Dialogue on a RES policy framework for 2030

towards2030

Background Report

(to Issue Paper No. 9)

Global prospects for fossil fuels with special reference to resource rent effects and CCS

- A normative backcasting perspective

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About the project

The aim of **towards2030-*dialogue*** is to facilitate and guide the RES policy dialogue for the period towards 2030. This strategic initiative aims for an intense stakeholder dialogue that establishes a European vision of a joint future RES policy framework.

The dialogue process will be coupled with in-depth and continuous analysis of relevant topics that include RES in all energy sectors but with more detailed analyses for renewable electricity. The work will be based on results from the IEE project beyond 2020 (www.res-policy-beyond2020.eu), where policy pathways with different degrees of harmonisation have been analysed for the post 2020 period. **towards2030-*dialogue*** will directly build on these outcomes: complement, adapt and extend the assessment to the evolving policy process in Europe. The added value of Towards2030-dialogue includes the analysis of alternative policy pathways for 2030, such as the (partial) opening of national support schemes, the clustering of regional support schemes as well as options to coordinate and align national schemes. Additionally, this project offers also an impact assessment of different target setting options for 2030, discussing advanced concepts for related effort sharing.

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Summary

Background

Developments regarding the global supply of fossil fuels will have a major impact on post-2020 renewable energy deployment and deployment policies in the EU. To date, fossil fuels alone account for almost three quarters of the EU energy mix. Hence, achieving the at least 27% share of renewables in the EU's final energy consumption warrants – besides energy efficiency enhancement – substitution of fossil fuels by (primarily) renewables to a quite significant extent. The as such highly uncertain future global fossil energy market trends will have a huge impact on the future competitiveness of fossil fuels in the EU. This report assesses the global prospects for fossil fuels. Point of departure for the assessment are the IEA's central scenario projections, set out in its World Eenergy Outlook 2014 (WEO2014) publication.

Our assessment is made from a normative back-casting perspective. It is based on two basic premises. First, to date the world is in an advanced stage of completing a trend towards catastrophic climate change phenomena degrading habitats for flora and fauna, including humanity. Second, the policy area of non-GHG environmental impacts - notably air pollution – is on the verge of moving to the centre stage of leading issues driving energy policy making world-wide.

Initially, high-impact climate change phenomena are poised to unfold in their severest form in areas situated in the lower latitude areas around the equator, arid areas prone to desertification and low-lying coastal areas. This, in turn, is poised to set in motion unprecedented migratory movements of biological species, foremost human populations, in tandem with likewise social turmoil in climate-change driven migratory destination areas. Global trends regarding the immediate or postponed combustion of fossil fuels constitute the principal factor at play. In this paper a policy response is anticipated of policymakers around the globe of broadly fast accelerating — if indeed differentiated — intensity and foremost for pragmatic reasons of sheer political survival.

Meta-trends projected by IEA/WEO2014

The IEA's central scenario (New Policies Scenario) projections project the following meta-trends up to year 2040:

- *Strong if decelerating global population growth.*
- *Rising global-average living standards and a growing affluent middle class, especially in non-OECD countries.*
- *A world-wide strong urbanisation trend.*
- *Robustly rising global energy demand as energy intensity reduction does only partially offset the growth of the world economy.* Global primary energy demand is set to grow relentlessly if at a mildly decelerating rate from 559 EJ in 2012 to 700 EJ in 2030 and 766 EJ in 2040.
- *A sustained prominent, if rather slowly declining, role of fossil fuels.* The energy consumption of coal and oil is projected to grow significantly until 2030 and level off thereafter up to 2040; natural gas is projected to grow even faster and also after 2030. The share of fossil fuels in total primary energy demand would diminish only gradually from 82% in 2012, 77% in 2030 and 75% in 2040. Also in the world electricity sector fossil fuels would keeping on commanding a quite high, gradually declining share, i.e. 68% in 2012, to 58% in 2030 and 55% in 2040.
- *Under the WEO2014 NPS scenario unconventional oil production, such as tight/shale oil, is poised to increase significantly.* Unconventional gas production is projected to increase as well – especially shale gas production is poised to increase. To date, the biggest player in the area of unconventional oil and gas is the USA. This is projected to remain so during the period 2012-2040.
- *The projected global energy trends under the WEO2014 NPS scenario are to lead to catastrophic energy-driven climate change, consistent with 3.6 ^{0}C temperature rise by 2100 as expected value, whereas under the WEO2014 450S scenario expected temperature rise up to 2100 is projected to remain within 2 ^{0}C.* By 2040, in the central NPS scenario — as distinct from the 450S scenario — the take-up of CCS in the power sector would still be rather modest.

Evolving IEA/WEO central scenario projections on global energy demand and demand for fossil fuels

Recent WEO central scenario projections of world primary energy demand may have a significant, if modest, positive bias given broadly downward revisions in successive recent WEO publications. As such, the projected central scenario demand trend is highly worrisome from our postulated normative back-casting perspective. This holds even before factoring in the projected composition of the future energy mix. We strongly support IEA's recommendations that world-wide efforts policy efforts should be intensified to speed up the progress on energy efficiency.

Moreover, a strong positive bias is revealed in the reviewed WEO central scenario projections regarding the share of fossil fuels in world primary energy demand. Analysing the contributions of oil, natural gas and coal to this bias, indications are found that this positive fossil fuels bias can be largely attributed to the even stronger positive bias in the projections on the share of oil.

The conspicuously high dispersion in IEA/WEO2005 through 2015 central scenario oil price assumptions attest to the innate difficulty in making reliable short-run oil price predictions, let alone medium and longer term oil price forecasts. Indeed, given the complex and partly unpredictable undercurrents at play, the IEA nor other purveyors of long-term oil price trend assumptions can claim that their assumptions of modelling outcomes will come true with a fair amount of certainty, unless these are moulded into very wide and correspondingly less meaningful forecast intervals.

Fossil fuel prices, EU imports of fossil fuels and geopolitical externalities

Should our postulated normative back-casting perspective dominate the future of fossil fuels indeed, the premium of oil to coal will keep on rising as the global demand for coal will have the strongest tendency to lag behind other major primary energy sources including natural gas and, to a lesser extent, oil. On medium and longer term the prospects for oil are poised to become bleaker as well. On medium term and possibly on longer term as well natural gas will keep on holding a significant share in the world energy mix, given its less negative impact on climate change and other environmental impact categories, notably air pollution. All in all, we expect the current high price premium of oil to gas to diminish rapidly and even to turn negative in the medium term. In contrast, the rising trend in oil price premium versus the price of coal is poised to continue.

The resource rent created by European demand for oil and natural gas has negative externalities regarding the internal political and economic stability in oil and gas producing countries and negative wider geopolitical externalities. By sheer weight of the EU trading block the resource rent of EU demand for fossil fuels is further amplified by its impact on global fossil fuel prices.

Reduction of EU demand for coal, oil and gas has quite benign impacts for global sustainable development. These benign impacts relate to reduced global climate change externalities, reduced local environmental externalities along the global fossil-fuels supply chains and reduced (geo)political stability externalities because of reduced resource rent creation in oil and gas producing countries.

The resource rent aspect should get much more attention in the public communication on the benefits of energy efficiency improvement and enhanced deployment of renewables. Not only does reduction in international trade in scarce natural resources, notably oil and natural gas, tend to have positive geopolitical feedback externalities for importing countries. Dwindling resource rents in oil and natural gas exporting countries tend to render it more urgent for political survival of ruling elites to introduce economic restructuring as well as foreign trade and investment reforms. Moreover, it forces autocratic governments to be more receptive to basic demands for access to basic amenities and elementary democratic rights by fledgling grass-root civil rights movements and ethnic minorities in rentier petro states.

The IMF (Coady et al, 2015) puts global post-tax subsidies at $4.9 trillion, i.e. 6.5% of global GDP, on a post-tax basis. Fossil fuel subsidies have sizable negative externalities for climate change, public health, land degradation, bio diversity, global socio-political stability and the sustainability of the state budget. Moreover, fossil-fuel subsidies slow down the transition towards a high-efficiency, renewables-based energy system. This chapter contains main guidelines to address the urgent issue of phasing out fossil fuel subsidisation.

The prospects for CCS in fossil-based power generation

CCS applied to fossil fuel plants is a technology with fairly high and, at least to date, highly uncertain GHG avoidance costs. This hold the more so, when these cost are analysed from a global perspective using LCA methodology. This report provides substantive arguments that the projected cost of GHG emissions avoidance with CCS applied to fossil power plants in publications by IEA, EIA and IPCC are likely to substantially err on the low side.

GHG emission levels of fossil-fuelled power plants without CCS are too high to be compatible with the main objective of the FCCC and the ambitions enshrined in the 2015 Paris Agreement on Climate Change. The projected performance of CCS-equipped fossil-fuelled power plants on global warming is substantially better than reference power plants without CCS. Nevertheless, GHG emission levels of coal-fired power plants with CCS still remain too high to reach compatibility in an enduring way. Moreover, persistent air pollution problems in a progressively urbanising world is a second important driver to strengthen the political forces that rally to phase out coal-fired power plants altogether. Not only in the rich countries but in the emerging economies and developing countries as well. Indeed, coal-fired power plants, and even more so the ones with CCS, tend to have a poor performance on several other environmental impact categories. In these respects, natural-gas-fired plants tend to have much lower impacts.

The prospects for gas-fuelled power plants equipped with CCS on compatibility with the FCCC's main objective on longer term look appreciably brighter than with coal-fired ones. Natural gas has at least a role to play as a transition fuel. Yet, it cannot be firmly concluded that gas-fired power plants with CCS will endure in a stringently carbon-constrained world necessary to keep average human-induced temperature changes below 2 degrees above pre-industrial levels. This depends in particular on the actual cost of CCS applied to gas-fired power plants and adequate containment of fugitive methane emissions.

In the assessment of CCS application in the power sector also the impact on geopolitical tensions have to be duly weighted. Given the broadly modest resource rent transfers from international trade in coal and fairly easy short-term supply alternatives for importing countries and regions the geopolitical externality for coal and hence for application of CCS to coal-fired power plants are very small. For natural gas this negative externality is significant. World Bank data, elaborated in this report indicate that resource rents from extraction of natural gas can be quite substantial.

For large-scale deployment of CCS suitable solutions will have to be found for huge CO_2 storage space requirements. Mounting technology acceptance issues will further complicate the implementation of CO_2 storage, necessitating the preparation and use of high-cost remote onshore and sub-oceanic geological storage space. Moreover, environmental integrity of geological storage still needs to be proven. World-wide strict monitoring procedures on leakages have to be introduced.

Overall conclusions

Notably, but not only, based on the normative back-casting perspective pursued in this report, we foresee prospective turn-outs for global demand for coal and for oil to deviate progressively in negative direction from the interval spanning NPS and 450S scenario projections by the IEA/WEO2014. For 2030 this interval is 124 EJ – 182 EJ for coal and 166 EJ – 196 EJ for oil.[1] For coal, these expected deviations are likely to start unfolding any time soon; for oil starting some 5-10 years from now, contingent in particular on the penetration of electric/hydrogen passenger cars in the global passenger car market.

The global demand for natural gas might be more in line with the lower end of the interval delineated by IEA/WEO2014 NPS and 450S scenario projections, i.e. 142 EJ – 159 EJ by 2030[1], contingent on whether each of the two following conditions will hold:

- Fugitive methane emissions in the natural gas supply chain up to delivery for final use will be measured with acceptably smaller confidence intervals than is the case at present and will be reduced to acceptably low levels on a per unit of natural gas production basis through widespread deployment of best practices
- The cost of CCS applied to natural gas power plants nor public resistance against this CCS application will turn out to be a show-stopper for natural gas fired power plants on longer term.

Regarding the control of global energy-related GHG, socio-economically efficient energy savings and renewable energy deployment should be given absolute priority by policy makers. However, geo-engineering options need to be developed as well, as warranted by the precautionary motive, should direct and indirect EE/RES deployment policies[2] not deliver enough GHG emissions abatement to avoid catastrophic climate change. Efforts in this direction so far have been virtually totally concentrated on CCS. *Non-CCS geo-engineering options should be given due research funding attention*: such policy adjustment may hold out pleasant innovation surprises with possible emergence of one of the non-CCS carbon removal options being more cost-effective than CCS with geological storage.

Dynamically efficient substitution of fossil fuels by renewables not only has potentially huge positive climate and local environmental externalities: declining resource rent transfers also contribute importantly to geopolitical stability. When this substitution is to unfold indeed, oil and natural gas producing countries will be incentivised to introduce/reinforce sound and more inclusive domestic economic and social policies. They will have to face less wherewithal to possibly finance inefficient domestic social and economic policies and/or to engage in antagonistic foreign policies.

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[1] See Table 2.4 below.

[2] The nuclear option is beyond the scope of this report; it will be addressed in another Towards2030-Dialogue paper.

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1 Introduction

1.1 Background

In this report, prepared under WP6 of the Towards2030-Dialogue project, results are presented of an assessment of IEA's projections on the global for fossil fuels in the global energy mix. The IEA is the most reputed and leading purveyor of official world-wide energy projections IEA modelling are characterized by a high level of professional skills in ensuring internal consistency and enriching detail. The evolving issues of IEA's World Economic Outlook excel in high-level energy policy analysis and valuable policy recommendations. The World Energy Outlook being highly regarded as most authoritative, their central scenario projections are quite frequently adopted as basic input assumptions for policy and underlying research documents by EU Member State (MS) government and other governmental organisations for medium and long-term energy policy design.

A major part of the preparation of this report took place prior to the issue date of the 2015 edition of IEA's annual World Energy Outlook (WEO) report. Therefore, this report focuses in particular on the 2014 edition, i.e. WEO2014. The reason for concentrating on IEA's central scenario projections are the following. Modest resources for preparing this paper call for a limited research focus. We therefore focus on IEA/WEO central scenario projections. Moreover, attention is given to the WEO2014 projections under the 450S scenario, which assumes world-wide implementation of much stricter GHG abatement policies than under WEO2014's central scenario, i.e. the New Policies Scenario (NPS).

Our assessment is made from a normative back-casting perspective. It is based on two basic premises. First, to date the world is in an advanced stage of completing a trend towards catastrophic climate change phenomena putting the global habitats for flora and fauna, including humanity, in the balance. Second, the policy area of non-GHG environmental impacts - notably air pollution – is on the verge of moving to the centre stage of guiding issues driving energy policy making world-wide.

Initially, high-impact climate change phenomena are poised to unfold in their severest form in areas situated in the lower latitude areas around the equator, arid areas prone to desertification and low-lying coastal areas. For example, a recent modelling study projects that climate-related deaths is set to reach a level of more than half a million per annum by year 2050 already.[3] This, in turn, is poised to set in motion unprecedented migratory movements of biological species, including human populations, in tandem with likewise social turmoil in climate-change driven migratory destination areas. Global trends regarding the immediate or postponed combustion of fossil fuels is the principal factor at play. An indeed differentiated response — if of broadly fast accelerating intensity — of policymakers worldwide is anticipated in this paper, for mostly pragmatic reasons of sheer political survival.

At present, the primordial guidance to EU and MS energy policy design is provided by the *energy trilemma*:

(i) Competitive and affordable energy costs

(ii) Energy supply security

(iii) Transition to a low carbon economy.

Sometimes "environment" is stated instead as "third pillar". Indeed, in the world's advanced economies non-GHG environmental impacts are taken seriously, e.g. through imposition and enforcements of standards. But most MS still have to put in place long-term climate and energy planning for guiding the design of actual environmental and energy policy. And, so far, MS that do commit to such planning, have tended to relegate non-

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[3] (Springmann et al., 2016). See also: (IPCC, 2014a and 2014b).

energy environmental impacts as second-order concerns for energy policy design. We postulate that non-GHG environmental impacts/ air pollution will, at least in practice, become "the fourth overarching pillar" on which energy policy will be predicated sooner (in the western world and some emerging economies, including notably China) or (somewhat) later world-wide. This is prompted by the rising awareness of the seriousness of non-GHG environmental impacts on world-wide degradation of the biosphere and more specifically the quality of human life. Rising urbanization and a growing middle class are driving factors towards inclusion of the "the fourth pillar" among the overarching issues of concern for energy policy.

This "fourth pillar" is notably distinct from the climate change issue in that poor performance on this energy policy headline category has a direct, if locally differentiated (e.g. hot spots), negative impact on the quality of life of political constituencies. In contrast, as for the climate change issue, opportunistic, short-term-oriented politicians may be inclined to optimize their choices in accordance with the Prisoner's Dilemma. On medium term and the more so on longer term, this will leave all nations, including the nations ruled by short-term oriented politicians, worse off than under a full climate policy cooperation scenario. Even in the absence of a progressively stronger countervailing domestic grass-root pro climate-policy movement in some nations, the latter scenario may evolving from international pressure, leading broadly world-wide to increasingly stringent governance on climate policy.

1.2 Outline

This report is structured as follows. Chapter 2 highlights and discusses megatrends underpinning WEO2014 projections of global demand for energy and fossil fuels. Chapter 3 discusses the evolving central scenario projections on the demand for energy and fossil-fuel components in the projected energy mix in recent WEO publications. In Chapter 4 recent trends regarding the EU imports of fossil fuels and fossil fuel price trends are analysed. It zooms in on geopolitical externalities of the EU imports of oil and natural gas with case studies of two prominent oil and natural gas exporters, i.e. the Russian Federation and Saudi Arabia. The prospects for CCS deployment in coal- and natural gas-fired power plants are analysed in Chapter 5. Chapter 6 winds up this report with policy recommendations.

2 Global energy trends

2.1 Introduction

This chapter seeks to highlight the future global mega trends regarding primary world energy supply/demand and the uptake of fossil fuels as projected by WEO2014. As the central scenario projections are the ones national policy makers widely consider as background for national energy policy design, this report focuses on IEA's central scenario, called New Policies Scenario (NPS), and also gives limited attention to one of the two WEO2014 alternative scenarios, the 450 Scenario which is modelled to be consistent with a maximum global warming potential equal to 450 ppm CO_2 concentration. The IEA baseline scenario might be warranted for modelling purposes. But from the postulated normative back-casting perspective adopted in the present report, this scenario would seem highly unlikely to unfold in practise. In order to refrain from overstretching the scope and resources of this limited study, IEA2014 baseline scenario projections are not being paid explicit attention to in this report. A brief description of WEO2014 scenarios is given in Annex 1.

In this chapter, key energy trends and underlying factors emanating from WEO2014 regarding the world at large are set out. In order to supplement global mega trends presented in this chapter with some regional flavor, historical and projected energy trends are also disaggregated for the following countries/regions: EU, USA, China, India, Middle East and the rest of the world (ROTW). To limit the main text this information is presented in Annex 2. Some tables in this chapter present trends by fuel. As this report focuses on fossil fuels, only the trends regarding fossil fuels are highlighted and explained in the main text.

The Chapter is structured as follows. Section 2.2 deals with population and economic growth, primary energy demand and energy intensity trends. Section 2.3 highlights projected trends regarding non-conventional fossil fuels. Projected trends regarding the global energy and electricity mix are discussed in Sections 2.4. GHG emissions trends as projected by the IEA NPS and 450S scenarios are set out in Section 2.5. To conclude, section 2.6 summarizes projected mega trends.

2.2 Population and economy

2.2.1 Population

In mid-2015, world population reached 7.3 billion. The increase in world population from 6.3 billion to 7.3 billion took only twelve years. World population continues to grow, but UN/DESA projects population growth to gradually decelerate. At present, the annual population growth rate is 1.2% per annum, as against 1.4% p.a. during the period 1990-2012. For the period of 2012-2040 this rate is projected to be 0.9% in the UN medium variant scenario (Table 2.1). This projected slowdown in population growth is attributed to an assumed reduction in fertility, with population ageing as a result. The majority of population growth until 2050 is projected to occur in Africa and non-OECD Asia. Population in India, China, USA and the Middle East region is projected to increase, while population in Europe is expected to decrease (UNDP, 2015a).[4]

Table 2.1 also bears out another important demographic trend, i.e. urbanization. In 1950 30% of the world population lived in urban areas, while by 2014 this proportion has risen to 54%. Projections are that this trend will continue in all regions over the coming decades. In Africa and Asia urbanization will increase the most in relative terms. It is projected that by 2050 in these continents respectively 56% and 64% will live in urban areas,

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[4] See Annex 2 for regionalised historical data and projections.

against currently 90% of the population of both Africa and Asia living in rural areas. China, India and Nigeria alone are projected to account for 37% of the growth of world urban population between 2014-2050 (UNDP, 2014a).

We note that the UN central (medium variant) projections might well turn out to be skewed to the high side resulting from the demographic impact of rising urbanization. A world-wide expanding middle class and improved access to education and information may result in faster deceleration of world population growth than currently projected by UN/DESA. Moreover, climate change may affect inter-regional migration flows more than assumed by UN/DESA. Should the ongoing human-induced climate change continue relentlessly, high migration flows from Africa, the Middle East and South Asia to the EU and from South and Central America to North America have to be reckoned with.

Table 2.1 UN/DESA central scenario projections of world and EU28 total and urban population

	Population							Urban population		
	(millions)					CAAGR (%)		(millions)		CAAGR (%)
	1990	2012	2020	2030	2040	1990-2012	2012-2040	2012	2040	2012-2040
World	5278,91	7042,94	7758,16	8500,77	9157,23	1,4	0,9	3726	5715	1,5
EU-28	477,84	505,12	508,23	509,65	506,76	0,3	0,0	376	416	0,4

CAAGR: compound annual average growth rate
Source: (UN/DESA, 2014a/b,2015a/b)

2.2.2 Economic development

After the peak of the global financial crisis in 2008, global economic growth is picking up at a rather tepid pace. Moderately expanding economic activity is being recorded in the USA and weak economic growth in Europe, while many emerging economies and raw material exporting developing countries are still facing hard times. Even so, most of the future global economic growth is projected to be accounted for by emerging and developing economies. IMF (2014) projects world GDP to grow in real terms (purchasing power parity basis) by a 3.4% annual average compound rate in the period 2012-2040 (Table 2.2). Non-OECD Asia (led by India with 6%) and Africa (especially Nigeria) are projected to achieve the highest GDP growth rate, i.e. by 5.1% and 4.7% per year respectively. The Chinese economy is projected to grow by 5% per year from 2012-2040, as against a whopping 10% in the decade before. This decline in rate of growth is caused by the transformation of the Chinese economy from heavy-industry oriented towards services and light-industry-oriented. Also demographic trends including an ageing population and a leveling off of population growth negatively affect the future growth of the Chinese economy (IMF, 2014). The IMF (2014) projects growth in all main regions (See also Annex 2). The IMF projects the world per capita GDP to grow by a propitious 2.4% per annum during the period 2012-2040: see Table 2.3.

Table 2.2 Central scenario projections of world and EU28 GDP in trillion international dollars of constant year 2013 purchasing power parity

GDP($international 2013 trillions, purchasing power parity)   IMF 2012 GDP ppp data * 2012-2013 US inflator

	GDP at constant 2013 prices						
	($2013 trillion, Purchasing Power Parity)					CAAGR (%)	
	1990	2012	2020	2030	2040	1990-2012	2012-2040
World	41,33	84,43	112,91	160,82	216,13	3,3	3,4
EU-28	11,20	16,23	18,43	22,03	25,57	1,7	1,6

Note: (trillion) dollars used have a constant purchasing power at parity with (trillion) US dollars in year 2013
Source: (IMF, 2014), (IEA, 2014a: 41; CAAGRs)

Table 2.3 UN/DESA central scenario projections of world and EU28 GDP per capita in international dollars of constant year 2013 purchasing power parity

	GDP per capita at constant 2013 prices						
	($2013; Purchasing Power Parity)					CAAGR (%)	
	1990	**2012**	**2020**	**2030**	**2040**	**1990-2012**	**2012-2040**
World	7.830	11.988	14.554	18.918	23.602	2,0	2,4
EU-28	23.443	32.134	36.262	43.224	50.448	1,4	1,6

Note: dollars used have a constant purchasing power at parity with US dollars in year 2013
Source: (UN/DESA, 2014a/b,2015a/b), (IMF, 2014), (IEA, 2014a: 41; CAAGRs)

We would like to make some qualifications to the projections of economic growth presented in Table 2.2 and 2.3 above and Tables A2.2 and A2.3 in Annex 2. Should the normative back-casting perspective prevail to a major extent at global level, as indeed assumed in this report, and allowing for the (broadly negative) effects of climate change on world-wide economic growth, we foresee that by and large these projections will turn out to err on the high side to a considerable extent. Projected GDP growth rates for all regions, especially the ones for India, the Middle East and the Rest of the World, might well be prone to erring on the high side. Should our assessment of projected population growth and GDP per capita growth prove to be by and large right, this were to imply that, across-the-board, WEO2014 central scenario projections of world primary energy demand are poised to be too high.

2.2.3 Primary and final energy demand

In 2040 the demand for energy is to reach 766 EJ, which would imply an increment of around 205 EJ or 37% to the level of world primary energy demand in year 2012, i.e. 559 EJ. This is the projection under the WEO2014 central scenario, i.e. New Policies Scenario (NPS). Under 450S world primary energy demand is projected to raise from year 2012 to year 2040 by 95 EJ, i.e. 17%. Table 2.4 below provides an overview.

Almost all of the projected growth in primary energy demand is accounted for by non-OECD countries. Non-OECD-Asia is projected to even contribute 60% of this increase in demand. China is projected to contribute the highest share in global energy demand growth until 2025, but is projected to be overtaken by India in this respect after 2025. The only region in which the energy demand is projected to decrease over the period until 2040 is the European Union (IEA, 2014a). We note that, in our view, projections by UN/DESA, IMF, and IEA do not adequately allow for the high probability of major population migration flows into the EU.

According to 450S projections, global primary energy demand are poised to increase from year 2012 to year 2040 by 17%. The corresponding average annual growth rates are respectively 1.1% (NPS) and 0.6% (450) for the period 2012-2040 (IEA, 2014a). Almost all of the growth in primary energy demand comes from non-OECD countries. Under the central scenario (NPS) Asia is even projected to account for 60% of this increase in demand. Until 2025 China has the highest share in global energy demand growth and accounts for one-third of the increase, but is projected by the IEA to be overtaken by India after 2025 (See Annex 2).

Table 2.4 breaks down global primary energy demand by main fuel. IEA projects under the WEO2014 central scenario rising levels of coal, oil and natural gas demand, with a small but even so *positive* incremental demand for coal and oil during the 2030-2040 decade. Under the 450S scenario the projected demand for coal and oil is notably going down. Yet under the latter scenario the global primary demand levels by 2040 for natural gas (145 EJ), but also for oil (136 EJ) and coal (108 EJ) are projected to still to take on huge proportions.

Table 2.4 Realised values (years 1990 and 2012) and WEO2014 NPS and 450S scenario projections (years 2020, 2030, 2040) of world primary energy demand by fuel

(EJ)

Scenario	Actuals		New Policies Scenario			450 Scenario		
Year	**1990**	**2012**	**2020**	**2030**	**2040**	**2020**	**2030**	**2040**
World								
Coal	**93**	**162**	**176**	**182**	**186**	**164**	**124**	**108**
Oil	**135**	**176**	**188**	**196**	**199**	**183**	**166**	**136**
Natural gas	**70**	**119**	**133**	**159**	**185**	**130**	**142**	**145**
Nuclear	22	27	35	44	51	36	54	70
Renewables	47	75	94	119	145	95	140	195
Hydro	*7,7*	*13,2*	*16,4*	*19,6*	*22,4*	*16,4*	*21,4*	*25,0*
Bioenergy	*37,9*	*56,3*	*65,1*	*75,2*	*83,8*	*65,5*	*84,7*	*106,1*
Other renewables	*1,5*	*5,9*	*12,9*	*24,3*	*38,4*	*13,4*	*34,3*	*63,9*
Total	**368**	**559**	**627**	**700**	**766**	**608**	**625**	**654**

Source: (IEA 2014a)

Under the central scenario of IEA/WEO2014, NPS, the annual rate of growth in world primary energy demand is projected to slow down in the coming decades. Growth per annum is to decline from a recorded 2.1% in 1990-2012 to 1.0% during 2020-2030 to 0.8% over the period 2030-2040. In the carbon constrained 450S scenario the growth rates per annum over the periods 2012-2020, 2020-2030 and 2030-2040 are projected to boil down to 1.0%, 0.3% and 0.5% respectively. Predicated on projected demographic and macroeconomic trends set out in the previous section, the projected slowdown in primary energy demand growth result from modelled efficiency gains, as well as structural changes in the global economy, presumed at global level to be less focused on energy-intensive activities (IEA, 2014b). See Table 2.5 below.

Table 2.5 presents primary energy demand growth per annum by main fuel. This table confirms the trends as projected by the IEA, already set out above. In the WEO2014 central scenario, NPS, projected demand growth per annum for coal and oil decelerates notably but remains in positive territory during the 2012-2020 projection period, whilst the projected demand growth for natural gas remains strong. Under 450S demand growth per annum for coal, oil and natural gas decelerates over the projection period 2012-2040 with projected annual growth rates for coal and oil turning notably negative as from 2020 onward.

Table 2.5 Realised values (years 1990 and 2012) and WEO2014 NPS and 450S scenario projections (years 2020, 2030, 2040) of growth in world primary energy demand

(Compound average annual growth rates)

Scenario	Actuals	New Policies Scenario			450 Scenario		
Year	1990-2012	**2012-20**	**2020-30**	**2030-40**	**2012-20**	**2020-30**	**2030-40**
World							
Coal	**2,5%**	**1,0%**	**0,3%**	**0,2%**	**0,1%**	**-2,8%**	**-1,3%**
Oil	**1,2%**	**0,8%**	**0,4%**	**0,2%**	**0,5%**	**-1,0%**	**-2,0%**
Natural gas	**2,5%**	**1,4%**	**1,8%**	**1,5%**	**1,1%**	**0,9%**	**0,2%**
Nuclear	0,9%	3,5%	2,2%	1,5%	3,7%	4,1%	2,7%
Renewables	2,2%	2,8%	2,4%	2,0%	3,0%	3,9%	3,3%
Hydro	2,5%	2,7%	1,8%	1,3%	2,7%	2,7%	1,6%
Bioenergy	1,8%	1,8%	1,5%	1,1%	1,9%	2,6%	2,3%
Other renewables	6,4%	10,2%	6,5%	4,7%	10,7%	9,9%	6,4%
Total	**1,9%**	**1,4%**	**1,1%**	**0,9%**	**1,0%**	**0,3%**	**0,5%**

Source: (IEA 2014a)

Information on projected gross final energy demand by main end-use sector is presented in Table 2.6 below. The WEO2014 projects **electricity** to reinforce its position in the energy mixes of all end-use sectors for both scenarios considered here, although strikingly moderately so in the transport sector. Two projected features standout in this regard, viz.:

1. The, in our view, too conservative assumptions used on the future adoption of electric vehicles as against biofuels and other fuels (such as natural gas derivatives) in the transport sector;
2. The projected strong performance of bioenergy as against electricity in the buildings sector under the 450S scenario.

We have strong doubts on whether either one of these projected features will prove to show up in reality. As a result of strong fiscal incentives for electric passenger cars in a number of OECD countries including the U.S. federal state of California, Norway and the Netherlands as well as, importantly, China, electric cars have fledgingly started to take off in the global passenger car market. Consequently, their costs, including the cost of car batteries, are coming down rapidly. Moreover, the ascending priority given to combatting air pollution world-wide will further prod the large car manufacturers to boost R&D on developing more cost-competitive electric and hydrogen cars. The commotion on the recent VW (Volkswagen) scandal has reinforced this trend. Conversely, the prospects for biofuels seem to be less bright than factored in, because of growing opposition against biofuels from food crops and second-generation technologies appearing to advance slower than anticipated by the IEA.

Moreover, biomass is a scarce commodity with –compared to use as transport fuel for passenger cars –higher social-value applications in nice markets, including in the transport sector (aviation, shipping, high pay-load vehicles) and as oil and natural gas substituting industrial feedstock. For the same reason, we also doubt that the second projected feature mentioned above, i.e. the projected strong performance of bioenergy in buildings, will happen indeed.

Coal is projected to sustain an important role in industry under both the NPS and the 450S scenario. E.g. in China, industrial use of coal includes its use in steel and cement manufacturing, in blast furnaces and coke ovens, as a petrochemical feedstock and a projected increasing use in other conversion processes such as coal-to-gas and coal-to-liquids. Coal has a modest role in buildings and transportation sectors. The projected role of coal and other fossil fuels in electricity generation will be discussed in Section 2.4 below. For **oil** a slowly declining but still major role is projected: under 450S somewhat more declining than under NPS. This applies to transport, industries and buildings. Remarkably, even under 450S WEO2014 projects that oil would still boast the lion's share (63%) in the transport sector by 2040. For **natural gas** WEO2014 projects a gradually increasing role as a final energy fuel under both NPS and 450S. This is projected to be especially the case in transport (subsumed in 'other fuels'). We already commented on this projected trend in the preceding paragraph. In buildings natural gas is projected to keep its major role while the IEA projects that in industry the role of natural gas will become gradually smaller.

Table 2.6 Realised values (years 1990 and 2012) and WEO2014/IEA NPS and 450S scenario projections of the world final energy demand mix by sector; 2012-2040

Scenario	Actuals		New Policies Scenario			450 Scenario		
Year	1990	2012	2020	2030	2040	2020	2030	2040
Total								
Coal	12%	10%	10%	9%	8%	10%	9%	8%
Oil	41%	41%	39%	38%	36%	39%	35%	29%
Natural gas	15%	15%	15%	16%	18%	15%	16%	18%
Electricity	13%	18%	20%	22%	23%	19%	21%	24%
Heat	5%	3%	3%	3%	3%	3%	3%	3%
Bioenergy	13%	12%	12%	12%	11%	12%	14%	16%
Other renewables	0%	0%	0%	1%	1%	1%	1%	2%
Total (in EJ)	263	374	426	479	523	416	439	450
Industry								
Coal	26%	28%	27%	24%	22%	27%	24%	22%
Oil	18%	12%	11%	10%	9%	11%	10%	8%
Natural gas	18%	13%	11%	10%	9%	11%	10%	8%
Electricity	21%	27%	29%	30%	32%	28%	29%	31%
Heat	8%	5%	5%	4%	4%	5%	4%	4%
Bioenergy	6%	7%	7%	8%	9%	8%	9%	11%
Other renewables	0%	0%	0%	0%	0%	0%	0%	1%
Total (in EJ)	76	109	128	145	159	125	134	141
Transport								
Oil	94%	93%	91%	88%	85%	91%	81%	63%
of which Bunkers	*13%*	*14%*	*14%*	*14%*	*14%*	*13%*	*12%*	*13%*
Electricity	1%	1%	1%	2%	2%	1%	3%	7%
Biofuels	13%	14%	14%	14%	14%	13%	12%	13%
Other fuels	4%	4%	4%	5%	7%	4%	7%	12%
Total (in EJ)	66	105	118	134	145	115	117	111
Buildings								
Coal	11%	4%	4%	3%	2%	4%	3%	2%
Oil	14%	11%	10%	8%	7%	9%	7%	6%
Natural gas	19%	20%	21%	22%	22%	21%	20%	20%
Electricity	18%	29%	32%	36%	40%	32%	35%	37%
Heat	14%	11%	10%	8%	7%	9%	7%	6%
Bioenergy	30%	29%	27%	24%	22%	28%	27%	26%
Other renewables	0%	1%	1%	2%	3%	2%	3%	5%
Total (in EJ)	94	123	134	148	162	131	136	144
Other								
Total (in EJ)	28	38	46	52	56	46	51	54

Source: (IEA, 2014a)

2.2.4 Energy intensity

Energy intensity is an approximate measure of the energy efficiency of a nation's economy and is calculated over time as units of energy per unit of real GDP on a Purchasing Power Parity basis. High energy intensities indicate high energy prices or cost of converting energy into GDP and vice versa. Economic activity is thus the principal driver of demand for each type of energy service. So far energy demand has tended to grow in line with GDP, though notably in the (economically) more advanced countries typically at a lower rate. Especially in the more advanced economies, where saturation effects curb income-driven increases in demand for material-intensive goods, structural shift towards services occur. Indeed, this is broadly the case for OECD countries. Lately China has made a fledgling start with this fundamental economic transition. Global and EU historical energy intensity trends and trends projected by the WEO2014 (central) new policies scenario and its (low GHG emissions) 450 scenario respectively are shown in Table A2.5 below.

There are considerable differences across regions in the amount of energy used per dollar of GDP and trends over time. China had for instance a high energy intensity in the 1990s because of a large increase in energy-intensive manufacturing and huge investment in physical infrastructures. In OECD countries economic activities are generally less energy intensive and thus the link between GDP and energy use has weakened over the last decades (See Annex 2, Table A2.4). It can be expected that China follows suit. WEO2014 predicts for India a remarkably fast decline in energy intensity through year 2040. Possibly this relates to the projected, likewise remarkably, fast economic growth speed projected for this juggernaut country combined with assumed strong technology leap frogging.

Table 2.7 Realised values (years 1990,2012) and WEO2014/IEA NPS and 450S scenario projections (years 2020,2030,2040) of world and EU28 energy intensity; 2012-2040

	EJ/trillion$2013 (PPP)					CAAGR (%)	
	1990	**2012**	**2020**	**2030**	**2040**	**1990-2012**	**2012-2040**
New Policies Scenario							
World	8,9	6,6	5,6	4,4	3,5	-1,3	-2,2
EU-28	6,1	4,2	3,7	2,9	2,5	-1,7	-1,9
450 Scenario							
World	8,9	6,6	5,4	3,9	3,0	-1,3	-2,8
EU-28	6,1	4,2	3,6	2,8	2,3	-1,7	-2,2

Note: (trillion) dollars used have a constant purchasing power at parity with (trillion) US dollars in year 2013
Source: (UN/DESA, 2014a/b,2015a/b), (IMF, 2014), (IEA, 2014a)

2.3 Supply of unconventional gas and oil

When considering the World Energy Outlook by IEA (2014a), projections on unconventional oil and gas production are important to consider, because of their relatively recent implementation and potential in some regions. IEA (2014a) projects unconventional oil (mainly US-tight oil, Canadian oil sands and Brazilian deepwater output) to push non-OPEC supply higher until at least the early 2020s.

A crucial implicit assumption underlying WEO2014's modelling exercises and oil price projections is that excess production capacity is assumed to remain unchanged (IEA2014a: 114). This leads WEO2014 to project oil prices gradually firming (See Section 3.4 below). We will revert to the issue of IEA oil price projections in Chapters 3 and 4 below.

US tight oil assumes an important role in current and projected unconventional oil supply. Major tight oil production areas in the US are the Bakken, Eagle Ford and Permian plays. WEO2014 projects a peak production of US tight oil to the tune of 4.5 mb/d, until production is projected to level off in the 2020s and to subsequently decline gradually (IEA, 2014a). This decline occurs as it becomes less economically feasible compared to other sources, if (as assumed in the WEO2014 NPS scenario) no major improvements in technology or other measures substantially increasing the cost efficiency occur. Decline rates for individual tight oil wells are higher than for conventional wells, implying a greater intensity of drilling to maintain overall production at a given level. As each play typically has "sweet spots", where recovery per well is high and the rest of the tight oil containing formation, where recovery is lower. As the sweet spots are depleted and drilling move to less productive zones, the economics are poised to deteriorate, leading to stabilization and subsequent decrease in production. (IEA, 2014: 118-119).

Even though the US boasts only 17% of currently known global tight oil reserves, WEO2014 projects the country to stay the largest tight oil producer at least until 2040. Also Canada boasts favourable tight oil production conditions. Elsewhere conditions seem less favourable, making it likely that tight oil production outside North America will come on stream much later in the future. Only China and Russia appear to have the potential to reach the same scale as projected peak production in the US. China is currently focusing on shale gas rather than tight oil. Should this prove successful, the country might also upscale tight oil production (330 kb/d in 2040 in NPS). The same holds for Russia. WEO2014 projects that Russian production of tight oil stays low (600 kb/d in 2040 in NPS). For India, it might also interesting to explore tight oil production since conventional oil production is at its peak, but to date this is too early to tell (IEA, 2014a).

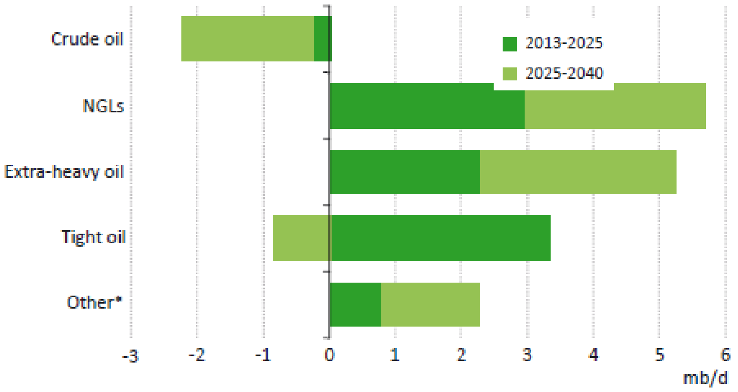
Without technological improvements, for tight oil production it is going to be difficult to grow throughout the IEA projection period. The decline rates for tight oil wells are higher than for conventional oil wells and thus currently more drilling needs to take place for the same production. In addition, volatility in oil prices could cause fluctuations in proven tight oil reserves, as drilling can be put on hold when prices are lower (IEA, 2014a). For these reasons, WEO2014 projects that other sources of unconventional oil, notably extra-heavy oil, coal to-liquids and gas-to-liquids, as well as NGLs, will relatively increase more over period until 2040. Mainly oil sands in Canada and Venezuela will increase, as well as tight oil production in Argentina, Russia, China and elsewhere (IEA, 2014a). In Table 2.8 the development of unconventional oil production in Non-OPEC, OPEC and the world is shown per type of oil and in Figure 2.1 the projected changes in world oil production, both conventional and unconventional, are shown for the periods 2013-2025 and 2025-2040 respectively.

Table 2.8 Projected unconventional oil production per oil category for OPEC, non-OPEC and the world for the period 2012- 2040, New Policies Scenario

(in mb/d)

Region		Year						2013-40
	Category	2013	2020	2025	2030	2035	2040	CAAGR
OPEC		0.7	1.5	1.9	2.3	2.8	3.2	5.8%
	Venezuela extra-heavy	0.4	1.1	1.4	1.7	2.1	2.4	6.9%
	Gas-to-liquids	0.2	0.2	0.2	0.3	0.3	0.4	2.6%
Non-OPEC		5.4	9.3	10.7	11.9	12.8	13	3.3%
	Canada oil sands	1.9	3	3.3	3.7	4.2	5.2	3.8%
	Tight oil	2.9	5.5	6.2	6.5	6.3	5.3	2.3%
	Coal-to-liquids	0.1	0.2	0.5	0.7	1	1.1	9.3%
	Gas-to-liquids	0	0	0.1	0.3	0.5	0.5	n.a.
Total		**6.1**	**10.8**	**12.6**	**14.2**	**15.6**	**16.2**	**3.7%**

Source: (!EA, 2014a)



* includes coal-to-liquids and gas-to-liquids projects, production of additives an of kerogen oil

Source: (IEA, 2014a; Figure 3.11)

Figure 2.1 Graphical depiction of projected changes in unconventional world oil production by type in the WEO2014 New Policies Scenario (central scenario)

Unconventional gas - consisting mainly of shale gas, coalbed methane and tight gas and to smaller extent coal-to-gas and methane hydrates - is projected to account for almost 60% of the growth in global gas production until 2040 in the New Policies Scenario. Growth projections for unconventional gas are to increase from a share of 17% of total gas production in 2012 to 31% in 2040. Currently, the USA and Canada are the largest producers of unconventional gas and are estimated to still produce 50% of the global production by 2040, even though unconventional gas production will become more widespread (IEA, 2014a).

In WEO2014 US shale gas production is projected to decline from the second half of 2030 onwards. Economic feasibility is poised to decline as from around 2035 as low-cost resources are projected to be depleted by then and, consequently, the cost of production are to increase.

Another large producer of unconventional gas is projected to be China, with a projected increase of shale production from 25 bcm to 110 bcm in the period 2025-2040 (NPS). Additionally, China is projected also to produce significant volumes of unconventional gas by way of captured coalbed methane and coal-to-gas. The share of unconventional gas is projected to have a share of 80% of total Chinese gas production in 2040. China is projected to expand output significantly to harnass its large gas resource base. The strong political willingness to expand the role of gas in the Chinese energy mix relates to the huge air pollution problem, China is currently facing.

In contrast, public and political acceptance of unconventional gas is poised to remain low in most European Union member states. WEO2014's NPS scenario projects for the EU on aggregate, that in 2040 unconventional supply is contributing to 15% to total gas production. This production is projected to take place mainly in Poland and the United Kingdom. In Table 2.9 the development of unconventional gas production from 2012-2040 is shown per type of gas.

Table 2.9 Projected unconventional gas production per type during the period 2012- 2040, New Policies Scenario (central scenario)

(in bcm)

Category	Year						2012-40
	2012	2020	2025	2030	2035	2040	CAAGR
Shale gas	279	54	610	772	895	954	4.5%
Coalbed methane	76	148	216	274	314	356	5.7%
Tight gas	237	294	292	291	308	327	1.2%
Coal-to gas	0.3	32	42	47	49	51	20.4%
Methane hydrates	0	0	0.1	0.3	0.7	0.9	n.a.
Total	**592**	**928**	**1160**	**1385**	**1567**	**1689**	**3.8%**
of which OECD	68%	84%	78%	72%	68%	64%	
Non-OECD	4%	16%	24%	29%	33%	38%	

Note: CAAGR stands for compound average annual growth rate
Source: (IEA, 2014a)

2.4 The global energy and electricity mix

In Sub-Section 2.2.3 above, WEO2014 projected trends on the evolution of aggregate global demand for primary energy and the final energy demand mix per main end-use sector were set out. Table 2.10 below informs on how WEO2014 projections on the primary energy mix look like. Under the WEO2014 NPS scenario world primary energy demand for coal, oil and natural gas are projected to grow during the period 2012-2040 by 0.5% per annum, 0.5%pa and 1.6% pa respectively. This would lead to shares for coal, oil and gas in the world primary energy demand by 2040 of no less than 24%, 26% and 24% respectively, i.e. a share for fossil fuels of 74%. Especially the projected 24% and 26% shares for coal and oil respectively are quite ominous from a normative back-casting perspective.

The corresponding results for the WEO2014 450S scenario look somewhat less discomforting but still far from propitious. Under 450S world primary energy demand for coal, oil and natural gas are projected to grow during the period 2012-2040 by -1.4% pa, -0.9%pa and 0.7% pa respectively. The resulting shares for coal, oil and gas in the world primary energy demand by 2040 would be 17%, 21% and 22% respectively, i.e. a (rounded) share for fossil fuels of 59%. More regionalized WEO2014 projections on the primary energy demand mix is presented in Annex 2, Table A2.5.

Coal demand has increased by more than half in the period 2003-2013. China was the principal source of this increase. Towards 2040, this demand is projected to decrease in all major regions, except for China and India. The demand in China is projected to grow sharply initially, but to peak around 2030. Coal demand in India is projected to keep on growing up to 2040. Deployment of Carbon Capture and Storage (CCS) is projected to remain very limited under the NPS scenario, whilst the adoption of high efficiency coal fired generation technology is poised to rise. In the 450S scenario CCS is projected to penetrate in a non-negligible fashion towards 2040.[5] The IEA projects continued high shares for coal in the primary energy demand mix of China and India. By 2040 this share in China would be 58 % as a (NPS) central scenario projection or 38 % when the world, including China, was to adopt more stringent climate policies (450S). For India the projected corresponding coal shares are 44 % and 26 %. It also stands out that also for the economically most advanced regions/countries considered, i.e. the U.S. and EU-28, under the NPS and, if to a lesser extent, under the 450S scenario the IEA projects still quite significant shares for coal by 2040. For the U.S. the projected corresponding shares for coal are 13% (NPS) and 11% (450S) and for the EU-28 these (coal) shares are 9% and 7% respectively.

For **oil** the projected share by year 2040 is 27 % in the U.S. under the NPS scenario and 20% under 450S, for China 17% (NPS) and 13% (450S), and for India 25% (NPS) and 20% (450S). As for the projected shares of oil in the world's most populous countries China and India, again the IEA presents a dismal picture from a normative back-casting perspective. Considering oil demand and supply, in the new policies scenario (NPS) in the period until 2040, the net growth in demand entirely comes from non-OECD countries. China and India are projected to be two big importers of oil during the period 2012-2040. This increases their vulnerability to possible short-lived or protracted oil supply crunches. IEA's central scenario projections suggest that in 2040, two out of three barrels of crude oil traded internationally are destined for Asian countries as against one out of six in 2012. Iraq, Canada and Brazil are projected to produce the bulk of incremental oil demand. Another projection in oil demand and supply is the rise of unconventional oil production, of which production of US tight oil already levels off in 2020 and prospects on Canadian oil sands are still highly uncertain (IEA, 2014a). WEO2014 is optimistic about the remaining recoverable oil reserves relative to the proven reserves (which are skewed as well in favour of OPEC).

Natural gas use grows in all WEO2014 scenarios. Demand is projected to increase in all the selected and major regions except for Europe. Global gas demand is poised to be mainly pushed by China (to decrease air pollution) and the Middle East (to limit the use of oil for inlands power generation). For the US the share of gas in primary energy demand by 2040 is projected to be 33% (NPS) and 27% (450S), for China 11% (NPS) and 12% (450S) and for India 11% (NPS) and 15%(450S). In the U.S., natural gas is the largest fuel in the energy mix in 2040. The U.S. is projected to remain the largest producer, even though production are set to levels off in 2030 as shale gas output falls back. In Europe demand is projected to be sluggish, due to CO_2 pricing and due to concerns about gas security. LNG imports are poised to rise in Europe and Asia. The IEA projects that unconventional gas will account for around 60% of the growth in global production during the period 2012-2040 (IEA, 2014a).

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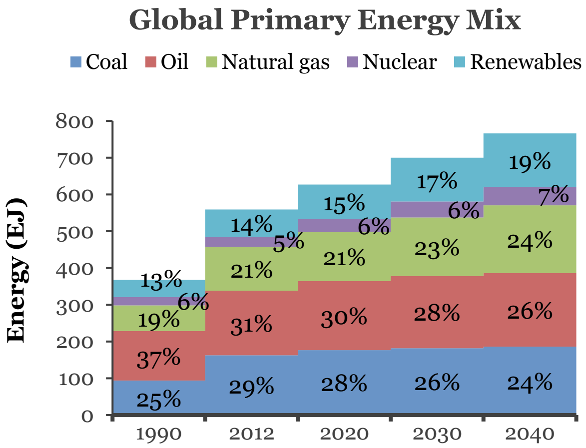
[5] See IEA (2014a: p.92, Figure 2.23).

Table 2.10 Realised (years 1990, 2012) and projected (years 2020, 2030, and 2040) global primary energy demand mix according to the WEO2014 NPS and 450S scenarios

Scenario	Actuals		New Policies Scenario			450 Scenario		
Year	**1990**	**2012**	**2020**	**2030**	**2040**	**2020**	**2030**	**2040**
World								
Coal	**37%**	**41%**	**37%**	**33%**	**31%**	**35%**	**20%**	**13%**
Oil	**11%**	**5%**	**3%**	**2%**	**1%**	**3%**	**1%**	**1%**
Natural gas	**15%**	**22%**	**22%**	**23%**	**24%**	**22%**	**22%**	**16%**
Nuclear	**17%**	**11%**	**12%**	**12%**	**12%**	**12%**	**16%**	**18%**
Hydro	**18%**	**16%**	**16%**	**16%**	**16%**	**17%**	**20%**	**20%**
Bioenergy	**1%**	**2%**	**3%**	**3%**	**4%**	**3%**	**5%**	**6%**
Wind	**0%**	**2%**	**5%**	**7%**	**8%**	**5%**	**11%**	**14%**
Geothermal	**0%**	**0%**	**0%**	**1%**	**1%**	**0%**	**1%**	**2%**
Solar PV	**0%**	**0%**	**2%**	**3%**	**3%**	**2%**	**4%**	**6%**
CSP	**0%**	**0%**	**0%**	**0%**	**1%**	**0%**	**1%**	**3%**
Marine	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Total (TWh)	**11.825**	**22.721**	**27.771**	**33.881**	**40.104**	**26.760**	**30.296**	**35.043**
PM								
Share fossil fuels	**63%**	**68%**	**62%**	**58%**	**55%**	**60%**	**43%**	**30%**
Share renewables	**20%**	**21%**	**26%**	**30%**	**33%**	**27%**	**41%**	**51%**

Source: (IEA, 2014a)



Source: (IEA, 2014a)

Figure 2.2 Evolution of the global primary energy mix including WEO2014 New Policies Scenario (central scenario) projections for the period 2012-2040; 1990-2040

In the remaining part of this section we will discuss IEA's WEO2014 projections of global and regional trends regarding the electricity mix. Table 2.11 below and A2.6 in Annex 2 present a summary of quantitative data from the WEO2014 in this regard. WEO2014 projects the global demand for electricity to grow during the period 2012-2040 by 2.5% p.a. under its NPS scenario and by 1.5% p.a. under the 450S scenario, compared to a realized growth of 3.0% p.a. during 1990-2012. Under the NPS scenario it is projected to reach on aggregate a global level of 40,104 TWh by 2040, as against 35,043 TWh under the 450S scenario. This compares to a realised level of 22,721 TWh in year 2012.

Under NPS the share of **coal** in the global energy mix is projected to decline from 41% in 2012 to 31% in 2040. Under 450S the share of coal would shrink to 13% in 2040. As distinct from the NPS scenario, under 450S deployment of CCS to coal-fired power plants would be substantial. Yet we were unable to find details in the WEO2014 report on projected coverage of CCS use to coal- and natural-gas-fired power plants. WEO2014 projects under the NPS scenario by 2040 a share of coal in the regional/country electricity mix of the EU-28, US, China, India and ROTW of respectively 9% (EU-28), 22% (US), 52% (China), 55% (India), 0% (Middle East) and 21% (ROTW), compared to respectively 5% (EU-28), 16% (US), 23% (China), 18% (India), 0% (Middle East) and 7% (ROTW) under the 450S scenario.

Although the projected 450S share of 13% for coal in the global electricity mix by year 2040 means a strong decline, it is still hardly consistent with the back-casting perspective adopted in this report. A 13% share for coal in global electricity generation, would seem not compatible with stringent climate policies. This relates to the elevated CO_2 emission level per coal-based kWh on a lifecycle analysis basis, *even with application of CCS* (see Chapter 5). *Furthermore, the high coal shares in India, China, the US and the ROTW projected by WEO2014 are at odds with dramatically enhanced priority (poised to be) given to non-GHG environmental issues, foremost to improving air quality, in these regions/countries by 2040.* Also, for India and many countries encompassed by the ROTW a high coal share would boil down to a major negative effect on the current account. What's more, the significant penetration of CCS assumed by the IEA with regard to coal-based electricity generation under the 450S scenario by 2040 is unlikely to materialize, as will be further explained in Chapter 5. A quite recent publication (Shearer *et al.*, 2016) provides further evidence and considerations why the role of coal in the global energy mix is set to diminish soon.

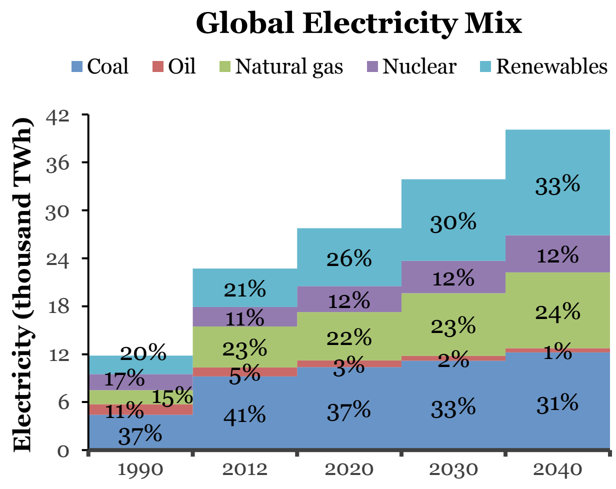
Oil plays a minor and declining role in (public-grid-injected) generation of electricity. Only in the Middle East, a region endowed with giant low-cost oil resources, oil plays a significant role in power generation. WEO2014 projects a share for oil in the electricity mix of the Middle East by 2040 of 12% under NPS and 8% under 450S against a recorded 36% (!) in year 2012.

WEO2014 is upbeat about the evolving role of *natural gas* in electricity generation. In year 2012 natural gas accounted for 22% of gross electricity generated world-wide. According to WEO2014, by 2040 natural gas is poised to boast a share in the global electricity mix of 24% under NPS and 16% under 450S. The region with the highest projected gas share in its electricity mix by 2040 is the Middle East with a projected share of 65% under NPS and 46% under 450S. In the country where the proverbial shale gas revolution is unfolding, i.e. the US, the projected share of natural gas by 2030 is 34% under NPS and 18% under 450S, compared to a recorded 30% in year 2012.

Table 2.11 **WEO2014/IEA NPS and 450S scenario projections of world and EU28 electricity consumption by fuel; 2012-2040**

Scenario	Actuals		New Policies Scenario			450 Scenario		
Year	**1990**	**2012**	**2020**	**2030**	**2040**	**2020**	**2030**	**2040**
World								
Coal	**37%**	**41%**	**37%**	**33%**	**31%**	**35%**	**20%**	**13%**
Oil	**11%**	**5%**	**3%**	**2%**	**1%**	**3%**	**1%**	**1%**
Natural gas	**15%**	**22%**	**22%**	**23%**	**24%**	**22%**	**22%**	**16%**
Nuclear	**17%**	**11%**	**12%**	**12%**	**12%**	**12%**	**16%**	**18%**
Hydro	**18%**	**16%**	**16%**	**16%**	**16%**	**17%**	**20%**	**20%**
Bioenergy	**1%**	**2%**	**3%**	**3%**	**4%**	**3%**	**5%**	**6%**
Wind	**0%**	**2%**	**5%**	**7%**	**8%**	**5%**	**11%**	**14%**
Geothermal	**0%**	**0%**	**0%**	**1%**	**1%**	**0%**	**1%**	**2%**
Solar PV	**0%**	**0%**	**2%**	**3%**	**3%**	**2%**	**4%**	**6%**
CSP	**0%**	**0%**	**0%**	**0%**	**1%**	**0%**	**1%**	**3%**
Marine	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Total (TWh)	**11,825**	**22,721**	**27,771**	**33,881**	**40,104**	**26,760**	**30,296**	**35,043**
PM								
Share fossil fuels	**63%**	**68%**	**62%**	**58%**	**55%**	**60%**	**43%**	**30%**
Share renewables	**20%**	**21%**	**26%**	**30%**	**33%**	**27%**	**41%**	**51%**

Source: (IEA, 2014a)



Source: (IEA, 2014a)

Figure 2.3 **Evolution of the global electricity mix including WEO2014 New Policies Scenario (central scenario) projections for the period 2012-2040; 1990-2040**

2.5 Global GHG emission trends

In 2012 the energy sector accounted for two thirds of all GHG emissions. Within the energy sector coal is estimated to account for 44% of total global energy-related emissions in year 2012, oil for 36% and natural gas for 20%. Central IEA/WEO2014 projections (under the NPS scenario) suggest a rise of global CO_2 emissions by 20% during 2012-2040 from 31.6 Gt to 38.0 Gt. Projecting out the trend to 2050 and beyond, this is consistent with a GHG concentration in the atmosphere of over 700 ppm in 2100. This would lead globally on average at least to 3.6 degrees Celsius temperature rise. In Table 2.12 the (projected) global CO_2 emissions are shown under the New Policies Scenario (NPS), with percentage point contributions per fossil fuel.

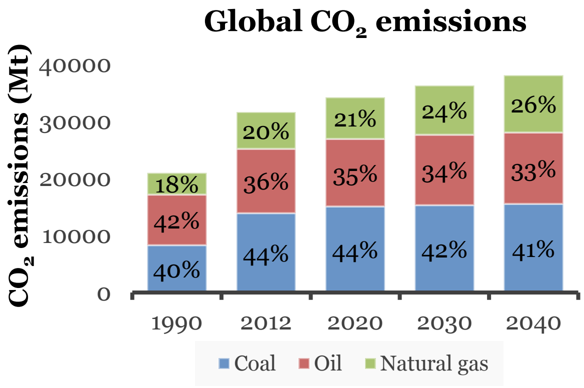
The 450 Scenario is projected to lead to 450 ppm GHG concentration in 2100. This is projected to be consistent with globally on average a 2.0 degrees Celsius human induced temperature rise. Under this scenario energy-related CO_2 would peak at 33.0 Gt before 2020 and then fall back to 25.4 Gt in 2030 and 19.3 Gt in 2040. The 450 scenario assumes a successful COP21 in Paris and in its wake much stronger government policies. These include much stronger energy efficiency improvements than under the NPS scenario, limits to the use and construction of inefficient coal power stations, minimizing methane emissions from upstream oil and gas, accelerating the phase-out of fossil-consumption subsidies and carbon pricing in the power sector.

In Table A2.6 of Annex 2 some regionalized details on global energy-related GHG emissions are presented, as adapted from WEO2014 (IEA, 2014a) data. WEO2014 projects that China, India and the amalgamation of countries subsumed under ROTW will dominate the corresponding global GHG emissions. By 2040 energy-related GHG emissions under NPS are projected to be for China, India and ROTW respectively 10.0 Gt (CO_2eq.) , 4.5 Gt, and 14.2 Gt as against under 450S respectively 3.6 Gt, 2.2 Gt and 8.4 Gt. In China and India coal combusting is projected to contribute the largest share, while in ROTW this would be oil.

Table 2.12 Realised values (years 1990 and 2012) and WEO2014/IEA NPS and 450S scenario projections (yeas 2020, 2030, 2040) of world and EU28 electricity consumption by fuel; 2012-2040

Scenario	Actuals		New Policies Scenario			450 Scenario		
Year	**1990**	**2012**	**2020**	**2030**	**2040**	**2020**	**2030**	**2040**
World								
Coal	40%	44%	44%	42%	41%	43%	32%	24%
Oil	42%	36%	35%	34%	33%	35%	40%	40%
Natural gas	18%	20%	21%	24%	26%	22%	29%	36%
Total (Mt CO2eq.)	20.938	31.615	34.203	36.291	38.037	32.479	25.424	19.300

Source: (IEA, 2014a)



Source: (IEA, 2014a)

Figure 2.4 Evolution of global energy-related CO_2 emissions during the period 1990-2040 including WEO2014 New Policies Scenario projections for years 2020, 2030 and 2040; 1990-2040

2.6 Conclusions

The IEA's central scenario (New Policies Scenario) projections, partly based on UN/DESA and IMF projections, suggest the following prospective meta-trends up to year 2040:

- *Strong if decelerating global population growth.* Modest or even stagnating population growth in Europe, Japan, Russia, China and North America, against quite strong if decelerating population growth elsewhere. This is a very potent driver of GHG emissions and other negative environmental impacts such as e.g. lesser biodiversity.
- *Rising global-average living standards and a growing affluent middle class, especially in non-OECD countries.* Contingent on evolving consumption and energy mix patterns, this is a strong GHG emissions driver as well.
- *A world-wide strong urbanisation trend.* This trend, along with rising living standards, has a negative feedback on population growth and raises concerns for environmental performance among a rising share of the population, notably regarding air quality.
- *Robustly rising global energy demand as energy intensity reduction does only partially offset the growth of the world economy.* Global primary energy demand is set to grow relentlessly if at a mildly decelerating rate from 559 EJ in 2012 to 700 EJ in 2030 and 766 EJ in 2040.
- *A sustained prominent if rather slowly declining role of fossil fuels.* The energy consumption of coal and oil is projected to grow significantly until 2030 and level off thereafter up to 2040; natural gas is projected to grow even faster and also after 2030. The share of fossil fuels in total primary energy demand would diminish only gradually from 82% in 2012, 77% in 2030 and 75% in 2040. Also in the world electricity sector fossil fuels would keeping on commanding a quite high, gradually declining share, i.e. 68% in 2012, to 58% in 2030 and 55% in 2040.
- *Under the WEO2014 NPS scenario unconventional oil production, such as tight/shale oil, is poised to increase.* Unconventional gas production will projected to increase as well – especially shale gas production is expected to increase. The biggest player on unconventional oil and gas currently is the USA. This is projected to remain so during the period 2012-2040.
- *The projected global energy trends under the WO2014 NPS scenario are to lead to catastrophic energy-driven climate change, consistent with 3.6% C temperature rise by 2100 as expected value, whereas in the WEO2014 450S scenario expected temperature rise up to 2100 is projected to remain within the 2% C.* By 2040, in the central NEP scenario — as distinct from the 450S scenario — the take-up of CCS in the power sector would still be rather modest.

By and large we concur with these projected megatrends, as depicted by IEA/WEO2014's NPS and 450S scenarios. Yet, as explained in the main text of this chapter, we have some doubts on the projected (high) prospective time trajectories of global energy demand in the WEO2014 central scenario projections. Our doubts are even stronger about the projected sustained dominance of fossil fuels, especially of coal and oil, in the overall energy demand mix picture outlined by WEO2014. Regarding the projected evolution of the energy mixes of the global end use sectors, we singled out two features as projected by WEO2014:

1. The, in our view, too conservative assumptions used on the future adoption of electric vehicles as against biofuels and other fuels (such as natural gas derivatives) in the transport sector under both the NPS and the 450S scenarios.
2. The projected (in our view too) strong performance of bioenergy as against electricity in the buildings sector under the 450S scenario.

We will further articulate our views in more detail on specific fossil fuels related issues in the ensuing chapters of this report.

3 Evolving IEA/WEO central scenario projections

3.1 Introduction

This chapter reviews the evolution in IEA/WEO central scenario projections regarding world total primary energy demand (TPED), the share of fossil fuels in TPED and the price of crude oil in the consecutive WEO2005 through WEO2015 editions. Several publications have indicated a more or less systemic negative bias in the IEA/WEO central scenario projections with regard to the deployment of certain new renewable energy technologies (e.g. de Vos and de Jager, 2014). The same goes for IEA/WEO projections of oil demand (e.g. Maugeri, 2009). In this chapter it is analysed as to whether or not indications can be found of (revealed) biases in IEA's projections regarding the evolution of energy demand and the role of fossil fuels.

Section 3.2 discusses WEO central scenario projections of world primary energy demand. Successive WEO central scenario projections of the role of fossil fuels in world primary energy demand are analysed in Section 3.3. Section 3.4 zooms in on future oil price assumptions. Section 3.5 presents the main findings of this chapter.

3.2 Evolving global energy demand projections

Table 3.1 presents an overview of evolving projections of world primary energy demand under the respective central scenario of WEO2005 through WEO2015. The various WEO's project an annual growth rate for the decennium 2010-2020 ranging from 1.4% to 1.7%, against 0.9%-1.5% during 2020-2030 and (in the two most recent WEO publications) 0.9% during 2030-2040. The general pattern is a mildly decelerating annual growth down to 0.9% per annum during 2030-2040. The most recent WEO central scenario projection of world primary energy demand (in WEO2015) is 17934 Mtoe, equal to 751 EJ (exajoules = 10^{18} joules).[6]

Of the 10 WEO editions reviewed preceding the WEO2015 edition, 7 editions present a higher central scenario projection of world energy demand in year 2030. In this regard, exceptions are presented in the WEO2005, WEO21010 and WEO2011 editions, whilst the highest projection is presented in WEO2007 exceeding the corresponding one in WEO2015 by 7%. On average, the central scenario 2030 TPED projections in WEO2005-WEO2014 are approximately 2% higher than the one of WOE2015. For the central scenario projections of TPED in 2020 the corresponding percentage is approximately +1%. This points into the direction of a significant, if fairly modest, positive bias in the reviewed WEO central scenario demand projections.

The projected central scenario demand trend is highly worrisome from our postulated normative back-casting perspective, even before factoring in the projected composition of the future energy mix. We strongly support IEA's recommendations that world-wide efforts to contain energy demand growth need to be stepped up. Indeed, technological progress on energy efficiency is a central component; population growth and the nature of shifts in consumption preferences of, notably, middle and high income families are key parameters as well.

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[6] EJ is (a multiple of) a *Système International* unit, which – as against Mtoe – has a fuel-neutral connotation. Not only organisations such as IEA and World Bank but, to date, also the European Commission still uses fossil-based measures in forward-looking energy scenario analyses in its official publications. This is all the more remarkable, as the EU aims to reduce the role of fossil fuels and to enhance the role of renewables in the European energy economy.

Table 3.1 **Projections of world total primary energy demand in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015**

(in ExaJoules)

					CAAGR			Difference w.r.t. WEO2015	
Year	2010	2020	2030	2040	2010-20	2020-30	2030-40	2020	2030
WEO2005	519	603	681		1.5%	1.2%		-2%	0%
WEO2006	531	629	716		1.7%	1.3%		2%	5%
WEO2007	536	645	742		1.9%	1.4%		4%	9%
WEO2008	533	633	712		1.7%	1.2%		2%	5%
WEO2009	525	605	703		1.4%	1.5%		-2%	4%
WEO2010	531	609	670		1.4%	1.0%		-1%	-1%
WEO2011	520	618	679		1.8%	0.9%		0%	0%
WEO2012	**533**	625	687		1.6%	1.0%		1%	1%
WEO2013	**533**	629	696		1.7%	1.0%		2%	3%
WEO2014	**533**	627	700	766	1.6%	1.1%	0.9%	1%	3%
WEO2015	**533**	617	684	751	1.5%	1.0%	0.9%		

Estimated realisations in bold
CAAGR = compound annual average growth rate
Source: (IEA, 2005-2015)

3.3 The share of fossil fuels in the global energy mix

Table 3.2 presents an overview of evolving projections of the share of fossil fuels in world primary energy demand under the respective central scenario of WEO2005 through WEO2015. In 2010 the fossil fuels share is estimated to be 81.1%. The various WEO's project in the applicable central scenario a fossil fuels share in 2020 ranging from 79.1% to 81.9%, in 2030 from 76,2 % to 82,0% and 74.5% - 74.7% in 2040. The general picture is a mildly decelerating annual growth down to a still very dominant 74+% in 2040.

- On average, the central scenario 2030 projections of the share of fossil fuels in WEO2005-WEO2014 are approximately 2% higher than the one of WOE2015 with the highest positive deviation (82%) regarding the WEO2007 projection concerned. As from WEO2010 onward the projected share of fossil fuels in year 2030's world primary energy demand vacillates in between 75.5% and 77.2%.

As for these central scenario projections of year 2020 the corresponding percentage is approximately +1%. This points into the direction of a rather strong positive bias in the reviewed earlier WEO editions (WEO2005-WEO2009) regarding central scenario projections on the share of fossil fuels.

The point here is that it regards (deviations measured for) a parameter that is expressed in percentage terms (the share of fossil fuels), as against a parameter expressed in absolute terms (e.g. the level of world primary energy demand). Should we have considered the level of fossil fuels instead, then the average deviation of WEO2005-WEO2014 central projections from the corresponding WEO2015 projections are quite significant, i.e. +2 % for year 2020 and +5 % for year 2030.

Table 3.3, Table 3.4 and Table 3.5 take a closer look at the central scenario projections for the shares of oil, natural gas and coal respectively. The essentials are:

- To date, *oil* is the most important fossil fuel in terms of the level of primary energy demand with a share in world primary energy demand, estimated at 31.1% in 2013. The projected trend in accordance with the successive WEO central scenarios is that of a mildly declining share, which would render the role of oil still quite important by 2040 (projected share 26.0% and 26.4% in WEO2014 and WEO2015 respectively).

Secondly, the average positive deviation of the projected share for oil (central scenario) in WEO2005-WEO2014 from the one in WEO2015 is quite significant. This deviation is 0.9% for year 2020 and 1.6% for year 2030. *A significant positive bias in IEA/WEO's central scenario projections up to WEO2009 as regards the projected medium and longer term role of oil in the global energy economy, whereas as from WEO2010 onward the projected share of oil in year 2030's world primary energy demand vacillates in between 27.7% and 28.4%.*

- To date, *natural gas* is a slightly lesser important fossil fuel in terms of the level of primary energy demand with a share in world primary energy demand, estimated at 21.4% in 2013. The projected central scenario trend is one of a mildly rising share up to between 23.6% (WEO2015) and 24.2% (WEO2014) by 2040. *There is no significant deviation of the average projected share of natural gas for years 2020 and 2030 in WEO2005-WEO2014 from the one in WEO2015.*
- To date, *coal* assumes a role in between the one for oil and natural gas in terms of the level of primary energy demand with a share in world primary energy demand, estimated at 29.0% in 2013. The projected central scenario trend is a mildly declining share down to between 24.3% (WEO2014) and 24.6% (WEO2015) by 2040. *There is a slight deviation of the average projected share for years 2020 (-0.1%) and 2030 (+0.5%) in WEO2005-WEO2014 from the one in WEO2015.* In fact, broadly up to WEO2009 the IEA became more bullish on the role of coal but reversed her outlook for coal in broadly negative direction as from WEO2010.

Table 3.2 Projections of the share of fossil fuels in world total primary energy demand in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015

(in %)

Year	2010	2020	2030	2040	Difference w.r.t. WEO2015	
					2020	2030
WEO2005	80.3	81.1	81.2		2%	7%
WEO2006	80.9	81.2	81.2		3%	7%
WEO2007	81.4	81.9	82.0		4%	8%
WEO2008	81.0	81.0	80.4		2%	6%
WEO2009	81.2	80.3	80.1		1%	5%
WEO2010	81.0	78.6	75.5		-1%	-1%
WEO2011	80.9	79.1	76.2		0%	0%
WEO2012	**81.1**	79.1	76.6		0%	1%
WEO2013	**81.1**	79.5	77.2		1%	1%
WEO2014	**81.1**	79.3	76.7	74.5	0%	1%
WEO2015	**81.1**	79.2	76.6	74.7		

Estimated realisations in bold
Source: (IEA, 2005-2015)

Table 3.3 Projections of the share of oil in world total primary energy demand in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015

(in %)

Year	2010	2020	2030	2040	Difference w.r.t. WEO2015	
					2020	2030
WEO2005	35.8	35.0	34.1		18%	22%
WEO2006	34.4	33.4	32.6		12%	16%
WEO2007	33.9	32.4	31.5		9%	12%
WEO2008	33.3	31.4	30.0		6%	7%
WEO2009	33.1	30.7	29.8		4%	6%
WEO2010	32.4	29.9	28.4		1%	1%
WEO2011	32.6	29.7	28.1		0%	0%
WEO2012	**32.3**	29.9	27.9		1%	-1%
WEO2013	**32.3**	29.8	27.7		0%	-1%
WEO2014	**32.3**	30.0	28.0	26.0	1%	0%
WEO2015	**32.3**	30.3	28.2	26.4		

Estimated realisations in bold

Source: (IEA, 2005-2015)

Table 3.4 Projections of the share of natural gas in world total primary energy demand in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015

(in %)

Year	2010	2020	2030	2040	Difference w.r.t. WEO2015	
					2020	2030
WEO2005	21.5	23.2	24.2		7%	6%
WEO2006	21.0	21.8	22.6		0%	-1%
WEO2007	20.9	21.6	22.3		-1%	-2%
WEO2008	20.5	20.7	21.6		-5%	-5%
WEO2009	20.9	21.0	21.2		-3%	-7%
WEO2010	21.2	21.5	22.2		-1%	-3%
WEO2011	21.0	21.8	22.8		0%	0%
WEO2012	**21.5**	21.9	23.3		1%	2%
WEO2013	**21.5**	21.8	23.1		0%	1%
WEO2014	**21.5**	21.2	22.7	24.2	-2%	0%
WEO2015	**21.5**	21.6	22.6	23.6		

Estimated realisations in bold

Source: (IEA, 2005-2015)

Table 3.5 Projections of the share of coal in world total primary energy demand in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015

(in %)

Year	2010	2020	2030	2040	Difference w.r.t. WEO2015	
					2020	2030
WEO2005	23.1	22.9	22.9		-17%	-10%
WEO2006	25.5	26.0	26.0		-6%	3%
WEO2007	26.5	27.9	28.2		1%	11%
WEO2008	27.1	28.9	28.8		5%	14%
WEO2009	27.2	28.5	29.1		3%	15%
WEO2010	27.4	27.2	24.9		-1%	-2%
WEO2011	27.3	27.6	25.3		0%	0%
WEO2012	**27.3**	27.4	25.5		-1%	1%
WEO2013	**27.3**	28.0	26.3		1%	4%
WEO2014	**27.3**	28.1	26.0	24.3	2%	3%
WEO2015	**27.3**	27.4	25.8	24.6		

Estimated realisations in bold
Source: (IEA, 2005-2015)

3.4 The price of oil

Consecutive IEA/WEO central scenario assumptions in WEO2005 through WEO2015 regarding the future price evolution of crude oil are shown in Table 3.6. The picture that emerges is that the oil price is extremely difficult to forecast ex ante in a fashion that will yield small deviations from future realisations. The last estimated realisation of the IEA benchmark is $97/bbl on average in year 2014 (WEO2015). As for 2015 we do not avail of the IEA data to date but given the gyrations of well-known crude oil price benchmarks such as Brent, it poised to have shrunk by some 45 $/bbl.

The conspicuously high dispersion in IEA/WEO2005 through 2015 central scenario oil price assumptions attest to the innate difficulty in making reliable short-run oil price predictions, let alone medium and longer term oil price forecasts. Given the complex and partly unpredictable undercurrents at play, no purveyor of long-term oil price trend assumptions can claim that his or her assumptions of modelling outcomes will come true with a fair amount of certainty unless these are made in terms of very wide and correspondingly less meaningful forecast intervals. This may seem to be a discomforting conclusion for modelling to inform climate and energy policy as well as macroeconomic policy. We will revert to this issue in the next chapter.

Table 3.6 **Projections of IEA import prices of crude oil in consecutive editions of the World Energy Outlook from WEO2005 through WEO2015**

(in US$2014/bbl)

					CAAGR			Difference w.r.t. WEO2015 (%)	
Year	2010	2020	2030	2040	2010-20	2020-30	2030-40	2020	2030
WEO2005	43	45	47		0.6%	0.5%		-44%	-58%
WEO2006	61	*59*	65		-0.3%	0.9%		-26%	-43%
WEO2007	67	*67*	71		0.0%	0.5%		-16%	-37%
WEO2008	111	122	136		1.0%	1.0%		53%	20%
WEO2009	*103*	109	125		0.6%	1.4%		36%	11%
WEO2010	*70*	107	119		4.4%	1.1%		34%	5%
WEO2011	**84**	116	125		3.4%	0.8%		45%	11%
WEO2012	**84**	125	130		4.1%	0.3%		57%	15%
WEO2013	**84**	116	125		3.4%	0.7%		45%	10%
WEO2014	**84**	114	125	134	3.1%	0.9%	0.7%	42%	10%
WEO2015	**84**	80	113	128	-0.4%	3.5%	1.3%		

Figures in bold are realisations; figures in italics concern geometric intrapolations
CAAGR = compound annual average growth rate
Source: (IEA, 2005-2015)

3.5 Conclusions

We identified a significant, if modest, positive bias in the reviewed WEO central scenario projections of world primary energy demand. As such, the projected central scenario demand trend is highly worrisome from our postulated normative back-casting perspective. This holds even before factoring in the projected composition of the future energy mix. We strongly support IEA's recommendations that world-wide efforts policy efforts should be intensified to speed up the progress on energy efficiency.

Moreover, we observed a stronger positive bias in the central scenario projections in pre-2010 WEOs regarding the share of fossil fuels in world primary energy demand. Analysing the contributions of oil, natural gas and coal to this bias, indications were found that this positive fossil fuels bias can be largely attributed to the even stronger positive bias in the projections on the share of oil.

The conspicuously high dispersion in IEA/WEO2005 through 2015 central scenario oil price assumptions attest to the innate difficulty in making reliable short-run oil price predictions, let alone medium and longer term oil price forecasts. Indeed, the prospective oil price trajectory is hard to predict. Yet, it is remarkable that the WEO2014 did not anticipate the imminent oil glut.

For several reasons the IEA/WEO central scenario projections for fossil fuel seem likely to err on the high side, as was already explained in the previous chapter. The evolution of the oil price is highly unpredictable as it results from a complex interplay of undercurrents such as "the race"[7] between technological progress of oil extraction and exhaustion of the – to date still plentiful but geographically quite unevenly distributed – global oil resources. Moreover, interventions affecting the price of crude by governments of oil exporting countries and counterpart governments of oil importing countries have a less predictable "gaming" element.

From a normative back-casting perspective, the projected medium to long term role of fossil fuels – i.e. foremost coal and secondly oil – in the WEO central scenarios reviewed, strongly reinforces the call to policymakers world-wide to act effectively and, what is more, to act now.

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[7] This contextual phrase was coined by one of the first two Nobel laureates in economics, the late Jan Tinbergen.

4 Geopolitical externalities of EU oil and natural gas imports

4.1 Introduction

This chapter focuses on the prospects for EU imports of fossil fuels in terms of value, import prices and the geopolitical dimension of these imports. From an economic perspective it can be rational to import fossil fuels instead of other goods including inlands energy carriers, if the EU has a comparative advantage –in both a static and a dynamic sense –in the production of other goods and services. This is certainly not paramount to saying that policies reducing the use of fossil fuels do not make sense. To the contrary: it has already been set out in Chapter 1 that current global trends on the production and use of fossil fuels are not sustainable. Key factors at play are the existential threat of climate change as well as other environmental externalities. But the narrative to justify the reduction of fossil fuel use or the stimulation of renewables on account of the high fossil import bill as such does not necessarily make economic sense.

Rather, a related financial phenomenon will be highlighted in the present chapter. A phenomenon with a pronounced, negative externality stemming from the use of fossil fuels, i.e. *resource rent creation*. The EU is relatively poorly endowed with fossil fuel reserves. Indeed, the distribution of economically extractable oil and natural gas reserves is quite uneven world-wide. As the global fuel mix (still) is heavily oriented towards fossil fuels, the geographic disparities in fossil fuel reserves –foremost oil and natural gas reserves – make for huge international financial transfers to exporting countries of oil and natural gas.

What's more relevant from a political and associated economic perspective, a major part of these financial transfers consists of resource rent created by oil and natural gas extraction. This rent consists of the surplus proceeds from extracting and selling oil and natural gas by oil & gas companies on behalf of the producer country governments concerned, after all normal extraction and marketing costs — including a normal return on capital employed — have been subtracted. Note that in emerging economies and developing countries state-owned oil & gas companies tend to be the dominant oil & gas producers. In principle, in these countries the resource rent wealth is freely available at the discretion of ruling elites and their favoured business connections. As will be further discussed later on in this chapter, the high and at the same time highly volatile wealth creation by way of resource rent has major destabilising political externalities.

In contrast, the resource rent from global coal extraction pales in comparison. Not only is the price of coal per unit of energy much lower than the price of oil and natural gas (See next section). Also the economically exploitable reserves of coal are distributed appreciably more evenly across the world. Moreover, a major part of the delivered coal price in importing countries consists of freight costs. Unit freight costs are rather volatile and a certain positive correlation exists between the unit freight cost (as represented e.g. the Dry Baltic Index, a dry bulk commodity freight cost index) and the coal price (as represented e.g. by the API2 c.i.f. ARA benchmark). Hence when the coal price is increasing, a major part of the additional revenues from coal extraction and marketing tend to be chipped away by rising freight costs.

Section 4.2 sets out some main features of recent EU fossil fuel imports. Section 4.3 analyses price trends of fossil fuels. Section 4.4 takes a look at geopolitical impacts of resource rent inflows into two prominent exporters of fossil fuels, i.e. the Russian Federation and Saudi Arabia. Section 4.5 contains the main conclusions of this chapter.

4.2 Recent EU fossil fuel import trends

The historical trend of the EU import value of fossil fuels and derivatives from 2005-2013 is clearly upward. This is indicated by the Eurostat information compiled and presented in Table 4.1. This relates to an increasing import dependency, as for notably oil and gas (European Commission, 2014) as well as broadly rising unit import prices during this period (see Section 4.3 below). By 2013 the value of gross import into the EU of oil and natural gas amounted to 3.0 % of EU28 GDP. By 2013 the share of coal in the fuel mix of EU primary energy demand has risen appreciably (see Section 4.2). But the contribution of coal in the value of EU fossil fuel imports in 2013 is a modest 4.1%, against 74.5% for oil and 21.4% for gas (See Table 4.1). Moreover, the enormous size of global coal reserves and their much more even global distribution than applicable to oil and natural gas keep the resource rent and the related geopolitical externalities created by coal extraction, within modest proportions. By contrast, as will be set out hereafter by case studies on Russia and Saudi Arabia, global resource rent wealth creation by natural gas and foremost oil extraction assumes huge, if also quite volatile, proportions. Therefore, regarding the resource rent issue our focus (in Section 4.4 hereafter) will be on oil and natural gas extraction.

Table 4.1 Value of gross EU imports of fossil fuels from the rest of the world, 2005-2013

(Billion €)

	2005	2006	2007	2008	2009	2010	2011	2012	2013
Gross imports									
Oil	177.4	214.0	212.0	279.4	170.2	231.1	297.6	340.0	302.3
Crude oil	*172.8*	*207.5*	*206.5*	*273.1*	*165.7*	*226.2*	*291.1*	*333.2*	*295.0*
Oil products	*4.6*	*6.5*	*5.5*	*6.3*	*4.5*	*4.9*	*6.5*	*6.8*	*7.3*
Natural gas	47.2	68.4	61.3	89.4	67.3	74.2	88.1	97.2	87.0
Pipeline gas	*40.7*	*57.9*	*52.3*	*76.4*	*55.4*	*58.3*	*66.9*	*79.6*	*73.4*
LNG	*6.5*	*10.5*	*9.0*	*13.0*	*11.9*	*15.9*	*21.2*	*17.6*	*13.6*
Coal	13.8	14.5	15.0	23.8	15.2	16.6	22.2	21.0	16.6
Coal	*12.9*	*13.9*	*14.3*	*22.4*	*14.8*	*16.1*	*21.7*	*20.7*	*16.1*
Lignite				*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
Coke	*0.9*	*0.6*	*0.7*	*1.3*	*0.3*	*0.4*	*0.4*	*0.2*	*0.4*
TOTAL	**238.4**	**296.9**	**288.3**	**392.6**	**252.7**	**321.9**	**407.9**	**458.2**	**405.8**

Source: Eurostat

4.3 Recent fossil fuel price trends

During 2005-2014 the average annual price of crude oil trended upward, if in a volatile way. This can be gleaned from price data published in (BP, 2015), reproduced in Table 4.2 after some re-processing. Year 2009 marks the strongest global economic downturn resulting from the financial crisis that took off in the US. The price of oil strongly receded but resumed its upward trend thereafter with the price of Brent plateauing from 2011 through June 2014 at around 110 US dollar per barrel.

However, since June 2014 Brent, the most widely regarded world oil price benchmark, is showing an almost uninterrupted deep dive down to US$ 28 /bbl on 20 Jan. 2016 (closing price of 29 Jan. 2016 on the International Commodity Exchange: US$ 36 / bbl): see Figure 4.1. As 2014 is the most recent year of currently available time series data of annual average fossil fuel prices, Table 4.2 does not yet show the full depth of the current global oil glut.

It cannot be predicted with certainty when the price will turn around and if it will ever break through the ceiling of the annual average price during 2011/2012 after adjustment for general price inflation. The ongoing oil market crunch is predominantly supply-led. *Global demand for crude oil still grows, if to date at a tepid rate.* The slow aggregate demand growth in non-OECD countries (foremost China) is partly offset by slowly but structurally shrinking aggregate oil demand in OECD countries. With India as the major exception, most emerging economies, including juggernaut China, are going through a period of economic downturn of the business cycle.

On the *global supply* side, the present oil glut started off with the strong production performance of non-conventional oil (mainly tight oil) in the US.[8] OPEC countries, notably but not only Saudi Arabia, and Russia responded by defending their market share, boosting production as much as possible. But for Iran, Iraq and Libya, to date the effective spare capacity[9] of OPEC and Russia appears to running out fairly rapidly. Given prevailing conditions on the ground, the potential to quickly boost production by a high volume in the former three countries seems limited. Nonetheless the official reappearance of Iran on the world oil market[10] will initially widen the current demand-supply gap of some 1.5-2.0 mb/d by an additional 0.6 mb/d in 2016. To the extent that this has not yet already been anticipated by the market, this puts further downward pressure on the world crude oil price. Conversely, the upstream activities of oil companies operating in non-OPEC producer countries are facing rapidly dwindling black margins at best but in many cases increasingly wide red operating margins. As a result, investments in oil exploration and development are rapidly declining. All in all, any time soon in the next three years a partial price recovery seems likely. It would seem likely that in the short run, say up to 2020, the (CAPEX + OPEX) development cost of tight oil in the U.S. from low-cost plays, which is about $US 45-55 /bbl to date, will form a strong upward price barrier. In fact, US tight oil producers may assume the role of swing producers in the global oil market.*Until 2020, only short spells of high geopolitical disturbance may enable the crude oil price to temporarily break through the $2013 US 55/bbl ceiling.*

In Section 3.4 above it was set out that the IEA, not unlike other purveyors of official oil price projections, does have a checkered track record in making realistic oil price projections. Indeed, projecting the oil price reliably is hardly doable given the very complex market forces at play in the world oil market. However, the implicit unchanged excess production capacity assumption in modelling exercises underlying WEO2014 (IEA, 2014a: 114) used for making oil price projections is remarkable, as well ahead of publication of the WEO2014 ample signs had been reported upon about the impending oil glut. For example in an excellent study by Leonardo Maugeri (2012).

For the prospective oil market trend in the medium to long-term, demand-side developments will be of dominating importance. *From the normative back-casting perspective postulated in this report, on medium and longer term oil demand prospects look bleak*. The potentially greatest oil demand destructing factor will be the take-off of electricity and possibly on longer term hydrogen as energy carriers for low-payload passenger cars. Moreover, in this and other market segments, oil products will face increasing competition from biofuels, natural gas as well as in non-energy industrial feedstock applications from bio-based substitutes.

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[8] See also Section 2.3 above.

[9] Potential oil production capacity that can be activiated in a very short period of time (Maugeri, 2012),

[10] Following the removal of international trade sanctions against Iran after the international agreement on restrictions of Iran's nuclear programme.

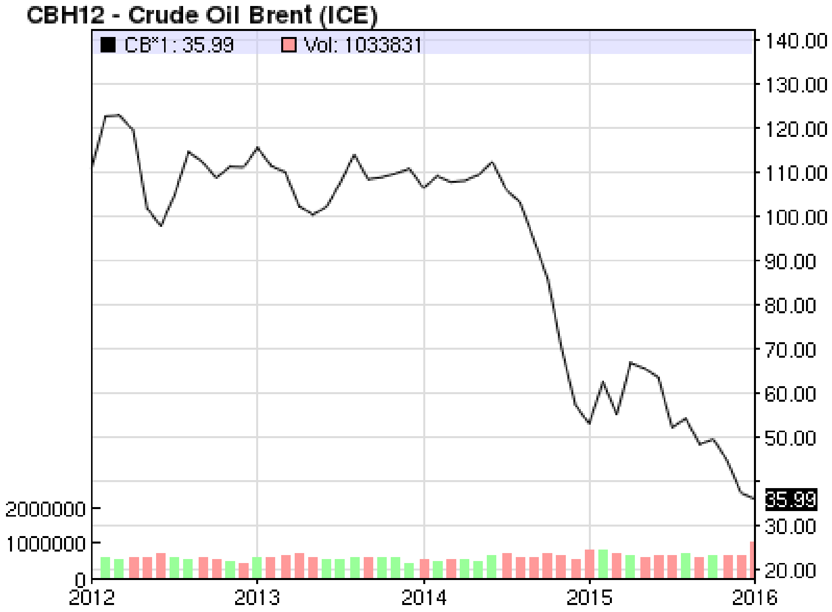

Figure 4.1 Brent crude oil price during February 2012 – January 2016 (Source http://NASDAQ.com)

Table 4.2 Recent fossil fuel price trends at current prices, 2005-2014

Fuel	Unit	Year									
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Oil											
Brent	$US/bll	54.52	65.14	72.39	97.26	61.67	79.50	111.26	111.67	108.66	98.95
Avg OECD import price	$/MMBtu	8.74	10.66	11.95	16.76	10.41	13.47	18.56	18.82	18.25	16.80
Natural gas											
Pipeline, cif Germany	$/MMBtu	5.88	7.85	8.03	11.56	8.52	8.01	10.49	10.93	10.73	9.11
LNG, cif Japan	$/MMBtu	6.05	7.14	7.73	12.55	9.06	10.91	14.73	16.75	16.17	16.33
Pipeline, Henry Hub	$/MMBtu	8.79	6.76	6.95	8.85	3.89	4.39	4.01	2.76	3.71	4.35
Coal											
Steam coal, cif NW Europe	$/t	60.54	64.11	88.79	147.67	70.66	92.50	121.52	92.50	81.69	75.38
Oil											
Brent	$US/GJ	9.30	11.11	12.35	16.59	10.52	13.56	18.98	19.05	18.54	16.88
Avg OECD import price	$US/GJ	8.27	10.09	11.32	15.87	9.86	12.76	17.57	17.82	17.28	15.91
Natural gas											
Pipeline (PL), cif Germany	$US/GJ	5.57	7.44	7.60	10.95	8.07	7.59	9.94	10.35	10.16	8.63
LNG, cif Japan	$US/GJ	5.73	6.76	7.32	11.88	8.58	10.33	13.95	15.86	15.31	15.47
Pipeline, Henry Hub	$US/GJ	8.32	6.41	6.58	8.38	3.69	4.16	3.80	2.61	3.51	4.12
Coal											
Steam coal API2 , cif ARA	$US/GJ	2.17	2.30	3.18	5.29	2.53	3.31	4.35	3.31	2.93	2.70
Price premium											
Brent vs PL gas cif Germany	%	49	36	49	45	22	68	77	72	70	84
PL gas cif Germany vs Henry Hub	%	-33	16	15	31	119	83	162	297	189	110
LNG cif Japan vs Henri Hub	%	-1	58	72	89	167	207	363	583	392	286
Gas Germany vs coal	%	281	339	256	200	290	285	304	438	490	489

Source: (BP, 2015), own calculations by the authors

Table 4.2 also brings out trends on important reference prices for natural gas and coal during the period 2005-2014. Currently, world-wide demand for imported natural gas is more or less split into three main regional markets (Europe, North America and East Asia) and smaller and more fragmented markets in the rest of the world. Yet the share of LNG is gradually increasing with a share of some 25% of internationally traded gas at present. Through LNG the market for internationally traded natural gas is becoming more global with globally more convergence in the pricing of imported gas. This trend is boosted by cost reductions on liquefaction, maritime transport and regasification (currently taking a margin of 2.5 $ /Mbtu or less, contingent on distance, size of shipments, etc.) as well as an increased willingness to pay a small premium for increased security of supply through import diversification through access to LNG shipments.

During the period 2005-2014, in the EU gas tended to be available at an increasing discount compared to oil. An important factor at play here is the increasing role of gas-to-gas competition in NW and Central Europe as against the conventional oil-linked long-term contract pricing. This tendency will be reinforced by the increasing role of LNG imports into the EU along with improving interconnectivity between EU member states.[11]

As from 2006 onward, the gas competitiveness of the EU versus North-America strongly deteriorated (See Table 4.2, row “PL gas cif Germany vs Henri Hub”). In the latter region gas-to-gas competition was introduced earlier on. Moreover, and even more importantly, technological progress enabled an astonishing take-off of shale gas production in the US from 2008 onwards. These two factors exerted a very strong downward pressure on the Henry Hub price, the foremost gas reference price in the US. As a result, in the US gas became quite competitive to coal in the power industry. Consequently, US coal producers started to massively export coal to Europe.

In the Japanese gas market LNG imports have a long tradition. No pipeline gas interconnections to Japan have been realised so far. Strongly rising LNG demand in East Asia (Japan, China, Korea) made for a suppliers market based on long-term pricing. This resulted in a very strong rise of the premium for the Japanese gas import price compared to the US and — to a lesser extent — the German import gas price. This trend was exacerbated by the Fukushima Daichi nuclear disaster, after which in Japan a strong substitution trend unfolded from nuclear-based power to gas-based power. Recently, the market power of LNG suppliers started to weaken as many LNG trains have come on stream and nuclear power generation is again rising in East Asia. Moreover, the long-term agreement struck by China in May 2014 to acquire 38 bcm/y of pipeline gas from Russia at favourable terms strengthens the negotiating position of East-Asian LNG importers.

World-wide, coal import prices are strongly going down of late. Both the ongoing economic restructuring and unsustainable air pollution levels in China as well as the shale gas take-off in the US are key factors accounting for this trend. Moreover, recent overcapacity in bulk freight reinforces the current down trend in the delivered price of imported coal. In turn, in the power sector of the EU but also in Asian coal import markets such as Japan, India and Korea, generating plants using imported coal improved their competitiveness with respect to gas-based power plants. As for the EU region this is indicated by the rising premium of the import price of pipeline gas into Germany over the steam coal reference price AP2 CIF ARA (See Table 4.2, bottom row).

Should our postulated normative back-casting perspective dominate the future of fossil fuels indeed, this will heavily impact the prospective evolution of the premiums of oil to gas and oil to coal. Under this scenario, the premium of oil to coal will keep on rising as the global demand for coal will have the strongest tendency to lag behind other major primary energy sources including natural gas and, to a lesser extent oil. As already explained above, on medium and longer term the prospects for oil become bleaker as well. On medium term and possibly on longer term as well natural gas will keep on having a significant share in the world energy mix, given its less negative impact on climate change and other environmental issues, notably air pollution. As further explained in the next chapter on the prospects for CCS, this depends mainly on adequate reduction of fugitive methane emissions in the natural gas supply chain and technological progress with respect to CCS applied to gas-based power plants. *All in all, we expect the current very high price premium of oil to gas to diminish rapidly and even to turn negative on medium or somewhat longer term.*

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[11] In principle, LNG exporters seek to reduce their high up-front risks by requiring long-term take or pay contracts. Yet given the current fierce competition among gas exporters, a gradual tendency towards a larger share of LNG deliveries covered by short-term, more flexible contracts and even spot market deliveries is noticeable.

4.4 Resource rent and its impact on political stability

4.4.1 Introduction of the concept

In this section we seek to shed some light on the major negative feedback impacts on (geo)political stability of the very large international resource rent transfers to exporters of precious physical natural resources. Our focus is on countries with authoritarian governments with sizable exports of oil and/or natural gas, zooming in on the Russian Federation and Saudi Arabia. Resource rent can be considered as a form of unearned income: it is the scarcity value that remains after the normal extraction, processing and transport costs including a *normal* risk-adjusted reward for capital invested are deducted from the oil and gas proceeds.

Box 4.1 Access to large financial resource rent inflows: key ingredients of a potent tonic for terrorism and (internal and geo-) political instability

Main sources of income of terrorists groups such as the self-proclaimed Islamic State, Al Nusra and Al Qaida are donations from billionaires supporting terrorists groups whose wealth stems from appropriation of resource rent inflows into countries such as Saudi Arabia and Qatar, interventions from states such as Saudi Arabia, Kuwait, Iran and Turkey and direct access to oil and gas resources.[12] The latter countries are able to finance their interventions to a large extent from massive resource rent income (Saudi Arabia, Qatar, Kuwait). Untol recently Turkey reportedly benefitted from lucrative trade in illegal oil and gas deliveries from the self-proclaimed Islamic State.

To date, the *paradox of plenty*[13] holds for countries such as Russia and Venezuela. *Highly contingent on the volatile size of resource rent inflows*, after private resource rent appropriation through unofficial transactions Russia's ruling elite under Putin is able to finance, amongst others, key domestic public media control operations, social welfare transfers and subsidies to appease targeted sections of Russian society that are key to the consolidation of the power and prerogatives of this ruling elite as well as excursions of Russia's proxy and official army well beyond Russia's territorial jurisdiction[14].

Also countries with western democratic governments, well-endowed with oil and gas resources, may suffer from negative resource rent impacts on internal macroeconomic and social stability.[15] The economy of such countries may face exposure to highly volatile revenues from oil and/or gas exports. Also negative effects may become manifest as regards the competitiveness of domestic non-oil/gas related economic activities due to currency appreciation and severe labour scarcities (also known as the "Dutch disease"), notably but not only with regard to lower-skilled jobs. This may trigger immigrants with different cultural and religious backgrounds on a significant scale, giving rise to social tensions between disenchanted persons from the local and migrant underclass and strong showings in parliamentary elections of extremist right-wing anti-immigrant parties.[16]

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[12] See *inter alia*: Matthew Levitt (2015)
http://www.washingtoninstitute.org/policy-analysis/view/the-islamic-states-backdoor-banking
http://www.shariahfinancewatch.org/
http://www.washingtoninstitute.org/uploads/Documents/testimony/LevittTestimony20141113.pdf

[13] This expression was introduced by (Karl, 1997)

[14] Including the annexation of the Crimea and occupation of other parts in eastern Ukraine by the Russian (proxy and regular) armee. See e.g. (Czuperski et al., 2015) for detailed evidence.

[15] This point was raised earlier in (Jansen and Seebregts, 2010: 1657).

[16] The Dutch giant Groningen natural gas field was discovered in 1959. Norway started to develop its even more bountiful oil and gas reserves by 1969. The large-scale influx from non-European migrants started in the Netherlands in the 1960s well before the peak of the Dutch disease phenomena in among others the Dutch labour market towards 1980, in Norway much more recently. Ethnic social tensions culminated in acts of terrorrrism such as the killing of film producer Theo van Gogh in Amsterdam on 2 November 2004 and the mass murder in Oslo and at Utøya island on 22 July 2011. Hitherto, the

4.4.2 The cases of Russia and Saudi Arabia

Eurostat data show that Russia is the EU's foremost supplier of imported fossil fuels, whilst Saudi Arabia is the EU's third supplier of crude oil. In 2013 the EU28 imported:

- €99 billion worth of crude oil from Russia, i.e. 34% of the EU's total crude oil import value (€299 billion). Norway and Saudi Arabia accounted for 12% (€28 billion) and 9% (€25 billion) of this total respectively.
- €36 billion worth of natural gas from Russia, i.e. 41% of the EU's total natural gas import value. Norway and Algeria accounted for 32% (€28 billion) and 14% (€12 billion) of this total respectively. Saudi Arabia did not export natural gas in 2013.

World-wide, oil production in 2014 amounted to 88.9 mb/d with the US (11.6 mb/d), Saudi Arabia (11.5 mb/d) and Russia (10.8 mb/d) as top-3 producing countries (BP, 2015).[17] Crude oil (gross) exports in 2014 totalled world-wide 40,1 mb/d, to which these countries contributed 4.5 mb/d (Russia), 7.2 mb/d (Saudi Arabia) and 0.3 mb/d (US). Saudi Arabia and Russia are the world's top-2 crude oil exporters with runner-up Iraq on third place (2.5 mb/d) (OPEC, 2015). In 2014 world marketed production of natural gas amounted to 3566 bcm, of which 730 bcm by the US, 643 bcm by Russia and 213 bcm by Iran. Saudi Arabia with a marketable production of 102 bcm has a much less prominent position in natural gas than in crude oil production (OPEC, 2015). The world's (gross) natural gas exports in 2014 totalled 1037 bcm with top-3 exporters being Russia (195 bcm), Qatar (123 bcm) and Norway (107 bcm). All in all, both Saudi Arabia (oil) and Russia (oil and gas) are top supply-side players in the global market for internationally traded crude oil and natural gas (OPEC, 2015).

Table 4.3 brings out some salient characteristics of the evolution of the Russian oil and gas sector during the period 2009-2014. During this period Russia was able to gradually boost crude oil and (even somewhat faster) natural gas production. Russia's domestic crude oil use rose faster. As a result, Russia's export volume of crude oil waned slightly in volume terms, whilst the export volume of oil products was more or less stable. In 2014 the volume of natural gas exports dropped by 28 bcm year-on-year down to a level of 195 bcm. Russia being the world's largest producer of fossil fuels to date, the fossil fuels upstream and downstream sector is of paramount importance to the Russian economy. The Russian economy clearly suffers from the Dutch disease in that the non-natural-resources sectors tend to have a poor competitive position, with the oil and gas sectors crowding out scarce production factors.

Although the production cost base of oil and natural gas extraction is fairly high, the resource rent accruing to the Russian state, the ruling elite and other economic agents directly involved in the oil and gas sector is massive. The rough estimates of the resource rent income accruing somewhere within the Russian economy from oil and gas extraction shown in Table 4.3 are based on World Bank estimates of resource rent margins that are created by the Russian oil and natural gas extraction activities for the period up to 2013.

Evidently, unofficial appropriations of resource rent to satisfy the greed of the ruling elite or official appropriations for politically sensitive activities tend to be covered up by a lack of transparency. In the case of Russia political sensitive activities include e.g. the financing the occupation of swatches of land in the jurisdictions of three other independent countries that up to her dissolution in 1991 were part of the former Soviet Union. Also the ruling class of Saudi Arabia has an interest in secrecy of the financial accounts of the national oil company

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Dutch internal security service AIVD has been successful in foiling several more recent terrorrist plots planned by Dutch residents, including those by the so-called Hofstad Group. The Al Shabaab terrorist attack on a Nairobian shopping mall on 21 September 2013 involved a Norwegian resident (since 1999) from Somali origin. For quite some years, both in Norway and in the Netherlands clear bell-wethers of ethnic tensions have made their appearance in parliament in the form of rightwing anti-immigration parties, potentially attracting a substantive portion of the electorate in these countries.

[17] In statistics presented by BP's annual publication *Statistical Review of World Economy* statistics on *oil production* include crude oil, shale oil, oil sands, and NGLs. Liquid fuels from other sources such as biomass and derivatives from coal and natural gas are excluded.

of their country, Saudi Aramco, as unofficial financial transfers to representatives of this class remain undisclosed.

Therefore, and also for reasons of commercially driven confidentiality, resource rent margins can only be estimated in an approximative way. In the period considered, the resource rent from oil and gas production is estimated to constitute in between 41% (in 2013 and 2014) and 54% (in 2011) of Russian GDP. In the period 2009-2014 the annual resource rent accruing from oil and gas extraction is estimated to have varied within the €201 billion - €354 billion range.[18] Probably the largest part of this share was available for official use with a high degree of freedom for special purposes of the Putin administration and the remaining share for unofficial appropriations.[19]

The highest priority in Russian energy policy is given to acceleration of the upstream oil and gas activities and related conversion and transport infrastructure to penetrate on East and South Asian markets for imported oil and natural gas. The dominant Asian market is China, but Russia is also intent on further market penetration in Japan, Korea and India in order to contain overdependence on the Chinese market. Western sanctions came into effect after the Russian annexation of the Crimea and further incursions by the Russian proxy and official army into Ukrainian territory. These sanctions, as well as legal procedures by the European Commission inhibiting Gazprom to sustain monopolistic practises forced upon individual EU Member States, prompted the Putin administration to speed up the development of Siberia and the Far East (ESFE) as “national priority for the entire 21st century” (Shradrina, 2016).

The Western sanctions supported by Japan and Korea and sliding oil and gas prices made Putin to give in to the traditional Russian reluctance to deals with China to jointly develop Siberian oil and gas resources and pipeline infrastructure to export oil and gas to China. Mainly through Russian state oil company Rosneft Russia became the second largest oil supplier to China (after Saudi Arabia) in 2015. On 21 May 2014 a watershed bilateral agreement was sealed by presidents Xi and Putin in Shanghai between China’s CNPC and Russia’s Gazprom to jointly construct the 38 bcm/y Power of Siberia gas pipeline and a 30-year gas supply contract, worth a projected $400 billion. Whereas the contract terms are secret, press reports suggest quite high price concessions by the Russian side. The Russian side intended to link the price to the prevailing Far East LNG price whilst the Chinese side reportedly successfully bargained a price similar to the German pipeline import price. The Chinese deal sweetener is availability of large Chinese upfront investment financing. On several other fronts the Chinese-Russian cooperation is strengthening further of late.

To date, stagnating deliveries to the EU still bring in the lion’s share of Russian revenues from oil and gas exports. It is rational to diversify market and geopolitical risks for Russia through export diversification towards the global economic centre of gravity, i.e. East and South-East Asia. However, the current global oil and gas glut, warranting Russia to make deep price concessions, as well as Western sanctions seriously constrain investment finance and the acquisition of advanced Western technology. As a result, the ESFE policy faces long delays in realisations of

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[18] Available data at the time of writing do not permit to make an estimate for 2015. But as illustrated by Figure 4.1 above oil and (with a time lag) natural gas prices have made a dramatic fall. Consequently, in 2015 the Russian economy had to absorb a likely even more dramatic reduction (in percentage point terms) in the nation’s resource rent from oil and natural gas extraction, down to a level appreciably below the €201 billion lower bound of the stated interval.

[19] Russia was ranked 119 out of 167 countries assessed on the (latest) 2015 corruption perceptions index extent of transparency of government administration in the latest list of Transparency International : http://www.transparency.org/cpi2015#results-table . Detailed probes into the political carrier of Vladimir Putin established that as from 1991, when he assumed high official functions in St Petersburg up to now, Putin himself managed to amass billions of US dollars worth of non-inherited private wealth through what by Western standards is considered corrupt behaviour (Dawischa, 2015). Based on leaked documents in 2007 from the US CIA, Putin’s personal wealth has been assessed at US$ 40 billion, including real estate in Russia and abroad and an alledged (by former Putin assciates; source: Dawischa, 2015) ownership share of 4.5 % in Gazprom, 37% in Surgutneftegaz, and 50% in Gunvor. This compares to Putin’s published annual salary of 7,600,000 Rubles (i.e. about $US 100,000) in 2014. A well-researched BBC documentary revealed scathing details of Putin’s secret riches. See also: http://www.bbc.com/news/world-europe-35385445.

investment plans. Moreover, the prevailing demographic trend of a declining population in Russia's vast and thinly populated ESFE area is both a severe development constraint and a geopolitical risk for Russia. [20]

Given the current predicament of the Russian economy, the state and direction of Russia politics is poised to enter a rather fluid phase.[21] For EU policy makers it would seem warranted to continue energy exchanges with Russia to mutual advantage without political reneging on fundamental European values nor on the EU's climate and energy policy goals.

Table 4.3 Value of Russian gross exports of crude oil and gas and estimated resource rent from Russian oil and gas production; 2009-2014

	2009	2010	2011	2012	2013	2014
Marketed production						
Crude oil (1000 b/d)	**9650**	**9841**	**9943**	**10043**	**10147**	**10221**
Natural gas (bcm)	**547**	**610**	**628**	**656**	**672**	**643**
Gross exports						
Crude oil (1000b/d)	4967	4978	4786	4757	4710	4487
of which to EU (mb)	1102	1117	1081	1188	1145	1056
Petroleum products (1000 b/d)	2159	2230	1923	1986	2121	2183
Natural gas (bcm)	212	229	227	207	223	195
Crude oil (€ billion; fob)	101	136	182	181	174	154
of which crude to EU (€ billion; cif)	67	87	119	131	123	104
Natural gas (€ billion)	42	48	64	62	67	55
of which to EU (€ billion)	37	26	28	33	34	36
TOTAL crude oil + natural gas (€ billion)	**143**	**184**	**246**	**243**	**241**	**209**
of which approximate EU contribution (%)	**73%**	**62%**	**60%**	**68%**	**66%**	**67%**
Resource rent						
Oil (€ billion)	117	169	220	234	214	197
Oil (% of GDP)	13%	15%	16%	15%	14%	14%
Oil ($US per barrel)	42	64	89	89	77	74
Natural gas (€ billion)	41	43	44	31	31	27
Natural gas (% of GDP)	5%	4%	3%	2%	2%	2%
Natural gas ($US/MBtu)	2.94	2.59	2.72	1.72	1.73	1.58
Oil and gas (€ billion)	**201**	**276**	**353**	**354**	**323**	**298**
Oil and gas (% of GDP)	**18%**	**18%**	**19%**	**17%**	**16%**	**16%**
Oil and gas (% of government expenditure)	**55%**	**63%**	**72%**	**61%**	**54%**	**55%**
PM						
GDP (€ billion)	877	1149	1368	1568	1565	1400
Government expenditure (%of GDP)	41%	38%	36%	37%	38%	39%
Government expenditure (€ billion)	363	437	489	584	598	541

Note: Resource rent figures for 2014 are estimations by the authors, reconciled with 2009-2013 figures from the World Bank
Source: Adapted from data published by Central Bank of the Russian Federation, Eurostat, OPEC, World Bank

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[20] See e.g. (Trenin, 2015) for further background.

[21] http://www.economist.com/news/europe/21679701-popular-president-muffles-his-anti-western-rhetoric-russias-economy-shrinks-vladimir-putin

The second case study on resource rent as the financial dynamite for internal socio-political instability and geopolitical tensions regards Saudi Arabia. Table 4.4 shows main trends of the oil and gas sector of Saudi Arabia during 2009-2014. Saudi Arabia is the world's second crude oil producer with a production of 9.7 mb/d in 2014 and with 7.2 mb/d the largest oil exporter by far. Moreover, it is the most influential OPEC member in terms of oil production and exports. At times Saudi Arabia functioned as swing producer with a coordinating role in OPEC. For now it has opted to defend market share through raising production up to almost maximum level and offering overseas clients oil consignments of its high quality light oil at attractive prices. This market behaviour is prompted by intensifying supply-side competition from established competitors and new exporters and sources (non-conventional oil, biofuels, etc.), slow global demand growth and rising uncertainty for oil suppliers on the prospective oil demand evolution after the Paris Climate Agreement. Saudi Arabia is a less prominent player on the world natural gas market, selling its marketable gas production only on the domestic market so far. In 2013 only 4.5 % of its crude oil exports found an outlet in the EU. For the EU, Saudi Arabia contributed 12% (11%) of the cif value of aggregate EU crude oil imports (crude and oil products imports).

OPEC data indicate that Saudi-Arabian crude oil extraction amounted to 9.2 mb/d in 2014. According to rough estimates, departing from World Bank data covering the period up to year 2013, this generated a resource rent amount totalling €215 billion in 2014. Marketed gas production in 2014 amounted to 102 bcm and the associated resource rent is roughly estimated at €15 billion, rendering less prominence to natural gas in the fossil fuels production portfolio of Saudi Arabia than is the case with e.g. Russia. In total, the Saudi gas and oil sector brought in an estimated €230 billion worth of resource rent in 2014, appropriated by the Saudi government and other stakeholders. The estimated oil and gas resource rent as a proportion of GDP varied from 41% (year 2014) to 51% (year 2011) in the period reviewed, i.e. 2009-2014. Estimated oil and gas resource rent as a percentage of government expenditures varied from an amazing 101% (year 2014) to an even more astounding 152% (year 2011) during the same period. These numbers in excess of 100% indicate the hugh affluence the oil and gas sector created within Saudi society and indicate that, contingent on other government revenues than appropriations of oil and gas resource rent, a significant part of the total resource rent was appropriated off-budget.

Saudi Arabia has key characteristics of a rentier petro-state, including[22]:

- The overwhelming role the resource rent plays in the Saudi economy and government revenues portfolio. The oil and gas sector and the public sector are very dominant in the Saudi economy, whereas in comparison non-oil/gas private business activities have a rather modest size.
- Until mid-2015 a wide range of public amenities were available for free to Saudi nationals or highly subsidised (e.g. water and electricity for households and natural gas for inlands electricity generation and basic industry). The omnipresent state, autocratically governed by the ruling elite headed by the Saudi royal family, uses its resources to buy off potential opposition from civil society. Rent-seeking behaviour rather than entrepreneurial hard work by a diminishing merchant class is the route to higher positions open to Saudi nationals only. Foreign entrepreneurs can only be active in Saudi Arabia under highly discretionary conditionality and rent-seeking red tape, including mandated ownership sharing with ruling elite protégées.
- In Saudi Arabia autocratic top-down government entails violent oppression of grass-root civil society movements to improve the rights of women and ethnic minorities. An independent judicial system is absent. Capital punishment is lightly administered by the Saudi judges obeying orders from the ruling class (e.g. to top cleric Nimr al-Nimr of the Shiite Saudi minority on 2 January 2016)[23] .
- The Saudi ministry of finance publishes the budget revenues from oil production. Yet financial transparency of the state-owned oil company Saudi Aramco is lacking, enabling undisclosed rent

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[22] See *inter alia*: Hertog (2012), Kouchaksaraei and Bustami (2012),

[23] http://abc7.com/news/saudi-executes-47-including-top-shiite-cleric-nimr-al-nimr/1143958/

> transfers to the ruling elite (Seznec, 2015). The Saudi government uses the oil rent, among other allocations, to maintain a rentier social contract with the Saudi population and to subsidize the oil-based industry, such as the Saudi chemical company SABIC. Uses of the gas rent include subsidisation of the electricity supply sector and the fertilizer industry. Large private donations by rent-rich Saudi nationals and appropriations by Saudi state agencies are made for foreign aid and in support of humanitarian projects, for foreign policy purposes and for proselytising abroad the fundamental Wahhabi variant of Islam through bankrolling mosques.[24] Large off-budget resource appropriation have resulted in a highly skewed income distribution.

At the time of writing we do not avail of 2015 data. Yet it is clear that the ongoing precipitous oil price fall of more than 70% to date with respect to beginning of 2015 deeply bites into the Saudi budget, raising great concerns to the Saudi government and ruling elite to hold sway. The government budget deficit for year 2015 has been reported to amount to $98 billion (Seznec, 2016). Moreover, the Saudi government has rising concerns that a post-oil era might evolve on longer term.

These concerns tend to usher in modest reforms towards a more sustained economic restructuring and modest concessions to demands from grass-root civil society that do not pose immediate challenges to the prevailing regime. In 2012 under the late King Abdullah grand plans were promulgated for diversifying Saudi Arabia's energy mix. Yet in January 2015 the delay by eight years was announced of the completion a $US 109 billion solar project to install 41 GW of PV and CSP generating capacity, which was to be completed by 2032. Recently energy savings policies have been introduced to reduce the wasteful domestic use of oil products in order to realise higher oil export volumes.[25] Various new taxes such as a 5% V.A.T. and fees for public services are being introduced to counter the large budget deficit, that might have reached an unprecedented 16% in year 2015. Also restrictions on foreign investment have been eased of late.[26] Moreover, the extremely limited civil rights of women have been modestly improved.[27]

4.4.3 Resource rent volatility and possible oil glut responses

The ongoing oil and natural gas glut has devastating effects on the economy of major oil and gas exporting countries, such as Saudi Arabia, Russia, Nigeria and Venezuela with surging public finance deficits. A major factor determining the oil price elasticity of the resource rent of an oil producing country is the average cost per barrel of oil produced and marketed. This can be roughly inferred from information presented in Table 4.3 and Table 4.4.

In 2014, oil extraction in Russia and Saudi Arabia has yielded an estimated resource rent of €197 billion and €215 billion respectively. The roughly estimated resource rent per barrel amounted that year $US 75 and $US 85 respectively. Assuming for the sake of simplicity that for both countries the average revenue per barrel amounted to the average price of the Brent benchmark, i.e. $US 99 in 2014 (See Table 4.2), each $US price drop will reduce the Russian resource rent – other factors remaining the same – by 1.33% and 1.18% respectively. Because of a higher cost base in the case of Russia compared to Saudi Arabia, the sensitivity of Russia's oil resource rent is higher than is the case for Saudi Arabia. If the average revenue per barrel in 2015 has been $US 50, then *mutatis mutandis* the oil resource rent fetched in Russia and Saudi Arabia that year has dropped to a level of €67 billion and €89 billion respectively. Both countries suffer badly from the oil glut, but Russia more than Saudi Arabia. This

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[24] http://www.gsdrc.org/docs/open/hdq839.pdf and http://www.pbs.org/wgbh/pages/frontline/shows/saudi/analyses/wahhabism.html

[25] See the article of Anjli Raval of 7 september 2015 on the Financial Times website: "*Saudi Arabia looks beyond oil to exploit its sunshine*". Download: http://www.ft.com/cms/s/0/d08be460-3a06-11e5-bbd1-b37bc06f590c.html#axzz3ytaGsVsL

[26] http://www.oxfordbusinessgroup.com/news/saudi-arabia-year-review-2015

[27] http://www.bbc.com/news/world-middle-east-35075702

differential effect will become even stronger at lower price levels. Moreover, Russian official cash reserves of about $320 billion are dwarfed by those of Saudi Arabia, i.e. $ 616 billion with the ability to raise another $250 billion from internal institutions (Seznec, 2016).

Responses will very much depend on the anticipated behaviour of other market players, especially other oil producers. Given the lack of political cohesion and the very differential cost base between major oil producing and exporting countries, the most likely behaviour will be prompted by the famous Prisoner's Dilemma. Representatives of each producing country will not trust the promises of representatives of other oil producing countries. Responses are therefore poised to be a combination of the following options:

With regard to the upstream oil activities:

- Raising oil production to the maximum level possible: however, countries such as Russia and Saudi Arabia the short-term capacity to raise production will be quite limited percentage-wise. This makes it easier for them to agree to containment of production to actual levels in a bid to affect the oil price in upward direction.
- Intensifying efforts to reduce the extraction cost base
- Reducing cross-subsidies from upstream to downstream activities within the inlands oil sector
- More pressure exerted by exporting countries with the weakest negotiation position (including notably those with a high cost base and less flexibility to make economic adjustment) upon the ones with the strongest position (notably Saudi Arabia) to agree to coordinated production cuts.

With regard to the wider economy and socio-political governance:

- Retrenchments on government expenditure on foreign missionary activities (such as Novorossiya; Wahhabism)
- Retrenchment on direct subsidies, including those on fuels, i.e. on subsidies targeted to nurture the social rentier contract with constituencies that matter[28]
- Widening the tax base and introduction of new taxes and retributions
- Monetary reforms, such as diversification of sources of funding e.g. increasing domestically held government bonds, interest rate rises to stem the fall of the local currency and to dampen domestic inflation levels
- Saudi Arabia is considering the privatisation of Saudi Aramco. This would warrant more financial transparency and thus less scope for hidden resource rent appropriations by the Saudi ruling elite (Seznec, 2016).
- Seeking credit from IMF and World Bank, thereby reluctantly accepting economic reform conditionalities by these lenders (e.g. Nigeria)
- Stepping up efforts to diversify the national economy. Internal public resources to do so are extremely scarce. This, in turn, may prompt measures such as:
    - Introduction of economic reform to reduce barriers for domestic private merchant class and for foreign investors
    - Reducing the rhetoric against foreign countries, used by the ruling class to frame a "great enemy" perception among own constituencies to divert attention from internal political problems
    - Reducing oppression of civil society initiatives and minorities, unless perceived by the central government as regime change threats.

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[28] E.g. on 17 February 2016 the Maduro regime in Venezuela raised the retail price of gasoline from 0.097 bolivar (0.015 $US) to 6 bolivars (0.945 $US) per liter: http://www.theguardian.com/world/2016/feb/18/venezuela-president-raises-fuel-price-by-1300-and-devalues-bolivar-to-tackle-crisis. In December 2015 the Saudi government raised a range of oil products by up to 225% (for diesel oil) and natural gas by 67%. Also the prices of water and electricity were raised substantially. (Seznec, 2016).

Table 4.4 Value of Saudi-Arabian gross exports of oil and natural gas and estimated resource rent from Saudi-Arabian oil and gas production; 2009-2014

	2009	2010	2011	2012	2013	2014
Marketed production						
Crude oil (1000 b/d)	8184	8166	9311	9763	9637	9712
Natural gas (bcm)	72	88	92	99	100	102
Gross exports						
Crude oil (1000 b/d)	6268	6644	7218	7557	7571	7153
of which to EU (mb)	215	226	299	354	324	324
Petroleum products (1000 b/d)	1008	951	902	862	794	988
Natural gas (bcm)	0	0	0	0	0	0
Oil and products (€ billion; fob)	182	215	309	329	314	285
of which crude to EU (€ billion)	*13*	*18*	*33*	*39*	*35*	*32*
Resource rent						
Oil (€ billion)	118	160	231	261	244	215
Oil (% of GDP)	38%	40%	48%	46%	44%	38%
Oil ($US per barrel)	49	74	100	102	92	85
Natural gas (€ billion)	10	12	13	14	15	15
Natural gas (% of GDP)	3%	3%	3%	3%	3%	3%
Natural gas ($US/MBtu)	5,51	4,86	5,51	5,19	5,63	5,55
Oil and gas (€ billion)	**128**	**172**	**244**	**276**	**259**	**230**
Oil and gas (% of GDP)	**42%**	**43%**	**51%**	**48%**	**46%**	**41%**
Oil and gas (% of government expenditure)	**112%**	**127%**	**152%**	**145%**	**130%**	**101%**
P.M.						
GDP (€ billion)	308	397	481	571	560	561
Government expenditure (%of GDP)	37%	34%	33%	33%	36%	41%
Government expenditure (€ billion)	114	135	160	190	200	229

Note: Resource rent figures for 2014 are estimations by the authors, reconciled with 2009-2013 figures from the World Bank
Source: Adapted from data published by OPEC, Eurostat, World Bank

Both in Russia and, to a lesser extent, Saudi Arabia as well as in other major autocratic oil producing and exporting countries we see that a number of these options are being exercised. In some of them a transition towards a major regime change appears to be unfolding with more transparency and less corruption, such as possibly Nigeria and Venezuela. In general, there are many instances of responses to resource rent crunches of economic reform towards a stronger, more diversified economy that is better integrated in the global economy and better chances for economic agents outside the inner circle of the ruling classes. As the outcomes of infighting within the ruling class are less predictable, transitions to even more stringent autocratic terror regimes in a minority of cases cannot be excluded. Carrots and sticks from foreign powers and institutions (UN organisations, multilateral development banks, etc.) can be decisive to turn the political pendulum in oil exporting countries into the direction of economic and social reform.

4.5 Removing the subsidisation of fossil fuels

In this section, we will briefly reflect on the impact of changes in fossil fuel prices on the uptake of renewables and on lowering the embedded carbon in overall final consumption. For tackling this issue, it is essential to anticipate how price changes in crude oil propagate in the forward supply chain until final energy use. Of paramount importance is how direct and indirect oil price intervention policies will evolve in the jurisdictions where crude oil and derivatives are consumed.

Historically, at times of sharp rising oil prices major oil consuming countries tend to pay much more attention to improving energy efficiency. This is done, among other measures, by way of prescribing higher energy efficiency product standards, (e.g. the US CAFE standards, which were introduced in 1975), more public financing for industrial process energy efficiency RD&D and more stringent energy-efficient building standards. Moreover, the political priority for stimulating RD&D and market deployment of renewable energy technology tended to rise. On the other hand, it is politically more difficult in such a period to raise indirect energy tax on oil products, notably on middle distillates that are important for freight transportation by road.

At times of oil gluts, the opposite can be observed in major economies: lower policy priority tends to be attached to stimulation of energy efficiency and renewables. In oil importing countries the economy is stimulated by lower resource rent leakages into the direction of oil exporting countries. This can translate into higher economic growth, hence higher carbon emission levels and higher embedded carbon levels in final inlands consumption. This tends to be partially offset by faster turnover/replacement of low efficiency energy-using producer and consumption goods and faster penetration of higher efficiency energy-using equipment.

Yet if and when the two basic premises of the postulated normative back-casting perspective will turn out to hold, end-use prices of oil-based energy carriers and feedstocks will be heavily impacted in upward direction by taxation. This, in turn, will be calibrated in ways that more than offset public interventions with a negative price effect in oil producing countries, e.g. ad hoc decisions to raise production by certain OPEC member states and/or Russia. *Governments embracing the normative back-casting perspective should seek to enhance the stability of the investment climate in favour of investment in renewables and energy-and-materials saving technology. Besides, incentives should be introduced in favour of more inclusive employment opportunities.* In these respects, the following policy guidelines on taxing fossil fuel derivatives might be considered for (coordinated) implementation by EU member states:

1. *Phasing out coal fired power generation altogether*..This can be done by withholding a licence to operate new coal-fired power plants in combination with taxing coal-based generation in existing coal-fired plants in accordance with recommendations hereafter and, at least as a last-resort measure, the introduction of increasingly stringent emission performance standards (EPS).
2. *Strengthening of the carbon price signal* by a reformed ETS. Should the so-called market stability reserve (MSR) mechanism turn out to function below expectations, more drastic reforms are in order. Moreover, *introduction of an initially modest carbon tax* – preferably at the highest geographical level that is politically feasible – needs to be considered, with concurrent introduction of commensurate carbon border price adjustments (Jansen, 2014). Special attention is needed for factoring in the CO_2eq emissions externality in the price of oil derivatives (including gasoline, diesel, home heating oil, petrochemicals), natural gas and coal for non-ETS applications. Ideally, these two interventions combined will ensure that that economy-wide CO_2eq emissions are penalised to the tune of their global damage cost. At EU level an assumed damage cost per tonne of $CO_{2eq.}$ needs to be agreed upon, based on scientific estimates.
3. *Internalisation of non-carbon environmental externalities, mainly local air pollution.* Parry et al. (2014) have written an excellent guide for policymakers and practisioners in great detail how to design and implement fiscal measures to do so. Coady et al. (2015) postulate that internalising in the price of fossil fuels environmental externalities including climate change damages (set by them at 35$/t$CO_2$eq). and a general economy-wide consumption tax (value added tax or general sales tax) to fossil fuels lead to so-called efficient prices facing firms and households. The substraction of existing market prices from efficient prices provide estimates of post-tax subsidies. On this basis, Coady et al. (2015) estimate that global post-tax subsidies to fossil fuels amount to $ 4.9 trillion in 2015, i.e. 6.5 % of global GDP. This huge amount does not yet allow for geopolitical and national socio-political externalities.

4. *Geopolitical externalities*. In Section 4.4 above these externalities, applicable foremost to oil and to a lesser extent on natural gas, have been set out. Quantification of these externalities is difficult and contestable, A moderate fuel-specific energy security levy could be imposed on oil and gas on a per energy unit basis. A higher rate per GJ for oil than for natural gas would stand to reason.
5. *Inclusion of fossil fuels in economy-wide consumption taxation*. Contingent on prevailing nation tax systems this can take the form of value added tax or general sales tax. The consumption tax is to be raised on the ad valorem price including externality surcharges. It is essential that no exemptions are given to e.g. fossil power generators and local industries using fossil fuels as feedstock.
6. *Special attention for interventions in the price of motor fuels and vehicles to factor in externalities.* (e.g., Anderson and Auffhammer, 2014; Parry et al., 2014; Usmani et al., 2015). Gasoline and gasoil (diesel) account for close to half of world oil demand. Apart from points 2-5 above interventions for serious consideration include:
    - Surcharge on car sales based on CO_2 emissions per km performance of the car model concerned to influence the car-buy decision in a lower climate-impact fashion
    - Stringent CO_2, energy-efficiency and/or local pollutant emission performance standards (EPSs) for original equipment manufacturers (OEMs) of cars to address climate change and local/regional environmental impact
    - Electronic road pricing and cordon tolls to address congestion and to bring down the level of annual vehicle-kilometers
    - Super credits for OEMs of zero-emission vehicles (ZEVs). To kick-start the ZEV market, OEMs are temporily awarded a certain multiple exceeding unity per ZEV produced in the calculation of the OEM (under)compliance with the prevailing CO_2 EPS
    - ZEV quotas. Every OEM has to achieve a set minimum share of ZEVs of their total annual car production volume, with a set penalty per car below the set ZEV quota.
    - Tradable emission rights / quota schemes. Tradable schemes enable OEMs to achieve a set CO_2 EPS / a set ZEV quota in the most cost-effective way for all OEMs together.
7. *Introduction of an additional dynamic price-stabilisation energy levy on fossil fuels.* This fuel-specific levy is set lower when given fossil fuel benchmark prices exceed pre-set price trajectories and higher when the respective benchmark prices are lower than the relevant pre-set price trajectory. This tax component seeks to create a more stable climate for investment in energy efficiency and renewable energy technology.[29]
8. *The revenues from fossilfuel taxation is to be used efficiently and in the first place to bolster general state revenues.* A certain, modest proportion can be earmarked for upgrading transport infrastructure (including public transportation, bicycle paths and pedestrian sidewalks), RD&D on energy-efficient and low carbon energy conversion and use technology.

4.6 Conclusions

Should our postulated normative back-casting perspective dominate the future of fossil fuels indeed, the premium of oil to coal will keep on rising as the global demand for coal will have the strongest tendency to lag behind other major primary energy sources including natural gas and, to a lesser extent, oil. On medium and longer term the prospects for oil are poised to become bleaker as well. On medium term and possibly on longer term as well natural gas will keep on holding a significant share in the world energy mix, given its less negative impact on climate change and other environmental impact categories, notably air pollution. *All in all, we expect*

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[29] The idea of end-user price-stabilizing measures, notably on oil-based motor fuels is not new. See e.g. (Borenstein, 2008). We do not concur with the statement that the introduction of stringent carbon prices do *completely* obviate the rational for price stabilizing measures. First, there is the need for interventions that allow for non-GHG environmental and geopolitical externalities (see main text). Second, measures such as carbon trading do not necessarily yield stable carbon prices.

the current high price premium of oil to gas to diminish rapidly and even to turn negative in the medium term. In contrast, the rising trend in oil price premium versus the price of coal is poised to continue.

The implicit unchanged excess production capacity assumption in modelling exercises underlying WEO2014 (IEA, 2014a: 114) used for making oil price projections is remarkable, as well ahead of publication of the WEO2014 ample signs had been reported upon about the impending oil glut. For example in an excellent study by Leonardo Maugeri (2012).

For the prospective oil market trend in the medium to long-term, demand-side developments will be of dominating importance. *From the normative back-casting perspective postulated in this report, on medium and longer term oil demand prospects look bleak. The potentially greatest oil demand destructing factor will be the take-off of electricity and possibly on longer term hydrogen as energy carriers for low-payload passenger cars. Moreover, in this and other market segments, oil products will face increasing competition from biofuels, natural gas as well as in non-energy industrial feedstock applications from bio-based substitutes.*

A key conclusion to be drawn for EU energy policy making is that the resource rent created by European demand for oil and natural gas has negative externalities regarding the internal political and economic stability in oil and gas producing countries and negative wider geopolitical externalities. By sheer weight of the EU trading block the resource rent of EU demand for fossil fuels is further amplified by its impact on global fossil fuel prices. Higher fossil fuel prices will, in turn, also negatively affect the terms of trade for the EU in its overall external trade portfolio.

The key arguments that demand reduction of EU demand for oil and gas has benign impacts for global sustainable development relates to a suite of externalities. These include notably reduced global climate change externalities, reduced local environmental externalities along the global fossil-fuels supply chains and reduced (geo)political stability externalities though reduced resource rent creation in oil and gas producing countries. The latter aspect should get much more attention in the public communication on the benefits of energy efficiency improvement and enhanced deployment of renewables. Not only does reduction in international trade in scarce natural resources, notably oil and natural gas, tend to have positive geopolitical feedback externalities for importing countries. Dwindling resource rents in oil and natural gas exporting countries tend to improve the political climate to introduce economic restructuring as well as foreign trade and investment reforms. Moreover, it forces autocratic governments to be more receptive to the demands of fledgling grass-root civil rights movements and ethnic minorities in rentier petro states.

The IMF (Coady et al, 2015) puts global post-tax subsidies at $4.9 trillion, i.e. 6.5% of global GDP, on a post-tax basis. Fossil fuel subsidies have sizable negative externalities for climate change, public health, land degradation, bio diversity, global socio-political stability and the sustainability of the state budget. Moreover, fossil-fuel subsidies slow down the transition towards a high-efficiency, renewables-based energy system. This chapter contains main guidelines to address the urgent issue of phasing out fossil fuel subsidisation.

5 The prospects for CCS in fossil-based power generation

5.1 Introduction

In this chapter the prospects for application of carbon capture and storage (CCS) to power plants fired by coal and natural gas are considered, based among others on a brief literature scan. It is remarked that carbon capture, utilisation (in industrial processes) and storage (CCUS) is fully beyond the scope of this report. The same goes for application of CCS to biomass-based power generation (BECCS). The IEA projects that under the IEA Energy Technology Perspectives 2012 2^0 C Scenario (2DS) application to fossil-based power generation will account for approximately 45 % of the carbon captured by CCS by 2050.[30]

At current knowledge, three main CO_2 capture technologies are considered for application to coal-fired and NGCC plants (e.g. Pehnt and Henkel, 2009; Rubin et al, 2015):

- *Post-combustion capture*: amine (typically MEA)-based separation of CO_2 in the flue gas from other components, mainly N_2 and water vapour. For application to pulverised coal (PC) and natural gas combined cycle (NGCC) plants
- *Pre-combustion capture*: physical sorbents-based pre-combustion conversion of the feedstock fuel into CO_2 and a carbon-free combustible, e.g. hydrogen, and subsequent separation of CO_2 from the hydrogen. For application to integrated coal gasification combined cycle (IGCC) plants
- *Oxyfuel technology*: separation of the combustion air into nitrogen and oxygen, and subsequent combustion of the fuel in pure O_2; this results in a mixture of CO_2 and water vapour as flue gas, from which a pure CO_2 stream is separated with relative ease. For application to PC plants.

Small-scale post-combustion capture is a proven technology, whilst pre-combustion capture and oxyfuel technology are expected to become proven in the medium-term future. To date, large-scale application of CCS to power plants is not yet commercially mature. Experience with upscaling of CO_2 capture at fossil-fuel power plant level needs to be gained in demonstration projects. The IEA deems that for coal-fired power plants no single capture technology can be excluded to be the ultimate 'winner', but for natural gas-fired power plants post-combustion is thought to have the best chances to become the dominant capture technology (Finkenrath, 2011). Globally, so far just one "large-scale" demonstration project applying post-combustion capture on a 110 MW coal-fired power plant has been commissioned (by the end of 2014), while after a spate of cancellations[31] a handful of power-plant CCS demonstration projects – all applying post-combustion technology – remain to be in an advanced development stage.[32]

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[30] See (IEA, 2013: 22, Fig. 4). CCS applied to coal-fired plants would result in capture of approx. 3.5 $GtCO_2$ under the 2DS scenario, while for gas-fired pants this would be approx. 0.5 $GtCO_2$ Under the 2DS scenario by 2050 950 GW of power plant capacity would be equiped with capture, or 8% of all power generation globally. This would include two-thirds of all coal capacity and one-fifth of all natural-gas-fired capacity (IEA, 2013:22).

[31] Apparently the UK government has discarded CCS altogether as a major component in the UK long-term decarbonisation strategy. This was implicitly announced right after the cancellation of support for Shell's Peterhead CCS project, the preparations of which had advanced quite far already. See: http://www.londonstockexchange.com/exchange/news/market-news/market-news-detail/other/12597443.html

[32] Most large-scale CCS projects to date do not relate to power generation nor to dedicated geological storage. See: https://www.globalccsinstitute.com/projects/large-scale-ccs-projects.

The ultimate societal justification of applying CCS to fossil power generation regards the contribution this technology can make to addressing the global concern of climate change mitigation.[33] As climate change is a global issue, ideally the main impacts of fossil-fuel-based power generation with application of CCS are to be assessed on a life-cycle analysis basis. Evidently, this also applies to non-fossil power generation, i.e. based on renewables and nuclear. LCA will be a major point of departure for the assessment in the present chapter. The analysis will be of limited detail, focussing on key aspects.

The prospects for CCS in fossil power generation depend importantly on (future changes in):

- The extent to which the incremental financial and socio-economic costs of CCS application are compatible with achieving pre-set GHG emissions targets in a cost-effective way. Section 5.2 deals with the incremental cost of CCS in power generation.
- The extent to which this technology can reduce CO_2 emissions and accompanying impacts in other environmental domains. These are briefly discussed in Section 5.3.
- The incremental costs of CO_2 reduction by CCS in the fossil-based power production. See Section 5.4.
- Incremental geopolitical impact, further explained in Section 5.5.
- The political economy and public acceptance of CCS deployment. See section 5.6.

The concluding observations of this chapter are presented in Section 5.7.

5.2 The incremental cost of CCS

For an in-depth assessment of projected incremental CCS cost to new fossil-fuel based power plants, Edward S. Rubin, John E. Davidson and Howard J. Herzog have made a recent survey of existing studies and well-known engineering firms in the power industry (Rubin *et al.*, 2015). Given the reputation of the authors of the (Rubin *et al.*, 2015) paper, it was decided to take their survey results as point of departure for our assessment of the prospects for CCS applied to fossil power generation plants. Edward Rubin was coordinating lead author and Howard Herzog was one of the lead authors of a major IPCC report on CCS.[34]. The CCS studies they surveyed considered either North -America or European conditions or both. Rubin *et al* (2015) report ranges of cost projections.

In order to gain insight into acquired up-to-date state-of-the-art “mainstream” knowledge on the projected economics of CCS application to fossil-fuels based power generation, a summary of their results is reproduced here in a slightly adapted and further elaborated way in Table 5.1 below. This table provides a summary overview of projected cost performance of fossil power plants applying CCS under current technological frontier conditions. The figures presented in the table are largely directly reproduced from the “Rubin paper” (Rubin et al, 2015) and to a minor extent (i.e. the figures in italics) calculated by the present authors based on explicit or implicit assumptions in the Rubin paper on parameters such as discount rates (mostly 8%) and plant life-time (25 years). As distinct from (Rubin et al, 2015), for the sake of a simple bird’s eye overview their “representative values” instead of their bandwidths of cost projections are shown here. Following Rubin *et al.* (2015), monetary values in Table 5.1 are expressed in constant 2013 US dollars.

So far hardly any practical experience has been gained with carbon capture at power plant scale. Moreover, to some extent pre-combustion and to a larger extent oxy-combustion capture at power plant scale are not even technically completely mature. Hence, the performance and cost projections of carbon capture technology are surrounded with considerable uncertainty. Moreover, the cost conditions in the EU and North-America can vary a lot, considering e.g. the currently typically much lower fuel cost in North-America and the large gyrations of

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[33] A review of competing non-fossil options on, among others, this score is beyond the scope of this report.

[34] (IPCC, 2005).

both fuel prices and the €/US$ exchange rate. Given the preceding reflections, the levelized cost of energy (LCOE) results for the five main cases considered do not indicate a robust winner. For instance, typical EU import prices of pipeline natural gas at present under long-term contracts are on the order of $230 per 1000 scm or higher to which an additional allowance for transmission up to the premises of the power plant is applicable as against $216 /1000 scm as the (derived) "representative" value in the natural-gas based NGCC case.

One of the observations we like to make that the projected cost of CO2 avoided by CCS application, reported by Rubin et al. (2015), and consequently in Table 5.1**,** *are of a partial nature.* The reported cost regard solely the capture cost, and only of "burner-tip" GHG emissions, i.e. those GHG emissions engendered by the production of electricity that are projected to be released at the plant premises only. It could be countered that for level-playing-field comparisons also competing options (notably renewables-based and nuclear power generation) also cost of CO_2 avoided should be assessed on a life cycle basis. For the latter technologies GHG emission factors tend to be much less affected by a shift in focus from power-plant-site GHG emissions to GHG emissions on a LCA basis.

The representative values of projected cost of CO_2 avoided reported above as regards new coal-fired power plants vary from $\$US_{2013}$ 46 per tonne of CO_2 avoided (IGGC, pre-combustion) to $\$US_{2013}$ 81 per tonne of CO_2 avoided (IGCC/SCPC). The fact that in the latter case an IGCC capture plant is compared to a conventional reference SCPC without capture makes for a rather large investment per kW differential, which translate into relatively large capture cost on a per tonne avoided basis. Yet if for an IGCC with pre-combustion capture the same relatively expensive IGCC plant, but without capture, is assumed as the reference plant this renders the capture cost on a per tonne avoided basis relatively cheap. Still the reported LCOE cost for the capture plant in these cases are quite comparable (124 against 120 $US\$_{2013}$/MWh). The USC plant with oxy-combustion capture comes out with the lowest reported representative (projected) LCOE value, i.e. 110 $US\$_{2013}$/MWh. Also on a per tonne avoided basis taking a conventional SCPC plant as the reference plant. In this result the assumed low-rank coal feedstock with the associated low energy cost assumption is a key underlying factor.

Given the different fuel input assumptions of the distinct studies reviewed by Rubin *et al.* no robust conclusions can be drawn on which of the considered technologies is likely to become the most cost-competitive. This holds the more so as the cost of, notably but not only, the oxy-combustion capture technology is surrounded by high uncertainty. As for natural gas based NGCC plants with (post-combustion) capture, the reported representative LCOE cost projection appears quite attractive, i.e. 91 $US\$_{2013}$/MWh. This relates to the much lower investment costs of gas-based power plants, compared to coal-based power plants and the assumed respective fuel feedstock costs. Under current European conditions a gas input price of 216 US$/1000 scm is on the low side. *Even so, when plant operators are to be exposed to a fair extent of internalisation of the CO2 emission cost – for example through mandated participation in emissions trading or a CO2 tax – at some point gas power plants with carbon capture will reach a robust competitive position compared to coal power plants with carbon capture.*

Note that the central scenarios of most CCS cost studies typically assume quite high plant utilisation rates. Yet under adverse market conditions – resulting typically in a capacity factor for NGCC with CCS, lower than the 84% rate assumed in Table 5.1 – the CO_2 price needed to render gas power plants with CCS the most cost-effective fossil fuel power plants with CCSwill be higher. In several European countries, the merit order effect plays a significant role by putting downward pressure on wholesale power prices as a result of increasing penetration of variable, low-marginal-cost renewables. This, in turn, tends to negatively affect the average capacity factor of gas-based generation more than is the case for coal-based generation.

Table 5.1 **Summary of recent representative performance and cost projections for CO_2 capture at new coal and natural gas fueled power plants with monetary values in constant 2013 US$ based on (Rubin et al, 2015)**

Plant characteristics					
Reference plant type	SCPC	IGCC	IGCC/SCPC	SCPC/USC	NGCC
Fuel	bit. coal	bit. coal	bit. coal	low-rk coal	nat. gas
Standardised fuel heating value, HHV (GJ/unit) *	*27,87*	*27,87*	*27,87*	*27,87*	*38,23*
Reference plant net output (MW)	742	645	753	684	661
Reference plant capacity factor (%)	86	80	84	86	85
Carbon capture technology	post-com	pre-com	pre-com	oxy-com	post-com
Capture plant capacity factor (%)	*86*	*80*	*84*	86	84
Emission rate w/o capture (tCO2/MWh)	0,79	0,78	0,79	0,83	0,36
CO2 capture efficiency (%)	90	89	89	92	90
Emission rate with capture (tCO2/MWh)	0,104	0,107	0,104	0,09	0,042
Total CO2 captured or stored (Mt/yr)	4,6	3,2	4,4	4,1	1,6
Plant efficiency w/o capture, HHV basis (%)	41,4	40	41	39	51
Plant efficiency w/capture, HHV basis (%)	31,6	31	33	32	44
Capture energy requirement (% more input/MWh)	32	28	25	25	16
Plant cost measures					
Total capital requirement w/o capture (US$/kW)	2618	3181	2513	2589	1049
Total capital requirement with capture (US$/kW)	4580	4366	4838	4939	2061
Fuel cost (US$/unit)	*76*	*62*	*74*	*49*	*216*
Fuel cost, HHV (US$/GJ)	2,74	2,24	2,67	1,76	5,64
LCOE w/o capture only (US$/MWh)	70	90	69	64	64
- of which levelized capital cost (US$/MWh)	*34*	*48*	*36*	*43*	*13*
- of which fuel cost (US$/MWh)	*24*	*20*	*23*	*16*	*40*
- of which O&M cost (US$/MWh)	*12*	*22*	*9*	*5*	*11*
LCOE with capture only (US$/MWh)	113	120	124	110	91
- of which levelized capital cost (US$/MWh)	*60*	*66*	*70*	*82*	*32*
- of which fuel cost (US$/MWh)	*31*	*26*	*29*	*20*	*46*
- of which O&M cost (US$/MWh)	*22*	*28*	*25*	*8*	*13*
Cost of CO2 captured (US$/ t CO2)	46	34	63	49	74
Cost of CO2 avoided, excluding T&S ($/ t CO2)	63	46	81	62	87

Legend

SCPV:	super-critical (boiler) pulverised coal (both reference and capture plant)
IGCC:	coal-based integrated gasification combined cycle (both reference and capture plant)
IGCC/SCPV:	IGCC capture plant with a SCPV plant as reference plant
USC:	ultra super-critical (boiler)
NGCC:	natural gas combined cycle
bit. coal	bituminous coal
low-rk coal	low-rank coal: subbituminous coal, lignite

*) The standardised unit inputted for the sake of comparison by this paper's authors is:

- for coal	NCV	25,08 GJ/t (= 6000 kcal/t)	HHV	27,87 GJ/t (ARA AP2 coal)
- for nat. gas	NCV	34,41 GJ/1000 scm	HHV	38,23 GJ/1000 scm (Russian gas)

Source: Rubin et al. (2015); figures in italics are from the authors of this paper, primarily based on information in Rubin at al. (2015)

Given the large uncertainties at play, we conducted a simple a analysis to gauge the sensitivity of the results shown in Table 5.1 on the reported cost of CO_2 avoided and three other key cost indicators. Four key factors were assessed on their impact sensitivity:

1. A 25% increase in fuel prices. Notably for natural gas prices the long-term trend may be upward from currently depressed levels with a switch from a strong discount to the price of oil into an environmental impact driven premium and substitution of oil products by electricity, natural gas, syngas and other biogenic products, and on longer term possibly hydrogen.
2. A 25% increase in the incremental capital requirement of power plants with capture. We revert to this sensitivity in the present section below. Note that compared to other plant components, the additional costs

of the carbon capture components have the highest cost uncertainty. Yet also uncertain extra costs need to be incurred for system integration of carbon capture components. To keep the analysis simple, the incremental capital requirement (i.e. the capital requirement of the with CCS plant minus the corresponding requirement of the reference without CCS plant) is considered. This simplification might give rise to a some underestimation of investment cost escalation risk for with CCS power plants (on account of possible system integration costs and possibly higher weighted average capital cost for CCS plants compared to reference non-CCS plants).

3. A 25% decrease in plant capacity factors of the reference and the capture plant respectively. Given the world-wide evolving transition from utility based central dispatch to market-led dispatch in a liberalised electricity market, the typically assumed plant capacity factors in recent literature on CCS would seem prone to substantially erring on the high side.
4. A 25% decrease in the incremental energy requirement of carbon capture with respect to the reference plant. High expectations have been raised on innovations leading to a substantial reduction of the, what is called, "energy penalty" of CCS.

Results of our sensitivity calculations, presented in Table 5.2 suggest that, among the four sensitivity factors indicated, the key cost indicators of CCS capture are:

- *The economics of CCS are least sensitive to fuel price changes*
- *The economics of CCS are most sensitive by far to changes in the plant capacity factor and to changes in the incremental capital requirement of capture plants*
- *The economics of CCS with regard to coal-based IGCC capture plants when compared to similar without capture reference plants and natural-gas based post-combustion capture plants are fairly sensitive to changes in the CCS energy penalty rate.*

As regards the track record of CCS in the power generation sector, so far solely one (1) – rather small-scale (110 MW) – PC demonstration plant (retrofitted) with post-combustion CCS is in operation (as per October 2014). It concerns the Boundary Dam project in Canada with use of CO_2 for enhanced oil recovery. Detailed cost data regarding this project are hard to come by.[35]

A key assumption in virtually all power with CCS cost projections in recent literature, as reflected by survey results of Rubin et al (2015), is that first-of-a-kind (FOAK) costs are "significantly greater" than mature Nth-of-a-kind (NOAK)" costs. As an empirical basis at the relevant scale is virtually absent, a big question mark is the reliability of cost-engineering projections of NOAK costs. For example, cost-engineering cost projections of scaling up cost engineering exercises in other complex generation technology such as EPR nuclear power plants proved to grossly underestimate ex post costs. Admittedly, increasing safety and security requirements played a part in this, which may hold to a lesser extent for CCS. A related questions is how independent the cost projections concerned are from the interests of technology vendors and the fossil fuel industry. Indeed, the asymmetric information problem holds in that independent researchers can hardly avoid relying on these sources for performance and cost information to a certain extent. Another issue is the underlying rather high assumptions on average annual capacity factors. These appear to stylize a continued prevalence of the pre-market-

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[35] Some links with non-financial project information:
http://sequestration.mit.edu/tools/projects/boundary_dam.html
http://www.saskpowerccs.com/ccs-projects/saskpower-initiatives/carbon-capture-project/
Moreover, the following site contains some financial information and (less encouraging) news on the project operations up to March 2015: http://www.saskwind.ca/boundary-ccs From the latter website the, possibly not the most objective but still informative, report (Saskatchewan Community Wind, 2015) can be downloaded. Recently the project developers had to concede that they were unable to meet contractual obligations for delivery of captured CO_2 for enhanced oil recovery: http://www.powermag.com/saskpower-admits-to-problems-at-first-full-scale-carbon-capture-project-at-boundary-dam-plant/

liberalisation era with the virtual absence of competition from variable renewable power generation. The potential for cost reducing innovations would seem to fall short by far to offset the potential for unpleasant "surprises" regarding investment cost overruns of capture plants and lower than imputed (by recent CCS cost projection studies) learning rate assumptions. *All in all, our conclusion is that projections of the economics of CCS in the power sector in recent literature and organisations such as IEA and IPCC have a substantial potential to err on the low side.*

Table 5.2 **Sensitivity analysis of the impact of four major underlying assumptions on key recent representative cost projections for CO_2 capture at new coal and natural gas fueled power plants with monetary values in constant 2013 US$**

Reference plant type Fuel Carbon capture technology	SCPC coal post-com	IGCC coal pre-com	IGCC/SCPC coal pre-com	SCPC/USC coal oxy-com	NGCC nat. gas post-com	SCPC coal post-com	IGCC coal pre-com	IGCC/SCPC coal pre-com	SCPC/USC coal oxy-com	NGCC nat. gas post-com
	Representative value					Change in representative value				
Key summary results of Table 5.1 above										
LCOE w/o capture only (US$/MWh)	70	90	69	64	64					
LCOE with capture only (US$/MWh)	113	120	124	110	91					
Cost of CO2 captured (US$/ t CO2)	46	34	63	49	74					
Cost of CO2 avoided, excl T&S ($/ t CO2)	63	46	81	62	87					
If fuel feedstock prices are	**25%**	**higher, then:**								
LCOE w/o capture only (US$/MWh)	76	95	75	68	74	9%	6%	8%	6%	16%
LCOE with capture only (US$/MWh)	121	127	131	115	103	7%	5%	6%	4%	13%
Cost of CO2 captured (US$/ t CO2)	48	35	64	49	76	4%	4%	2%	1%	3%
Cost of CO2 avoided, excl T&S ($/ t CO2)	**66**	**47**	**83**	**63**	**90**	**4%**	**2%**	**2%**	**2%**	**4%**
If incr. capital req'ment with capture is	**25%**	**higher, then:**								
LCOE w/o capture only (US$/MWh)	70	90	69	64	64	0%	0%	0%	0%	0%
LCOE with capture only (US$/MWh)	119	124	132	120	96	6%	4%	7%	9%	5%
Cost of CO2 captured (US$/ t CO2)	53	39	72	59	85	15%	14%	14%	20%	14%
Cost of CO2 avoided, excl T&S ($/ t CO2)	**72**	**51**	**93**	**75**	**100**	**15%**	**12%**	**15%**	**21%**	**15%**
If the plant capacity factor is	**25%**	**less then:**								
LCOE w/o capture only (US$/MWh)	81	106	81	78	68	16%	18%	17%	22%	7%
LCOE with capture only (US$/MWh)	133	142	147	137	102	18%	18%	19%	25%	12%
Cost of CO2 captured (US$/ t CO2)	55	41	75	62	89	20%	19%	20%	27%	20%
Cost of CO2 avoided, excl T&S ($/ t CO2)	**75**	**54**	**97**	**80**	**105**	**20%**	**17%**	**20%**	**29%**	**21%**
If the capture energy requirement is	**25%**	**less then:**								
LCOE w/o capture only (US$/MWh)	70	90	69	64	64	0%	0%	0%	0%	0%
LCOE with capture only (US$/MWh)	111	118	123	109	89	-1%	-1%	-1%	0%	-2%
Cost of CO2 captured (US$/ t CO2)	44	32	61	48	68	-4%	-6%	-3%	-2%	-8%
Cost of CO2 avoided, excl T&S ($/ t CO2)	60	42	79	61	80	**-4%**	**-8%**	**-3%**	**-1%**	**-8%**

Source: authors' calculations, based on data from Rubin et al. (2015)

Rubin et al. (2015) also reviewed recent cost projections of pipeline CO_2 transport as well as for storage. Transport cost are typically based on unit cost assumptions per tCO_2 per 250 km onshore and offshore respectively. As for onshore storage they cite projections ranging from 1-13 US$$_{2013}$ per tCO_2 including monitoring. Unit offshore transport cost projections are appreciably higher than unit onshore transport projections. Projections of total offshore transport cost projects are not shown. Rubin et al. (2015) assume enhanced Oil Recovery (EOR) credits with a "conventional wisdom" valuation per $/thousand standard cubic feet of 2% of the oil price per barrel. We note that in practice these credits might be much lower in Europe, where EOR is less common than in North America. In their concluding projections, Rubin et al. factor in:

- Transport costs: 0-7 US$/$tCO_2$
- Geological storage cost: 1-12 US$/$tCO_2$
- Storage cost with EOR: -/- 15-40 US$/$tCO_2$ (i.e. a significant net EOR premium).

As for the EU situation with typically much higher population densities and fierce public resistance to onshore storage, also these assumptions would seem to have substantial potential to err on the low side. Also in the longer run a storage availability issue may pop up if IEA's long-term central scenario projections for CCS deployment were to materialise requiring gigantic storage needs. Engineering studies on storage availability suggest that even then this would not be a major issue.

The issue of possible carbon leakage is not discussed in Rubin *et al.* (2015). We revert to this issue in Section 5.5.

5.3 Environmental impacts

As for the cost of CO2 avoided by CCS, the (Rubin et al.*, 2015) paper — not unlike major analyses of IPCC , IEA, and other highly regarded information providers by policy makers— tend to present to policy makers rather partial results, when considered from a global vantage point. As climate change is a global issue, it would seem logical for assessment of GHG mitigation options including application of CCS in the power sector to adopt the world rather than the premises of the capture plant as spatial boundaries for assessment of costs and GHG emissions avoidance benefits.*

Most research publications, assessing the economics of CCS in the power sector strongly focus on the carbon capture process as such, whilst paying limited if at all additional consideration to the downstream activities of post-capture CO_2 compression , transport, storage and monitoring. In a minority of CCS studies, attention is paid to upstream, pre-capture processes, relating to the supply chains of fuels and other material consumables used in the construction and operation of power plants and auxiliary structures.

Yet Life Cycle Analysis (LCA) is the most appropriate methodology to perform environmental impact analysis in a comprehensive and systematic way. LCA is a compilation and evaluation of the inputs and outputs and the environmental impacts of a product system throughout its entire energy and production and manufacturing, to use and end of life treatment and final disposal. The objective of LCA is to understand and evaluate the magnitude and significance of the potential environmental impacts of a product system (ISO 14040, 2006; Korre et al., 2010).

In principle, LCA of a power plant environmental impacts of all energy and material inputs as well as capital equipment and infrastructure used for operation of the plant need to be accounted for over their respective life cycles. For power plants with CO_2 capture, this includes fuel extraction and transport as well as CO_2 capture, compression, transport and storage. Fugitive methane emissions along the fuel supply chain and CO_2 leakages up to (and including) storage should be included as well.

Corsten et al. (2013), a study to be further discussed in some more detail hereafter, distinguishes between direct and indirect emissions. The authors define direct emissions as emissions from the power plant installation as well as for plants with CCS emissions from transport and storage of the captured CO_2 [36] and indirect emissions resulting from fuel and material supply, waste management and by-products. They also distinguish the *direct* and *indirect* emissions categories from *first level* emissions, i.e. emissions from fuel extraction to the storage of CO_2 as against *second level* emissions, i.e. emissions from infrastructure and the extraction of non-fuel raw materials extraction, e.g. iron ore.

The functional unit chosen in the lion's share of LCA studies on coal- or gas-fired power plants without and with CCS is 1 kWh of net electricity delivered to the grid. Hence the impact levels for distinct environmental categories are expressed on a per net kWh basis. This implies that in principle electricity used by the power plant itself including, when applicable, for carbon capture is comprised in existing LCA studies. Network losses up to final electricity consumers are typically not considered. For a comparison of environmental impacts between power plants feeding directly into the transmission network this is adequate. Yet for comparisons with distributed

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[36] Alternatively, it could be argued to categorise only emssions originating from the premises of the power palnt installation as direct emissions, excluding downstream emssions from CO_2 transportation and storage.

generation technologies the system boundaries would have to be extended to include grid losses as well. Note that the latter boundary extension were to further increase the complexity of the LCA studies concerned.

Corsten et al. (2013) have reviewed a selection of power plant CCS studies which applied a more or less comprehensive LCA approach. They analysed explicitly the following impact categories:

- Cumulative energy demand (*CED*): cumulative incremental energy demand of power plants with CCS compared to reference power plants without CCS
- Global warming potential (*GWP*): potential temperature rise impacts at the earth's surface
- Eutrophication potential (*EP*): potential impacts of excessively high environmental levels of macronutrients such as phosphate
- Acidification potential (*AP*): potential acidifying impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials of i.a. sulphur oxides
- Human toxicity potential (*HTP*): potential impacts on human health of toxic substances released to air, water and soil
- Photo-chemical oxidation potential (*POP*): formation potential of reactive chemical compounds, such as ozone, by the action of sunlight on certain primary air pollutants
- Particulate matter (*PM10*): floating solid particles or liquid droplets from 2.5 up to 10 micrometers in size
- Fresh water aquatic ecotoxocity potential (*FAETP*): potential impacts of toxic substances on aquatic ecosystems
- Terrestrial ecotoxicity potential (*TETP*): potential impacts of toxic substances on terrestrial ecosystems

Most of the LCA studies examined did not explicitly consider other environmental impact categories such as stratospheric ozone depletion, depletion of non-fuel abiotic (non-living) natural resources such as minerals and impact on biodiversity (the variety of plant and animal life).

The 15 LCA studies reviewed and retained by Corsten et al. (2013) are more or less full LCA studies but they are not fully harmonised in terms of comprehensiveness and assumed date of plant commissioning. The latter varies from 'current' to 2020 or 2050. For future generation CCS-equipped power plants appreciably higher efficiencies in mitigating negative environmental impacts, such as lower GHG emission impacts, might be projected compared to 'current' generation installations by imputed high learning rates assumptions. Furthermore, differences regarding the assumed fuel quality and origin explain part of the reported diversity in outcomes.

Results of LCA studies on global warming potential, reviewed by Corsten et al. (2013) suggest that applying CCS, relative to a benchmark power plant without CCS:

- Reduces GHG emissions on LCA basis for *pulverised coal (PC) power plants* by 65-84%, against 88-95% when considering direct emissions from the power plant only
- Reduces GHG emissions on LCA basis for *integrated coal gasification combined cycle (IGCC) power plants* by 68-87%
- Reduces GHG emissions on LCA basis for *natural gas combined cycle (NGCC) power plants* by 47-80 %, against 88-95% when considering direct emissions from the power plant only
- Reduces GHG emissions on LCA basis for *PCC power plants applying oxyfuel CO2 capture technology* by 76-97%.

As for GHG reduction, NGCC power plants with CCS are projected to directly and indirectly cause 76-245 $gCO_2eq./net$ kWh, *contingent notably on assumed upstream fugitive emissions.* For pulverised coal-fired plants with CCS the projected LCA-basis GHG emission in the studies examined by Corsten et al. (2013) vary from a (seemingly implausible) low 76 to a high of 275 $gCO_2eq./net$ kWh. Oxyfuel is projected to be best performant on global warming impact for both coal and gas-based power plants with for coal a bandwidth of (8) study projections between 25 and 176 $gCO_2eq./net$ kWh.

All LCA reports covered by Corsten et al. (2013) project deteriorating performance on energy use (CED) when applying CCS with energy penalties on an LCA basis of some 16% (NGCC) to 44% (PC using MEA solvent) with a PC outlier of 66% with lignite as fuel. The scores for most of the other impact categories tend to deteriorate roughly in line with reduced LCA-based energy efficiency, i.e. broadly inverse to relative CED changes. But, among others, measures to mitigate undesirable impacts improve performance in some respects. E.g. to improve the effectiveness of the MEA sorbent, at the plant level SO_2 and particulates are largely removed, likewise for NO_2. Yet other NO_x plant emissions still largely remain, as do upstream SO_2 and NO_x emissions. All in all, eutrophication, acidification, fresh water aquatic as well as terrestrial ecotoxicity are projected to worsen, whilst most but not all studies project an increase in photochemical oxidation (POP) resulting from CCS application. Hence, the possible negative nature of the relative impact of CCS on the latter category (POP) has not yet been firmly established. In general, projected negative environmental impact levels of coal power plants tend to be higher than corresponding scores of natural gas plants. Furthermore, it is worth mentioning that power plants applying oxyfuel technology are projected to have the least impact, as regards most other categories than total energy use. This is based on the assumption of those few studies that covered the oxyfuel technology, that almost all pollutants are co-captured with CO_2 capture. According to Pehnt and Henkel (2009), this depends highly on two uncertain factors: the energy demand for air separation and the technical and economic feasibility of co-capture of CO_2 and other pollutants. Given the novel status of oxyfuel technology, robust environmental impact information still needs to be established and reconfirmed.

In general, LCA studies indicate mutually widely varying performance changes on other environmental impact categories. The LCA studies concerned vary considerably in level of detail, assumptions on fuel quality/origin and net efficiencies. A great number of caveats may apply, of which some key ones are discussed hereafter.

Not all studies seem to have included the significant negative impacts of the (mostly MEA) solvent production chain. Assumed (absence of) additional measures to mitigate impacts of solvents used also account for significantly different impact projections. Neither do all studies seem to make allowance for impacts of plant and auxiliary infrastructure construction. Those studies that do, find relatively minor impacts. Another apparent omission in some studies accounting for significant differences in cumulative GHG impact projections is the neglect of fugitive methane emissions, notably at the mining site.

Last but not least, as was pointed out already technology biases favouring CCS cannot be excluded. By necessity, CCS analysts have to partly rely on performance information from vested stakeholders. These include technology vendors, institutes with a mandate to promote CCS, such as Zero Emissions Platform (ZEP) and the Global CCS Institute, the (oil and) gas, the coal industry and large electricity companies. Moreover, industrial vested interest are often well-represented in the supervisory board of dedicated government research programmes on CCS. Typically (almost) state-of the-art power plants, able to realise close to technical maximum load factors, and optimally performing CCS processes are assumed based on to-day's proven technology or on projected technological performance assuming substantial learning effects, e.g. 20-30% efficiency improvement on (projected!) current state-of-the-art performance by 2030 (e.g. IEA, 2009; ZEP, 2011).

For the natural gas supply chain and to a lesser but even so non-negligible extent for the coal supply chain (notably coalbed methane emissions), GHG fugitive emissions, especially methane[37] *leakages, are quite relevant for the overall GHG performance of fossil-fuel power plants.* Several LCA studies seems to have made simple assumptions, putting these emissions at notional, rather marginal levels, whilst other have examined these emissions in more detail. In the U.S. a heated academic debate is going on about fugitive emissions with a focus on shale gas production. Howarth et al. (2011) postulate that: "3.6-7.9 % of the methane from U.S. natural gas production from shale formations escapes to the atmosphere in venting and leaks over the life-time of a well" or according to the authors "at least 30% more than and perhaps twice as great as those from conventional gas".

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[37] Methane is a potent greenhouse gas with a global warming potential 34 times CO_2 on a per tonne basis over a 100 year period (IPCC AR5 default value). This default GWP factor was previously put by the IPCC at 25.

The 3-6-7.9% bandwidth stated by Howarth covers the whole upstream supply chain. In contrast, Cathles et al. (2012) put the corresponding bandwidth at 0.9-2.2% for shale gas. DOE/EPA documents in great detail, with explanation of uncertainties, fugitive methane emissions from US gas production in 2013 over the whole upstream gas supply chain, amounting to 1.3% of inlands natural gas production.[38] These emissions are reported to total 6.295 MT (million metric tonnes) and set equal to 157.4 MT CO_2eq. Contributing activities to these emissions are:

- Field production: 30% of total estimated fugitive methane emissions in the natural gas supply chain. Fugitive emissions from field production include venting and flaring.
- Processing: 14%. Mainly fugitive emissions from compressors.
- Transmission and storage: 35%. Notably fugitive emissions from compressor stations.
- Distribution: 21%.

At global level fugitive methane emissions have been flagged as a serious issue. Based on official submissions to UNFCCC (United Nations framework Convention on Climate Change) of national Greenhouse Gas Inventories, current global annual methane emissions along the oil and natural gas supply chain up to fossil power plants are put at 3.6 Tcf/yr in year 2012 (Larsen et al., 2015) , i.e. 104 bcm/yr. This boils down to about 3% of global production of natural gas (3380 bcm in year 2012: BP, 2015). Corresponding carbondioxide equivalent emissions are approximately 1,680 MtCO_2eq. *Based on national GHG inventories, global average methane leakage rates from the entire natural gas value chain up to end-use delivery are put at 2-3% (Bruckner et al., 2014).* In appreciating these figures, it should be noted that estimations of fugitive methane emissions are shrouded with great uncertainties. Moreover, underreporting in national GHG emission inventories apprears to be a non-trivial problem. For instance, China's submitted national methane emissions estimates imply a leakage rate of about 0.02% (Larsen et al., 2015). In general, as for the GHG inventories of the economically developing and emerging countries there is still ample scope for improvement.

The foregoing categories do not include fugitive methane emissions of gas-fired power plants. These emissions, which at least in relative terms are reported to be modest in the US, are attributed to the final energy use categories. It is noted that a significant part of all of the above figures is based on assumptions to make up for incomplete knowledge rather than fact-based (sample) measurements.[39] Fact-based sample measurements on gas-fired CHP engines in the Dutch horticulture sector have identified the seriousness of fugitive methane emissions for at least this category of gas-fired power plants: see Box 5.1 below. Further research, monitoring and verification of compliance with existing emissions regulations should help to realise uncertainty reduction for improved design of evolving effective and cost-efficient emissions reduction policies and measures.

Most research on methane emissions in the power sector suggest that upstream (mainly coal-bed) methane emissions per unit of net electricity are appreciably lower for coal-based power supply than power from natural gas. Nonetheless in coal-producing countries and, *a fortiori*, world-wide, methane emissions in the coal supply chain add up to sizeable amounts (see e.g. footnote 38).

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[38] http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf

In 2013 25.57 Tcf of dry gas (roughly 490 MT metric) was produced in the US. EPA puts the methane emission resulting from natural gas production at 6.295 Mt (million metric ton) or 157.4 Mt CO_2eq emissions. For coal the corresponding figures are 891 MT (metric) production with according to EPA 2.584 Mt of resulting methane emssions, i.e. 64.6 Mt CO_2eq emissions. EPA uses a 100-year GWP factor of 25 (IPCC AR4 default value). A comprehensive study (Brandt *et al.*, 2014) suggests that methane emissions from natural gas and oil mining in the US might well be 1.25 to 1.75 times higher than EPA's GHG inventory estimates and points at major remaining uncertainties.

[39] E.g. in (The White House, 2014: 12) it is stated that "...The quality of methane data for some sources in the GHGI [U.S. Greenhouse Gas Inventory] can be highly variable, and comsequently, emissions estimates for some sources entail considerable uncertainty."

Box 5.1 **Fugitive methane emissions of CHP electricity production from natural gas in the Dutch horticulture sector**

In 2013 total installed capacity of CHP gas motor installations operated by the Dutch horticulture sector amounted to ca 3 GW_{el}. About 3 million scm of (Groningen quality with 31.65 MJ/scm net heating value) natural gas was used by this sector to generate 10.4 TWh (10^9kWh) of electricity. Based on sample tests, fugitive methane emissions released by the aforementioned CHP installations in 2013, mainly because of incomplete combustion, are estimated to total 35 kt (about 3% of the gas input used). This equals 0.9 Mt CO_2eq., applying a GWP factor of 25. Dutch GHG emissions in 2013 are estimated to total 196 Mt CO_2eq. Hence the CHP installations in the horticulture sector account for about 0.5 % of total Dutch GHG emissions in 2013. This issue has attracted close attention of the Dutch authorities and has prompted incentives for investments in gas motor installations with comparatively superior environmental performance (carrots) and stricter regulation (sticks) and as well as intensified monitoring and enforcement. This regime makes that greenhouse operators tend to give higher attention to environmental performance, with gas motor brands performing well on this criterion such as notably Mannheim-based MFM gaining market share.

It is interesting to note that also the gas motor manufacturing branch is not impervious to stricter environmental regulation in notably western countries. The well-performing gas motors of MFM have not gone unnoticed. In 2011 MFM was acquired by one of its erstwhile competitors, US multinational Caterpillar.

Source: Quantitative data in this text box are based on (MONIT database, ECN)

5.4 Impact on geopolitical tensions

In Chapter 4, quantitative and qualitative information was presented, shedding light on geopolitical impacts of the huge and highly volatile resource rent transfers from international trade in fossil fuels. It was brought out that, in general, by far the highest transfers are generated by international trade in oil, but resource rent transfers through international trade in gas are large as well. The introduction and subsequent expansion of CCS application to gas-fired power plants strengthens the gas option in a progressively carbon-constrained world in two ways: (i) the carbon-intensity of gas use in the power industry will be substantially reduced and (2) through the direct energy penalty of CCS application in gas-fired power plants, and consequential incremental use upstream in gas transmission and fugitive methane emissions, gas demand compared to gas-fired power stations without CCS is amplified. In turn, this sustains resource rent inflows into gas exporting countries with potential knock-on effects on geopolitical tensions.

In assessing the net benefits of CCS application to gas-fired power plants, the costs of enhancing potential geopolitical tensions and how this can be mitigated, both have to be duly taken into account.

5.5 Public acceptance

According to organisations such as IEA, EIA, and the IPCC a 450 ppm CO_2eq scenario cannot be realised without wide-scale deployment of CCS to fossil power generation. The Global Energy Assessment (2012) deems that under such scenario more than 60% of coal-fired generating capacity is required to be equipped with CCS and that, depending on the specific scenario variant, cumulative CO_2 storage will be no less than 55 Gt CO_2 and closer to 250 Gt CO_2 (Corsten, 2013: 59).[40] Apart from the issue whether or not the necessary storage capacity can be made available, public perception and the perception of stakeholders of carbon leakage risks needs to be

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[40] See also footnote 30 above.

convincingly addressed. If not, then existing negative perceptions may prove to be a considerable hurdle to the roll-out of CCS in the power sector.

Typically the possibility of carbon leakage is assumed to be naught in the bulk of recent CCS literature. This boils down to assuming that both the probability of CO_2 leakage events during transportation (such as accidents during excavation e.g. for cabling activities) and the probability of CO_2 leakage events in storage reservoirs are assumed to be virtually zero.[41] This residual risk assessment would seem a hard sell to the general public and those commercial stakeholders that would have to financially bear this risk liability. Moreover, inspite of the strong reassurances of the mainstream scientists on CCS (e.g. IPCC, 2005) quite a few geologists consider the alleged virtually zero residual risk far from a foregone conclusion.[42]

To date, most legislation on CCS seeks to pass on the residual risk liability to the public sector after a specified period of time (Dixon, 2015). Typically this is made contigent on whether or not the (fossil power plant) operators wishing to obtain imdemnity for residual risks meet specified requirements. For example, the EU CCS Directive 2009/31/EC, provides for the transfer of responsibility in the long-term from the operator to the competent authority when ***inter alia*** “all available evidence indicates that the stored CO_2 will be completely and permanently contained” and “a minimum period, to be determined by the competent authority has elapsed. This minimum period shall be no shorter than 20 years, unless the competent authority is convinced that the criterion referred to [in the previous quote] …is complied with before the end of that period”. Apart from the issue of inhibitive costs explained in Section 5.2 above, we have great doubts as to whether the CCS option applied to power plants will fly in the EU when the operators concerned will have to face the uncertainty of unpleasant surprises within “the minimum period, to be determined by the competent authority” and the risk that by the end of that period the competent authority deems that the condition that “all available evidence indicates that the stored CO_2 will be completely and permanently contained” does not obtain. Moreover, the assumption of risk by a meber state’s competent authority, i.e. ultimately society at large in that member state, might well meet with stiff public resistance in Europe.

5.6 Other climate engineering options

A more balanced approach is needed with regard to RD&D for the technology development of geoengineering technology. The extreme bias towards capture at power plants should be reduced, whilst giving due attention to other technologies that might turn out to be cheaper than capture and storage of CO_2 released by natural-gas based power plant in terms of cost per tonne of avoided CO_2eq. emissions on LCA basis. *Prima facie*, it would seem, for instance, that at least capture of CO_2 by mineral reactions, such as reactions with olivine in aqueous environments may have may have interesting prospects to prove a lower cost negative-emissions option (Schuiling and de Boer, 2013).[43] Also albedo enhancement has been identified as an option, warranting serious attention (Crutzen, 2006). It goes without saying that in RD&D projects with such technologies the negative non-GHG environmental impacts needs to be subjected to close monitoring for fact-based integrated assessment purposes.

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[41] According to IPCC (2005), quoted by Pehnt and Henkel (2009): “the fraction retained in appropriate is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1000 years.”

[42] See e.g. the article by Liam Jackson of 11 February 2016: “Carbon dioxide stored underground can find multiple ways to escape”, downloadable from:

http://news.psu.edu/story/392047/2016/02/11/research/carbon-dioxide-stored-underground-can-find-multiple-ways-escape

[43] The costs of this CO_2 removal option are projected by Schuiling and De Boer at less than US$ 11 /tCO_2 of which about US$ 7.5 /tCO_2 for mining and crushing of hard rocks like granite and about US$ 3 /tCO_2 for megacarrier transport. See:

http://costs.infomine.com/costdatacenter/miningcostmodel.aspx

5.7 Conclusions

CCS applied to fossil fuel plants is a technology with high and, at least to date, highly uncertain GHG avoidance costs. This hold the more so, when these cost are analysed from a global perspective using LCA methodology. *For several reasons, explained in this chapter, GHG emissions avoidance costs projected in publications by IEA, EIA and IPCC may well turn out to significantly err on the low side.*

GHG emission levels of fossil-fuelled power plants without CCS are too high to be compatible with the main objective of the UNFCCC and the ambitions enshrined in the 2015 Paris Agreement on Climate Change. The projected performance of CCS-equipped fossil-fuelled power plants on global warming is substantially better than reference power plants without CCS. *GHG emission levels of coal-fired power plants with CCS still remain too high to reach compatibility in an enduring way*. Subject to prospective results with demonstration projects, application of the oxyfuel process might become a notable exception in this regard. *Moreover, persistent air pollution problems in a progressively urbanising world is a second important driver to strengthen the political forces that rally to phase out coal-fired power plants not only in the rich countries but in the emerging economies and developing countries as well.* Indeed, coal-fired power plants, and even more so the ones with CCS, tend to have a poor performance on several other environmental impact categories. In these respects, natural gas tends to have much lower impacts.

What is more, *the prospects for gas-fuelled power plants equipped with CCS on compatibility with the UNFCCC's main objective on longer term look somewhat brighter than for coal-fired power plants.* Natural gas has at least a role to play as a transition fuel. *Yet, it cannot be firmly concluded that gas-fired power plants with CCS will endure in a stringently carbon-constrained world necessary to keep average human-induced temperature changes below 2 degrees above pre-industrial levels. This depends in particular on adequate containment of fugitive methane emissions and on whether CCS applied to gas-fuelled power plants will take off*.[44]

In the assessment of CCS application in the power sector also the impact on geopolitical tensions have to be duly weighted. Given the broadly modest resource rent transfers from international trade in coal and fairly easy short-term supply alternatives for importing countries and regions the geopolitical externality for coal and hence for application of CCS to coal-fired power plants are very small. For natural gas this negative externality is significant: in Chapter 3 it was tentatively indicated that resource rents can be significant. Moreover, depending on the extent of meshed nature of international gas pipeline transmission infrastructure and reverse-flow capabilities as well as access to LNG import terminals, dominant pipeline-gas exporters can exercise market power for profit-enhancing or political purposes (Toth et al., 2014). In principle, the geopolitical externality of pipeline gas can be managed as was demonstrated in Toward2030-Dialogue's Issue paper No. 1, but needs serious attention.

For oxyfuel CCS technology, by and large, the least negative impact scores have been projected. Yet for this least mature CCS technology the highest uncertainties exists on both cost and performance scores. To date, at least for gas-fired power plants post-combustion technology is still regarded to stand the best chance of commercial take-off, but given prevailing uncertainties this is not a foregone conclusion.

For large-scale deployment of CCS suitable solutions will have to be found for huge CO_2 storage space requirements. Mounting technology acceptance issues will further complicate the implementation of CO_2 storage, necessitating the preparation and use of high-cost remote onshore and sub-oceanic geological storage space.

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[44] (Logan et al., 2015: 38) conclude for the U.S. power sector that: "...More fundamentally, the natural gas sector could meet a "dead end"within a decade or two if the United States chooses to reduce [greenhouse] gas emissions by 80% from 1990 levels by the year 2050. Unless carbon capture and sequestration technologies are deployable by 2030 or soon thereafter, natural gas combustion in the power secvtor may need to peak, at least assuming that the power sector contributes substantially to move such an emssions pathway...".

Using captured CO_2 for enhanced oil or gas recovery is recommended when this is financially feasible for the stakeholders developing the oil or gas fields concerned. In this application it has to be ensured that the latter pay a fair market-based price. Moreover, *world-wide strict monitoring procedures on leakages have to be introduced, when applying geological CO2 storage, including the use of CO2 for enhanced recovery purposes.* This is a logical consequence of the 2015 Paris Climate Agreement.

6 Concluding observations

The EU's fossil import bill is huge. This bill mainly concerns imports of oil and natural gas. But the level of the fossil import bill as such is not necessarily a valid key argument in favour of dedicated policies to foster energy efficiency and renewables. Rather it concerns the negative externalities of the resource rent income created by the extraction of oil and natural gas, that is consumed in the EU in whatever form (crude, products, feedstock).

Resource rent creation tends to have quite negative externalities regarding the governance of nations where the extraction of oil and gas occurs, notably (but not exclusively) in emerging economies and developing countries with authoritarian regimes. This, in turn, has negative implications for geopolitical stability and prosperity world-wide. Because of its share in world trade, the EU as a trade bloc has quite some leverage. Reduction in the consumption of crude oil and natural gas and derivatives in the EU will strongly stimulate oil & gas exporting countries to diversify their economies away from oil & gas related activities and to introduce economic and social reforms to improve their international competitiveness in other economic domains. Ultimately this has strongly positive effects on geopolitical stability and prosperity world-wide.

A strong policy push in the EU to foster cost-effective energy efficiency and deployment of renewables will help to diminish the role of fossil fuels in the European energy economy with lasting direct benefits for the EU economy (incremental employment, value added) and environment, the health of EU citizens, as well as the world's climate. Moreover, major indirect external benefits result in terms of improved governance of oil & gas producing countries towards achieving inclusive and enduring national socio-economic development as well as world-wide socio-economic gains from rising geopolitical stability.

Global energy development scenario analyses of the IEA and IPCC suggest that fossil fuels will continue to play a dominant role for very long into the future. *Yet evidence was found suggesting that recent IEA central scenario projections are likely to overstate the actual global energy demand evolution and, more specifically, the role of coal and oil to meet future global energy demand.*

Consequently, these prominent advisory institutes to policymakers world-wide foresee that a large roll-out of carbon capture and storage (CCS) for fossil-fueled power generation will be an indispensable component of an effective strategy to avoid catastrophic climate change.Therefore, we reviewed information published by IPCC and IEA on the cost per tonne of CO_2eq. avoided through application of CCS in fossil power plants. Our findings suggest that this information cannot be taken for granted by policy makers. Underlying assumptions on incremental investment and operating costs as well as future cost reduction would seem overly optimistic. In combination with the bleak prospects for coal, the chances of a take-off of CCS for coal-fired power plants would seem very small indeed.

Moreover, the summary cost information presented by IPCC and IEA to policy makers tends to be partial in nature. Typically this information is based on GHG emissions originating from electricity generation at the premises of the power plant. GHG emissions occurring in the fossil fuel supply chain before entering the power plant and during transport and storage of CO_2 tend to be hardly accounted for in aforementioned summary information. *Notably fugitive methane emissions in the natural gas supply chain take on large proportions. Conservative estimates surrounded by large uncertainty suggest that, world-wide, on average fugitive methane emissions along the natural gas supply chain occur on the order of 2%-3% of natural gas production. In a carbon-constrained world the long-term prospects for natural gas are largely dependent on: (1) whether the fugitive methane emissions issue will be adequately addressed, (2) acceptable cost performance of CCS power technology applied to natural gas fired power plants and (3) public acceptance of geological storage.*

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Annex 1 Brief description of WEO2014 scenarios

In this Annex a brief description is given of the three energy scenarios of the IEA's World Energy Outlook 2014.

1) Central scenario: New Policies Scenario (NPS)

This scenario describes a pathway for energy markets based on the continuation of existing policies and measures as well as the implementation of policy proposals, even if they are yet to be formally adopted. These proposals include targets and programs to support renewable energy, energy efficiency, and alternative fuels and vehicles, as well as commitments to reduce CO2 emissions, reform energy subsidies and expand or phase out nuclear power (IEA, 2014a).

2) Baseline scenario: Current Policies Scenario (CPS)

This scenario only takes account of policies that were enacted as of mid-2014. It describes a business-as- usual future in which governments fail to follow through on policy proposals that have yet to be backed-up by legislation or other bases for implementation and do not introduce ant other policies that affect the energy sector (IEA, 2014a). This scenario is needed as a baseline for modelling. But if our assumption that the normative back-casting will be embraced (at least partially) by key policy makers around the globe, this scenario is poised to have little practical meaning. Therefore, in this report the CPS scenario is disregarded.

3) Stringent CC policy scenario: 450 Scenario

This scenario illustrates what it would take to achieve an energy trajectory consistent with limiting the long-term increase in average global temperature to 2 degrees Celsius. The scenario assumes a set of policies that bring about a trajectory of greenhouse-gas emissions from the energy sector that is consistent with the goal. Before 2020 these measures consist of targeting energy efficiency improvements in industry, buildings and transport; limits on use and construction of inefficient coal-fired power plants; curbs on methane emissions in upstream oil and gas production; the partial phase-out of fossil fuels subsidies to end users. After 2020, there is assumed that an CO2 price is adopted in OECD countries and other major economies in the power generation and industry sectors, at a level high enough to make investment in low-carbon technologies attractive. Next to this, there is assumed that fossil fuel subsidies are removed in all regions except for the Middle East by 2035 and that by then the CO2 pricing is extended to the transport sector (IEA, 2014a).

In addition to these scenario descriptions, technological development and deployment and their rates and impact on energy efficiency vary per scenario as well. This development and deployment is based on developments in 6 technologies, namely: renewable power, nuclear power, carbon capture and storage, biofuels, hybrid and electric vehicles and energy efficiency. As a general assumption, energy technologies that are in use today or that are approaching commercialization achieve continued cost reductions due to wider deployment and thus more efficient production. However, the rates of improvement vary by scenario since the levels of deployment are driven by the policies assumed and by the energy and CO_2 prices (IEA, 2014a).

Annex 2 Projections on population, GDP, energy, electricity and CO_2 emission for selected regions

Table A2.1 Central scenario projections of world total and urban population, by selected regions

	Population							Urban population		
	(millions)					CAAGR (%)		(millions)		CAAGR (%)
	1990	2012	2020	2030	2040	1990-2012	2012-2040	2012	2040	2012-2040
World	5278,91	7042,94	7758,16	8500,77	9157,23	1,3	0,9	3726	5715	1,5
EU-28	477,84	505,12	508,23	509,65	506,76	0,3	0,0	376	416	0,4
USA	249,62	314,11	333,55	355,76	373,77	1,1	0,6	258	329	0,9
China	1135,19	1350,70	1402,85	1408,32	1394,71	0,8	0,1	715	1044	1,4
India	868,89	1236,69	1388,86	1527,66	1633,73	1,6	1,0	391	701	2,1
Middle East	126,85	213,42	247,72	286,74	320,53	2,4	1,5	148	241	1,8
ROTW	2420,52	3422,90	3876,96	4412,64	4927,73	1,6	1,3	1838	2983	1,7

Source: (UN/DESA, 2014a/b,2015a/b)

Table A2.2 Central scenario projections of world GDP in trillion international dollars of constant year 2013 purchasing power parity, by selected regions

	GDP at constant 2013 prices						
	($2013 trillion, Purchasing Power Parity)					CAAGR (%)	
	1990	2012	2020	2030	2040	1990-2012	2012-2040
World	41,33	84,43	112,91	160,82	216,13	3,3	3,4
EU-28	11,20	16,23	18,43	22,03	25,57	1,7	1,6
USA	9,58	16,49	20,24	24,68	29,79	2,5	2,1
China	1,56	12,44	21,22	35,57	48,74	9,9	5,0
India	1,20	4,79	7,74	14,67	24,59	6,5	6,0
Middle East	1,17	3,03	4,05	5,93	8,21	4,4	3,6
ROTW	16,62	31,46	41,23	57,94	79,24	2,9	3,4

Note: (trillion) dollars used have a constant purchasing power at parity with (trillion) US dollars in year 2013
Source: (IMF, 2014), (IEA, 2014a: 41; CAAGRs)

Table A2.3 Central scenario projections of world and EU28 GDP per capita in international dollars of constant year 2013 purchasing power parity

	GDP per capita at constant 2013 prices						
	($2013; Purchasing Power Parity)					CAAGR (%)	
	1990	2012	2020	2030	2040	1990-2012	2012-2040
World	7.830	11.988	14.554	18.918	23.602	2,0	2,4
EU-28	23.443	32.134	36.262	43.224	50.448	1,4	1,6
USA	38.364	52.486	60.695	69.366	79.699	1,4	1,5
China	1.374	9.213	15.128	25.256	34.944	9,0	4,9
India	1.378	3.870	5.576	9.605	15.053	4,8	5,0
Middle East	9.250	14.177	16.334	20.688	25.606	2,0	2,1
ROTW	6.868	9.191	10.634	13.130	16.080	1,3	2,0

Note: dollars used have a constant purchasing power at parity with US dollars in year 2013
Source: (UN/DESA, 2014a/b,2015a/b), (IMF, 2014), (IEA, 2014a: 41; CAAGRs)

Table A2.4 Realised values (years 1990,2012) and WEO2014 NPS and 450S scenario projections of primary energy demand for selected regions

	Level (EJ)					CAAGR (%)	
	1990	**2012**	**2020**	**2030**	**2040**	**1990-2012**	**2012-2040**
New Policies Scenario							
World	368	559	627	700	766	1,9	1,1
EU-28	69	69	68	65	64	0,0	-0,3
USA	80	89	94	92	92	0,5	0,1
China	37	122	147	168	175	5,6	1,3
India	13	33	42	57	74	4,2	2,9
Middle East	9	28	34	42	48	5,5	1,9
ROTW	160	218	242	276	313	1,4	1,3
450 Scenario							
World	368	559	608	625	654	1,9	0,6
EU-28	69	69	66	61	58	0,0	-0,6
USA	80	89	92	83	82	0,5	-0,3
China	37	122	142	146	148	5,6	0,7
India	13	33	41	48	57	4,2	2,0
Middle East	9	28	32	35	38	5,5	1,0
ROTW	160	218	242	276	313	1,4	1,3

Source: (IEA, 2104a)

Table A2.5 Realised values (years 1990, 2012) and WEO2014 NPS and 450S scenario projections for years 2020, 2030, and 2040 of energy intensity for selected regions; 1990-2040

	EJ/trillion$2013 (PPP)					CAAGR (%)	
	1990	**2012**	**2020**	**2030**	**2040**	**1990-2012**	**2012-2040**
New Policies Scenario							
World	8,9	6,6	5,6	4,4	3,5	-1,3	-2,2
EU-28	6,1	4,2	3,7	2,9	2,5	-1,7	-1,9
USA	8,4	5,4	4,7	3,7	3,1	-2,0	-2,0
China	23,6	9,8	6,9	4,7	3,6	-3,9	-3,5
India	11,1	6,9	5,4	3,9	3,0	-2,1	-2,9
Middle East	7,5	9,4	8,3	7,0	5,9	1,0	-1,7
ROTW	9,6	6,9	5,9	4,8	4,0	-1,5	-2,0
450 Scenario							
World	8,9	6,6	5,4	3,9	3,0	-1,3	-2,8
EU-28	6,1	4,2	3,6	2,8	2,3	-1,7	-2,2
USA	8,4	5,4	4,5	3,4	2,8	-2,0	-2,4
China	23,6	9,8	6,7	4,1	3,0	-3,9	-4,1
India	11,1	6,9	5,3	3,3	2,3	-2,1	-3,8
Middle East	7,5	9,4	7,9	6,0	4,6	1,0	-2,5
ROTW	9,6	6,9	5,9	4,8	4,0	-1,5	-2,0

Note: (trillion) dollars used have a constant purchasing power at parity with (trillion) US dollars in year 2013
Source: (UN/DESA, 2014a/b,2015a/b), (IMF, 2014), (IEA, 2014a)

Table A2.6 Realised primary energy demand mix (years 1990, 2012) and WEO2014 NPS and 450S scenario projections of the primary energy demand mix for years 2020, 2030, and 2040 for selected regions

Scenario	Actuals		New Policies Scenario			450 Scenario			CAAGR 2012-2040	
Year	1990	2012	2020	2030	2040	2020	2030	2040	NPS	450S
World										
Coal	25%	29%	28%	26%	24%	27%	20%	17%	0,5%	-1,4%
Oil	37%	31%	30%	28%	26%	30%	27%	21%	0,5%	-0,9%
Natural gas	19%	21%	21%	23%	24%	21%	23%	22%	1,6%	0,7%
Nuclear	6%	5%	6%	6%	7%	6%	9%	11%	2,3%	3,5%
Renewables	13%	13%	15%	17%	19%	16%	22%	30%	2,4%	3,5%
Total (EJ)	368	559	627	700	766	608	625	654	1,1%	0,6%
EU28										
Coal	28%	18%	15%	12%	9%	14%	8%	7%	-2,9%	-4,0%
Oil	37%	32%	29%	26%	22%	30%	23%	16%	-1,6%	-3,1%
Gas	18%	24%	25%	28%	30%	25%	26%	24%	0,6%	-0,6%
Nuclear	13%	14%	14%	13%	14%	14%	16%	18%	-0,4%	0,2%
Renewables	5%	12%	16%	21%	26%	17%	27%	36%	2,5%	3,4%
Total (EJ)	69	69	68	65	64	66	61	58	-0,3%	-0,6%
USA										
Coal	24%	20%	18%	15%	13%	16%	9%	11%	-1,4%	-2,5%
Oil	40%	36%	35%	31%	27%	35%	29%	20%	-1,0%	-2,4%
Gas	23%	28%	29%	32%	33%	29%	31%	27%	0,7%	-0,5%
Nuclear	8%	10%	10%	11%	11%	10%	13%	15%	0,5%	1,1%
Renewables	5%	6%	8%	12%	16%	9%	18%	28%	3,4%	5,2%
Total (EJ)	80	89	94	92	92	92	83	82	0,1%	-0,3%
China										
Coal	61%	68%	62%	56%	51%	61%	46%	38%	0,3%	-1,4%
Oil	14%	16%	16%	18%	17%	16%	17%	13%	1,6%	-0,1%
Gas	1%	4%	6%	9%	11%	6%	10%	12%	4,8%	4,5%
Nuclear	0%	1%	3%	6%	7%	3%	9%	13%	9,1%	11,0%
Renewables	24%	11%	12%	12%	14%	12%	17%	24%	2,2%	3,6%
Total (EJ)	37	122	147	168	175	142	146	148	1,3%	0,7%
India										
Coal	33%	45%	45%	44%	44%	44%	32%	26%	2,8%	0,0%
Oil	19%	22%	24%	24%	25%	24%	24%	20%	3,3%	1,5%
Gas	3%	6%	7%	8%	10%	7%	11%	15%	4,6%	5,3%
Nuclear	1%	1%	2%	3%	4%	2%	5%	9%	7,8%	9,8%
Renewables	44%	25%	23%	20%	18%	24%	27%	30%	1,7%	2,7%
Total (EJ)	13	33	42	57	74	41	48	57	2,9%	2,0%
Middle East										
Coal	0%	0%	1%	0%	0%	1%	1%	0%	1,8%	1,4%
Oil	65%	49%	49%	45%	42%	49%	43%	35%	1,3%	-0,2%
Gas	34%	50%	49%	50%	50%	48%	49%	48%	2,0%	0,9%
Nuclear	0%	0%	1%	2%	3%	1%	3%	5%	16,0%	17,6%
Renewables	1%	0%	1%	2%	5%	1%	4%	11%	11,1%	13,3%
Total (EJ)	9	28	34	42	48	32	35	38	1,9%	1,0%
ROTW										
Coal	18%	16%	15%	15%	15%	15%	11%	9%	1,2%	-1,2%
Oil	41%	37%	35%	32%	29%	35%	30%	25%	0,5%	-0,7%
Gas	22%	26%	25%	26%	27%	25%	25%	24%	1,4%	0,5%
Nuclear	4%	3%	5%	5%	5%	5%	6%	8%	2,9%	4,0%
Renewables	16%	18%	20%	22%	24%	21%	28%	35%	2,2%	3,1%
Total (EJ)	160	218	242	276	313	236	252	271	1,3%	0,8%

Source: (IEA 2014a)

Table A2.7 Realised gross electricity demand mix (years 1990, 2012) and WEO2014 NPS and 450S scenario projections of the gross electricity demand mix for years 2020, 2030, and 2040 for selected regions

Scenario	Actuals		New Policies Scenario			450 Scenario			CAAGR 2012-2040	
Year	1990	2012	2020	2030	2040	2020	2030	2040	NPS	450S
World										
Coal	37%	41%	37%	33%	31%	35%	20%	13%	1,0%	-2,4%
Oil	11%	5%	3%	2%	1%	3%	1%	1%	-3,0%	-5,3%
Natural gas	15%	22%	22%	23%	24%	22%	22%	16%	2,2%	0,4%
Nuclear	17%	11%	12%	12%	12%	12%	16%	18%	2,3%	3,5%
Renewables	20%	21%	26%	30%	33%	27%	41%	51%	3,7%	4,8%
Total (TWh)	11825	22721	27771	33881	40104	26760	30296	35043	2,1%	1,6%
EU28										
Coal	41%	29%	23%	15%	9%	20%	7%	5%	-3,5%	-5,7%
Oil	9%	2%	1%	0%	0%	1%	0%	0%	-6,6%	-8,0%
Gas	7%	18%	17%	22%	24%	18%	18%	9%	1,5%	-2,1%
Nuclear	31%	27%	25%	22%	21%	26%	26%	26%	-0,4%	0,2%
Renewables	12%	24%	33%	41%	46%	34%	48%	59%	2,8%	3,6%
Total (TWh)	2576	3260	3400	3563	3742	3320	3362	3541	0,5%	0,3%
USA										
Coal	53%	38%	35%	25%	22%	31%	16%	16%	-1,4%	-2,5%
Oil	4%	1%	1%	0%	0%	0%	0%	0%	-4,4%	-7,1%
Gas	12%	30%	30%	34%	34%	32%	32%	18%	1,2%	-1,3%
Nuclear	19%	19%	18%	18%	18%	19%	21%	22%	0,5%	1,1%
Renewables	12%	12%	16%	22%	27%	17%	31%	43%	3,5%	5,1%
Total (TWh)	3203	4270	4641	4904	5209	4484	4520	4897	0,7%	0,5%
China										
Coal	72%	76%	63%	56%	52%	61%	36%	23%	1,3%	-2,1%
Oil	8%	0%	0%	0%	0%	0%	0%	0%	-3,2%	-4,4%
Gas	0%	2%	4%	6%	8%	5%	10%	10%	8,2%	8,3%
Nuclear	0%	2%	6%	9%	10%	6%	16%	20%	9,1%	11,0%
Renewables	19%	20%	27%	28%	30%	28%	38%	47%	4,2%	5,3%
Total (TWh)	650	5024	7204	9310	10734	6944	8069	9120	2,7%	2,2%
India										
Coal	65%	72%	68%	59%	55%	66%	35%	18%	3,3%	-1,5%
Oil	5%	2%	1%	1%	0%	1%	0%	0%	-4,0%	-5,6%
Gas	3%	8%	8%	11%	12%	9%	15%	19%	5,7%	6,9%
Nuclear	2%	3%	4%	6%	7%	4%	10%	14%	7,8%	9,8%
Renewables	24%	11%	10%	11%	12%	11%	20%	19%	6,4%	8,1%
Total (TWh)	293	1166	1673	2640	3787	1630	2323	3172	4,3%	3,6%
Middle East										
Coal	0%	0%	0%	0%	0%	0%	0%	0%	10,5%	8,8%
Oil	44%	36%	26%	15%	12%	27%	13%	8%	-1,4%	-3,2%
Gas	51%	61%	69%	72%	65%	67%	63%	46%	2,9%	1,0%
Nuclear	0%	0%	2%	5%	6%	2%	7%	11%	16,0%	17,6%
Renewables	5%	2%	4%	8%	17%	4%	16%	35%	9,9%	12,1%
Total (TWh)	224	905	1187	1554	1882	1082	1318	1595	2,6%	2,0%
ROTW										
Coal	21%	24%	24%	22%	21%	22%	12%	7%	1,7%	-2,6%
Oil	16%	8%	5%	2%	2%	4%	2%	1%	-3,6%	-6,6%
Gas	22%	31%	30%	29%	29%	29%	24%	18%	2,0%	-0,2%
Nuclear	12%	8%	10%	11%	10%	11%	14%	15%	2,9%	4,0%
Renewables	29%	28%	32%	36%	38%	33%	48%	58%	3,3%	4,3%
Total (TWh)	4880	8097	9665	11910	14750	9300	10704	12719	2,2%	1,6%

Source: (IEA 2014a)

Table A2.8 Realised (years 1990, 2012) and projected (years 2020, 2030, and 2040) global energy-related CO2 emissions by fossil fuels according to the WEO2014 NPS and 450S scenarios for selected regions

Scenario	Actuals		New Policies Scenario			450 Scenario			CAAGR 2012-2040	
Year	1990	2012	2020	2030	2040	2020	2030	2040	NPS	450S
World										
Coal	40%	44%	44%	42%	41%	43%	32%	24%	0,4%	-3,9%
Oil	42%	36%	35%	34%	33%	35%	40%	40%	0,4%	-1,3%
Natural gas	18%	20%	21%	24%	26%	22%	29%	36%	1,6%	0,2%
Total (Mt)	**20938**	**31615**	**34203**	**36291**	**38037**	**32479**	**25424**	**19300**	0,7%	-1,7%
EU28										
Coal	43%	34%	31%	26%	20%	29%	17%	14%	-2,9%	-6,0%
Oil	42%	41%	40%	39%	37%	41%	43%	37%	-1,4%	-3,3%
Gas	15%	26%	29%	35%	43%	30%	40%	49%	0,6%	-0,8%
Total (Mt)	**3959**	**3723**	**3480**	**3060**	**2702**	**3285**	**2281**	**1566**	-1,1%	-3,0%
USA										
Coal	37%	32%	31%	26%	24%	28%	11%	7%	-1,8%	-8,7%
Oil	42%	41%	40%	38%	36%	41%	47%	46%	-1,2%	-3,0%
Gas	21%	27%	30%	36%	41%	31%	43%	48%	0,7%	-1,5%
Total (Mt)	**4850**	**5043**	**5075**	**4513**	**4119**	**4819**	**3001**	**1902**	-0,7%	-3,4%
China										
Coal	85%	83%	79%	74%	71%	79%	64%	50%	0,2%	-4,6%
Oil	14%	14%	15%	17%	18%	15%	22%	26%	1,5%	-0,7%
Gas	1%	3%	6%	9%	11%	6%	14%	23%	5,2%	4,1%
Total (Mt)	**2278**	**8229**	**9459**	**10200**	**10018**	**8962**	**6290**	**3630**	0,7%	-2,9%
India										
Coal	68%	70%	68%	66%	64%	67%	56%	48%	2,8%	-0,9%
Oil	28%	25%	26%	27%	27%	26%	33%	32%	3,3%	1,3%
Gas	4%	5%	6%	8%	9%	7%	12%	20%	4,8%	5,3%
Total (Mt)	**580**	**1953**	**2515**	**3454**	**4518**	**2385**	**2288**	**2216**	3,0%	0,5%
Middle East										
Coal	0%	1%	1%	1%	1%	1%	1%	1%	1,6%	0,4%
Oil	71%	54%	53%	49%	47%	53%	49%	44%	0,9%	-1,0%
Gas	29%	45%	47%	50%	52%	46%	50%	55%	1,9%	0,5%
Total (Mt)	**554**	**1671**	**1917**	**2264**	**2486**	**1819**	**1762**	**1568**	1,4%	-0,2%
ROTW										
Coal	28%	26%	27%	27%	28%	26%	21%	16%	1,1%	-2,7%
Oil	49%	46%	45%	44%	41%	46%	47%	48%	0,5%	-0,9%
Gas	23%	27%	27%	29%	31%	28%	32%	36%	1,4%	0,1%
Total (Mt)	**8716**	**10995**	**11757**	**12800**	**14193**	**11209**	**9800**	**8417**	0,9%	-0,9%

Source: (IEA 2014a)