10

Contents

Executive Summary 743

10.1 Introduction 745

10.2 New developments in extractive mineral industries, manufacturing industries and services 747

10.3 New developments in emission trends and drivers 749

10.3.1 Industrial CO_2 emissions 749

10.3.2 Industrial non-CO_2 GHG emissions 753

10.4 Mitigation technology options, practices and behavioural aspects 753

10.4.1 Iron and steel 757

10.4.2 Cement 758

10.4.3 Chemicals (plastics/fertilizers/others) 759

10.4.4 Pulp and paper 760

10.4.5 Non-ferrous (aluminium/others) 761

10.4.6 Food processing 761

10.4.7 Textiles and leather 762

10.4.8 Mining 762

10.5 Infrastructure and systemic perspectives 763

10.5.1 Industrial clusters and parks (meso-level) 763

10.5.2 Cross-sectoral cooperation (macro-level) 764

10.5.3 Cross-sectoral implications of mitigation efforts 764

10.6 Climate change feedback and interaction with adaptation 764

10.7 Costs and potentials 765

10.7.1 CO_2 emissions 765

10.7.2 Non-CO_2 emissions 767

10.7.3 Summary results on costs and potentials 767

10.8 Co-benefits, risks and spillovers 770

10.8.1 Socio-economic and environmental effects 771

10.8.2 Technological risks and uncertainties 772

10.8.3 Public perception 772

10.8.4 Technological spillovers 774

10.9 Barriers and opportunities 774

10.9.1 Energy efficiency for reducing energy requirements 774

10.9.2 Emissions efficiency, fuel switching, and carbon dioxide capture and storage 774

10.9.3 Material efficiency 775

10.9.4 Product demand reduction 776

10.9.5 Non-CO_2 greenhouse gases 776

10.10 Sectoral implications of transformation pathways and sustainable development 776

10.10.1 Industry transformation pathways 776

10.10.2 Transition, sustainable development, and investment 779

10.11 Sectoral policies 780

10.11.1 Energy efficiency 781

10.11.2 Emissions efficiency 782

10.11.3 Material efficiency 783

10.12 Gaps in knowledge and data 783

10.13 Frequently Asked Questions 784

10.14 Appendix: Waste 785

10.14.1 Introduction.... 785

10.14.2 Emissions trends.... 785
10.14.2.1 Solid waste disposal 785
10.14.2.2 Wastewater 787

10.14.3 Technological options for mitigation of emissions from waste 788
10.14.3.1 Pre-consumer waste 788
10.14.3.2 Post-consumer waste 788
10.14.3.3 Wastewater 790

10.14.4 Summary results on costs and potentials.... 791

References 793

Executive Summary

An absolute reduction in emissions from the industry sector will require deployment of a broad set of mitigation options beyond energy efficiency measures (*medium evidence, high agreement*). In the last two to three decades there has been continued improvement in energy and process efficiency in industry, driven by the relatively high share of energy costs. In addition to energy efficiency, other strategies such as emissions efficiency (including e.g., fuel and feedstock switching, carbon dioxide capture and storage (CCS)), material use efficiency (e.g., less scrap, new product design), recycling and re-use of materials and products, product service efficiency (e.g., car sharing, maintaining buildings for longer, longer life for products), or demand reductions (e.g., less mobility services, less product demand) are required in parallel (*medium evidence, high agreement*). [Section 10.4, 10.7]

Industry-related greenhouse gas (GHG) emissions have continued to increase and are higher than GHG emissions from other end-use sectors (*high confidence*). Despite the declining share of industry in global gross domestic product (GDP), global industry and waste/wastewater GHG emissions grew from 10.4 $GtCO_2eq$ in 1990 to 13.0 $GtCO_2eq$ in 2005 to 15.4 $GtCO_2eq$ in 2010. Total global GHG emissions for industry and waste/wastewater in 2010, which nearly doubled since 1970, were comprised of direct energy-related CO_2 emissions of 5.3 $GtCO_2eq$, indirect CO_2 emissions from production of electricity and heat for industry of 5.2 $GtCO_2eq$, process CO_2 emissions of 2.6 $GtCO_2eq$, non-CO_2 GHG emissions of 0.9 $GtCO_2eq$, and waste/wastewater emissions of 1.4 $GtCO_2eq$. 2010 direct and indirect emissions were dominated by CO_2 (85.1 %) followed by CH_4 (8.6 %), HFC (3.5 %), N_2O (2.0 %), PFC (0.5 %) and SF_6 (0.4 %) emissions. Currently, emissions from industry are larger than the emissions from either the buildings or transport end-use sectors and represent just over 30 % of global GHG emissions in 2010 (just over 40 % if Agriculture, Forestry, and Other Land Use (AFOLU) emissions are not included). (*high confidence*) [10.2, 10.3]

Globally, industrial GHG emissions are dominated by the Asia region, which was also the region with the fastest emission growth between 2005 and 2010 (*high confidence*). In 2010, over half (52 %) of global direct GHG emissions from industry and waste/wastewater were from the Asia region (ASIA), followed by the member countries of the Organisation for Economic Co-operation and Development in 1990 (OECD-1990) (25 %), Economies in Transition (EIT) (9 %), Middle East and Africa (MAF) (8 %), and Latin America (LAM) (6 %). Between 2005 and 2010, GHG emissions from industry grew at an average annual rate of 3.5 % globally, comprised of 7 % average annual growth in the ASIA region, followed by MAF (4.4 %), LAM (2 %), and the EIT countries (0.1 %), but declined in the OECD-1990 countries (–1.1 %). [10.3]

The energy intensity of the sector could be reduced by approximately up to 25 % compared to current level through wide-scale upgrading, replacement and deployment of best available technologies, particularly in countries where these are not in practice and for non-energy intensive industries (*robust evidence, high agreement*). Despite long-standing attention to energy efficiency in industry, many options for improved energy efficiency remain. [10.4, 10.7]

Through innovation, additional reductions of approximately up to 20 % in energy intensity may potentially be realized before approaching technological limits in some energy intensive industries (*limited evidence, medium agreement*). Barriers to implementing energy efficiency relate largely to the initial investment costs and lack of information. Information programmes are the most prevalent approach for promoting energy efficiency, followed by economic instruments, regulatory approaches, and voluntary actions. [10.4, 10.7, 10.9, 10.11]

Besides sector specific technologies, cross-cutting technologies and measures applicable in both large energy intensive industries and Small and Medium Enterprises (SMEs) can help to reduce GHG emissions (*robust evidence, high agreement*). Cross-cutting technologies such as efficient motors, electronic control systems, and cross-cutting measures such as reducing air or steam leaks help to optimize performance of industrial processes and improve plant efficiency cost-effectively with both energy savings and emissions benefits [10.4].

Long-term step-change options can include a shift to low carbon electricity, radical product innovations (e.g., alternatives to cement), or carbon dioxide capture and storage (CCS). Once demonstrated, sufficiently tested, cost-effective, and publicly accepted, these options may contribute to significant climate change mitigation in the future (*medium evidence, medium agreement*). [10.4]

The level of demand for new and replacement products has a significant effect on the activity level and resulting GHG emissions in the industry sector (*medium evidence, high agreement*). Extending product life and using products more intensively could contribute to reduction of product demand without reducing the service. Absolute emission reductions can also come through changes in lifestyle and their corresponding demand levels, be it directly (e.g. for food, textiles) or indirectly (e.g. for product/service demand related to tourism). [10.4]

Mitigation activities in other sectors and adaptation measures may result in increased industrial product demand and corresponding emissions (*robust evidence, high agreement*). Production of mitigation technologies (e.g., insulation materials for buildings) or material demand for adaptation measures (e.g., infrastructure materials) contribute to industrial GHG emissions. [10.4, 10.6]

Systemic approaches and collaboration within and across industrial sectors at different levels, e.g., sharing of infrastructure, information, waste and waste management facilities, heating,

and cooling, may provide further mitigation potential in certain regions or industry types (*robust evidence, high agreement*). The formation of industrial clusters, industrial parks, and industrial symbiosis are emerging trends in many developing countries, especially with SMEs. [10.5]

Several emission-reducing options in the industrial sector are cost-effective and profitable (*medium evidence, medium agreement*). While options in cost ranges of 20–50, 0–20, and even below 0 USD_{2010}/tCO_2eq exist, to achieve near-zero emission intensity levels in the industry sector would require additional realization of long-term step-change options (e.g., CCS) associated with higher levelized costs of conserved carbon (LCCC) in the range of 50–150 USD_{2010}/tCO_2. However, mitigation costs vary regionally and depend on site-specific conditions. Similar estimates of costs for implementing material efficiency, product-service efficiency, and service demand reduction strategies are not available. [10.7]

Mitigation measures in the industry sector are often associated with co-benefits (*robust evidence, high agreement*). Co-benefits of mitigation measures could drive industrial decisions and policy choices. They include enhanced competitiveness through cost reductions, new business opportunities, better environmental compliance, health benefits through better local air and water quality and better work conditions, and reduced waste, all of which provide multiple indirect private and social benefits. [10.8]

Unless barriers to mitigation in industry are resolved, the pace and extent of mitigation in industry will be limited and even profitable measures will remain untapped (*robust evidence, high agreement*). There are a broad variety of barriers to implementing energy efficiency in the industry sector; for energy-intensive industry, the issue is largely initial investment costs for retrofits, while barriers for other industries include both cost and a lack of information. For material efficiency, product-service efficiency, and demand reduction, there is a lack of experience with implementation of mitigation measures and often there are no clear incentives for either the supplier or consumer. Barriers to material efficiency include lack of human and institutional capacities to encourage management decisions and public participation. [10.9]

There is no single policy that can address the full range of mitigation measures available for industry and overcome associated barriers (*robust evidence, high agreement*). In promoting energy efficiency, information programs are the most prevalent approach, followed by economic instruments, regulatory approaches and voluntary actions. To date, few policies have specifically pursued material or product service efficiency. [10.11]

While the largest mitigation potential in industry lies in reducing CO_2 emissions from fossil fuel use, there are also significant mitigation opportunities for non-CO_2 gases. Key opportunities comprise, for example, reduction of HFC emissions by leak repair, refrigerant recovery and recycling, and proper disposal and replacement by alternative refrigerants (ammonia, HC, CO_2). Nitrous oxide (N_2O) emissions from adipic and nitric acid production can be reduced through the implementation of thermal destruction and secondary catalysts. The reduction of non-CO_2 GHGs also faces numerous barriers. Lack of awareness, lack of economic incentives, and lack of commercially available technologies (e.g., for HFC recycling and incineration) are typical examples. [10.4, 10.7, 10.9]

Long-term scenarios for industry highlight improvements in emissions efficiency as an important future mitigation strategy (*robust evidence, high agreement*). Detailed industry sector scenarios fall within the range of more general long-term integrated scenarios. Improvements in emissions efficiency in the mitigation scenarios result from a shift from fossil fuels to electricity with low (or negative) CO_2 emissions and use of CCS for industry fossil fuel use and process emissions. The crude representation of materials, products, and demand in scenarios limits the evaluation of the relative importance of material efficiency, product-service efficiency, and demand reduction options. (*robust evidence, high agreement*) [6.8, 10.10]

The most effective option for mitigation in waste management is waste reduction, followed by re-use and recycling and energy recovery (*robust evidence, high agreement*) [10.4, 10.14]. Direct emissions from the waste sector almost doubled during the period from 1970 to 2010. Globally, approximately only 20 % of municipal solid waste (MSW) is recycled and approximately 13.5 % is treated with energy recovery while the rest is deposited in open dumpsites or landfills. Approximately 47 % of wastewater produced in the domestic and manufacturing sectors is still untreated. As the share of recycled or reused material is still low, waste treatment technologies and energy recovery can also result in significant emission reductions from waste disposal. Reducing emissions from landfilling through treatment of waste by anaerobic digestion has the largest cost range, going from negative cost to very high cost. Also, advanced wastewater treatment technologies may enhance GHG emissions reduction in the wastewater treatment but they tend to concentrate in the higher costs options (*medium evidence, medium agreement*). [10.14]

A key challenge for the industry sector is the uncertainty, incompleteness, and quality of data available in the public domain on energy use and costs for specific technologies on global and regional scales that can serve as a basis for assessing performance, mitigation potential, costs, and for developing policies and programmes with high confidence. Bottom-up information on cross-sector collaboration and demand reduction as well as their implications for mitigation in industry is particularly limited. Improved modelling of material flows in integrated models could lead to a better understanding of material efficiency and demand reduction strategies and the associated mitigation potentials. [10.12]

10.1 Introduction

This chapter provides an update to developments on mitigation in the industry sector since the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report (AR4) (IPCC, 2007), but has much wider coverage. Industrial activities create all the physical products (e.g., cars, agricultural equipment, fertilizers, textiles, etc.) whose use delivers the final services that satisfy current human needs. Compared to the industry chapter in AR4, this chapter analyzes industrial activities over the whole supply chain, from extraction of primary materials (e.g., ores) or recycling (of waste materials), through product manufacturing, to the demand for the products and their services. It includes a discussion of trends in activity and emissions, options for mitigation (technology, practices, and behavioural aspects), estimates of the mitigation potentials of some of these options and related costs, co-benefits, risks and barriers to their deployment, as well as industry-specific policy instruments. Findings of integrated models (long-term mitigation pathways) are also presented and discussed from the sector perspective. In addition, at the end of the chapter, the hierarchy in waste management and mitigation opportunities are synthesized, covering key waste-related issues that appear across all chapters in the Working Group III contribution to the IPCC Fifth Assessment Report (AR5).

Figure 10.1, which shows a breakdown of total global anthropogenic GHG emissions in 2010 based on Bajželj et al. (2013), illustrates the logic that has been used to distinguish the industry sector from other sectors discussed in this report. The figure shows how human demand for energy services, on the left, is provided by economic sectors, through the use of equipment in which devices create heat or work from final energy. In turn, the final energy has been created by processing a primary energy source. Combustion of carbon-based fuels leads to the release of GHG emissions as shown on the right. The remaining anthropogenic emissions arise from chemical reactions in industrial processes, from waste management and from the agriculture and land-use changes discussed in Chapter 11.

Mitigation options can be chosen to reduce GHG emissions at all stages in Figure 10.1, but caution is needed to avoid 'double counting'. The figure also demonstrates that care is needed when allocating emissions to specific products and services ('carbon footprints', for example) while ensuring that the sum of all 'footprints' adds to the sum of all emissions.

Emissions from industry (30 % of total global GHG emissions) arise mainly from material processing, i.e., the conversion of natural resources (ores, oil, biomass) or scrap into materials stocks which are then converted in manufacturing and construction into products. Pro-

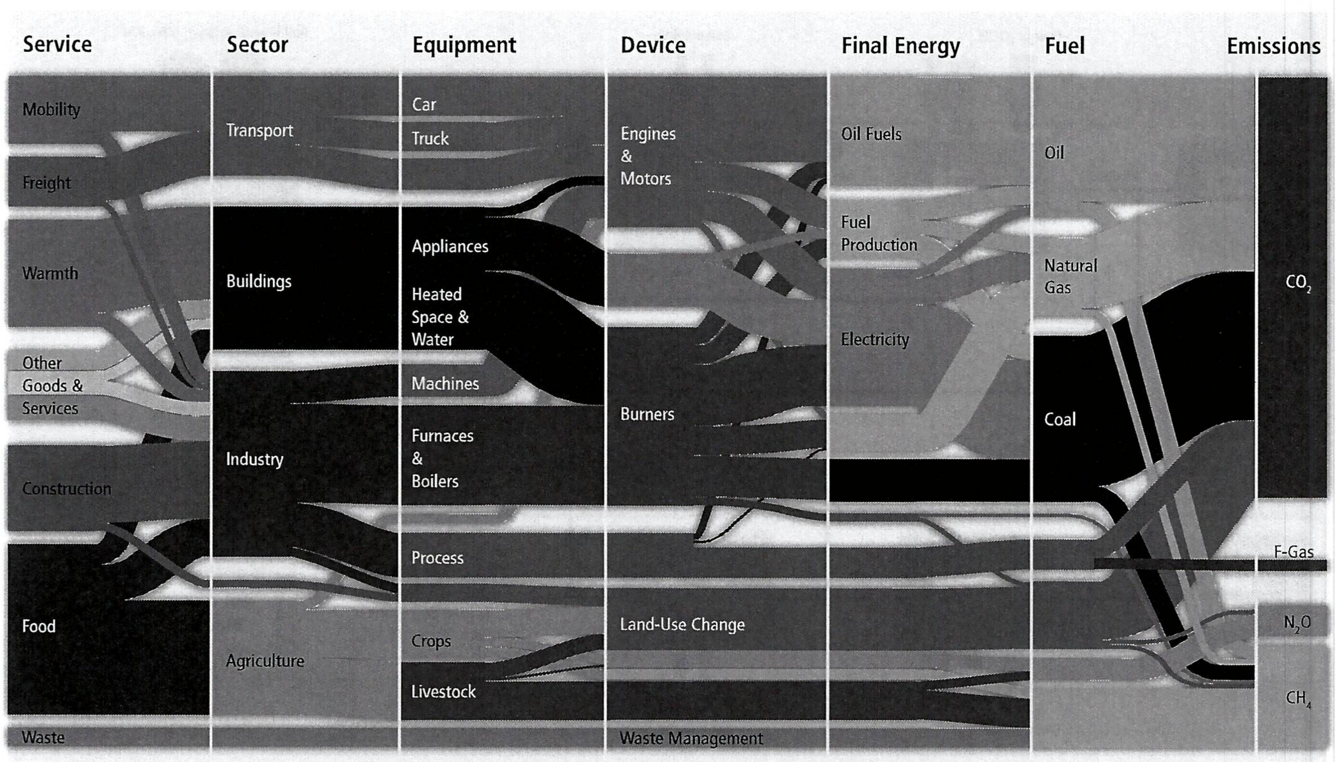

Figure 10.1 | A Sankey diagram showing the system boundaries of the industry sector and demonstrating how global anthropogenic emissions in 2010 arose from the chain of technologies and systems required to deliver final services triggered by human demand. The width of each line is proportional to GHG emissions released, and the sum of these widths along any vertical slice through the diagram is the same, representing all emissions in 2010 (Bajželj et al., 2013).

duction of just iron and steel and non-metallic minerals (predominately cement) results in 44 % of all carbon dioxide (CO_2) emissions (direct, indirect, and process-related) from industry. Other emission-intensive sectors are chemicals (including plastics) and fertilizers, pulp and paper, non-ferrous metals (in particular aluminium), food processing (food growing is covered in Chapter 11), and textiles.

Decompositions of GHG emissions have been used to analyze the different drivers of global industry-related emissions. An accurate decomposition for the industry sector would involve great complexity, so instead this chapter uses a simplified conceptual expression to identify the key mitigation opportunities available within the sector:

$$G = \frac{G}{E} \times \frac{E}{M} \times \frac{M}{P} \times \frac{P}{S} \times S$$

where G is the GHG emissions of the industrial sector within a specified time period (usually one year), E is industrial sector energy consumption and M is the total global production of materials in that period. P is stock of products created from these materials (including both consumables and durables added to existing stocks), and S is the services delivered in the time period through use of those products.

The expression is indicative only, but leads to the main mitigation strategies discussed in this chapter:

G/E is the *emissions intensity* of the sector expressed as a ratio to the energy used: the GHG emissions of industry arise largely from energy use (directly from combusting fossil fuels, and indirectly through purchasing electricity and steam), but emissions also arise from industrial chemical reactions. In particular, producing cement, chemicals, and non-ferrous metals leads to the inevitable release of significant 'process emissions' regardless of energy supply. We refer to reductions in G/E as *emissions efficiency* for the energy inputs and the processes.

E/M is the *energy intensity*: approximately three quarters of industrial energy use is required to create materials from ores, oil or biomass, with the remaining quarter used in the downstream manufacturing and construction sectors that convert materials to products. The energy required can in some cases (particularly for metals and paper) be reduced by production from recycled scrap, and can be further reduced by material re-use, or by exchange of waste heat and exchange of by-products between sectors. Reducing E/M is the goal of *energy efficiency*.

M/P is the *material intensity* of the sector: the amount of material required to create a product and maintain the stock of a product depends both on the design of the product and on the scrap discarded during its production. Both can be reduced by *material efficiency*.

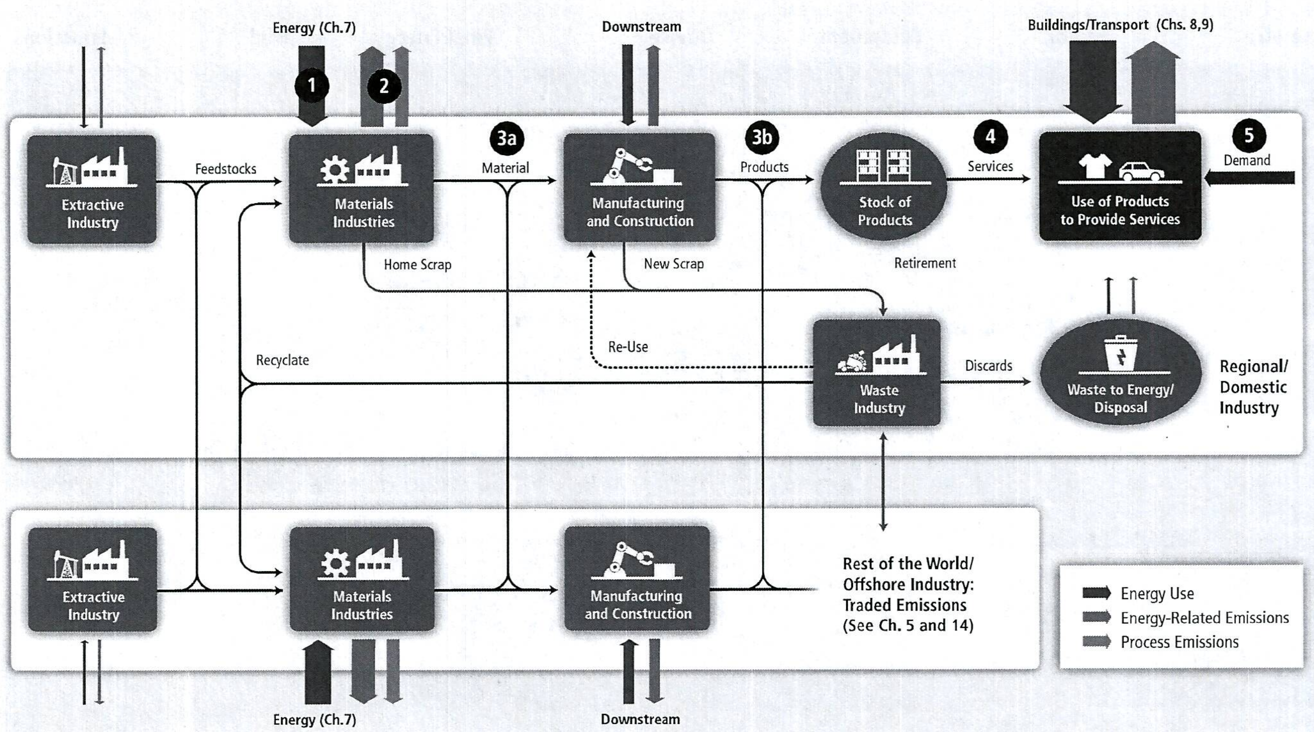

Figure 10.2 | A schematic illustration of industrial activity over the supply chain. Options for climate change mitigation in the industry sector are indicated by the circled numbers: (1) Energy efficiency (e.g., through furnace insulation, process coupling, or increased material recycling); (2) Emissions efficiency (e.g., from switching to non-fossil fuel electricity supply, or applying CCS to cement kilns); (3a) Material efficiency in manufacturing (e.g., through reducing yield losses in blanking and stamping sheet metal or re-using old structural steel without melting); (3b) Material efficiency in product design (e.g., through extended product life, light-weight design, or de-materialization); (4) Product-Service efficiency (e.g., through car sharing, or higher building occupancy); (5) Service demand reduction (e.g., switching from private to public transport).

P/S is the *product-service intensity*: the level of service provided by a product depends on its intensity of use. For consumables (e.g., food or detergent) that are used within the accounting period in which they are produced, service is provided solely by the production within that period. For durables that last for longer than the accounting period (e.g., clothing), services are provided by the stock of products in current use. In this case P is the flow of material required to replace retiring products and to meet demand for increases in total stock. Thus for consumables, P/S can be reduced by more precise use (for example using only recommended doses of detergents or applying fertilizer precisely) while for durables, P/S can be reduced both by using durable products for longer and by using them more intensively. We refer to reductions in P/S as *product-service efficiency*.

S: The total global demand for service is a function of population, wealth, lifestyle, and the whole social system of expectations and aspirations. If the total demand for service were to decrease, it would lead to a reduction in industrial emissions, and we refer to this as *demand reduction.*

Figure 10.2 expands on this simplified relationship to illustrate the main options for GHG emissions mitigation in industry (circled numbers). The figure also demonstrates how international trade of products leads to significant differences between 'production' and 'consumption' measures of national emissions, and demonstrates how the 'waste' industry, which includes material recycling as well as options like 'waste to energy' and disposal, has a significant potential for influencing future industrial emissions.

Figure 10.2 clarifies the terms used for key sectors in this chapter: 'Industry' refers to the totality of activities involving the physical transformation of materials within which 'extractive industry' supplies feedstock to the energy-intensive 'materials industries' which create refined materials. These are converted by 'manufacturing' into products and by 'construction' into buildings and infrastructure. 'Home scrap' from the materials processing industries, 'new scrap' from downstream construction and manufacturing, and products retiring at end-of-life are processed in the 'waste industry.' This 'waste' may be recycled (particularly bulk metals, paper, glass and some plastics), may be re-used to save the energy required for recycling, or may be discarded to landfills or incinerated (which can lead to further emissions on one hand and energy recovery on the other hand).

10.2 New developments in extractive mineral industries, manufacturing industries and services

World production trends of mineral extractive industries, manufacturing, and services, have grown steadily in the last 40 years (Figure 10.3). However, the service sector share in world GDP increased from 50 % in 1970 to 70 % in 2010; while the industry world GDP share decreased from 38.2 to 26.9 % (World Bank, 2013).

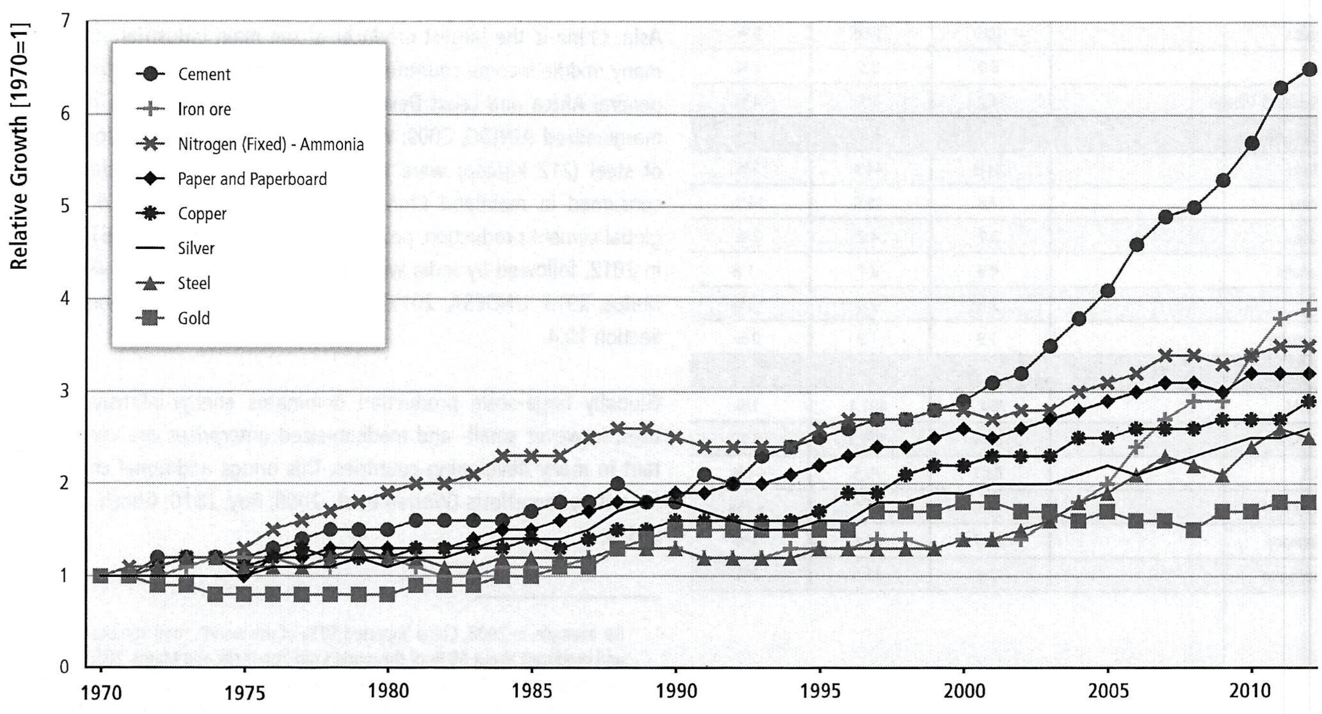

Figure 10.3 | World's growth of main minerals and manufacturing products (1970 = 1). Sources: (WSA, 2012a; FAO, 2013; Kelly and Matos, 2013).

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Table 10.1 | Total production of energy-intensive industrial goods for the world top-5 producers of each commodity: 2005, 2012, and average annual growth rate (AAGR) (FAO, 2013; Kelly and Matos, 2013).

Commodity/Country	2005 [Mt]	2012 [Mt]	AAGR
Iron ore			
World	1540	3000	10 %
China	420	1300	18 %
Australia	262	525	10 %
Brazil	280	375	4 %
India	140	245	8 %
Russia	97	100	0.4 %
Steel			
World	1130	1500	4 %
China	349	720	11 %
Japan	113	108	−1 %
U.S.	95	91	−1 %
India	46	76	8 %
Russia	66	76	2 %
Cement			
World	2310	3400	6 %
China	1040	2150	11 %
India	145	250	8 %
U.S.	101	74	−4 %
Brazil	37	70	10 %
Iran	33	65	10 %
Ammonia			
World	121.0	137.0	2 %
China	37.8	44.0	2 %
India	10.8	12.0	2 %
Russia	10.0	10.0	0 %
U.S.	8.0	9.5	2 %
Trinidad & Tobago	4.2	5.5	4 %
Aluminium			
World	31.9	44.9	5 %
China	7.8	19.0	14 %
Russia	3.7	4.2	2 %
Canada	2.9	2.7	−1 %
U.S.	2.5	2.0	−3 %
Australia	1.9	1.9	0 %
Paper			
World	364.7	401.1	1 %
China	60.4	106.3	8 %
U.S.	83.7	75.5	−1 %
Japan	31.0	26.0	−2 %
Germany	21.7	22.6	1 %
Indonesia	7.2	11.5	7 %

Concerning extractive industries for metallic minerals, from 2005 to 2012 annual mining production of iron ore, gold, silver, and copper increased by 10 %, 1 %, 2 %, and 2 % respectively (Kelly and Matos, 2013). Most of the countries in Africa, Latin America, and the transition economies produce more than they use; whereas use is being driven mainly by consumption in China, India, and developed countries (UNCTAD, 2008)[1]. Extractive industries of rare earths are gaining importance because of their various uses in high-tech industry (Moldoveanu and Papangelakis, 2012). New mitigation technologies, such as hybrid and electric vehicles (EVs), electricity storage and renewable technologies, increase the demand for certain minerals, such as lithium, gallium, and phosphates (Bebbington and Bury, 2009). Concerns over depletion of these minerals have been raised, but important research on extraction methods as well as increasing recycling rates are leading to increasing reserve estimates for these materials (Graedel et al., 2011; Resnick Institute, 2011; Moldoveanu and Papangelakis, 2012; Eckelman et al., 2012). China accounts for 97 % of global rare earth extraction (130 Mt in 2010) (Kelly and Matos, 2013).

Regarding manufacturing production, the annual global production growth rate of steel, cement, ammonia, aluminium, and paper—the most energy-intensive industries—ranged from 2 % to 6 % between 2005 and 2012 (Table 10.1). Many trends are responsible for this development (e.g., urbanization significantly triggered demand on construction materials). Over the last decades, as a general trend, the world has witnessed decreasing industrial activity in developed countries with a major downturn in industrial production due to the economic recession in 2009 (Kelly and Matos, 2013). There is continued increase in industrial activity and trade of some developing countries. The increase in manufacturing production and consumption has occurred mostly in Asia. China is the largest producer of the main industrial outputs. In many middle-income countries industrialization has stagnated, and in general Africa and Least Developed Countries (LDCs) have remained marginalized (UNIDO, 2009; WSA, 2012a). In 2012, 1.5 billion tonnes of steel (212 kg/cap) were manufactured; 46 % was produced and consumed in mainland China (522 kg/cap). China also dominates global cement production, producing 2.2 billion tonnes (1,561 kg/cap) in 2012, followed by India with only 250 Mt (202 kg/cap) (Kelly and Matos, 2013; UNDESA, 2013). More subsector specific trends are in Section 10.4.

Globally large-scale production dominates energy-intensive industries; however small- and medium-sized enterprises are very important in many developing countries. This brings additional challenges for mitigation efforts (Worrell et al., 2009; Roy, 2010; Ghosh and Roy, 2011).

1 For example, in 2008, China imported 50 % of the world's total iron ore exports and produced about 50 % of the world's pig iron (Kelly and Matos, 2013). India demanded 35 % of world's total gold production in 2011 (WGC, 2011), and the United States consumed 33 % of world's total silver production in 2011 (Kelly and Matos, 2013).

Another important change in the world's industrial output over the last decades has been the rise in the proportion of international trade. Manufactured products are not only traded, but the production process is increasingly broken down into tasks that are themselves outsourced and/or traded; i.e., production is becoming less vertically integrated. In addition to other drivers such as population growth, urbanization, and income increase, the rise in the proportion of trade has been driving production increase for certain countries (Fisher-Vanden et al., 2004; Liu and Ang, 2007; Reddy and Ray, 2010; OECD, 2011). The economic recession of 2009 reduced industrial production worldwide because of consumption reduction, low optimism in credit market, and a decline in world trade (Nissanke, 2009). More discussion on GHG emissions embodied in trade is presented in Chapter 14. Similar to industry, the service sector is heterogeneous and has significant proportion of small and medium sized enterprises. The service sector covers 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; Reddy and Ray, 2010; OECD, 2011). OECD countries are shifting from manufacturing towards service-oriented economies (Sun, 1998; Schäfer, 2005; US EIA, 2010), however, this is also true for some non-OECD countries. For example, India has almost 64%–66% of GDP contribution from service sector (World Bank, 2013).

10.3 New developments in emission trends and drivers

In 2010, the industry sector accounted for around 28% of final energy use (IEA, 2013). Global industry and waste/wastewater GHG emissions grew from 10.37 $GtCO_2eq$ in 1990 to 13.04 $GtCO_2eq$ in 2005 to 15.44 $GtCO_2eq$ in 2010. These emissions are larger than the emissions from either the buildings or transport end-use sectors and represent just over 30% of global GHG emissions in 2010 (just over 40% if AFOLU emissions are not included). These total emissions are comprised of:

- Direct energy-related CO_2 emissions for industry[2]
- Indirect CO_2 emissions from production of electricity and heat for industry[3]
- Process CO_2 emissions
- Non-CO_2 GHG emissions
- Direct emissions for waste/wastewater

[2] This also includes CO_2 emissions from non-energy uses of fossil fuels.

[3] The methodology for calculating indirect CO_2 emissions is based on de la Rue du Can and Price (2008) and described in Annex II.5.

Figure 10.4 shows global industry and waste/wastewater direct and indirect GHG emissions by source from 1970 to 2010. Table 10.2 shows primary energy[4] and GHG emissions for industry by emission type (direct energy-related, indirect from electricity and heat production, process CO_2, and non-CO_2), and for waste/wastewater for five world regions and the world total.[5]

Figure 10.5 shows global industry and waste/wastewater direct and indirect GHG emissions by region from 1970 to 2010. This regional breakdown shows that:

- Over half (52%) of global direct GHG emissions from industry and waste/wastewater are from the ASIA region, followed by OECD-1990 (25%), EIT (9.4%), MAF (7.6%), and LAM (5.7%).
- Between 2005 and 2010, GHG emissions from industry grew at an average annual rate of 3.5% globally, comprised of 7.0% average annual growth in the ASIA region, followed by MAF (4.4%), LAM (2.0%), and the EIT countries (0.1%), but declined in the OECD-1990 countries (−1.1%).

Regional trends are further discussed in Chapter 5, Section 5.2.1.

Table 10.3 provides 2010 direct and indirect GHG emissions by source and gas. 2010 direct and indirect emissions were dominated by CO_2 (85.1%), followed by methane (CH_4) (8.6%), hydrofluorocarbons (HFC) (3.5%), nitrous oxide (N_2O) (2.0%), Perfluorocarbons (PFC) (0.5%) and sulphur hexafluoride (SF_6) (0.4%) emissions.

10.3.1 Industrial CO_2 emissions

As shown in Table 10.3, industrial CO_2 emissions were 13.14 $GtCO_2$ in 2010. These emissions were comprised of 5.27 $GtCO_2$ direct energy-related emissions, 5.25 $GtCO_2$ indirect emissions from electricity and heat production, 2.59 $GtCO_2$ from process CO_2 emissions and 0.03 $GtCO_2$ from waste/wastewater. Process CO_2 emissions are comprised of process-related emissions of 1.352 $GtCO_2$ from cement production,[6] 0.477 $GtCO_2$ from production of chemicals, 0.242 $GtCO_2$ from lime production, 0.134 $GtCO_2$ from coke ovens, 0.074 $GtCO_2$ from non-ferrous metals production, 0.072 $GtCO_2$ from iron and steel production, 0.061 $GtCO_2$ from ferroalloy production, 0.060 $GtCO_2$ from limestone and dolomite use, 0.049 $GtCO_2$ from solvent and other product use, 0.042 $GtCO_2$ from production of other minerals and 0.024 $GtCO_2$ from non-energy use of lubricants/waxes (JRC/PBL, 2013). Total industrial CO_2 values include emissions from mining and quarrying, from manufacturing, and from construction.

[4] See Glossary in Annex I for definition of primary energy.

[5] The IEA also recently published CO_2 emissions with electricity and heat allocated to end-use sectors (IEA, 2012a). However, the methodology used in this report differs slightly from the IEA approach as explained in Annex II.5

[6] Another source, Boden et al., 2013, indicates that cement process CO_2 emissions in 2010 were 1.65 $GtCO_2$.

Energy-intensive processes in the mining sector include excavation, mine operation, material transfer, mineral preparation, and separation. Energy consumption for mining[7] and quarrying, which is included in 'other industries' in Figure 10.4, represents about 2.7 % of worldwide industrial energy use, varying regionally, and a significant share of national industrial energy use in Botswana and Namibia (around 80 %), Chile (over 50 %), Canada (30 %), Zimbabwe (18.6 %), Mongolia (16.5 %), and South Africa (almost 15 %) in 2010 (IEA, 2012b; c).

7 Discussion of extraction of energy carriers (e.g., coal, oil, and natural gas) takes place in Chapter 7.

Manufacturing is a subset of industry that includes production of all products (e.g., steel, cement, machinery, textiles) except for energy products, and does not include energy used for construction. Manufacturing is responsible for about 98 % of total direct CO_2 emissions from the industrial sector (IEA, 2012b; c). Most manufacturing CO_2 emissions arise due to chemical reactions and 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. 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

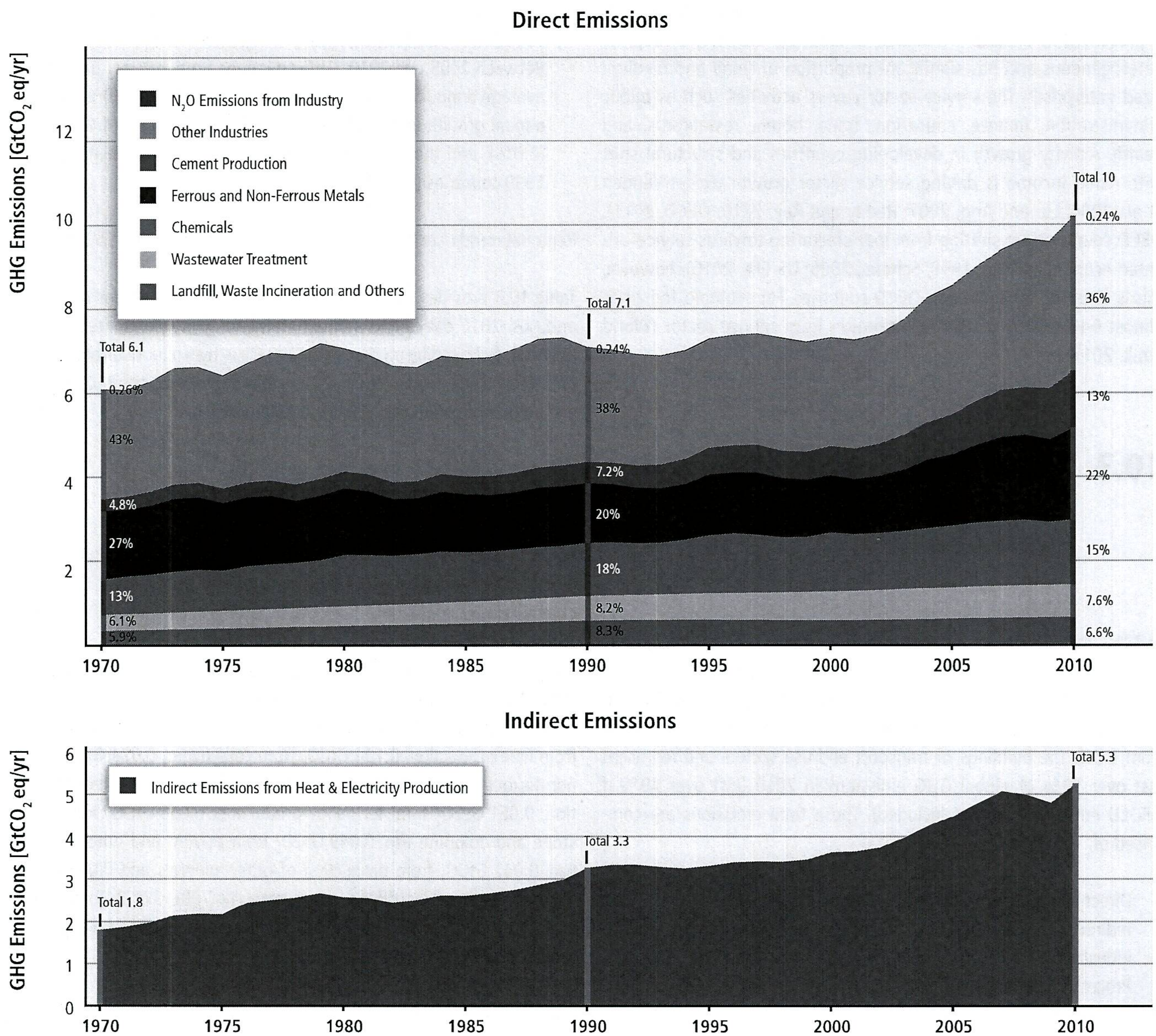

Figure 10.4 | Total global industry and waste/wastewater direct and indirect GHG emissions by source, 1970–2010 ($GtCO_2eq/yr$) (de la Rue du Can and Price, 2008; IEA, 2012a; JRC/PBL, 2013). See also Annex II.9, Annex II.5.

Note: For statistical reasons 'Cement production' only covers process CO_2 emissions (i.e., emissions from cement-forming reactions); energy-related direct emissions from cement production are included in 'other industries' CO_2 emissions.

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).

Overall reductions in industrial energy use/manufacturing value-added were found to be greatest in developing economies during 1995–2008. Low-income developing economies had the highest industrial energy intensity values while developed economies had the lowest. Reductions in intensity were realized through technological changes (e.g., changes in product mix, adoption of energy-efficient technologies, etc.) and structural change in the share of energy-intensive industries in the economy. During 1995–2008, developing economies had greater reductions in energy intensity while developed economies had greater reductions through structural change (UNIDO, 2011).

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, 2012b; c). Fossil fuels used as raw materi-

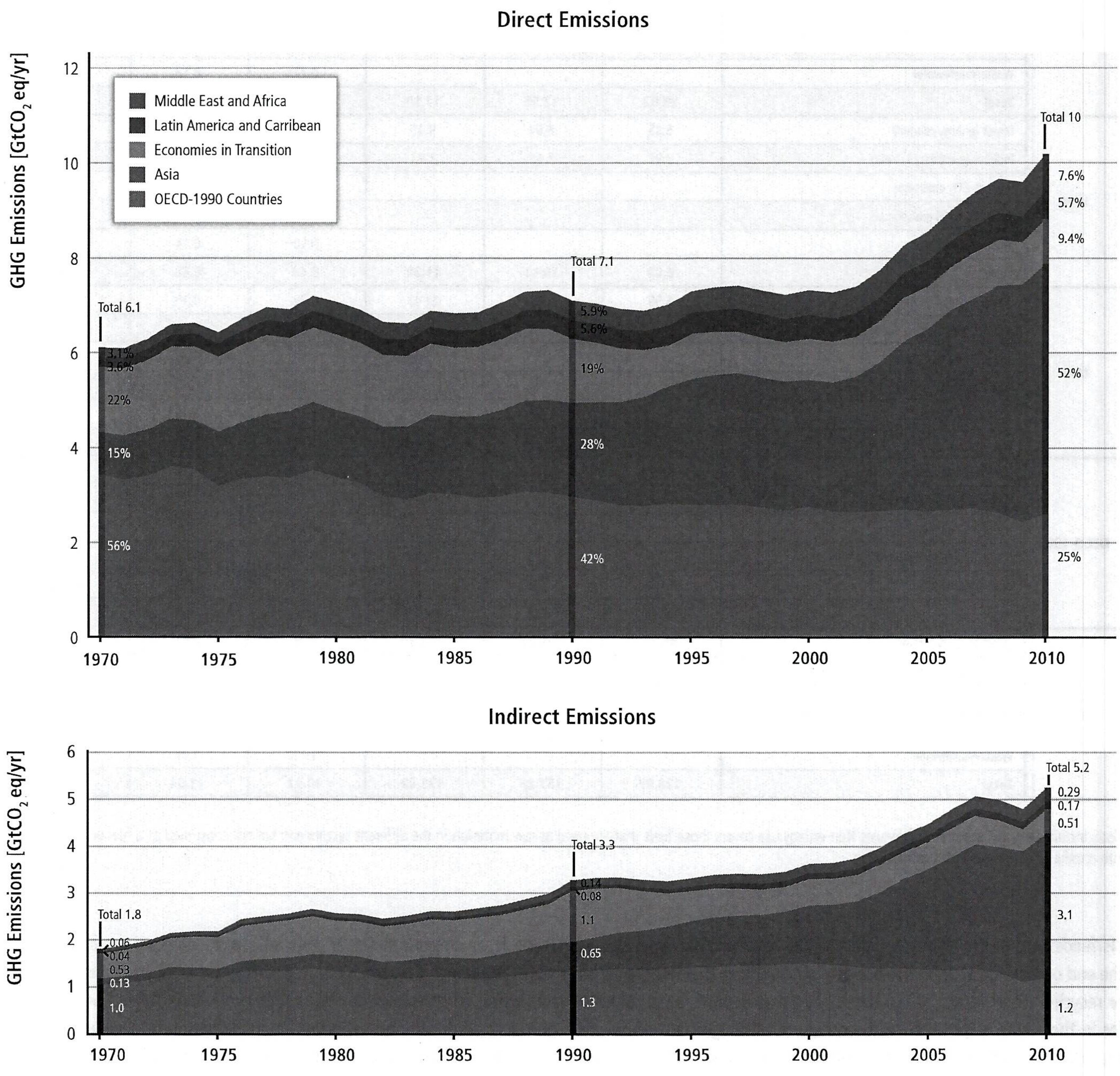

Figure 10.5 | Total global industry and waste/wastewater direct and indirect GHG emissions by region, 1970–2010 ($GtCO_2eq/yr$) (de la Rue du Can and Price, 2008; IEA, 2012a; JRC/PBL, 2013). See also Annex II.9, Annex II.5.

Table 10.2 | Industrial Primary Energy (EJ) and GHG emissions ($GtCO_2eq$) by emission type (direct energy-related, indirect from electricity and heat production, process CO_2, and non-CO_2), and waste/wastewater for five world regions and the world total (IEA, 2012a; b; c; JRC/PBL, 2013; see Annex II.9). For definitions of regions see Annex II.2.

		Primary Energy (EJ)			GHG Emissions ($GtCO_2eq$)		
		1990	2005	2010	1990	2005	2010
ASIA	Direct (energy-related)	20.89	42.83	56.80	1.21	2.08	2.92
	Indirect (electricity + heat)	5.25	15.11	24.38	0.65	2.14	3.08
	Process CO_2 emissions				0.36	0.96	1.49
	Non-CO_2 GHG emissions				0.05	0.25	0.27
	Waste/wastewater				0.35	0.54	0.60
	Total	**26.14**	**57.93**	**81.17**	**2.62**	**5.98**	**8.36**
EIT	Direct (energy-related)	21.98	13.47	13.68	0.79	0.41	0.45
	Indirect (electricity + heat)	6.84	4.10	3.42	1.09	0.59	0.51
	Process CO_2 emissions				0.32	0.23	0.23
	Non-CO_2 GHG emissions				0.11	0.12	0.12
	Waste/wastewater				0.12	0.13	0.15
	Total	**28.82**	**17.56**	**17.10**	**2.43**	**1.48**	**1.47**
LAM	Direct (energy-related)	5.85	8.64	9.45	0.19	0.26	0.28
	Indirect (electricity + heat)	0.97	1.67	1.93	0.08	0.15	0.17
	Process CO_2 emissions				0.08	0.11	0.13
	Non-CO_2 GHG emissions				0.03	0.03	0.03
	Waste/wastewater				0.10	0.14	0.14
	Total	**6.82**	**10.31**	**11.38**	**0.48**	**0.68**	**0.75**
MAF	Direct (energy-related)	5.59	8.91	11.43	0.22	0.30	0.37
	Indirect (electricity + heat)	1.12	1.99	2.58	0.14	0.24	0.29
	Process CO_2 emissions				0.08	0.15	0.21
	Non-CO_2 GHG emissions				0.02	0.02	0.02
	Waste/wastewater				0.10	0.16	0.17
	Total	**6.71**	**10.90**	**14.01**	**0.56**	**0.86**	**1.07**
OECD-1990	Direct (energy-related)	40.93	45.63	42.45	1.55	1.36	1.24
	Indirect (electricity + heat)	11.25	10.92	9.71	1.31	1.37	1.19
	Process CO_2 emissions				0.57	0.56	0.52
	Non-CO_2 GHG emissions				0.35	0.35	0.44
	Waste/wastewater				0.50	0.40	0.39
	Total	**52.18**	**56.55**	**52.16**	**4.28**	**4.04**	**3.79**
World	Direct (energy-related)	95.25	119.47	133.81	3.96	4.41	5.27
	Indirect (electricity + heat)	25.42	33.78	42.01	3.27	4.48	5.25
	Process CO_2 emissions				1.42	2.01	2.59
	Non-CO_2 GHG emissions				0.55	0.77	0.89
	Waste/wastewater				1.17	1.37	1.45
	Total	**120.67**	**153.25**	**175.82**	**10.37**	**13.04**	**15.44**

Note: Includes energy and non-energy use. 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. Also includes construction.

als/feedstocks in the chemical industry may result in CO_2 emissions at the end of their life-span in the disposal phase if they are not recovered or recycled (Patel et al., 2005). These emissions need to be accounted for in the waste disposal sector's emissions, although data on waste imports/exports and ultimate disposition are not consistently compiled or reliable (Masanet and Sathaye, 2009). Subsector specific details are also in Section 10.4.

Trade is an important factor that influences production choice decisions and hence CO_2 emissions at the country level. Emission inventories based on consumption rather than production reflect the fact 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 (Ahmad and Wyckoff, 2003; Wang and Watson, 2007; Peters and Hertwich, 2008;

Table 10.3 | Industry and waste/wastewater direct and indirect GHG emissions by source and gas, 2010 (in $MtCO_2eq$) (IEA, 2012a; JRC/PBL, 2013).

Source	Gas	2010 Emissions ($MtCO_2eq$)
Ferrous and non ferrous metals	CO_2	2,127
	CH_4	18.87
	SF_6	8.77
	PFC	52.45
	N_2O	4.27
Chemicals	CO_2	1,159
	HFC	206.9
	N_2O	139.71
	SF_6	11.86
	CH_4	4.91
Cement*	CO_2	1,352.35
Indirect (electricity + heat)	CO_2	5,246.79
Landfill, Waste Incineration and Others	CH_4	627.34
	CO_2	32.50
	N_2O	11.05
Wastewater treatment	CH_4	666.75
	N_2O	108.04
Other industries	CO_2	3,222.24
	SF_6	40.59
	N_2O	15.96
	CH_4	9.06
	PFC	20.48
	HFC	332.38
Indirect	N_2O	24.33

Gas		2010 Emissions ($MtCO_2eq$)
Carbon dioxide	CO_2	13,139
Methane	CH_4	1,326.93
Hydrofluorocarbons	HFC	539.28
Nitrous oxide	N_2O	303.35
Perfluorocarbons	PFC	72.93
Sulphur hexafluoride	SF_6	61.21
Carbon Dioxide Equivalent (total of all gases)	**CO_2eq**	**15,443**

Note: CO_2 emissions from cement-forming reactions only; cement energy-related direct emissions are included in 'other industries' CO_2 emissions.

Weber et al., 2008). Chapter 14 provides an in-depth discussion and review of the literature related to trade, embodied emissions, and consumption-based emissions inventories.

10.3.2 Industrial non-CO_2 GHG emissions

Table 10.4 provides emissions of non-CO_2 gases for some key industrial processes (JRC/PBL, 2013). N_2O emissions from adipic acid and nitric acid production and PFC emissions from aluminium production decreased while emissions from HFC-23 from HCFC-22 production increased from 0.075 $GtCO_2eq$ in 1990 to 0.207 $GtCO_2eq$ in 2010. In the period from 1990–2010, fluorinated gases (F-gases) and N_2O were the most important non-CO_2 GHG emissions 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 processes. Most of the N_2O emissions from the industrial sector are contributed by the chemical industry, particularly from the production of nitric and adipic acids (EPA, 2012a). A summary of the issues and trends that concern developing countries and Least Developed Countries (LDCs) in this chapter is found in Box 10.1.

Table 10.4 | Emissions of non-CO_2 GHGs for key industrial processes (JRC/PBL, 2013)[1]

Process	Emissions ($MtCO_2eq$)		
	1990	2005	2010
HFC-23 from HCFC-22 production	75	194	207
ODS substitutes (Industrial process refrigeration)[2]	0	13	21
PFC, SF_6, NF_3 from flat panel display manufacturing	0	4	6
N_2O from adipic acid and nitric acid production	232	153	104
PFCs and SF_6 from photovoltaic manufacturing	0	0	1
PFCs from aluminium production	107	70	52
SF_6 from manufacturing of electrical equipment	12	7	10
HFCs, PFCs, SF_6 and NF_3 from semiconductor manufacturing	7	21	17
SF_6 from magnesium manufacturing	12	9	8
CH_4 and N_2O from other industrial processes	3	5	6

Note:

1 the data from US EPA (EPA, 2012a) show emissions of roughly the same magnitude, but differ in total amounts per source as well as the growth trends. The differences are significant in some particular sources like HFC-23 from HCFC-22 production, PFCs from aluminium production and N_2O from adipic acid and nitric acid production.

2 Ozone depleting substances (ODS) substitutes values from EPA (2012a).

10.4 Mitigation technology options, practices and behavioural aspects

Figure 10.2, and its associated identity, define six options for climate change mitigation in industry.

- **Energy efficiency (E/M):** Energy is used in industry to drive chemical reactions, to create heat, and to perform mechanical work. The required chemical reactions are subject to thermodynamic limits. The history of industrial energy efficiency is one of innovating to

10

Box 10.1 | Issues regarding Developing and Least Developed Countries (LDCs)

Reductions in energy intensity (measured as final energy use per industrial GDP) from 1995 to 2008 were larger in developing economies than in developed economies (UNIDO, 2011). The shift from energy-intensive industries towards high-tech sectors (structural change) was the main driving force in developed economies, while the energy intensity reductions in large developing economies such as China, India, and Mexico and transition economies such as Azerbaijan and Ukraine were related to technological changes (Reddy and Ray, 2010; Price et al., 2011; UNIDO, 2011; Sheinbaum-Pardo et al., 2012; Roy et al., 2013). Brazil is a special case were industrial energy intensity increased (UNIDO, 2011; Sheinbaum et al., 2011). The potential for industrial energy efficiency is still very important for developing countries (see Sections 10.4 and 10.7), and possible industrialization development opens the opportunity for the installation of new plants with highly efficient energy and material technologies and processes (UNIDO, 2011).

Other strategies for mitigation in developing countries such as emissions efficiency (e.g., fuel switching) depend on the fuel mix and availability for each country. Product-service efficiency (e.g., using products more intensively) and reducing overall demand for product services must be accounted differently depending on the country's income and development levels. Demand reduction strategies are more relevant for developed countries because of higher levels of consumption. However, some strategies for material efficiency such as manufacturing lighter products (e.g., cars) and modal shifts in the transport sector that reduce energy consumption in industry can have an important role in future energy demand (see Chapter 8.4.2.2).

LDCs have to be treated separately because of their small manufacturing production base. The share of manufacturing value added (MVA) in the GDP of LDCs in 2011 was 9.7 % (7.2 % Africa LDCs; Asia and the Pacific LDCs 13.3 % and no data for Haiti), while it was 21.8 % in developing countries and 16.5 % in developed countries. The LDCs' contribution to world MVA represented only 0.46 % in 2010 (UNIDO, 2011; UN, 2013).

In most LDCs, the share of extractive industries has increased (in many cases with important economic, social, and environmental problems (Maconachie and Hilson, 2013)), while that of manufacturing either decreased in importance or stagnated, with the exceptions of Tanzania and Ethiopia where their relative share of agriculture decreased while manufacturing, services, and mining increased (UNCTAD, 2011; UN, 2013).

Developed and developing countries are changing their industrial structure, from low technology to medium and high technology products (level of technology in production process), but LDCs remain highly concentrated in low technology products. The share of low technology products in the years 1995 and 2009 in LDCs MVA was 68 % and 71 %, while in developing countries it was 38 % and 30 % and in developed countries 33 % and 21 %, respectively (UNIDO, 2011).

Among other development strategies, two alternative possible scenarios could be envisaged for the industrial sector in LDCs: (1) continuing with the present situation of concentration in labour intensive and resource intensive industries or (2) moving towards an increase in the production share of higher technology products (following the trend in developing countries). The future evolution of the industrial sector will be successful only if the technologies adopted are consistent with the resource endowments of LDCs. However, the heterogeneity of LDCs circumstances needs to be taken into account when analyzing major trends in the evolution of the group. A report prepared by the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat summarizes the findings of 70 Technology Needs Assessments (TNA) submitted, including 24 from LDCs. Regarding the relationship between low carbon and sustainable development, the relevant technologies for most of the LDCs are related to poverty and hunger eradication, avoiding the loss of resources, time and capital. Almost 80 % of LDCs considered the industrial structure in their TNA, evidencing that they consider this sector as a key element in their development strategies. The technologies identified in the industrial sector and the proportion of countries selecting them are: fuel switching (42 %), energy efficiency (35 %), mining (30 %), high efficiency motors (25 %), and cement production (25 %) (UNFCCC SBSTA, 2009).

A low carbon development strategy facilitated by access to financial resources, technology transfer, technologies, and capacity building would contribute to make the deployment of national mitigation efforts politically viable. As adaptation is the priority in almost all LDCs, industrial development strategies and mitigation actions look for synergies with national adaptation strategies.

create 'best available technologies' and implementing these technologies at scale to define a reference 'best practice technology', and investing in and controlling installed equipment to raise 'average performance' nearer to 'best practice' (Dasgupta et al., 2012).

Energy efficiency has been an important strategy for industry for various reasons for a long time. Over the last four decades there has been continued improvement in energy efficiency in energy-intensive industries and 'best available technologies' are increas-