. Gibbins, and M. Leach. (2009). Flexible Operation of Coal Fired Power Plants with Postcombustion Capture of Carbon Dioxide. *Journal of Environmental Engineering* **135**, 449.

Chang X., X. Liu, and W. Zhou. (2010). Hydropower in China at present and its further development. *Energy* **35**, 4400–4406.

Charpentier A.D., J.A. Bergerson, and H. L. MacLean. (2009). Understanding the Canadian oil sands industry's greenhouse gas emissions. *Environmental Research Letters* **4**. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-67650269786&partnerID=40&md5=234b9d5805675dea858bcbae040ff8c5.

Chen W., Z. Wu, J. He, P. Gao, and S. Xu. (2007). Carbon emission control strategies for China: A comparative study with partial and general equilibrium versions of the China MARKAL model. *Energy* **32**, 59–72.

Chen X., and M. Khanna. (2012). The Market-Mediated Effects of Low Carbon Fuel Policies. *AgBioForum* **15**, 1–17.

Cherian A. (2009). *Bridging the Divide Between Poverty Reduction and Climate Change through Sustainable and Innovative Energy Technologies.* Environment and Energy Group, United Nations Development Programme, New York, NY, USA.

Cherp A., A. Adenikinju, A. Goldthau, F. Hernandez, L. Hughes, J. Jansen, J. Jewell, M. Olshanskaya, R. Soares de Oliveira, B.K. Sovacool, and S. Vakulenko. (forthcoming). Energy and Security. In: *Global Energy Assessment: Toward a Sustainable Future*. N. Nakicenovic, A. Patwardhan, L. Gomez-Echeverri, T.B. Johansson, (eds.), International Institute for Applied Systems Analysis and Cambridge University Press, Laxenburg, Austria; Cambridge, UK & New York, USA, .

Cherubini F., G. Guest, and A.H. Strømman. (2012). Application of probability distributions to the modeling of biogenic CO2 fluxes in life cycle assessment. *GCB Bioenergy*, n/a–n/a.

Cherubini F., G.P. Peters, T. Berntsen, A.H. StrØMman, and E. Hertwich. (2011). CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. *GCB Bioenergy*, no–no.

Cherubini F., A.H. Strømman, and E. Hertwich. (2011). Effects of boreal forest management practices on the climate impact of CO2 emissions from bioenergy. *Ecological Modelling* **223**, 59–66.

Chum H., A. Faaij, J. Moreira, G. Berndes, P. Dhamija, H. Dong, and B. Gabrielle. (2011). Bioenergy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, A. Goss Eng, W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa, K. Pingoud, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Chum H., A. Faaij, J. Moreira, G. Berndes, P. Dhamija, H. Dong, B. Gabrielle, G. Goss Eng, W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa, and K. Pingoud. (2011). Bioenergy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, .

Cisneros B.J., and T. Oki. (Forthcoming). Chapter 3. Freshwater Resources. In: *IPCC WGII Report. CITATION DETAILS TO FOLLOW LATER.*

Clair S.S., Jonathan Hillier, and P. Smith. (2008). Estimating the pre-harvest greenhouse gas costs of energy crop production. *Biomass and Bioenergy* **32**, 442–452.

Clapp C., K. Karousakis, B. Buchner, and J. Chateau. (2009). *National and Sectoral GHG Mitigation Potential: A Comparison Across Models*. Organisation for Economic Co-operation and Development, Paris.

Clarke L., J Edmonds, H. Jacoby, H. Pitcher, J.M Reilly, and R. Richels. (2007). *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Subreport 2.1A of Synthesis and Assessment Product*. U.S. Climate Change Science Program and the Subcommittee on Global Change Research., Washington, DC.

Clarke L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels. (2007). *CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. U.S. Government Printing Office, Washington D.C.

Claussen M., V. Brovkin, and A. Ganopolski. (2001). Biogeophysical versus biogeochemical feedbacks of large-scale land cover change. *Geophys. Res. Lett.* **28**, 1011–1014.

Cohen S., G. Rochelle, and M. Webber. (2011). Optimal operation of flexible post-combustion CO2 capture in response to volatile electricity prices. *Energy Procedia* **4**, 2604–2611.

Cohen S., G.T. Rochelle, and M. Webber. (2012). Optimizing post-combustion CO2 capture in response to volatile electricity prices. *International Journal of Greenhouse Gas Control* **8**, 180–195.

Cohen S., H. Chalmers, M. Webber, and C. King. (2011). Comparing post-combustion CO2 capture operation at retrofitted coal-fired power plants in the Texas and Great Britain electric grids. *Environmental Research Letters* **6**, 024001.

Cole I.S., P. Corrigan, S. Sim, and N. Birbilis. (2011). Corrosion of pipelines used for CO2 transport in CCS: Is it a real problem? *International Journal of Greenhouse Gas Control* **5**, 749–756.

Cooke P., G. Kohlin, and W.F. Hyde. (2008). Fuelwood, Forests and Community Management: Evidence from Household Studies. *Environment and Development Economics* **13**, 103–135.

Corner A., D. Venables, A. Spence, W. Poortinga, C. Demski, and N. Pidgeon. (2011). Nuclear power, climate change and energy security: Exploring British public attitudes. *Energy Policy* **39**, 4823–4833.

Corry O., and D. Reiner. (2011). *Evaluating global Carbon Capture and Storage (CCS) communication materials: A survey of global CCS communications*. Cambruidge - Judge Business School. 46 pp. Available at:

http://cdn.globalccsinstitute.com/sites/default/files/publication_20110816_global_eval_ccs_comms.pdf.

Cossent R., L. Olmos, T. Gómez, C. Mateo, and P. Frías. (2011). Distribution network costs under different penetration levels of distributed generation. *European Transactions on Electrical Power* **21**, 1869–1888.

Cotula L. (2012). The international political economy of the global land rush: A critical appraisal of trends, scale, geography and drivers. *Journal of Peasant Studies* **39**, 649–680.

Courchesne A., V. Bécaert, R.K. Rosenbaum, L. Deschênes, and R. Samson. (2010). Using the Lashof Accounting Methodology to Assess Carbon Mitigation Projects With Life Cycle Assessment. *Journal of Industrial Ecology* **14**, 309–321.

Cozzani V., M. Campedela, E. Renni, and E. Krausmann. (2010). Industrial accidents triggered by fl ood events: Analysis of past accidents. *Journal of Hazardous Materials* **175**, 501–509.

Creutzig F., A. Popp, R. Plevin, G. Luderer, J. Minx, and O. Edenhofer. (2012a). Reconciling top-down and bottom-up modeling on future bioenergy deployment. *Nature Climate Change*.

Creutzig F., C. Stechow, D. Klein, C. Hunsberger, N. Bauer, A. Popp, and O. Edenhofer. (2012b). Can Bioenergy Assessments Deliver? *Economics of Energy & Environmental Policy* **1**, 65–82.

Creuzig F., and D. He. (2009). Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transportation Research Part D: Transport and Environment* **14**, 120–131.

Crossland I.G. (2012). The Economics of Nuclear Power. *Energy Policy*.

Crow W., J. W. Carey, S. Gasda, D. Brian Williams, and M. Celia. (2010). Wellbore integrity analysis of a natural CO2 producer. *International Journal of Greenhouse Gas Control* **4**, 186–197.

CRS. (2012). *Closing Yucca Mountain: Litigation Associated with Attempts to Abandon the Planned Nuclear Waste Repository*. CRS.

Crutzen P.J., A. R. Mosier, K.A. Smith, and W. Winiwarter. (2007). N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmos. Chem. Phys. Discuss.* **7**, 11191–11205.

CSLF. (2008). *Comparison between Methodologies Recommended for Estimation of CO2 Storage Capacity in Geological Media by the CSLF Task Force on CO2 Storage Capacity Estimation and the USDOE Capacity and Fairways Subgroup of the Regional Carbon Sequestration Partnerships Program*. Washington, D.C.

Cummins W.E., M.M. Corletti, and T.L. Schulz. (2003). Westinghouse AP1000 Advanced Passive Plant. In Proceedings: *Proceedings of International Congress on Advances in Nuclear Power Plants (ICAPP '03)*. Cordoba, Spain. May-2003, .

Dahowski R.T., C. Davidson, and J. Dooley. (2011). Comparing large scale CCS deployment potential in the USA and China: A detailed analysis based on country-specific CO2 transport & storage cost curves. *Energy Procedia* **4**, 2732–2739.

Dahowski R.T., X. Li, C. Davidson, N. Wei, and J. Dooley. (2010). *Regional Opportunities for Carbon Dioxide Capture and Storage in China: A Comprehensive CO2 Storage Cost Curve and Analysis of the Potential for Large Scale Carbon Dioxide Capture and Storage in the People's Republic of China*. Pacific Northwest National Laboratory, Richland, WA. Available at: http://www.sciencedirect.com/science/article/B984K-52HJH2J-GS/2/a741589b982205781e0fb902318713b1 http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B984K-52HJH2J-GS-1&_cdi=59073&_user=961305&_pii=S1876610211003729&_origin=gateway&_coverDate=12%2F31

%2F2011&_sk=999959999&view=c&wchp=dGLbVtz-zSkWA&md5=eb0dd2c552f5e78561832069336aa589&ie=/sdarticle.pdf.

Dai A. (2011). Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change* **2**, 45–65.

Damerau K., K. Williges, A.G. Patt, and P. Gauché. (2011). Costs of reducing water use 326 of concentrating solar power to sustainable levels: Scenarios for North Africa. *Energy Policy* **39**, 4391–4398.

Dauvergne P., and K.J. Neville. (2010). Forests, food, and fuel in the tropics: the uneven social and ecological consequences of the emerging political economy of biofuels. *Journal of Peasant Studies* **37**, 631–660.

Davin E.L., N. de Noblet-Ducoudré, and P. Friedlingstein. (2007). Impact of land cover change on surface climate: Relevance of the radiative forcing concept. *Geophys. Res. Lett.* **34**, L13702.

Davis S.J., K. Caldeira, and H.D. Matthews. (2010). Future CO2 emissions and climate change from existing energy infrastructure. *Science* **329**, 1330–3.

Davis S.C., W.J. Parton, S.J.D. Grosso, C. Keough, E. Marx, P.R. Adler, and E.H. DeLucia. (2012). Impact of second-generation biofuel agriculture on greenhouse-gas emissions in the corn-growing regions of the US. *Frontiers in Ecology and the Environment* **10**, 69–74.

Deane J.P., B.P. Ó Gallachóir, and E.J. McKeogh. (2010). Techno-economic review of existing and new pumped hydro energy storage plant. *Renewable and Sustainable Energy Reviews* **14**, 1293–1302.

Decarre S., J. Berthiaud, N. Butin, and J.-L. Guillaume-Combecave. (2010). CO2 maritime transportation. *International Journal of Greenhouse Gas Control* **4**, 857–864.

DECC. (2009). *Carbon Valuation in UK Policy Appraisal: A Revised Approach*. Department of Energy and Climate Change, London.

Degu A.M., F. Hossain, D. Niyogi, R.P. Sr, J.M. Shepherd, N. Voisin, and T. Chronis. (2011). The influence of large dams on surrounding climate and precipitation patterns. *Geophysical Research Letters* **38**. Available at: http://www.agu.org/pubs/crossref/2011/2010GL046482.shtml.

Deichmann U., C. Meisner, S. Murray, and D. Wheeler. (2011). The economics of renewable energy expansion in rural Sub-Saharan Africa. *Energy Policy* **39**, 215–227.

Delucchi M., and M. Jacobson. (2011). Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. *Energy Policy* **39**, 1170–1190.

Delucchi M. A. (2010). Impacts of biofuels on climate change, water use, and land use. *Annals of the New York Academy of Sciences* **1195**, 28–45.

Denholm Paul, J.C. King, C.F. Kutcher, and P.P.H. Wilson. (2012). Decarbonizing the electric sector: Combining renewable and nuclear energy using thermal storage. *Energy Policy* **44**, 301–311.

Deutsche Bank Advisers. (2009). *Investing in Agriculture: Far-Reaching Challenge, Significant Opportunity. An Asset Management Perspective. Investing in Agriculture: Far-Reaching Challenge, Significant Opportunity. An Asset Management Perspective.* DB Climate Change Advisers, Deutsche Bank Group. Available at: http://www.db.com/usa/download/Ag_whitepaper_062409.pdf.

Don A., B. Osborne, A. Hastings, U. Skiba, M.S. Carter, J. Drewer, H. Flessa, A. Freibauer, N. Hyvönen, M.B. Jones, G.J. Lanigan, Ü. Mander, A. Monti, S.N. Djomo, J. Valentine, K. Walter, W. Zegada-Lizarazu, and T. Zenone. (2012). Land-use change to bioenergy production in Europe: implications for the greenhouse gas balance and soil carbon. *GCB Bioenergy* **4**, 372–391.

Dones R., C. Bauer, R. Bolliger, B. Burger, M. Faist, Emmenegger, R. Frischknecht, T. Heck, N. Jungbluth, and A. Röder. (2007). *Life Cycle Inventories of Energy Systems: Results for Current Systems in Switzerland and other UCTE Countries*. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

Dooley J. J., and K.V. Calvin. (2011). Temporal and spatial deployment of carbon dioxide capture and storage technologies across the representative concentration pathways. *Energy Procedia* **4**, 5845–5852.

Dooley James J. (2012). Estimating the supply and demand for deep geologic CO2 storage capacity over the course of the 21st Century: A meta?analysis of the literature. *Energy Procedia*.

Dooley JJ, CL Davidson, and D. RT. (2009). *An Assessment of the Commercial Availability of Carbon Dioxide Capture and Storage Technologies as of June 2009*. Joint Global Change Research Institute. Pacific Northwest National Laboratory., College Park, MD.

Drabik D., and H. de Gorter. (2011). Biofuel policies and carbon leakage. *AgBioForum* **14**, 104–110.

Dumortier J., D.J. Hayes, M. Carriquiry, F. Dong, X. Du, A. Elobeid, J.F. Fabiosa, and S. Tokgoz. (2011). Sensitivity of Carbon Emission Estimates from Indirect Land-Use Change. *Applied Economic Perspectives and Policy* **33**, 428–448.

Durmayaz A., and O.S. Sogut. (2006). Influence of cooling water temperature on the efficiency of a pressurized water reactor nuclear power plant. *International Journal of Energy Research* **30**, 799–810.

Dyni J.R. (2006). *Geology and Resources of Some World Oil-Shale Deposits*. US Geological Survey, Reston, VA.

EBRD, and G. Institute. (2011). *The Low Carbon Transition*. European Bank for Reconstruction and Development, London.

Edenhofer O., B. Knopf, T. Barker, L. Baumstark, E. Bellevrat, B. Chateau, P. Criqui, M. Isaac, A. Kitous, S. Kypreos, M. Leimbach, K. Lessmann, B. Magne, S. Scrieciu, H. Turton, and D. van vuuren. (2010). The economics of low stabilization: Model comparison of mitigation strategies and costs. *The Energy Journal* **31**, 11–49.

EDIN. (2011). *Samsø, Denmark, Strives to Become a Carbon-Neutral Island*. Available at: http://www.edinenergy.org/samso.html.

Edmonds J., and M. Wise. (1998). The Economics of Climate Change: Building Backstop Technologies And Policies To Implement The Framework Convention On Climate Change. *Energy & Environment* **9**, 383–397.

Edmonds J., M. Wise, and D. Barns. (1995). Carbon Coalitions: The Cost and Effectiveness of Energy Agreements to Alter Trajectories of Atmospheric Carbon Dioxide Emissions. *Energy Policy* **23**, 309–336.

Edmonds JA, JJ Dooley, SH Kim, S. Friedman, and MA Wise. (2007). Technology in an Integrated Assessment Model: The Potential Regional Deployment of Carbon Capture and Storage in the Context of Global CO2 Stabilization. In: *Human-induced Climate Change: An Interdisciplinary Assessment*. Cambridge University Press, pp.pp. 181–197, .

EIA. (2011). *Retrospective review: Annual Energy Outlook 2010*. US Department of Energy, Energy Information Administration, Washington DC.

Eiken O., P. Ringrose, C. Hermanrud, B. Nazarian, T.A. Torp, and L. H√∏ier. (2011). Lessons learned from 14 years of CCS operations: Sleipner, In Salah and Snohvit. *Energy Procedia* **4**, 5541–5548.

Ellerman A.D., and B. Buchner. (2007). The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Review of Environmental Economics and Policy* **I**, 66–87.

Ellerman A.D., F.J. Convery, and C. de Perthuis. (2010). *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge University Press, Cambridge.

den Elzen M., A. Hof, and M. Roelfsema. (2011). The emissions gap between the Copenhagen pledges and the 2 8C climate goal: Options for closing and risks that could widen the gap. *Global Environmental Change* **21**, 733–743.

Enerdata. (2012). Global Energy & Co2 Data. Comprehensive and up-to-date online database for energy suppy & demand and GHG emissions. *Enerdata*. Available at: http://www.enerdata.net/.

EPRI. (2003). *High Temperature Gas-Cooled Reactors for the Production of Hydrogen: An Assessment in Support of the Hydrogen Economy*. Electric Power Research Institute (EPRI), Palo Alto, California.

Erdem H., and S. Sevilgen. (2006). Case study: Effect of ambient temperature on the electricity production and fuel consumption of a simple cycle gas turbine in Turkey. *Applied Thermal Engineering* **26**, 320–326.

European Commission. (2001). *Adding Gas from Biomass to the Gas Grid: Contract No: XVII/4.1030/Z/99-412*. Available at: http://gasunie.eldoc.ub.rug.nl/root/2001/2044668/.

European Commission. (2004). *Preparing for the Hydrogen Economy by Using the Existing Natural Gas System as a Catalyst.* Available at: http://www.naturalhy.net/.

EWG. (2008). *Zukunft der weltweiten Erdölversorgung*. Energy Watch Group, Ludwig-Bölkow-Systemtechnik GmbH, Ottobrunn, Germany.

Fabiosa J.F., J.C. Beghin, Fengxia Dong, A. Elobeid, S. Tokgoz, and Tun-Hsiang Yu. (2010). Land Allocation Effects of the Global Ethanol Surge: Predictions from the International FAPRI Model. *Land Economics* **86**, 687–706.

Fargione J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. (2008). Land Clearing and the Biofuel Carbon Debt. *Science* **319**, 1235–1238.

Farrell A.E. (2008). Energy Notes. *News from the University of California Energy Institute*.

Fenton F.H. (1982). Survey of Cyclic Load Capabilities of Fossil-Steam Generating Units. *IEEE Transactions on Power Apparatus and Systems* **PAS-101**, 1410–1419.

Figueroa J.D., T. Fout, S. Plasynski, H. McIlvried, and R.D. Srivastava. (2008). Advances in CO2 capture technology. *International Journal of Greenhouse Gas Control* **2**, 9–20.

Finkenrath M. (2011). *Cost and Performance of Carbon Dioxide Capture from Power Generation*. International Energy Agency, Paris. 51 pp. Available at: /content/workingpaper/5kgggn8wk05l-en http://dx.doi.org/10.1787/5kgggn8wk05l-en.

Fischedick M., R. Schaeffer, A. Adedoyin, M. Akai, T. Bruckner, L. Clarke, V. Krey, I. Savolainen, S. Teske, D. Ürge-Vorsatz, and R. Wright. (2011). Mitigation Potential and Costs. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Fischedick M., R. Schaeffer, A. Adedoyin, M. Akai, L. Clarke, V. Krey, I. Savolainen, S. Teske, D. Ürge-Vorsatz, and R. Wright. (2011). Mitigation Potential and Costs. In: *Special Report on Renewable Energy Sources and Climate Change Mitigation*. O.E., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (ed.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1076, (ISBN: 978-1-107-60710-1). Available at: http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch10.pdf.

Fisher C., and R.G. Newell. (2008). Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management* **55**, 142–162.

Fleishman L.A., W.B. De Bruin, and M.G. Morgan. (2010). Informed Public Preferences for Electricity Portfolios with CCS and Other Low-Carbon Technologies. *Risk Analysis* **30**, 1399–1410.

Franco J., L. Levidow, D. Fig, L. Goldfarb, M. Honicke, and L. Mendonça. (2010). Assumptions in the European Union biofuels policy: frictions with experiences in Germany, Brazil and Mozambique. *Journal of Peasant Studies* **37**, 661–698.

Franco G., and A.H. Sanstad. (2008). Climate change and electricity demand in California. *Climatic Change* **87**, 139–151.

Fripp M. (2011). Greenhouse Gas Emissions from Operating Reserves Used to Backup Large-Scale Wind Power. *Environmental Science & Technology*. Available at: http://dx.doi.org/10.1021/es200417b.

Fritsch R. (2011). Comparative financial analysis of electricity utilities in West Africa. *Energy Policy* **39**, 6055–6064.

Fritsche U.R., R.E.H. Sims, and A. Monti. (2010). Direct and indirect land-use competition issues for energy crops and their sustainable production – an overview. *Biofuels, Bioproducts and Biorefining* **4**, 692–704.

Fusco F., G. Nolan, and J.V. Ringwood. (2010). Variability reduction through optimal combination of wind/wave resources: An Irish case study. *Energy* **35**, 314–325.

Gagnon, Luc, Hall, Charles A.S., and Brinker, Lysle. (2009). A Preliminary Investigation of Energy Return on Energy Investment for Global Oil and Gas Production. *Energies* **2**, 490–503.

Gawel E., and G. Ludwig. (2011). The iLUC dilemma: How to deal with indirect land use changes when governing energy crops? *Land Use Policy* **28**, 846–856.

GBEP. (2011). *The Global BioEnergy Partnership Indicators for Bioenergy*. FAO/GBEP, Rome, Italy.

Gehlhar M., A. Somwaru, P.B. Dixon, M.T. Rimmer, and A.R. Winston. (2010). Economywide Implications from US Bioenergy Expansion. *American Economic Review* **100**, 172–77.

Generation IV International Forum. (2009). *GIF R&D Outlook for Generation IV Nuclear Energy Systems*. OECD Nuclear Energy Agency, Paris, France.

Georgescu M., David B. Lobell, and Christopher B. Field. (2011). Direct climate effects of perennial bioenergy crops in the United States. *Proceedings of the National Academy of Sciences* **108**, 4307 – 4312.

German L., G.C. Schoneveld, and P. Pacheco. (2011). Local Social and Environmental Impacts of Biofuels: Global Comparative Assessment and Implications for Governance. *Ecology and Society* **16**. Available at: file:///Users/carolhunsberger/Documents/My Documents/PhD files/Supporting literature/My EndNote Library-Saved.Data/PDF/German_etal_2011_ES_social_impacts_governance_SI_synthesis-2503974916/German_etal_2011_ES_social_impacts_governance_SI_synthesis.pdf.

Giannakopoulos C., P. Hadjinicolaou, C. Zerefos, and G. Demosthenous. (2009). Changing energy requirements in the Mediterranean under changing climatic conditions. *Energies* **2**, 805–815.

Gibbs H.K., M. Johnston, J.A. Foley, T. Holloway, C. Monfreda, N. Ramankutty, and D. Zaks. (2008). Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology. *Environmental Research Letters* **3**, 034001.

Gilfillan S.M.V., B.S. Lollar, G. Holland, D. Blagburn, S. Stevens, M. Schoell, M. Cassidy, Z. Ding, Z. Zhou, G. Lacrampe-Couloume, and C.J. Ballentine. (2009). Solubility trapping in formation water as dominant CO2 sink in natural gas fields. *Nature* **458**, 614–618.

Gillenwater M., and S. Seres. (2011). *The Clean Development Mechanism: A review of the first international offset program*. Pew Center. Available at: http://www.c2es.org/docUploads/clean-development-mechanism-review-of-first-international-offset-program.pdf.

Giroux J. (2008). Turmoil in the Delta: trends and implications. *Perspectives on Terrorism* **2**, 11–22.

Global CCS Institute. (2011a). *Economic Assessment of Carbon Capture and Storage Technologies: 2011 Update,*. Global CCS IInstitute, Canberra, Australia.

Global CCS Institute. (2011b). *Global CCS Institute, 2011. The global status of CCS: 2011*. Global CCS Institute, Canberra, Australia. 156 pp. Available at: www.globalccsinstitute.com/resources/publications/global-status-ccs-2011.

Gohin A. (2008). Impacts of the European Biofuel Policy on the Farm Sector: A General Equilibrium Assessment. *Applied Economic Perspectives and Policy* **30**, 623–641.

Goldberg S., and R. Rosner. (2011). *Nuclear Reactors: Generation to Generation*. American Academy of Arts & Sciences, Cambridge, MA.

Goldemberg J., S.T. Coelho, and P. Guardabassi. (2008). The sustainability of ethanol production from sugarcane. *Energy Policy* **36**, 2086–2097.

Goldstein B., G. Hiriart, R. Bertani, C. Bromley, L. Guitiérrez-Negrín, E. Huenges, and H. Muraoka. (2011). Geothermal Energy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, A. Ragnarsson, J. Tester, V. Zui, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Goodman A., A. Hakala, G. Bromhal, D. Deel, T. Rodosta, S. Frailey, M. Small, D. Allen, V. Romanov, J. Fazio, N. Huerta, D. McIntyre, B. Kutchko, and G. Guthrie. (2011). U.S. DOE methodology for the development of geologic storage potential for carbon dioxide at the national and regional scale. *International Journal of Greenhouse Gas Control* **5**, 952–965.

Graedel T.E. (2011). On the Future Availability of the Energy Metals. *Annual Review of Materials Research* **41**, 323–335.

Graedel T.E., and E. van der Voet (Eds.). (2009). *Linkages of Sustainability*. MIT Press, Cambridge, MA.

Grubb Michael, L. Butler, and P. Twomey. (2006). Diversity and security in UK electricity generation: The influence of low-carbon objectives. *Energy Policy* **34**, 4050–4062.

Grubler A. (2008). Energy transitions. In: *Encyclopedia of Earth*. C. Cleveland, (ed.), Environmental Information, Washington, D.C., .Available at: http://www.eoearth.org/article/Energytransitions.

Guivarch C., and S. Hallegatte. (2011). Existing infrastructure and the 2°C target. *Climatic Change*.

Gurung A., A. Kumar Ghimeray, and S.H.A. Hassan. (2011). The prospects of renewable energy technologies for rural electrification: A review from Nepal. *Energy Policy* **40**, 374–380.

Haberl H., D. Sprinz, M. Bonazountas, P. Cocco, Y. Desaubies, M. Henze, O. Hertel, R.K. Johnson, U. Kastrup, P. Laconte, E. Lange, P. Novak, J. Paavola, A. Reenberg, S. van den Hove, T. Vermeire, P. Wadhams, and T. Searchinger. (2012). Correcting a fundamental error in greenhouse gas accounting related to bioenergy. *Energy Policy* **45**, 18–23.

Ha-Duong M., M. Grubb, and J.C. Hourcade. (1997). Influence of socioeconomic inertia and uncertainty on optimal CO2 emissions abatment. *Nature* **390**, 270–273.

Haeseldonckx D., and W. D’haeseleer. (2007). Estimating Global Hydrogen Production from Wind. *International Journal of Hydrogen Energy* **32**, 1381–1386.

Hall J., S. Matos, L. Severino, and N. Beltrão. (2009). Brazilian biofuels and social exclusion: established and concentrated ethanol versus emerging and dispersed biodiesel. *Journal of Cleaner Production* **17, Supplement 1**, S77–S85.

Halsnaes K., P. Shukla, D. Ahuja, G. Akumu, R. Beale, J. Edmonds, C. Gollier, A. Grubler, M. Ha Duong, A. Markandya, M. McFarland, T. Sugiyama, and A. Villavicencio. (2007). Framing Issues. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,, .

Hamilton M.R., H.J. Herzog, and J.E. Parsons. (2009). Cost and U.S. public policy for new coal power plants with carbon capture and sequestration. *Energy Procedia* **1**, 4487–4494.

Hamlet A.F., and S.Y. Lee. (2010). Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. *Climatic Change* **102**, 103–128.

Hasan M.M.F., I.A. Karimi, and C.M. Avison. (2011). Preliminary synthesis of fuel gas networks to conserve energy and preserve the environment. *Industrial and Engineering Chemistry Research* **50**, 7414–7427.

Havlík P., U.A. Schneider, E. Schmid, H. Böttcher, S. Fritz, R. Skalský, K. Aoki, S. De Cara, G. Kindermann, F. Kraxner, S. Leduc, I. McCallum, A. Mosnier, T. Sauer, and Michael Obersteiner. (2011). Global land-use implications of first and second generation biofuel targets. *Energy Policy* **39**, 5690–5702.

Hekkenberg M., H.C. Moll, and A.J.M.S. Uiterkamp. (2009). Dynamic temperature dependence patterns in future energy demand models in the context of climate change. *Energy* **34**, 1797–1806.

Hernández J.C., A. Medina, and F. Jurado. (2008). Impact comparison of PV system integration into rural and urban feeders. *Energy Conversion and Management* **49**, 1747–1765.

Hertel T.W., A. Golub, A. D. Jones, M. O’Hare, R. Plevin, and D. M. Kammen. (2010). Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: Estimating Market-Mediated Responses. *BioScience* **60**, 223–231.

Hertwich E.G., Ester van der Voet, M. Huijbregts, S. Sangwon, A. Tukker, P. Kazmierczyk, M. Lenzen, J. McNeely, and Y. Moriguchi. (2010). *Environmental Impacts of Consumption and Production: Priority Products and Materials*. UNEP, Paris.

Herzog H.J. (2011). Scaling up carbon dioxide capture and storage: From megatons to gigatons. *Energy Economics* **33**, 597–604.

Herzog H., K. Smekens, P. Dadhich, J. Dooley, Y. Fujii, O. Hohmeyer, and K. Riahi. (2005). Cost and economic potential. In: *IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]*.Cambridge, UK and New York, NY, USA, pp.442, .Available at: http://www.ipcc.ch/publications_and_data/_reports_carbon_dioxide.htm.

Hillier JONATHAN, C. WHITTAKER, G. DAILEY, M. AYLOTT, E. CASELLA, G.M. RICHTER, A. RICHE, R. MURPHY, G. TAYLOR, and P. SMITH. (2009). Greenhouse gas emissions from four bioenergy crops in England and Wales: Integrating spatial estimates of yield and soil carbon balance in life cycle analyses. *GCB Bioenergy* **1**, 267–281.

von Hippel F., M. Bunn, A. Diakov, M. Ding, R. Goldston, T. Katsuta, M.V. Ramana, T. Suzuki, S. Voss, and S. Yu. (2011). Nuclear Energy. In: *Global energy assessment*. H.-H. Rogner, R.F. Aguilera, C.L. Archer, R. Bertani, S.C. Bhattacharya, M.B. Dusseault, L. Gagnon, V. Yakushev, (eds.), International Institute for Applied Systems Analysis and Cambridge University Press, Vienna, Austria; Cambridge, UK & New York, NY, .

Hirschberg S., P. Burgherr, G. Spiekerman, E. Cazzoli, J. Vitazek, and L. Cheng. (2003). Assessment of severe accident risks. In: Integrated Assessment of Sustainable Energy Systems in China. The China Energy Technology Program - A framework for decision support in the electric sector of Shandong province. *Alliance for Global Sustainability Series* **4**, 587–660.

Hirschberg S., P. Burgherr, G. Spiekerman, and R. Dones. (2004). Severe accidents in the energy sector: comparative perspective. *Journal of Hazardous Materials* **111**, 57–65.

Hochman G., D. Rajagopal, and D. Zilberman. (2010). The effect of biofuels on crude oil markets. *AgBioForum* **13**, 112–118.

Holttinen H., P. Meibom, A. Orths, B. Lange, M. O'Malley, J.O. Tande, A. Estanqueiro, E. Gomez, L. Söder, G. Strbac, J.C. Smith, and F. van Hulle. (2011). Impacts of large amounts of wind power on design and operation of power systems, results of IEA collaboration. *Wind Energy* **14**, 179–192.

Honnery D., and P. Moriarty. (2009). Estimating Global Hydrogen Production from Wind. *International Journal of Hydrogen Energy* **34**, 727–736.

Hood C. (2011). *Electricity Market Design for Decarbonisation*. IEA/OECD, Paris, France. 15–20 pp.

Hoogwijk M., and W. Graus. (2008). *Global Potential of Renewable Energy Sources: A Literature Assessment*. Ecofys, Utrecht, The Netherlands.

Hoogwijk M., D. van Vuuren, B. de Vries, and W. Turkenburg. (2007). Exploring the impact on cost and electricity production of high penetration levels of intermittent electricity in OECD Europe and the USA, results for wind energy. *Energy* **32**, 1381–1402.

Hoogwijk M.M, A Faaij, B.J.M de Vries, and W Turkenburg. (2009). Exploration of regional and global cost-supply curves of biomass energy from short-rotation crops at abandoned croplands and rest land under four IPCC SRES land-use scenarios. *Biomass and Bioenergy* **33**, 26–43.

van der Horst D., and S. Vermeylen. (2011). Spatial scale and social impacts of biofuel production. *Biomass and Bioenergy* **35**, 2435–2443.

Hotelling H. (1931). The Economics of Exhaustible Resources. *Journal of Political Economy* **39**, 137–175.

Hovorka S.D., Sally M. Benson, C. Doughty, B.M. Freifeld, S. Sakurai, T.M. Daley, Y.K. Kharaka, M.H. Holtz, R.C. Trautz, H.S. Nance, L.R. Myer, and K.G. Knauss. (2006). Measuring permanence of CO2 storage in saline formations: the Frio experiment. *Environmental Geosciences* **13**, 105–121.

Howarth R., R. Santoro, and A. Ingraffea. (2011). Methane and the Greenhouse-gas Footprint of Natural Gas from Shale Formations. *Climate Change* **106**, 679–690.

Hsu D.D., D. Inman, Garvin A. Heath, E.J. Wolfrum, M.K. Mann, and A. Aden. (2010). Life Cycle Environmental Impacts of Selected U.S. Ethanol Production and Use Pathways in 2022. *Environmental Science & Technology* **44**, 5289–5297.

Huang Y., S. Rezvani, D. McIlveen-Wright, A. Minchener, and N. Hewitt. (2008). Techno-economic study of CO2 capture and storage in coal fired oxygen fed entrained flow IGCC power plants. *Fuel Processing Technology* **89**, 916–925.

Hudiburg T.W., B.E. Law, C. Wirth, and S. Luyssaert. (2011). Regional carbon dioxide implications of forest bioenergy production. *Nature Clim. Change* **1**, 419–423.

Huijbregts M.A.J., S. Hellweg, Rolf Frischknecht, H.W.M. Hendriks, K. Hungerbühler, and A.J. Hendriks. (2010). Cumulative Energy Demand As Predictor for the Environmental Burden of Commodity Production. *Environmental Science & Technology* **44**, 2189–2196.

Hutton G., E. Rehfuess, and F. Tediosi. (2007). Evaluation of the Costs and Benefits of Interventions to Reduce Indoor Air Pollution. *Energy for Sustainable Development* **11**, 34–43.

IAEA. (2008). *The international nuclear and radiological event scale*. International Atomic Energy Agency, Vienna. 4 pp. Available at: internal-pdf://ines-2667996928/ines.pdf.

IAEA. (2011). Power Reactor Information System (IAEA PRIS). Available at: http://www.iaea.org/programmes/a2/.

IEA. (2003a). *World Energy Investment Outlook 2003*. International Energy Agency. OECD, Paris.

IEA. (2003b). *The Power to Choose. Demand Response in Liberalised Electricity Markets*. International Energy Agency, Paris, France.

IEA. (2005a). *Projected Costs of Generating Electricity*. International Energy Agency. OECD, Paris.

IEA. (2005b). *Resources to Reserves 2005: Oil and gas technologies for the energy markets of the future*. International Energy Agency, Paris.

IEA. (2006). *Hydrogen Production and Storage: R&D Priorities and Gaps.* International Energy Agency. OECD, Paris. Available at: http://www.iea.org/papers/2006/hydrogen.pdf.

IEA. (2007a). *Renewables for Heating and Cooling, Untapped Potential*. International Energy Agency. OECD, Paris.

IEA. (2007b). *Renewables in Global Energy Supply: An IEA Fact Sheet*. International Energy Agency. OECD, Paris.

IEA. (2008a). *Deploying Renewable Energies: Principles for Effective Policies*. International Energy Agency. OECD, Paris.

IEA. (2008b). *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*. International Energy Agency, Paris.

IEA. (2009a). *World Energy Outlook 2009*. International Energy Agency, Paris.

IEA. (2009b). *Coal Mine Methane in Russia - Capturing the safety and environmental benefits*. International Energy Agency, Paris.

IEA. (2010a). *World Energy Outlook 2010*. International Energy Agency, Paris, France.

IEA. (2010b). *Energy Balances of Non-OECD Countries*. International Energy Agency, Paris, France. 554 pp.

IEA. (2010c). *Energy Technology Perspectives 2010: Scenarios & Strategies to 2050*. International Energy Agency, Paris, France.

IEA. (2010d). *Projected Costs of Generating Electricity -- 2010 Edition*. International Energy Agency, Paris. 218 pp.

IEA. (2010e). *Technology Roadmap Solar Photovoltaic Energy*. International Energy Agency, Paris, France.

IEA. (2010f). *World Energy Outlook 2010*. International Energy Agency, Paris.

IEA. (2010g). *Reviewing existing and proposed emissions trading systems*. IEA/OECD, Paris, France.

IEA. (2010h). *Sustainable Production of Second-Generation Biofuels: Potential and Perspectives in Major Economies and Developing Countries*. International Energy Agency, Paris. Available at: http://www.mozilla.com/en-US/firefox/3.6.13/whatsnew/.

IEA. (2011a). *World energy outlook 2011*. International Energy Agency., Paris.

IEA. (2011b). *World Energy Outlook 2011 Special Report: Are We Entering a Golden Age of Gas?* International Energy Agency, Paris.

IEA. (2011c). *Co2 emission from fuel combustion*. International Energy Agency. OECD, Paris, France.

IEA. (2011d). *Energy Balances of Non-OECD Countries*. International Energy Agency, Paris, France. 538 pp.

IEA. (2011e). *Deploying Renewables 2011: Best and Future Policy Practice*. OECD/IEA, Paris, France.

IEA. (2011f). *Harnessing Variable Renewables: A Guide to the Balancing Challenge*. International Energy Agency, Paris, France.

IEA. (2011g). *Resources to Reserves 2011: Oil, gas and coal technologies for the energy markets of the future*. International Energy Agency, Paris.

IEA. (2011h). *Energy for all: Financing access for the poor. Special early excerpt of the World Energy Outlook 2011*. IEA/OECD, Paris, France.

IEA. (2011i). *Clean Energy*. OECD/IES, Paris, France. Available at: http://www.iea.org/papers/2011/CEM_Progress_Report.pdf.

IEA. (2011j). *Summing up the parts. Combining policy instruments for least-cost climate mitigation strategies*. IEA, OECD, Paris, France.

IEA. (2011k). *Energy Technology Perspectives 2010. Scenarios & Strategies to 2050*. IEA/OECD, Paris, France.

IEA. (2012a). *Golden Rules for a Golden Age of Gas. World Energy Outlook. Special Report on Unconventional Gas.* IEA, OECD.

IEA. (2012b). *Tracking Clean Energy Progress. Energy Technology Perspectives 2012 excerpt as IEA input to the Clean Energy Ministerial*. Paris, France.

IEA Bioenergy. (2006). *Biogas Upgrading to Vehicle Fuel Standards and Grid Injection*. IEA Bioenergy Task 37. Available at: http://www.iea-biogas.net/_download/publi-task37/upgrading_report_final.pdf.

IEA Bioenergy. (2009). *Biogas upgrading technologies-developments and innovations*. IEA Bioenergy Task 37. Available at: http://www.iea-biogas.net/_download/publi-task37/upgrading_rz_low_final.pdf.

IEA Bioenergy. (2011). *IEA Biogas Task 37 Country Reports and Plant Lists*. IEA Bioenergy Task 37. Available at: http://www.iea-biogas.net.

IEAGHG. (2009). *CO2 Storage in Depleted Gas Fields*. IEA Greenhouse Gas R&D Programme, Cheltenham, UK.

IEAGHG. (2011). *Global Analysis of Storage Resources and Recommendations to Policy Makers to Meet CCS Deployment Objectives*. IEA Greenhouse Gas R&D Programme, Cheltenham, UK.

IEPort.RU. (2012). *В 2011г электропотребление в Московской энергосистеме выросло на 0,5% (In 2011, electricity consumption in the Moscow Energy increased by 0.5%)*. IEPort.RU. Available at: http://ieport.ru/39132-v-2011g-yelektropotreblenie-v-moskovskoj.html.

IGES. (2012). *IGES CDM Project Data Analysis & Forecasting CER Supply*. Institute for Global Environmental Strategies. Available at: http://enviroscope.iges.or.jp/modules/envirolib/upload/1045/attach/iges_cdm_da.zip.

IPCC. (2005). *IPCC special report on carbon dioxide capture and storage*. Cambridge University Press for the Intergovernmental Panel on Climate Change, Cambridge.

IPCC. (2011a). *Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN)*. Cambridge University Press, Cambridge, UK.

IPCC. (2011b). Summary for Policymakers. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

IPIECA, and API. (2007). *Oil and Natural Gas Industry Guidelines for Greenhouse Gas Reduction Projects. Part II: Carbon Capture and Geological Storage Emissions Reduction Family*. International Petroleum Industry Environmental Conservation Association and American Petroleum Institute, Washington, D.C.

IPIECA, and API. (2008). *Oil and Natural Gas Industry Guidelines for Greenhouse Gas Reduction Projects. Part III: Flare Reduction Project Family*. International Petroleum Industry Environmental Conservation Association and American Petroleum Institute, Washington, D.C.

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

Jaccard M., and N. Rivers. (2007). Heterogeneous capital stocks and the optimal timing for CO2 abatement. *Resource and Energy Economics* **29**, 1–16.

Jackson R.B., T.R. James, G.C. Josep, G.A. Ray, A. Roni, D.B. Dennis, B.B. Gordon, C. Ken, S.D. Noah, B.F. Christopher, A.H. Bruce, G.J. Esteban, M.K. Lara, D.N. Marcelo, and E.P. Diane. (2008). Protecting climate with forests. *Environmental Research Letters* **3**, 044006.

Jacobson M.Z., and Mark A. Delucchi. (2011). Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy* **39**, 1154–1169.

Jakob M., R. Haller, and R. Marschinski. (2012). Will history repeat itself? Economic convergence and convergence in energy use patterns. *Energy Economics*.

Jansen J.C., and A.J. Seebregts. (2010). Long-term energy services security: What is it and how can it be measured and valued? *Energy Policy* **38**, 1654–1664.

Janssen R., and D.. Rutz. (2011). Sustainability of biofuels in Latin America: Risks and opportunities. *Energy Policy* **39**, 5717–5725.

Jaramillo P., W.M. Griffin, and H.S. Matthews. (2007). Comparative Life-Cycle Air Emissions of Coal, Domestic Natural Gas, LNG, and SNG for Electricity Generation. *Environmental Science and Technology* **42**.

Jernelöv A. (2010). The threats from oil spills: Now, then, and in the future. *Ambio* **39**, 353–266.

Jeuland M.A., and S.K. Pattanayak. (2012). Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. *PLoS ONE* **7**, e30338.

Johansson D., and Christian Azar. (2007). A scenario based analysis of land competition between food and bioenergy production in the US. *Climatic Change* **82**, 267–291.

Johnson M.R., and A.R. Coderre. (2011). An analysis of flaring and venting activity in the Alberta upstream oil and gas industry. *Journal of the Air and Waste Management Association* **61**, 190–200.

Johnson E. (2009). Goodbye to carbon neutral: Getting biomass footprints right. *Environmental Impact Assessment Review* **29**, 165–168.

Johnson N., and Joan Ogden. (2011). Detailed spatial modeling of carbon capture and storage (CCS) infrastructure deployment in the southwestern United States. *Energy Procedia* **4**, 2693–2699.

Johnson T.L., and David W. Keith. (2004). Fossil electricity and CO2 sequestration: how natural gas prices, initial conditions and retrofits determine the cost of controlling CO2 emissions. *Energy Policy* **32**, 367–382.

Jordaan S.M., D.W. Keith, and B. Stelfox. (2009). Quantifying land use of oil sands production: a life cycle perspective. *Environmental Research Letters* **4**, 024004.

Jordan P., and Sally Benson. (2009). Well blowout rates and consequences in California Oil and Gas District 4 from 1991 to 2005: implications for geological storage of carbon dioxide. *Environmental Geology* **57**, 1103–1123.

Joskow P.L. (2008). Capacity Payments in Imperfect Electricity Markets: Need and Design. *Utility Policy* **16**, 159–170.

Junginger M., W. van Sark, and Andre Faaij (Eds.). (2010). *Technological learning in the energy sector – Lessons for Policy, Industry and Science.* Edward Elgar, Cheltenham, UK.

Kaiser M.J., Y. Yu, and C.J.J. Jablonowski. (2009). Modeling lost production from destroyed platforms in the 2004-2005 Gulf of Mexico hurricane seasons. *Energy* **34**, 1156–1171.

Kanagawa M., and T. Nakata. (2008). Assessment of Access to Electricity and the Socio-Economic Impacts in Rural Areas of Developing Countries. *Energy Policy* **36**, 2016–2029.

Karacan C.Ö., F.A. Ruiz, M. Cotè, and S. Phipps. (2011). Coal mine methane: A review of capture and utilization practices with benefits to mining safety and to greenhouse gas reduction. *International Journal of Coal Geology* **86**, 121–156.

Karakurt I., G. Aydin, and K. Aydiner. (2011). Mine ventilation air methane as a sustainable energy source. *Renewable and Sustainable Energy Reviews* **15**, 1042–1049.

Kargbo D.M., R.G. Wilhelm, and D.J. Campbell. (2010). Natural gas plays in the Marcellus Shale: challenges and potential opportunities. *Environmental Science & Technology* **44**, 5679–5684.

Karl T., JM Melillo, and T. Peterson (Eds.). (2009). *Global climate change impacts in the United States*. Cambridge University Press, Cambridge, UK, 188 pp.

Kato T., K. Okugawa, Y. Sugihara, and T. Matsumura. (1999). Conceptual Design of Uranium Recovery Plant from Seawater. *Journal of the Thermal and Nuclear Power Engineering Society* **50**, 71–77.

Keane A., M. Milligan, C.J. Dent, B. Hasche, C. D'Annunzio, K. Dragoon, H. Holttinen, N. Samaan, L. Soder, and M. O'Malley. (2011). Capacity Value of Wind Power. *IEEE Transactions on Power Systems* **26**, 564–572.

Keppler J.H., and M. Cruciani. (2010). Rents in the European power sector due to carbon trading. *Energy Policy* **38**, 4280–4290.

Kesicki F., and P. Ekins. (2011). Marginal abatement cost curves: a call for caution. *Climate Policy*, 1–18.

Ketzer J.M., R. Iglesias, and S. Einloft. (2011). Reducing greenhouse gas emissions with CO2 capture and geological storage. In: *Handbook of Climate Change Mitigation*. C. Wei-Yin, J. Seiner, Toshio Suzuki, M. Lackner, (eds.),.

Khanna M., C.L. Crago, and M. Black. (2011). Can biofuels be a solution to climate change? The implications of land use change-related emissions for policy. *Interface Focus* **1**, 233–247.

Kheshgi H., S.J. Smith, and J Edmonds. (2005). Emissions and Atmospheric CO2 Stabilization: Long-term Limits and Paths," Mitigation and Adaptation Strategies for Global Change. *Climate Change and Environmental Policy* **10**, 213–220.

Kim H.-G. (2009). *The Design Characteristics of Advanced Power Reactor 1400*. International Atomic Energy Agency, Vienna, Austria.

Kim Seungdo, and B.E. Dale. (2011). Indirect land use change for biofuels: Testing predictions and improving analytical methodologies. *Biomass and Bioenergy* **35**, 3235–3240.

Kirby B. (2007). Load Response Fundamentally Matches Power System Reliability Requirements. In Proceedings: *Power Engineering Society General Meeting, 2007. IEEE*. (ISBN: 1932-5517), (DOI: 10.1109/PES.2007.386227). 2007, 1–6 pp.

Klara J.M., and J.E. Plunkett. (2010). The potential of advanced technologies to reduce carbon capture costs in future IGCC power plants. *International Journal of Greenhouse Gas Control* **4**, 112–118.

Kleijn R., and E. van der Voet. (2010). Resource constraints in a hydrogen economy based on renewable energy sources: An exploration. *Renewable and Sustainable Energy Reviews* **14**, 2784–2795.

Knapp S.R. (1969). PUMPED STORAGE: THE HANDMAIDEN OF NUCLEAR POWER. *IEEE (Inst. Elec. Electron. Eng.), Spectrum, 6: No. 4, 46-52 (Apr. 1969).*

Kolhe M., S. Kolhe, and J.C. Joshi. (2002). Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India. *Energy Economics* **24**, 155–165.

Kontovas C.A., H.N. Psaraftis, and N.P. Ventikos. (2010). An empirical analysis of IOPCF oil spill cost data. *Marine Pollution Bulletin* **60**, 1455–1466.

Koorneef J., T. van Keulen, A Faaij, and W Turkenburg. (2008). Life cycle assessment of a pulverized coal power plant with post-combustion capture, transport and storage of CO2. *International Journal of Greenhouse Gas Control* **2**, 448–467.

Koorneef J., A. Ramirez, Turkenburg W., and A. Faaij. (2011). The environmental impact and risk assessment of CO2 capture, transport and storage.An evaluation of the knowledge base. *Progress in Energy and Combustion Science*.

Kopp A., H. Class, and R. Helmig. (2009). Investigations on CO2 storage capacity in saline aquifers,ÄîPart 2: Estimation of storage capacity coefficients. *International Journal of Greenhouse Gas Control* **3**, 277–287.

Kopytko N., and J. Perkins. (2011). Climate change, nuclear power, and the adaptation-mitigation dilemma. *Energy Policy* **39**, 318–333.

Krevor S.C.M., R. Pini, L. Zuo, and S.M. Benson. (2012). Relative permeability and trapping of CO2 and water in sandstone rocks at reservoir conditions. *Water Resources* **48**.

Krey V., and K. Riahi. (2009). Implications of delayed participation and technology failure for the feasibility, costs, and likelihood of staying below temperature targets-greenhouse gas mitigation scenarios for the 21st century. *Energy Economics* **31**, S94–S106.

Kruyt B., D.P. van Vuuren, H.J.M. de Vries, and H. Groenenberg. (2009). Indicators for energy security. *Energy Policy* **37**, 2166–2181.

Kuik O.J., M. Bastos-Lima, and J. Gupta. (2011). Energy Security in a Developing World. *Climate Change* **2**, 627–634.

Kumar A., T. Schei, A. Ahenkorah, R. Caceras Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, and Z. Liu. (2011). Hydropower. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Kuznetsov V. (2008). Design and technology development status and common design considerations for innovative small and medium sized reactors. In Proceedings: *Proceedings of the 16th International Conference on Nuclear Engineering ICONE16*. Orlando, Florida. 11-May-2008, .

Leuchtenböhmer S., and C. Dienst. (2010). Future development of the upstream greenhouse gas emissions from natural gas industry, focussing on Russian gas fields and export pipelines. *Journal of Integrative Environmental Sciences* **7**, 39–48.

Lewis W.B. (1972). *Energy in the Future: the Role of Nuclear Fission and Fusion*. Proceedings of the Royal Society of Edinburgh, Sect. A.

Lewis, S. Estefen, J. Huckerby, W. Musial, T. Pontes, and J. Torres-Martinez. (2011). Ocean Energy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, pp.49 pp, .

Liang D., and W. Wu. (2009). Barriers and incentives of CCS deployment in China: results from semi-structured interviews. *Energy Policy* **37**, 2421–2432.

Lin C.-C., and Y.-W. Chen. (2011). Performance of a cross-flow rotating packed bed in removing carbon dioxide from gaseous streams by chemical absorption. *International Journal of Greenhouse Gas Control* **5**, 668–675.

Liska A.J., and R.K. Perrin. (2009). Indirect land use emissions in the life cycle of biofuels: regulations vs science. *Biofuels, Bioproducts and Biorefining* **3**, 318–328.

de Lucena A.F.P., A.S. Szklo, and R. Schaeffer. (2009). Renewable energy in an unpredictable and changing climate. *Energy Review* **1**, 22–25.

Luckow P., M.A. Wise, J. J. Dooley, and S. H. Kim. (2010). Large-scale utilization of biomass energy and carbon dioxide capture and storage in the transport and electricity sectors under stringent CO2 concentration limit scenarios. *International Journal of Greenhouse Gas Control* **4**, 865–877.

Madaeni S.H., R. Sioshansi, and P. Denholm. (2011). How Thermal Energy Storage Enhances the Economic Viability of Concentrating Solar Power. *Proceedings of the IEEE* **PP**, 1–13.

Malone E.L., James J. Dooley, and J.A. Bradbury. (2010). Moving from misinformation derived from public attitude surveys on carbon dioxide capture and storage towards realistic stakeholder involvement. *International Journal of Greenhouse Gas Control* **4**, 419–425.

Marland G., R.A. Pielke Sr, M. Apps, R. Avissar, R.A. Betts, K.J. Davis, P.C. Frumhoff, S.T. Jackson, L.A. Joyce, P. Kauppi, J. Katzenberger, K.G. MacDicken, R.P. Neilson, J.O. Niles, D. dutta S. Niyogi, R.J. Norby, N. Pena, N. Sampson, and Y. Xue. (2003). The climatic impacts of land surface change and carbon management, and the implications for climate-change mitigation policy. *Climate Policy* **3**, 149–157.

Marland G., and B. Schlamadinger. (1997). Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. *Biomass and Bioenergy* **13**, 389–397.

Martinot E. (1998). Energy efficiency and renewable energy in Russia: Transaction barriers, market intermediation and capacity building. *Energy Policy*, 905–915.

Masera O.R., B.D. Saatkamp, and Daniel M Kammen. (2000). From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. *World Development* **28**, 2083–2103.

Masui T., K. Matsumoto, Y. Hijioka, T. Kinoshita, T. Nozawa, S. Ishiwatari, E. Kato, P. Shukla, Y. Yamagata, and M. Kainuma. (2011). An emission pathway for stabilization at 6W/m2 radiative forcing. *Climatic Change* **109**, 59–76.

Matteo E.N., and G.W. Scherer. (2012). Experimental study of the diffusion-controlled acid degradation of Class H Portland cement. *International Journal of Greenhouse Gas Control*. Available at: http://www.sciencedirect.com/science/article/pii/S175058361100140X.

Mazón A.J., I. Zamora, P. Eguia, E. Torre, S. Miguelez, R. Medina, and J.R. Saenz. (2004). Analysis of traditional suspension strings with GTACSR conductors. *IEEE Transactions on Power Delivery* **Vol. 19**.

McCoy S.T., and Edward S. Rubin. (2008). An engineering-economic model of pipeline transport of CO2 with application to carbon capture and storage. *International Journal of Greenhouse Gas Control* **2**, 219–229.

McKechnie J., S. Colombo, J. Chen, W. Mabee, and Heather L. MacLean. (2011). Forest Bioenergy or Forest Carbon? Assessing Trade-Offs in Greenhouse Gas Mitigation with Wood-Based Fuels. *Environmental Science & Technology* **45**, 789–795.

Meinshausen M., N. Meinshausen, W. Hare, S.C. Raper, K. Frieler, R. Knutti, D.J. Frame, and M.R. Allen. (2009). Greenhouse-Gas Emission Targets for Limiting Global Warming to 2°C. *Nature* **458**, 1158–62.

Melillo J.M., John M. Reilly, D.W. Kicklighter, A.C. Gurgel, T.W. Cronin, S. Paltsev, B.S. Felzer, X. Wang, A.P. Sokolov, and C.A. Schlosser. (2009). Indirect Emissions from Biofuels: How Important? *Science* **326**, 1397–1399.

Mendez V.H., J. Rivier, J.I. de la Fuente, T. Gomez, J. Arceluz, J. Mari-n, and A. Madurga. (2006). Impact of distributed generation on distribution investment deferral. *International Journal of Electrical Power & Energy Systems* **28**, 244–252.

Meshakti N. (2007). The safety and reliability of complex energy processing systems. *Energy Sources Part B - Economics Planning and Policy* **2**, 141–154.

Mideksa T.K., and S. Kallbekken. (2010). The impact of climate change on the electricity market: a review. *Energy Policy* **38**, 3579–3585.

Miller E., L.M. Bell, and L. Buys. (2007). Public understanding of carbon sequestration in Australia: Socio-demographic predictors of knowledge, engagement and trust. *International Journal of Emerging Technologies and Society* **5**, 15–33.

Milligan M., and B. Kirby. (2010). *Utilizing Load Response for Wind and Solar Integration and Power System Reliability*. National Renewable Energy Laboratory, Golden, CO. Available at: www.nrel.gov/docs/fy10osti/48247.pdf.

Mills A., A. Phadke, and R. Wiser. (2011). Exploration of resource and transmission expansion decisions in the Western Renewable Energy Zone initiative. *Energy Policy* **39**, 1732–1745.

Millstein D., and S. Menon. (2011). Regional climate consequences of large-scale cool roof and photovoltaic array deployment. *Environmental Research Letters* **6**, 034001.

Mingorría S., G. Gamboa, and A. Alonso-Fradejas. (2010). *Metabolismo socio-ecológico de comunidades campesinas Q'eqchi' y la expansión de la agro-industria de caña de azúcar y palma Africana□: Valle del Río Polochic, Guatemala*. Instituto de Ciencia y Technología Ambientales and Instituto de Estudios Agrarios y Rurales, Barcelona and Mexico, (ISBN: 9789929561175).

MIT. (2011). *The future of natural gas*. Massachusetts Institute of Technology., Cambridge, USA.

Mitchell C., J. Sawin, G.R. Pokharel, D. M. Kammen, Z. Wang, S. Fifita, M. Jaccard, O. Langniss, H. Lucas, A. Nadai, R. Trujillo Blanco, E. Usher, A. Verbruggen, R. Wüstenhagen, and K. Yamaguchi. (2011). Policy, Financing and Implementation. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Moe E. (2010). Energy, industry and politics: Energy, vested interests, and long-term economic growth and development. *Energy* **35**, 1730–1740.

Möllersten Kenneth, and S. Grönkvist. (2007). All CO2 is equal in the atmosphere--A comment on CDM GHG accounting standards for methane recovery and oxidation projects. *Energy Policy* **35**, 3675–3680.

Mondal M.A.H., L. Kamp, and N. Pachova. (2010). Drivers, barriers and strategies for implementation of renewable energy technologies in rural areas in Bangladesh - An innovation system analysis. *Energy Policy* **38**, 4626–4634.

Moomaw W., F. Yamba, M. Kamimoto, L. Maurice, J. Nyboer, K. Urama, and T. Weir. (2011). Introduction: Renewable Energy and Climate Change. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Moriarty P., and D. Honnery. (2007). Intermittent Renewable Energy: The Only Future Source of Hydrogen? *International Journal of Hydrogen Energy* **32**, 1616–1624.

Moriarty P., and D. Honnery. (2012). What is the global potential for renewable energy? *Renewable and Sustainable Energy Reviews* **16**, 244–252.

Morris J., S. Paltsev, and John M. Reilly. (2008). *Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model*. MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA.

Mulugetta Y., and F. Urban. (2010). Deliberating on Low Carbon Development. *Energy Policy* **38**, 7546–7549.

Myung S., H. Choi, C. Jeong, K. Song, J. Lee, G. Park, H. Kim, W. Ko, JJ Park, K. Kim, H. Lee, and JH Park. (2006). The Status and Prospect of DUPIC Fuel Technology. *Nuclear Engineering and Technology* **38**.

Nassar A.M., L. Harfuch, L.C. Bachion, and M.R. Moreira. (2011). Biofuels and land-use changes: searching for the top model. *Interface Focus* **1**, 224–232.

Nauclér T., and P.A. Enkvist. (2009). *Pathways to a Low-Carbon Economy - Version 2 of the Global Greenhouse Gas Abatement Cost Curve*. McKinsey & Company.

NEA. (2006). *Forty Years of Uranium Resources, Production and Demand in Perspective – The Red Book Perspective*. OECD Nuclear Energy Agency, Paris, France.

NEA. (2008). *Nuclear Energy Outlook 2008*. Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD), Paris, France.

NEA, and IAEA. (2010). *Uranium 2009: Resources, Production and Demand*. OECD Nuclear Energy Agency / IAEA, Paris, France.

Neij L. (1997). Use of Experience Curves to Analyze the Prospects for Diffusion and Adoption of Renewable Energy Technology. *Energy Policy* **23**, 1099–1107.

Nemet G.F. (2009). Net Radiative Forcing from Widespread Deployment of Photovoltaics. *Environmental Science & Technology* **43**, 2173–2178.

NERI. (2009). *Socio-cultural barriers to the development of a sustainable energy system– the case of hydrogen*. National Environmental Research Institute, Aarhus University, Aarhus, Denmark.

NETL. (2010). Carbon Sequestration Atlas of the United States and Canada, Third Edition. Available at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlas/index.html.

DOE NETL. (2010). *Cost and performance baseline for fossil energy power plants study, Vol. 1: Bituminous coal and natural gas to electricity (Revision 2)*. United States.

Neuhoff K., B. Hobbs, and D. Newberry. (2011). *Congestion Management in European Power Networks: Criteria to Assess the Available Options*. DIW (German Institute for Economic Research).

Nguyen K.Q. (2007). Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. *Energy Policy* **35**, 2579–2589.

Njakou Djomo S., and R. Ceulemans. (2012). A comparative analysis of the carbon intensity of biofuels caused by land use changes. *GCB Bioenergy* **4**, 392–407.

Nobukawa H., M. Kitamura, S.A.M. Swylem, and K. Ishibashi. (1994). Development of a floating type system for uranium extraction from seawater using sea current and wave power. In Proceedings: *Proceedings of the 4th International Offshore and Polar Engineering Conference*. Osaka, Japan. 10-April-1994, .

Nord L.O., R. Anantharaman, and O. Bolland. (2009). Design and off-design analyses of a pre-combustion CO2 capture process in a natural gas combined cycle power plant. *International Journal of Greenhouse Gas Control* **3**, 385–392.

Nouni M.R., S.C. Mullick, and T.C. Kandpai. (2008). Providing electricity access to remote areas in India: Niche areas for decentralized electricity supply. *Renewable Energy* **34**, 430–434.

O'Neill B., Keywan Riahi, and I. Keppo. (2010). Mitigation implications of midcentury targets that preserve long-term climate policy options. *PNAS* **107**, 1011–1016.

ODYSSEE. (2011). Overall energy efficiency trends and policies in the EU 27. Available at: www.odyssee-indicaators.org/publications/PDF/brochures/macro.pdf.

OECD. (2012). *Energy. OECD Green Growth Studies*. OECD Publishing. Available at: http://dx.doi.org/10.1787/9789264115118-en.

OECD / NEA. (2007). *Management of Recyclable Fissile and Fertile Materials*. OECD Nuclear Energy Agency, Paris.

OFGEM. (2011). *Ofgem Review: Final Report, Department of Energy & Climate Change*. Office of the Gas and Electricity Markets, London. 53 pp.

Ogawa T., S. Nakanishi, T. Shidahara, T. Okumura, and E. Hayashi. (2011). Saline-aquifer CO2 sequestration in Japan-methodology of storage capacity assessment. *International Journal of Greenhouse Gas Control* **5**, 318–326.

Olmos L., R. Cossent, E. Lobato, and T. Gómez. (2011). Barriers to the implementation of response options aimed at mitigating the impact of wind power on electricity systems. *Wind Energy* **14**, 781–795.

Ongena J., and van Oost. (2004). Energy for Future Centuries - Will Fusion be an Inexhaustible, Safe, and Clean Energy Source? *Fusion Science and Technology* **45**, 3–14.

Oosterkamp A., and J. Ramsen. (2008). *State-of-the-Art Overview of CO2 Pipline Transport with relevance to offshore pipelines*. http://polytec.no/, Norway. 87 pp. Available at: http://www.polytec.no/wp-content/uploads/POL-O-2007-138-A.pdf.

Oparoacha S., and S. Dutta. (2011). Gender and Energy for Sustainable Development. *Current Opinion in Environmental Sustainability* **3**, 265–271.

Orr F.M. (2009). Onshore Geologic Storage of CO2. *Science* **325**, 1656–1658.

Overmars K.P., E. Stehfest, J.P.M. Ros, and A.G. Prins. (2011). Indirect land use change emissions related to EU biofuel consumption: an analysis based on historical data. *Environmental Science & Policy* **14**, 248–257.

Ozaki M., and T. Ohsumi. (2011). CCS from multiple sources to offshore storage site complex via ship transport. *Energy Procedia* **4**, 2992–2999.

Pachauri S., A. Brew-Hammond, D.F. Barnes, D.H. Bouille, D.H. Gitonga, V. Modi, G. Prasad, A. Rath, and H. Zerriffi. (forthcoming). Energy Access for Development. In: *Global Energy Assessment: Toward a Sustainable Future*. L. Gomez-Echeverri, T.B. Johansson, N. Nakicenovic, A. Patwardhan, (eds.), International Institute for Applied Systems Analysis and Cambridge University Press, Laxenburg, Austria; Cambridge, UK & New York, USA, .

Padurean A., C.-C. Cormos, A.-M. Cormos, and P.-S. Agachi. (2011). Multicriterial analysis of post-combustion carbon dioxide capture using alkanolamines. *International Journal of Greenhouse Gas Control* **5**, 676–685.

Partzsch L. (2009). The Legitimacy of Biofuel Certification. *Agriculture and Human Values* **28**, 413–425.

Peck S.C., and Y.S. Wan. (1996). Analytic Solutions of Simple Greenhouse Gas Emission Models. In: *Economics of Atmospheric Pollution*. E.C. Van Ierland, K. Gorka, (eds.), Spinger Verlag, Berlin, .

Pehnt M. (2008). Environmental impacts of distributed energy systems-The case of micro cogeneration. *Environmental Science and Policy* **11**, 25–37.

Pehnt Martin. (2006). Dynamic life cycle assessment (LCA) of renewable energy technologies. *Renewable Energy* **31**, 55–71.

Pehnt Martin, M. Oeser, and D.J. Swider. (2008). Consequential environmental system analysis of expected offshore wind electricity production in Germany. *Energy* **33**, 747–759.

Pérez-Arriaga I. (2009). *Regulatory Instruments for Deployment of Clean Energy Technologies*. MIT, Cambridge, MA.

Perez-Arriaga I.J., and C. Batlle. (2012). Impacts of Intermittent Renewables on Electricity Generation System Operation. *Economics of Energy & Environmental Policy* **1**. Available at: http://www.iaee.org/en/publications/eeeparticle.aspx?id=17.

PetroMin Pipeliner. (2010). *Flow assurance - Solutions for oil and gas pipeline problems*. PetroMin Pipeliner. 45–49 pp. Available at: http://www.pm-pipeliner.safan.com/mag/ppl1210/t45.pdf.

Petron G., G. Frost, B.R. Miller, A.I. Hirsch, S.A. Montzka, A. Karion, M. Trainer, C. Sweeney, A.E. Andrews, L. Miller, J. Kofler, A. Bar-Ilan, E.J. Dlugokencky, L. Patrick, C.T. Moore, T.B. Ryerson, C. Siso, W. Kolodzey, P.M. Lang, T. Conway, P. Novelli, K. Masarie, B. Hall, D. Guenther, D. Kitzis, J. Miller, D. Welsh, D. Wolfe, W. Neff, and P. Tans. (2012). Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. *J. Geophys. Res.* **117**, D04304.

Philibert Cédric. (2011). Interactions of Policies for Renewable Energy and Climate - International Energy Agency.

Philibert Cedric, and J. Pershing. (2002). *Beyond Kyoto, Energy Dynamics and Climate Stabilisation*. International Energy Agency, Paris. Available at: http://philibert.cedric.free.fr/Downloads/Beyond%20Kyoto_NS.pdf.

Pielke R.A., G. Marland, R.A. Betts, T.N. Chase, J.L. Eastman, J.O. Niles, D. dutta S. Niyogi, and S.W. Running. (2002). The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* **360**, 1705–1719.

Pilavachi P., T. Dalamaga, D. Rossetti Divaldalbero, and J. Guilmot. (2008). Ex-post evaluation of European energy models. *Energy Policy* **36**, 1726–1735.

Pilli-Sihvola K., P. Aatola, M. Ollikainen, and H. Tuomenvirt. (2010). Climate change and electricity consumption—Witnessing increasing or decreasing use and costs? *Energy Policy* **38**, 2409–2419.

Plevin R., Michael O'Hare, Andrew D. Jones, M.S. Torn, and H.K. Gibbs. (2010). Greenhouse Gas Emissions from Biofuels: Indirect Land Use Change Are Uncertain but May Be Much Greater than Previously Estimated. *Environmental Science & Technology* **44**, 8015–8021.

Pope C.A., M. Ezzati, and D.W. Dockery. (2009). Fine-Particulate Air Pollution and Life Expectancy in the United States. *New England Journal of Medicine* **360**, 376–386.

Popp A., J. Dietrich, H. Lotze-Campen, D. Klein, N. Bauer, M. Krause, T. Beringer, D. Gerten, and O. Edenhofer. (2011a). The potential contribution of bioenergy to climate change mitigation including its costs and side effects. *Environmental Research Letters* **6**, 034017.

Porter J.R., and L. Xie. (Forthcoming). Chapter 7. Food Security and Food Production Systems. In: *IPCC WGII Report. CITATION DETAILS TO FOLLOW LATER.*

Posiva Oy. (2011). *Nuclear waste management of the Olkiluoto and Loviisa nuclear power plants*. Posiva Oy, Olkiluoto, Finland.

Poumadére M., C. Mays, S. Le Mer, and R. Blong. (2005). The 2003 Heat Wave in France: Dangerous Climate Change Here and Now. *Risk Analysis* **25**.

Pouret L., N. Buttery, and W. Nuttall. (2009). Is Nuclear Power Flexible? *Nuclear Future* **5**, 333–341.

Prime Minister of Japan and His Cabinet. (2011). Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety – The Accident at TEPCO's Fukushima Nuclear Power Stations. Available at: http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html.

Rabl A., A. Benoist, D. Dron, B. Peuportier, J. Spadaro, and A. Zoughaib. (2007). How to account for CO2 emissions from biomass in an LCA. *The International Journal of Life Cycle Assessment* **12**, 281–281.

Rajagopal D., G. Hochman, and D. Zilberman. (2011). Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies. *Energy Policy* **39**, 228–233.

Ramírez A., B. Bakshi, P. Ashworth, J. Bergerson, A.M. Dowd, L.S. Fan, M. Griffin, T. Kuramochi, H. MacLean, S.M. Mahajani, M.M. Ketzer, and Y. Qian. (2012). Fossil fuels and Carbon Dioxide Capture and Storage. In: *Environmental Sustainability of Clean Electricity Production Techologies*. UNEP, Paris, .

Randerson J.T., H. Liu, M.G. Flanner, S.D. Chambers, Y. Jin, P.G. Hess, G. Pfister, M.C. Mack, K.K. Treseder, L.R. Welp, F.S. Chapin, J.W. Harden, M.L. Goulden, E. Lyons, J.C. Neff, E.A.G. Schuur, and C.S. Zender. (2006). The Impact of Boreal Forest Fire on Climate Warming. *Science* **314**, 1130–1132.

Reiche K., B. Tenenbaum, and C. Torres de Mästle. (2006). *Electrification and Regulation: Principles and a Model Law*. The World Bank Group, Washington D.C.

Reiner D.M., and W.J. Nuttall. (2011). Public Acceptance of Geological Disposal of Carbon Dioxide and Radioactive Waste: Similarities and Differences. In: *Geological Disposal of Carbon Dioxide and Radioactive Waste: A Comparative Assessment*. F.L. Toth, (ed.), Springer Netherlands, Dordrecht, pp.295–315, (ISBN: 978-90-481-8711-9, 978-90-481-8712-6). Available at: http://www.springerlink.com/content/t551745224336676/.

Remme U., M. Blesl, and U. Fahl. (2007). *Global resources and energy trade: An overview for coal, natural gas, oil and uranium*. IER, Stuttgart, Germany.

REN21. (2011). *Renewables 2011 Global Status Report*. Renewable Energy Policy Network for the 21st century, Paris, France.

REN21. (2012). *Renewables 2012 Global Status Report*. Renewable Energy Policy Network for the 21st century, Paris, France.

Repo A., M. Tuomi, and J. Liski. (2011). Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues. *GCB Bioenergy* **3**, 107–115.

Riahi A., F. Dentener, D. Gielen, A. Grubler, J. Jewell, Z. Klimont, V. Krey, D. McCollum, S. Pachauri, B. Rao, B. van Ruijven, D.P. van Vuuren, and C. Wilson. (2011). Energy Pathways for Sustainable Development. In: *Global Energy Assessment: Toward a Sustainable Future*. L. Gomez-Echeverri, T.B. Johansson, N. Nakicenovic, A. Patwardhan, (eds.), International Institute for Applied Systems Analysis and Cambridge University Press, Laxenburg, Austria; Cambridge, UK & New York, USA, .

Roberts B.P., and C. Sandberg. (2011). The Role of Energy Storage in Development of Smart Grids. *Proceedings of the IEEE* **99**, 1139–1144.

Robertson G.P., and P.M. Vitousek. (2009). Nitrogen in Agriculture: Balancing the Cost of an Essential Resource. *Annu. Rev. Environ. Resourc.* **34**, 97–125.

Rochelle G.T. (2009). Amine Scrubbing for CO2 Capture. *Science* **325**, 1652–1654.

Rogge K.S., M. Schneider, and V.H. Hoffmann. (2011). The innovation impact of the EU Emission Trading System - Findings of company case studies in the German Power Sector. *Ecological Economics* **70**, 513–523.

Rogner, R.F. Aguilera, C.L. Archer, R. Bertani, S.C. Bhattacharya, M.B. Dusseault, L. Gagnon, and V. Yakushev. (2011). *Global energy assessment*. International Institute for Applied Systems Analysis and Cambridge University Press, Vienna, Austria; Cambridge, UK & New York, NY.

Rogner, F. Barthel, M. Cabrera, A. Faaij, M. Giroux, D. Hall, V. Kagramanian, S. Kononov, T. Lefevre, R. Moreira, R. Nötstaller, P. Odell, and M. Taylor. (2000). Energy Resources. In: *World Energy Assessment. Energy and the Challenge of Sustainability*. J. Goldemberg, (ed.), United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council, New York, NY, USA, pp.30–37, .

Rogowska J., and J. Namiesnik. (2010). Environmental implications of oil spills from shipping accidents. *Reviews of Environmental Contamination and Toxicology* **206**, 95–114.

De Roo G., and J. Parsons. (2011). A methodology for calculating the levelized cost of electricity in nuclear power systems with fuel recycling. *Energy Economics* **33**, 826–839.

Rooney R.C., S.E. Bayley, and D.W. Schindler. (2012). Oil sands mining and reclamation cause massive loss of peatland and stored carbon. *Proceedings of the National Academy of Sciences of the United States of America* **109**, 4933–4937.

Rosner R., and S. Goldberg. (2011). *Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.* The University of Chicago Press, Chicago, Illinois.

Rübbelke D., and S. Vögele. (2011). Impacts of climate change on European critical infrastructures: The case of the power sector. *Environmental Science & Policy* **14**, 53–63.

Rubin E.S., and H. Zhai. (2012). The Cost of Carbon Capture and Storage for Natural Gas Combined Cycle Power Plants. *Environmental Science & Technology* **46**, 3076–3084.

Rubin Edward S, A. Marks, H. Mantripragada, P. Versteeg, and J. Kitchin. (2010). *Prospects for Improved Carbon Capture Technology (Report prepared for the Congressional Research Service)*. Pittsburgh, PA. 90 pp.

Rubin Edward S., Sonia Yeh, M. Antes, M. Berkenpas, and J. Davison. (2007). Use of experience curves to estimate the future cost of power plants with CO2 capture. *International Journal of Greenhouse Gas Control* **1**, 188–197.

Russ P., and T. van Ierland. (2009). Insights on different participation schemes to meet climate goals. *Energy Economics* **31, Supplement 2**, S163–S173.

Ruth M., and A.C. Lin. (2006). Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA. *Energy Policy* **34**, 2820–2833.

Sala O.E., D. Sax, and H. Leslie. (2009). Biodiversity consequences of increased biofuel production. In: *Biofuels: Environmental Consequences and Interactions with Changing Land Use.*Cornell University. Ithaca, NY, pp.127–137, .Available at: http://cip.cornell.edu/biofuels/.

Sathaye J., O. Lucon, A. Rahman, J. Christensen, F. Denton, J. Fujino, G. Heath, S. Kadner, M. Mirza, H. Rudnick, A. Schlaepfer, and A. Shmakin. (2011). Renewable Energy in the Context of Sustainable Development. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Scarlat N., and J.-F. Dallemand. (2011). Recent developments of biofuels/ bioenergy sustainability certification: A global overview. *Energy Policy* **39**, 1630–1646.

Schaeffer Roberto, Alexandre Salem Szklo, A.F. Pereira de Lucena, B.S. Moreira Cesar Borba, L.P. Pupo Nogueira, F.P. Fleming, A. Troccoli, M. Harrison, and M.S. Boulahya. (2012). Energy sector vulnerability to climate change: A review. *Energy* **38**, 1–12.

Scheffknecht G., L. Al-Makhadmeh, U. Schnell, and J. Maier. (2011). Oxy-fuel coal combustion--A review of the current state-of-the-art. *International Journal of Greenhouse Gas Control* **5**, S16–S35.

Schlamadinger B., and G. Marland. (1996). The role of forest and bioenergy strategies in the global carbon cycle. *Biomass and Bioenergy* **10**, 275–300.

Schmidt J., V. Gass, and E. Schmid. (2011). Land use changes, greenhouse gas emissions and fossil fuel substitution of biofuels compared to bioelectricity production for electric cars in Austria. *Biomass and Bioenergy* **35**, 4060–4074.

Schneider E., and Sailor. (2008). Long-Term Uranium Supply Estimates. *Nuclear Technology* **162**.

Schock R.N., W. Fulkerson, M.L. Brown, R.L. San Martin, D.L. Greene, and Edmonds J. (1999). How Much is Energy R&D Worth As Insurance? *Annual Review of Energy and the Environment* **24**, 487–512.

Schulze E.-D., C. Körner, B.E. Law, H. Haberl, and S. Luyssaert. (2012). Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral. *GCB Bioenergy*, n/a–n/a.

Scown C.D., W.W. Nazaroff, U. Mishra, B. Strogen, A.B. Lobscheid, E. Masanet, N.J. Santero, A. Horvath, and T.E. McKone. (2012). Lifecycle greenhouse gas implications of US national scenarios for cellulosic ethanol production. *Environmental Research Letters* **7**, 014011.

Searchinger T. (2010). Biofuels and the need for additional carbon. *Environmental Research Letters* **5**, 024007.

Searchinger T., S.P. Hamburg, Jerry Melillo, W. Chameides, P. Havlik, Daniel M. Kammen, G.E. Likens, R.N. Lubowski, Michael Obersteiner, M. Oppenheimer, G. Philip Robertson, W.H. Schlesinger, and G. David Tilman. (2009). Fixing a Critical Climate Accounting Error. *Science* **326**, 527–528.

Searchinger T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. (2008). Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change. *Science* **319**, 1238–1240.

Sensfuß F., M. Ragwitz, and M. Genoese. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy* **36**, 3086–3094.

Shackley S., D. Reiner, P. Upham, H. de Coninck, G. Sigurthorsson, and Jason Anderson. (2009). The acceptability of CO2 capture and storage (CCS) in Europe: An assessment of the key determining factors: Part 2. The social acceptability of CCS and the wider impacts and repercussions of its implementation. *International Journal of Greenhouse Gas Control* **3**, 344–356.

Shindell D., J.C.I. Kuylenstierna, E. Vignati, R. van Dingenen, M. Amann, Zbigniew Klimont, S.C. Anenberg, N. Muller, G. Janssens-Maenhout, F. Raes, J. Schwartz, G. Faluvegi, L. Pozzoli, K. Kupiainen, L. Höglund-Isaksson, L. Emberson, D. Streets, V. Ramanathan, K. Hicks, N.T.K. Oanh, G. Milly, M. Williams, V. Demkine, and D. Fowler. (2012). Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. *Science* **335**, 183 –189.

Shrestha R.M., and S. Pradhan. (2010). Co-benefits of CO2 emission reduction in a developing country. *Energy Policy* **38**, 2586–2597.

De Silva P.N.K., P.G. Ranjith, and S.K. Choi. (2012). A study of methodologies for CO2 storage capacity estimation of coal. *Fuel* **92**, 1–15.

Simpson A. (2007). The Environment-Energy Security Nexus: Critical Analysis of an Energy “Love Triangle” in South east Asia. *Third World Quarterly* **28**, 539–554.

Sims R., P. Mercado, W. Krewitt, G. Bhuyan, D. Flynn, H. Holttinen, G. Jannuzzi, S. Khennas, Y. Liu, M. O’Malley, L.J. Nilsson, J. Ogden, K. Ogimoto, H. Outhred, Ø. Ulleberg, and F. van Hulle. (2011). Integration of Renewable Energy into Present and Future Energy Systems. In: *Special Report on Renewable Energy Sources and Climate Change Mitigation*. O.E., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (ed.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1076, (ISBN: 978-1-107-60710-1). Available at: http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch08.pdf.

Sims R., R. Schock, A. Adegbululgbe, J. Fenhann, I. Konstantinaviciute, W. Moomaw, H. Nimir, B. Schlamadinger, J. Torres-Martínez, C. Turner, Y. Uchiyama, S. Vuori, N. Wamukonya, and X. Zhang. (2007). Energy Supply. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.Cambridge, UK and New York, NY, USA, .

Singh B., A.H. Stromman, and E.G. Hertwich. (2011). Comparative life cycle environmental assessment of CCS technologies. *International Journal of Greenhouse Gas Control* **5**, 911–921.

Sirola V.P. (2004). *Construction Costs and Other DH Pipeline Statistics of Finland*. Finnish District Heating Association.

Sjoberg L., and B.M. Drottz-Sjoberg. (2009). Public risk perception of nuclear waste. *International Journal of Risk Assessment and Management* **11**, 248–280.

SKB. (2011). *Long-term safety for the final repository for spent nuclear fuel at Forsmark*. Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden.

Smeets E., L.F. Bouwman, E. Stehfest, D. P. van Vuuren, and A. Posthuma. (2009). Contribution of N2O to the greenhouse gas balance of first-generation biofuels. *Global Change Biology* **15**, 780–780.

Smith K.A., Arvin R. Mosier, P.J. Crutzen, and Wilfried Winiwarter. (2012). The role of N2O derived from crop-based biofuels, and from agriculture in general, in Earth's climate. *Philosophical Transactions of the Royal Society B: Biological Sciences* **367**, 1169–1174.

Smith K.R., and E. Haigler. (2008). *Co-benefits of climate mitigation and health protection in energy systems: Scoping methods*. 11-25 pp. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-42649135185&partnerID=40&md5=d43be7e99afad79a4852f8fd2522038e.

Sokona Y., Y. Mulugetta, and H. Gujba. (2012). Widening Energy Access in Africa: Towards Energy Transition. *Energy Policy* **47**, 3–10.

Sovacool B.K. (2008). The Problem with the "Portfolio Approach" in American Energy Policy. *Policy Sciences* **41**, 245–261.

Sovacool Benjamin. (2009). The cultural barriers to renewable energy and energy efficiency in the United States. *Energy Policy* **31**, 365–373.

Sovacool B.K., and I. Mukherjee. (2011). Conceptualizing and Measuring Energy Security: A Synthesized Approach. *Energy* **36**, 5343–5355.

Spiecker S., V. Eickholt, and C. Weber. (2011). The relevance of CCS for the future power market. In Proceedings: *2011 IEEE Power and Energy Society General Meeting*. IEEE, (ISBN: 978-1-4577-1000-1), (DOI: 10.1109/PES.2011.6039754). 24-July-2011, 1–8 pp.

Stadler I. (2008). Power grid balancing of energy systems with high renewable energy penetration by demand response. *Utilities Policy* **16**, 90–98.

Stehfest E., L. Bouwman, D. P. van Vuuren, M.G.J. den Elzen, B. Eickhout, and P. Kabat. (2009). Climate benefits of changing diet. *Climatic Change* **95**, 83–102.

Steinberg L.J., H. Sengul, and A.M. Cruz. (2008). Natech risk and management: an assessment of the state of the art. *Natural Hazards* **46**, 143–152.

Steinberger J.K., and J.T. Roberts. (2010). From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. *Ecological Economics* **70**, 425–433.

Stephenson T., J.E. Valle, and X. Riera-Palou. (2011). Modeling the relative GHG emissions of conventional and shale gas production. *Environmental Science and Technology* **45**, 10757–10764.

Stern N.H. (2007). *The economics of climate change:* Cambridge Univeristy Press, London. Available at: http://books.google.de/books?hl=de&lr=&id=U-VmIrGGZgAC&oi=fnd&pg=PA1&dq=Stern,+N.+2007.+The+Economics+of+Climate+Change.+London:+Cambridge+University+Press.&ots=9coW-sisje&sig=ILuq0xQWzAKmK4L8ZgG5OA3e0Jc#v=onepage&q=Stern%2C%20N.%202007.%20The%20Economics%20of%20Climate%20Change.%20London%3A%20Cambridge%20University%20Press.&f=false.

Stern M.C., F. Simeon, T. Hammer, H. Landes, H.J. Herzog, and T. Alan Hatton. (2011). Electrochemically mediated separation for carbon capture. *Energy Procedia* **4**, 860–867.

Sterner M., and U.R. Fritsche. (2011). Greenhouse gas balances and mitigation costs of 70 modern Germany-focused and 4 traditional biomass pathways including land-use change effects. *Biomass and Bioenergy* **35**, 4797–4814.

Strachan N. (2011). Business-as-Unusual: Existing policies in energy model baselines. *Energy Economics* **33**, 153–160.

Strachan N., R. Hoefnagels, Andrea Ramirez, M. van den Broek, A. Fidje, K. Espegren, P. Seljom, Markus Blesl, T. Kober, and P.E. Grohnheit. (2011). CCS in the North Sea region: A comparison on the cost-effectiveness of storing CO2 in the Utsira formation at regional and national scales. *International Journal of Greenhouse Gas Control* **5**, 1517–1532.

Strietska-Ilina O., C. Hofmann, M. Durán Haro, and S. Jeon. (2011). *Skills for green jobs: a global view: synthesis report based on 21 country studies*. International Labour Office, Skills and Employability Department, Job Creation and Enterprise Development Department, Geneva. Available at: http://www.ilo.org/wcmsp5/groups/public/@ed_emp/@ifp_skills/documents/publication/wcms_156220.pdf.

Su S., J. Han, J. Wu, H. Li, R. Worrall, H. Guo, X. Sun, and W. Liu. (2011). Fugitive coal mine methane emissions at five mining areas in China. *Atmospheric Environment* **45**, 2220–2232.

Svensson R., M. Odenberger, F. Johnsson, and L. StrÃ¶mberg. (2004). Transportation systems for CO2 application to carbon capture and storage. *Energy Conversion and Management* **45**, 2343–2353.

Swart R., M. Berk, Janssen, E. Kreileman, and R. Leemans. (1998). The safe landing approach: Risks and trade-offs in climate change. In: *Global change scenarios of the 21st century - Results from the IMAGE 2.1. Model*. J. Alcamo, R. Leemans, E. Kreileman, (eds.), Pergamon/Elsevier, Oxforf, pp.193–218, .

Szulczewski M., C. MacMinn, Howard Herzog, and R. Juanes. (2012). *The lifetime of carbon capture and storage as a climate-change mitigation technology*. PNAS. Available at: www.pnas.org/cgi/doi/10.1073/pnas.0709640104.

Tabkhi F., C. Azzaro-Pantel, L. Pibouleau, and S. Domenech. (2008). A Mathematical Framework for Modelling and Evaluating Natural Gas Pipeline Networks Under Hydrogen Injection. *International Journal of Hydrogen Energy* **33**, 6222–6231.

Taheripour F., Thomas W. Hertel, and W.E. Tyner. (2011). Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis. *Agricultural Economics* **42**, 325–342.

Tahil T. (2007). *The Trouble with Lithium*. Meridian International Research, Martainville, France.

Tamada M. (2009). Current status of technology for collection of uranium from seawater. Erice, Italy. 2009, .

Ter Mors E., M.W.H. Weenig, N. Ellemers, and D.D.L. Daamen. (2010). Effective communication about complex environmental issues: Perceived quality of information about carbon dioxide capture and storage (CCS) depends on stakeholder collaboration. *Journal of Environmental Psychology* **30**, 347–357.

Terwel B.W., F. Harinck, N. Ellemers, and D.D.L. Daamen. (2011). Going beyond the properties of CO2 capture and storage (CCS) technology: How trust in stakeholders affects public acceptance of CCS. *International Journal of Greenhouse Gas Control* **5**, 181–188.

Thiam D.R. (2010). Renewable decentralized in developing countries: Appraisal from microgrids project in Senegal. *Renewable Energy* **35**, 1615–1623.

Thompson W., J. Whistance, and S. Meyer. (2011). Effects of US biofuel policies on US and world petroleum product markets with consequences for greenhouse gas emissions. *Energy Policy* **39**, 5509–5518.

Thomson M., and D.G. Infield. (2007). Impact of widespread photovoltaics generation on distribution systems. *IET Renewable Power Generation* **1**, 33–40.

Timilsina G.R., J.C. Beghin, D. van der Mensbrugghe, and S. Mevel. (2012). The impacts of biofuels targets on land-use change and food supply: A global CGE assessment. *Agricultural Economics* **43**, 315–332.

Troy N., E. Denny, and M. O'Malley. (2010). Base-Load Cycling on a System With Significant Wind Penetration. *IEEE Transactions on Power Systems* **25**, 1088–1097.

Tuohy A., and M. O'Malley. (2011). Pumped storage in systems with very high wind penetration. *Energy Policy* **39**, 1965–1974.

U.S. DOE. (2011). *Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.* U.S. Department of Energy.

UN. (2011). *Energy Balances and Electricity Profiles 2008*. The United Nations Department of Economic and Social Affairs.

UN Habitat, and Global Network for Urban Settlements (GENUS). (2009). *Promoting Energy Access for the urban poor in Africa: Approaches and Challenges in Slum Electrification*. UN Habitat & GENUS, Nairobi, Kenya.

UNDP and WHO. (2009). *The Energy Access Situation in Developing Countries, A Review Focusing on the Least Developed Countries and sub-Saharan Africa.* United Nations Development Programme (UNDP) and the World Health Organization (WHO), New York, NY, USA.

UNECE. (2010a). *United Nations International Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009*. United Nations Economic Commission for Europe (UNECE), Geneva, Switzerland.

UNECE. (2010b). *Best Practice Guidance for Effective Methane Drainage and Use in Coal Mines*. United Nations Economic Commission for Europe, Geneva and New York.

UNEP. (2008a). *Global trends in sustainable energy investment 2008*. UNEP.

UNEP. (2008b). *Green Jobs - Towards Decent Work in a Sustainable, Low-Carbon World*. UNEP/ILO/IOE/ITUC.

UNEP. (2011). *Towards a Green Economy. Pathways to Sustainable Development and Poverty Eradication*. United Nations Environment Programme, Nairobi, Kenya. 632 pp. Available at: http://www.unep.org/greeneconomy.

UNES. (2011). *2008 Energy Statistics Yearbook*. United Nations Department of Economic and Social Affairs. Statistics Division, New York.

UNFCCC. (2008). *Investment and financial flows to address climate change: an update*. Available at: http://unfccc.int/resource/docs/2008/tp/07.pdf.

UNFCCC. (2011). National inventory submissions 2011. *United nations framework convention on climate change*. Available at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5888.php.

Unruh G. (2002). Escaping Carbon Lock-in. *Energy Policy* **30**, 317–325.

Urmee T., D. Harries, and A. Schlapfer. (2009). Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. *Renewable Energy* **34**, 354–357.

US Climate Change Science Program. (2007). Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations.

US DOE. (1989). *A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Change*. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

US DOE. (2006). *Practical Experience Gained During the First Twenty Years of Operation of the Great Plains Gasifi Cation Plant and Implications for Future Projects*. U.S. Energy Information

Administration. Office of Integrated Analysis and Forecasting, Washington, D.C. Available at: www.eia.gov/oiaf/ieo/index.html.

US DOE. (2010). *International Energy Outlook 2010*. U.S. Energy Information Administration. Office of Integrated Analysis and Forecasting, Washington, D.C. Available at: www.eia.gov/oiaf/ieo/index.html.

US DOE. (2011a). *International Energy Outlook 2011*. U.S. Energy Information Administration. Office of Integrated Analysis and Forecasting. U.S. Department of Energy, Washington D.C.

US DOE. (2011b). *US DOE, Shale gas: applying technology to solve America's energy challenges, March 2011*. U.S. Energy Information Administration. Office of Integrated Analysis and Forecasting. U.S. Department of Energy, Washington D.C.

US EPA. (2006). *Global Mitigation of Non-CO2 Greenhouse Gases*. Office of Atmospheric Programs, United States Environmental Protection Agency, Washington, D.C.

US EPA. (2011). *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. US Environmental Protection Agency. 140 pp. Available at: http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/HFStudyPlanDraft_SAB_020711-08.pdf.

USEPA. (2008). *Effects of Climate Change on Energy Production and Use in the United States*. U.S. Climate Change Science Program.

Vaidhyanathan R., S.S. Iremonger, G.K.H. Shimizu, P.G. Boyd, S. Alavi, and T.K. Woo. (2010). Direct Observation and Quantification of CO2 Binding Within an Amine-Functionalized Nanoporous Solid. *Science* **330**, 650–653.

Vangkilde-Pedersen T., K.L. Anthonsen, N. Smith, K. Kirk, F. neele, B. van der Meer, Y. Le Gallo, D. Bossie-Codreanu, A. Wojcicki, Y.-M. Le Nindre, C. Hendriks, F. Dalhoff, and N. Peter Christensen. (2009). Assessing European capacity for geological storage of carbon dioxide,Äìthe EU GeoCapacity project. *Energy Procedia* **1**, 2663–2670.

Verbruggen Aviel, Manfred Fischedick, William Moomaw, Tony Weir, Alain Nadai, Lars J. Nilsson, John Nyboer, and Jayant Sathaye. (2010). Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy* **38**, 850–861.

Verbruggen A., W. Moomaw, and J. Nyboer. (2011). Annex I: Glossary, Acronyms, Chemical Symbols and Prefixes. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Vergragt P.J., N. Markusson, and H. Karlsson. (2011). Carbon capture and storage, bio-energy with carbon capture and storage, and the escape from the fossil-fuel lock-in. *Global Environmental Change* **21**, 282–292.

Versteeg P., and E.S. Rubin. (2011). A technical and economic assessment of ammonia-based post-combustion CO2 capture at coal-fired power plants. *International Journal of Greenhouse Gas Control* **5**, 1596–1605.

Viebahn P., Y. Lechon, and F. Trieb. (2011). The Potential Role of Concentrated Solar Power (CSP) in Africa and Europe - A Dynamic Assessment of Technology Development, Cost Development and Life Cycle Inventories Until 2050. *Energy Policy* **39**, 4420–4430.

Vivoda V. (2010). Evaluating energy security in the Asia-Pacific region: A novel methodological approach. *Energy Policy* **38**, 5258–5263.

van der Voet Ester, R.J. Lifset, and L. Luo. (2010). Life-cycle assessment of biofuels, convergence and divergence. *Biofuels* **1**, 435–449.

de Vries Bert J.M., Detlef P. van Vuuren, and Monique M. Hoogwijk. (2007). Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy* **35**, 2590–2610.

de Vries B.J.M, D.P van Vuuren, and M.M Hoogwijk. (2007). Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy* **35**, 2590–2610.

van Vuuren D. P, E. Stehfest, M.G.. den Elzen, J. van Vliet, and M. Isaac. (2010). Exploring IMAGE model scenarios that keep greenhouse gas radiative forcing below 3 W/m2 in 2100. *Energy Economics* **32**, 1105–1120.

Wagner H. (1998). Energievorräte und Mineralische Rohstoffe: Wie Lange Noch? In: *Zur Frage der Wirtschaftlichen Nutzung von Vorkommen Mineralischer Rohstoffe*. J. Zemann, (ed.), Verlag der Österreichische Akademie der Wissenschaften, Vienna, Austria, pp.149–175, .

Wall T., R. Stanger, and S. Santos. (2011). Demonstrations of coal-fired oxy-fuel technology for carbon capture and storage and issues with commercial deployment. *International Journal of Greenhouse Gas Control* **5, Supplement 1**, S5–S15.

Wallington T.J., J.E. Anderson, S.A. Mueller, E. Kolinski Morris, S.L. Winkler, J.M. Ginder, and O.J. Nielsen. (2012). Corn Ethanol Production, Food Exports, and Indirect Land Use Change. *Environmental Science & Technology*. Available at: file://localhost/Users/rjp/literature/w/Wallington%20-%20Corn%20ethanol%20production,%20exports,%20and%20ILUC%202012.pdf.

Wallquist L., V.H.M. Visschers, and M. Siegrist. (2009). Lay concepts on CCS deployment in Switzerland based on qualitative interviews. *International Journal of Greenhouse Gas Control* **3**, 652–657.

Wallquist L., V.H.M. Visschers, and M. Siegrist. (2010). Impact of Knowledge and Misconceptions on Benefit and Risk Perception of CCS. *Environmental Science & Technology* **44**, 6557–6562.

Walter A., P. Dolzan, O. Quilodrán, J.G. de Oliveira, C. da Silva, F. Piacente, and A. Segerstedt. (2011). Sustainability assessment of bio-ethanol production in Brazil considering land use change, GHG emissions and socio-economic aspects. *Energy Policy* **39**, 5703–5716.

Wan K.K.W., D.H.W. Li, D. Liu, and J.C. Lam. (2011). Future trends of building heating and cooling loads and energy consumption in different climates. *Building and Environment* **46**, 223–234.

Wang C., and R.G. Prinn. (2011). Potential climatic impacts and reliability of large-scale offshore wind farms. *Environmental Research Letters* **6**, 025101.

Wang D.T.-C., L.F. Ochoa, and G.P. Harrison. (2010). DG Impact on Investment Deferral: Network Planning and Security of Supply. *IEEE Transactions on Power Systems* **25**, 1134–1141.

Wang M.Q., Jeongwoo Han, Z. Haq, W.E. Tyner, M. Wu, and A. Elgowainy. (2011). Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes. *Biomass and Bioenergy* **35**, 1885–1896.

Wang J., D. Ryan, and E.J. Anthony. (2011). Reducing the Greenhouse Gas Footprint of Shale Gas. *Energy Policy* **39**, 8196–8199.

Wappel D., G. Gronald, R. Kalb, and J. Draxler. (2010). Ionic liquids for post-combustion CO2 absorption. *International Journal of Greenhouse Gas Control* **4**, 486–494.

Warner E.S., and Garvin A. Heath. (2012). Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation. *Journal of Industrial Ecology* **16**, S73–S92.

Weber C.L., and C. Clavin. (2012). Life cycle carbon footprint of shale gas: Review of evidence and implications. *Environmental Science and Technology* **46**, 5688–5695.

WEC. (2007). *Survey of Energy Resources*. World Energy Council (WEC), London, UK.

Weiss M., J. Haufe, M. Carus, M. Brandão, S. Bringezu, B. Hermann, and M.K. Patel. (2012). A Review of the Environmental Impacts of Biobased Materials. *Journal of Industrial Ecology*, no–no.

Weitzman M.L. (1974). Prices versus Quantities. *Review of Economic Studies* **41**, 477–491.

Weitzman M.L. (2007). A Review of The Stern Review on the Economics of Climate Change. *Journal of Economic Literature* **45**, 703–724.

Whittaker S., B. Rostron, C. Hawkes, C. Gardner, D. White, J. Johnson, R. Chalaturnyk, and D. Seeburger. (2011). A decade of CO2 injection into depleting oil fields: Monitoring and research activities of the IEA GHG Weyburn-Midale CO2 Monitoring and Storage Project. *Energy Procedia* **4**, 6069–6076.

Wicke B., P. Verweij, H. van Meijl, Detlef P. van Vuuren, and A.P.C. Faaij. (2012). Indirect land use change: review of existing models and strategies for mitigation. *Biofuels* **3**, 87–100.

Wigland R., T. Bauer, T. Fanning, and E. Morris. (2006). Separations and Transmutation Criteria to Improve Utilization of a Geologic Repository. *Nuclear Technology* **154**.

Wigley T.M.L. (2011). Coal to gas: the influence of methane leakage. *Climatic Change* **108**, 601–608.

Wilkins G. (2002). *Technology Transfer for Renewable Energy: Overcoming Barriers in Developing Countries*. Earthscan, london, UK, 129-156 pp.

Wilkinson J., and S. Herrera. (2010). Biofuels in Brazil: debates and impacts. *Journal of Peasant Studies* **37**, 749–768.

Wilkinson P., K.R. Smith, M. Davies, H. Adair, B.G. Armstrong, M. Barrett, N. Bruce, A. Haines, I. Hamilton, T. Oreszcyn, I. Ridley, C. Tonne, and Z. Chalabi. (2009). Public Health Benefits of Strategies to Reduce Greenhouse Gas Emissions.: Household Energy. *The Lancet* **374**, 1917–1929.

Wilson I., P. McGregor, and P. Hall. (2010). Energy storage in the UK electrical network: Estimation of the scale and review of technology options. *Energy Policy* **38**, 4099–4106.

Winkler H., A.F. Simoes, E.L. la Rovere, M. Alam, A. Rahman, and S. Mwakasonda. (2011). Access and Affordability of Electricity in Developing Countries. *World Development* **39**, 1037–1050.

Wise, and Dooley. (2004). Baseload and Peaking Economics and the Resulting Adoption of a Carbon Dioxide Capture and Storage System for Electric Power Plants. In: *Proceedings of 7th International Conference on Greenhouse Gas Control Technologies. Volume 1: Peer- Reviewed Papers and Plenary Presentations,*. E.S. Rubin, D.W. Keith, C.F. Gilboy, (eds.), IEA Greenhouse Gas Programme, Cheltenham, UK, .

Wise MA, and J.J. Dooley. (2005). Baseload and Peaking Economics and the Resulting Adoption of Carbon Dioxide Capture and Storage Systems for Electric Power Plants. In: *Greenhouse Gas Control Technologies*. Elsevier Science, pp.pp. 303–311, .

Wise MA, and JJ Dooley. (2009). The value of post-combustion carbon dioxide capture and storage technologies in a world with uncertain greenhouse gas emissions constraints. *International Journal of Greenhouse Gas Control* **3**, 39–48.

Wise Marshall, K. Calvin, A. Thomson, Leon Clarke, Benjamin Bond-Lamberty, R. Sands, Steven J. Smith, A. Janetos, and James Edmonds. (2009). Implications of Limiting CO2 Concentrations for Land Use and Energy. *Science* **324**, 1183–1186.

Wiser R., Z. Yang, M. Hand, O. Hohmeyer, D. Infield, P.H. Jensen, V. Nikolaev, M. O'Malley, G. Sinden, and A. Zervos. (2011). Wind Energy. In: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, .

Wong-Parodi G., and I. Ray. (2009). Community perceptions of carbon sequestration: insights from California. *Environmental Research Letters* **4**, 034002.

World Bank. (2011). *Climate Change Impacts on Energy Systems: Key Issues for Energy Sector Adaptation*. Energy Sector Management Assistance Program; The World Bank Group, Washington, DC, USA. 224 pp.

World Databank. (2011). World Development Indicators & Global Development Finance (GDF). Available at: http://databank.worldbank.org/ddp/home.do.

World Nuclear Association. (2011). Mixed Oxide (MOX) Fuel. Available at: internal-pdf://MOX, Mixed Oxide Fuel WNA-4093857792/MOX, Mixed Oxide Fuel WNA.pdf.

World Nuclear Association. (2012a). World Nuclear Power Reactors & Uranium Requirements. Available at: http://www.world-nuclear.org/info/reactors.html.

World Nuclear Association. (2012b). Small Nuclear Power Reactors.

WorleyParsons. (2011). *Economic Assessment of Carbon Capture and Storage Technologies.* Global CCS Institute, Canberra, Australia. Available at: www.zeroemissionsplatform.eu/downloads/757.html.

Xue Z., Z. Zhang, Jin Han, Y. Chen, and T. Mu. (2011). Carbon dioxide capture by a dual amino ionic liquid with amino-functionalized imidazolium cation and taurine anion. *International Journal of Greenhouse Gas Control* **5**, 628–633.

Yaksic A., and J.E. Tilton. (2009). Using the cumulative availability curve to assess the threat of mineral depletion: The case of lithium. *Resources Policy* **34**, 185–194.

Yang C., and Joan Ogden. (2007). Determining the Lowest-cost Hydrogen Delivery Mode. *International Journal of Hydrogen Energy* **32**, 268–286.

Yang Y., J. Bae, J. Kim, and S. Suh. (2012). Replacing Gasoline with Corn Ethanol Results in Significant Environmental Problem-Shifting. *Environ. Sci. Technol.* **46**, 3671–3678.

Yeh S., S.M. Jordaan, A.R. Brandt, M.R. Turetsky, S. Spatari, and D. W. Keith. (2010). Land use greenhouse gas emissions from conventional oil production and oil sands. *Environmental Science and Technology* **44**, 8766–8772.

Yeh S., and E.S. Rubin. (2010). Uncertainties in technology experience curves for energy-economic models. The National Academies, Washington, DC. 2010, .

Yoo B.-Y., S.-G. Lee, K. Rhee, H.-S. Na, and J.-M. Park. (2011). New CCS system integration with CO2 carrier and liquefaction process. *Energy Procedia* **4**, 2308–2314.

Zanchi G., N. Pena, and Neil Bird. (2011). Is woody bioenergy carbon neutral? A comparative assessment of emissions from consumption of woody bioenergy and fossil fuel. *GCB Bioenergy*, n/a–n/a.

ZEP. (2011a). *The Cost of CO2 Transport*. Zero Emissions Platform, Brussels, Belgium. 53 pp.

ZEP. (2011b). *The costs of CO2 capture, transport and storage*. European Technology Platform for Zero Emission Fossil Fuel Power Plants. Available at: www.zeroemissionsplatform.eu/library/publication/165-zep-cost-report-summary.html.

Zhang Min, and Stefan Bachu. (2011). Review of integrity of existing wells in relation to CO2 geological storage: What do we know? *International Journal of Greenhouse Gas Control* **5**, 826–840.

Zhang Ming, H. Mu, Y. Ning, and Y. Song. (2009). Decomposition of energy-related CO2 emission over 1991–2006 in China. *Ecological Economics* **68**, 2122–2128.

Zmeureanu R., and G. Renaud. (2008). Estimation of potential impact of climate change on the heating energy use of existing houses. *Energy Policy* **36**, 303–310.

van der Zwaan B.C.C., K. Schoots, R. Rivera-Tinoco, and G.P.J. Verbong. (2011). The Cost of Pipelining Climate Change Mitigation: An Overview of the Economics of CH4, CO2 and H2 Transportation. *Applied Energy* **88**, 3821–3831.