Ea Energy Analyses

Update of fossil fuel and CO2 price projection assumptions

CONVERGENCE PATHWAY

21-01-2014

Published by:

Ea Energy Analyses
Frederiksholms Kanal 4, 3. th.
1220 Copenhagen K
Denmark
T: +45 88 70 70 83
F: +45 33 32 16 61
Email: info@eaea.dk
Web: www.eaea.dk

Contents

Definitions

BVT – bruttoværditilvæksten; Gross Value-Added

CIF – Cost, Insurance and Freight

EIA – US Energy Information Administration

EIA AEO – US Energy Information Administration's Annual Energy Outlook

ENDEX – European Energy Derivatives Exchange

EUA – EU Emission Allowances

ICE – InterContinental Exchange

IEA – International Energy Agency

MCIS – McCloskey Coal Information Services

Nominal price – unadjusted current price

OECD – Organisation for Economic Co-operation and Development

OPEC – Organization of the Petroleum Exporting Countries

Real price – price adjusted for inflation and prevailing currency exchange rate (in the context of this study – expressed in currency values of year 2012)

TTF – Title Transfer Facility; a virtual trading point for natural gas in the Netherlands

WEM – World Energy Model; the principal tool employed to generate the projections underlying the World Energy Outlook scenario

WEO – World Energy Outlook

Dansk Resume

WORK IN PROGRESS

1 Introduction

The purpose of this report is to describe the methodological approach and data foundation for periodical updating of the economic fuel prices issued by the Danish Energy Agency. More specifically, the report deals with the integration of the latest projection from the IEA's annual publication World Energy Outlook (WEO) and market developments incurred since these assumptions have been locked.

The economic fuel prices have two main applications:

1. They are used as a common input assumptions for scenario analysis and energy market projections made in the Danish Energy Agency and Energinet.dk, who have commissioned the present report – and are a common unbiased reference for other professionals and academics in the field.
2. They are used in the economic assessment of collective heating projects (cf varmeforsyningsloven and projektbekendtgørelsen) in the Danish energy systems necessary for project approval.

Due to the central role of the economic fuel price projections in the economic assessment and scenario analyses, it is critical that the prices are, and are seen as:

- Based on a robust foundation which is unbiased and independent.
- Rooted in reality.

Due to the market volatility of energy prices and the lag between the IEA's lock of fuel price inputs, the market may have moved (particularly for short-term deliveries) before the Danish Energy Agency publishes their updated prices and even more so by the time they are used in projects and analyses. This gives rise to a need for a simple and transparent methodology for combining the long-term energy price projections from the last IEA publication with the most recent market view provided by forward prices. There is no robust scientific way of doing this, so an approach is developed to be pragmatic, transparent and comprehensible and which generates conceivable outcomes.

The present report deals only with the international price forecasts for coal, crude oil and natural gas. Additionally, the projection of the price of CO2-emissions allowances is covered.

2 Uncertainties

The fossil fuel price projections hereby set forth should not be regarded as forecasts; rather, as a possible development path of the respective prices provided fulfilment of a certain set of assumptions and pre-conditions.

In undertaking such an analysis, there is always a great deal of uncertainty related to among other the assumptions taken, models chosen and scenarios utilised. Some of the most relevant uncertainties relating to this study are highlighted below.

Duration of projection period

The projection period itself, more than 20 years, calls for caution, especially when taking uncertainties about the development of climate policies, population growth rates, GDP growth rates, technological developments etc. into account.

Assumptions in WEM modelling framework

As any modelling framework, World Energy Model (main tool used in the development of the World Energy Outlook scenario projections) simplifies reality, and the assumptions made have significant impact on the results. The validity of the long-term price projections set forth in the WEO New Policies scenario is subject to the materialization of the assumptions and dynamics (e.g. assumption of long-term equilibrium) underlying the said scenario.

Predictive power of forward prices

Forward and Future financial contract prices express the market actor's willingness (and commitment) to pay for the commodities in question at a predefined future point in time. It is fair to assume that the prices of these financial contracts have been set based on the best currently available information, and, as such, serve as an indication of the best estimate of future *price expectations* shared among the market participants. The *predictive power* of the Forward/Future financial contracts is, however, highly uncertain, hence the prices thereof should not be regarded as price *forecasts* of the commodities in question. In addition, the traded volume of the forward/future contract in question is an additional aspect to consider when evaluating the reliability of *price expectations* as expressed by their respective prices. The lower the traded volume (i.e. the contracts actually sold/bought), the less representative is the price level.

3 Methodology

The overall purpose of the current update is to develop a method and an MS Excel tool that can be used for adapting IEA price projections into projections of Danish economic prices at the point of consumption. This method comprises two main steps:

1. Converging the IEA projections in the short- to medium-term to better express the current market expectations.
2. Estimate price add-ons to transform the IEA prices (from step 1 above) into Danish consumer prices over the course of the projection period.

This report has focus only on step 1, namely the initial price conversion period. The main tool for doing so is by the forwards/futures financial contract prices.
IEA WEO 2013 New Policies scenario is the main ('central') price projection pathway in the current analysis, in line with the WEO methodology.

3.1 Rationale for price convergence

The World Energy Model (WEM), the main tool used in the development of the IEA WEO scenario projections, operates under the assumptions of long-term equilibrium, i.e. a state of the economy where the general price level is fully reflecting – and adjusted to - the existing set-up of the main price drivers and market factors (as opposed to short-term equilibrium or cyclicality where the price level might not be fully adjusted to the concurrent situation in the market due to different short-term market factors and distortions/fluctuations). As such, it is reasonable to apply the WEM in price projections in the medium- to long-term based on fundamental supply and demand dynamics (subject to the realization of the assumptions regarding these dynamics in the respective scenarios). In the short- to medium-term, however, it is reasonable to assume that the price projections based on the best available actual market information (likely incorporating the price effects of short-term market distortions and/or cyclicality) would be more representative.

Future and Forward contract prices represent specifically this kind of information, i.e. the price expectations shared among the market participants for the short- to medium-term (and it is reasonable to assume the contract prices are based on the best currently available market information). This is the reason for the Future/Forward contract prices to be used for price pathway pro-

jections in the short- to medium-term, whilst WEM scenario projections – in the long-term.

It should, however, be noted that the Future and Forward contract prices do not represent price predictions; rather, they express price expectations on the part of the market participants involved in the trade. In addition, it can be argued that the traded volume of a particular contract can serve as an indication of the extent to which the Forward and Future contract prices are legitimate representations of the market participants' expectations, i.e. representing market actors' actual willingness to pay. It is reasonable to argue that the lower the traded volume, the less informative is the contract's price level for the purpose of future price projection.

3.2 Coal, oil and natural gas price projections

The fossil fuel price projections are comprised of the historical prices 1990 – 2013 (to provide context), followed by the Forward/Future contract prices for short- to medium-term and eventually converged to the IEA WEO projected long-term prices.

Historic price treatment

Historic prices from 1990 to 2009 published in the IEA Energy Prices and Taxes publications have been collected (provided by the Danish Energy Agency) and included in the Convergence Excel Model to provide context to the convergence pathway and the price projections. Prices of IEA crude oil imports, OECD steam coal imports and Natural gas – Europe imports for 2010, 2011 and 2012 have been obtained from the WEO 2011, 2012, 2013 publications, respectively.

It should be noted that the historic natural gas prices have been converted to lower heating value (now corresponding to 11 kWh/m3).

Best estimates of the 2013 year-to-date prices (a proxy for the 2013 historic prices as of mid-December 2013) are produced by scaling the respective historic 2012 IEA prices (latest price point available) with the trend coefficient from 2012 to 2013 from the following sources:

- Coal: MCIS Steam Coal Marker Prices CIF North-West Europe 2012 and 2013 year-to-date average from McCloskey's Coal Report cited in (Verein der Kohlenimporteure, 2013)
- Crude oil: Brent Crude Oil average spot price for 2012 and projection for 2013 by the EIA (EIA, 2013)
- Natural gas: annual average of daily NCG day-ahead prices for 2012 and 2013 (NCG, 2014)

The formula below illustrates the scaling approach applied (oil price example):

$$Price\ estimate\ (IEA\ crude\ oil\ imports)_{2013}$$
$$= Price\ (IEA\ crude\ oil\ imports)_{2012}$$
$$\times \frac{Price\ projection\ (EIA\ Brent\ crude\ oil\ spot)_{2013}}{Price\ (Brent\ crude\ oil\ spot)_{2012}}$$

The historic price development is illustrated in Figure 1 below:

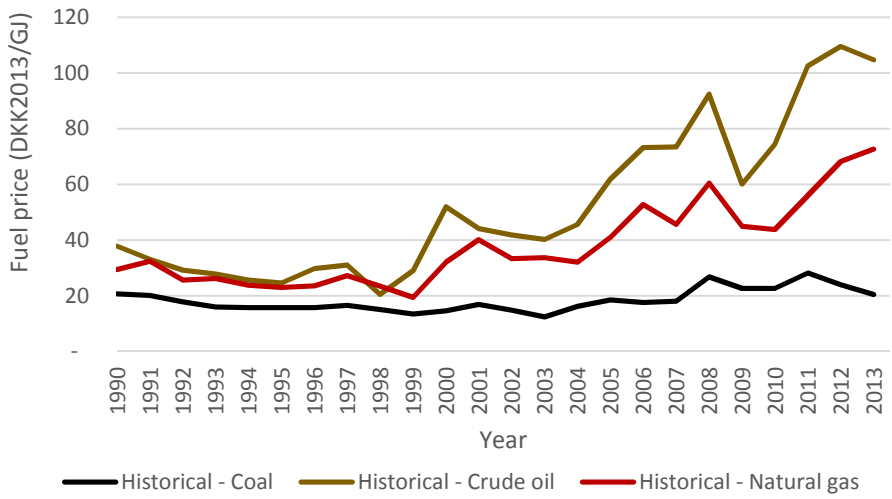

Figure 1: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) from 1990 to 2013 (trended estimates used for 2013)

Yearly values of the historic prices are presented in Appendix I: Historic prices.

Future/Forward contract price treatment

The Future/Forward contract prices over time are used to arrive at a short- to medium-term price development *trend*.

Data on the price of Future/Forward contracts has been collected from the following sources:

- Coal: Based on ARA Coal Year Futures (EEX, 2013). Last available price point is 2016 in the current analysis. The contract price is kept constant in real terms 2017 onwards
- Crude oil: Based on Brent Crude Oil Financial Future prices (CME-Group, 2013). Last available price point is 2019 in the current analysis. The contract price is kept constant in real terms 2020 onwards
- Natural gas: Based on NCG Natural Gas Year Futures (ICE, 2014). Last available price point is 2018 in the current analysis. The contract price is kept constant in real terms 2019 onwards

Due to the fact that the specific Future/Forward contracts in question might not fully correspond to the products underlying the historic and future IEA prices (i.e. Brent Crude Oil Financial Futures vis-à-vis IEA Crude oil imports), scaling of the Future contract price level is carried out for it to correspond to the IEA product price levels. An assumption is made that the relative difference between the spot prices is representative of the relative difference between the Future/Forward contract prices of the same underlying products, respectively.

The following formula is applied for scaling (oil used as an example):

$$Future\ price\ (oil, IEA - scaled)_{2014} = Future\ price\ (Brent\ Crude\ Oil)_{2014} \times \frac{Price\ estimate\ (IEA\ crude\ oil\ imports)_{2013}}{Price\ projection\ (EIA\ Brent\ crude\ oil\ spot)_{2013}}$$

In relation to coal, CIF ARA prices (underlying the Futures contracts) are assumed to be fully representative of North-West Europe CIF prices (the historical price for 2013).

Once the Future/Forward contract prices are scaled to be representative of the products underlying IEA prices, Future price *trend* is applied using the following formula (oil used as an example):

$$Future\ price\ (oil, IEA - scaled)_{t+1} = Future\ price\ (oil, IEA - scaled)_{t} \times \frac{Future\ price\ (Brent\ Crude\ Oil)_{t+1}}{Future\ price\ (Brent\ Crude\ Oil)_{t}}$$

where ***t*** is the year of the respective price point.

The Futures contract price quotations (preceded by the historic price development) are illustrated in Figure 2. The prices are kept constant in real terms following the last available Futures price point for each commodity, as stated in the description of the figure.

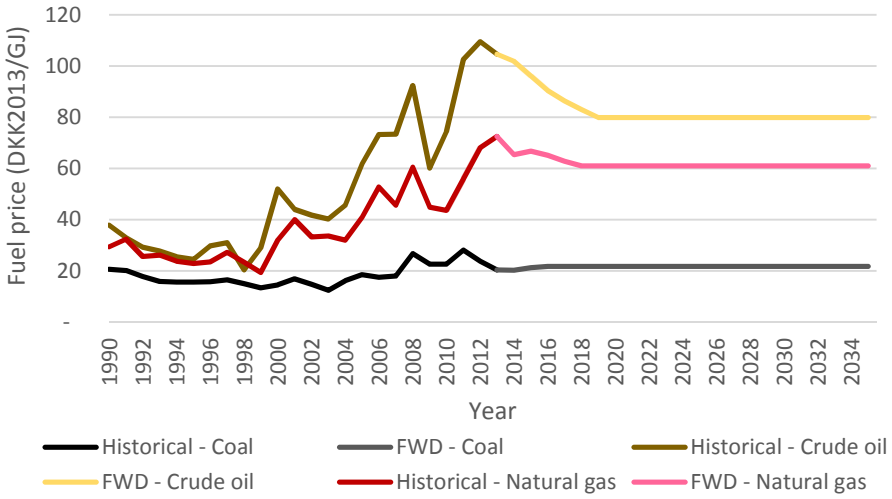

Figure 2: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) from 1990 to 2013, followed by IEA-scaled Futures prices for coal (until 2016, constant in real terms 2017 onwards to 2035), crude oil (until 2019, fixed in real terms onwards) and natural gas (until 2018, fixed in real terms onwards)

Convergence prices

The 'convergence prices' in the context of this analysis are to be understood as short- to medium-term price projections that are a combination of IEA-scaled Forward/Future prices and the IEA WEO long-term prices for a given period of time. The convergence prices are produced as a weighted mean between IEA prices and IEA-scaled Future/Forward prices (oil used as an example):

$$Convergence\ price\ (oil)_t = w_t \times Price\ (oil, IEA\ WEO)_t + (1 - w_t) \times Future\ price\ (oil, IEA - scaled)_t$$

where:

$\boldsymbol{w_{,t}}$ is the linear evolving weight from 0 to 1 in the years "Year of origin" to "Year of convergence" (e.g. if the convergence period is from 2014 to 2019, $w_{f,t}$ will be 0 for 2014 price points; 0.2 for 2015 price points; 0.4 for 2016 price pointed and so forth reaching 1 for 2019 price points, respectively);

t is the year of the respective price point.

The convergence prices provide a gradual link between the short- to medium-term price projections (as expressed by the IEA-scaled Future/Forward prices) and the long-term IEA WEO price projections in a way that puts more weight

on Future/Forward prices in the beginning of the convergence period, and on the IEA WEO prices towards the end of the convergence period, respectively.

This is done because it is reasonable to apply the WEM in price projections in the medium- to long-term based on fundamental supply and demand dynamics (subject to the realization of the assumptions regarding these dynamics in the respective scenarios). In the short- to medium-term, however, it is reasonable to assume that the price projections based on the best available actual market information (likely incorporating the price effects of short-term market distortions and/or cyclicality) would be more representative. The weighting allows for a gradual transition over time.

Within the framework of the current analysis, the convergence year is set to 2020 with IEA WEO 2013 as the starting point. This is done because, firstly, even for the most actively traded commodities in question (oil and coal), the trade – or even price quotations – in Future contracts are hardly available beyond 2020. As such, extending the convergence period (that is based on linear weighting of Future/Forward contract prices and IEA WEO projected prices over time) makes little sense above and beyond the period where Future contract prices are obtainable. Secondly, a 7-year convergence period would allow for consistency in the price projection updates in the future as long as they are based on IEA WEO long-term price projections as 7 years appears to be the longest possible period until the first projection year available in WEO publications (e.g. 2015 was the first projection year in IEA WEO 2012, and 2020 is the first projection year in IEA WEO 2013).

The convergence prices are illustrated in Figure 3 below:

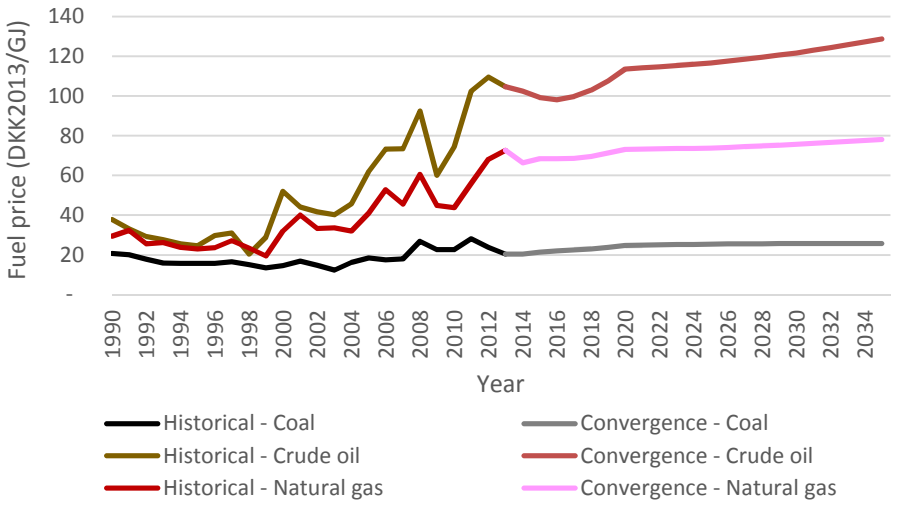

Figure 3: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) from 1990 to 2013 and the Convergence prices until 2020 (followed by the IEA WEO New Policies price projection pathway 2020 onwards)

IEA WEO price treatment

IEA WEO 2013 New Policies scenario price projections for 2020, 2025, 2030 and 2035 have been used.

It should be noted that the IEA WEO natural gas prices have been converted to lower heating value (now corresponding to 11 kWh/m3).

In order to obtain a representation of the IEA WEO price projections across the entire period (2013 – 2035) to be covered by the current fossil fuel price assumption update project, the following steps have been taken:

- 2013 historical prices have been linearly interpolated to 2020 (i.e. the first price point projected in the IEA WEO 2013)
- Linear interpolation has been applied between the price points provided by the WEO (2020, 2025, 2030, 2035) in order to obtain an IEA WEO price projection for every year

The IEA WEO price pathway projections are illustrated in Figure 4 below:

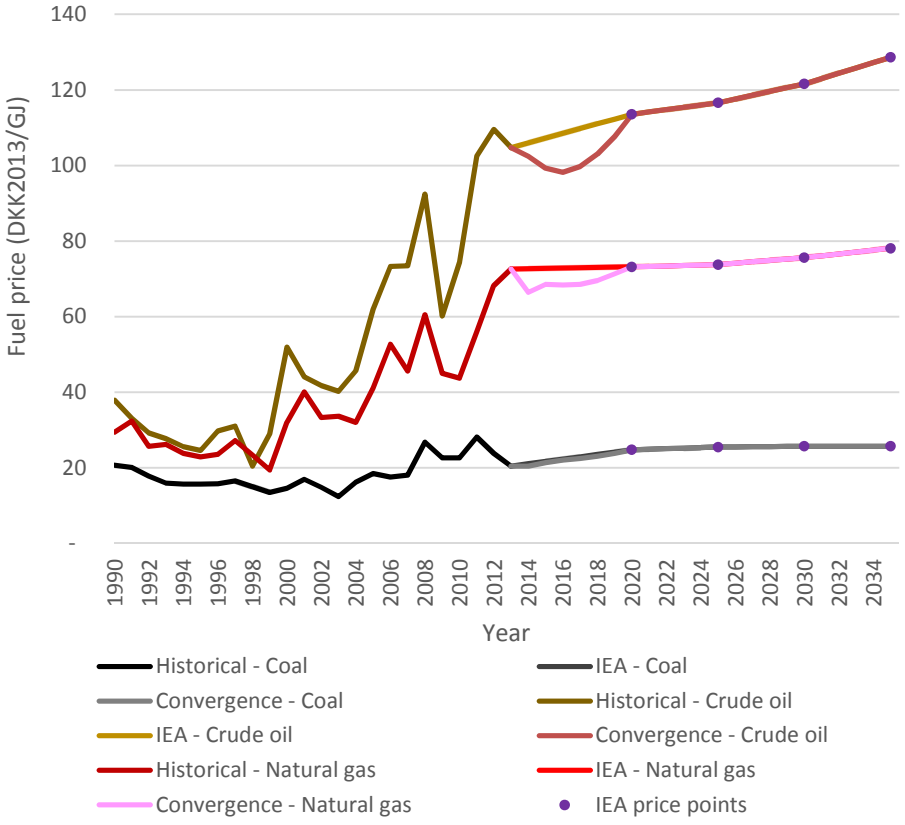

Figure 4: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) from 1990 to 2013 and the convergence prices until 2020. The IEA WEO New Policies price projection pathway is interpolated between the price point provided in the WEO publication (purple dots) and 2013 in order to illustrate the difference versus the convergence prices

Price and units

All fuel prices are available in nominal and real terms:

- Nominal prices: unadjusted current prices
- Real prices: converted to currency values of a specific year (user defined in the model e.g. 2012 DKK/GJ)

Inflation (via Gross Value-Added-deflator, the BVT-deflator) and currency exchange conversion factors by year are based on the Ministry of Finance convergence program (Økonomi- og Indenrigsministeriet, 2013).

Resulting price projections until 2035

The historic prices of all 3 fossil fuels as well as convergence prices until 2020 and the IEA WEO future price projections in real terms, denominated in 2013 DKK/GJ are illustrated in Figure 5 below:

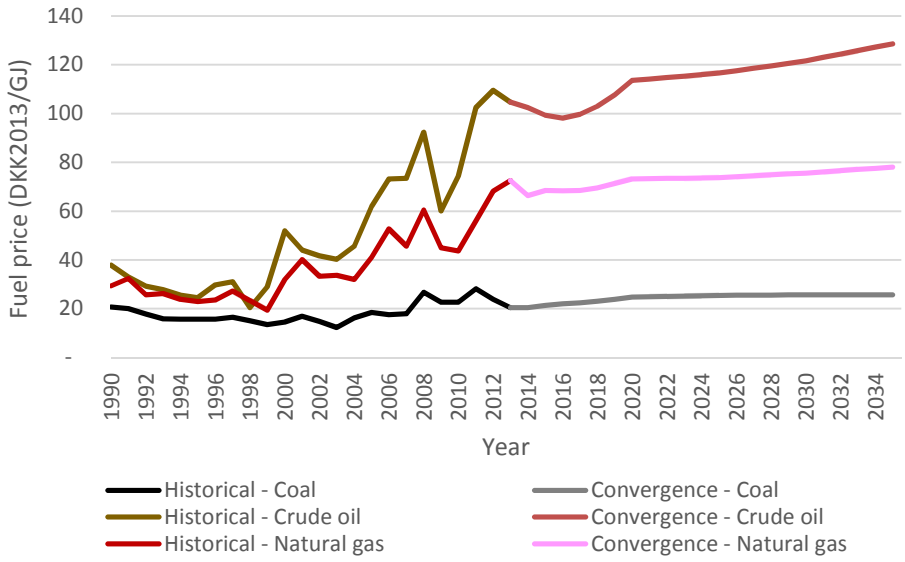

Figure 5: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) from 1990 to 2013 and the convergence prices until 2020 (followed by the IEA WEO New Policies price projection pathway 2020 onwards)

Yearly values of the price projections are presented in Appendix II: Price projections.

3.3 CO2 price projections

The CO2 price projections as expressed by the EU Emissions Allowances, EUA prices are comprised of the historical prices since the establishment of the trading scheme 2005 – 2013 (to provide context), followed by the For-

ward/Future contract prices for short- to medium-term and eventually converged to the IEA WEO projected long-term prices.

- Historic prices: source data relating to the Årlig Energistatistik 2012 publication (Energistyrelsen, 2012) has been used to obtain prices from 2005 to 2012. Historic data on ICE EUA Futures prices has been used to estimate the 'historic' year-to-date price for 2013, as of December 2013 (Quandl, 2013).
- Future/Forward prices: EUA Future prices (ICE, 2013). Expressed in nominal prices until the last available price point and kept constant in real terms onwards until 2035
- Convergence prices: calculated following the same method as for crude oil, coal and gas (see description above in the Convergence prices section).
- IEA WEO prices: IEA WEO 2013 New Policies price projections have been used following the same method as for crude oil, coal and gas (see description above in the IEA WEO price treatment section).

The historic CO2 prices (2005-2013), the Futures contract prices, as well as the convergence prices and the IEA WEO CO2 price projection pathway are illustrated in Figure 6 below:

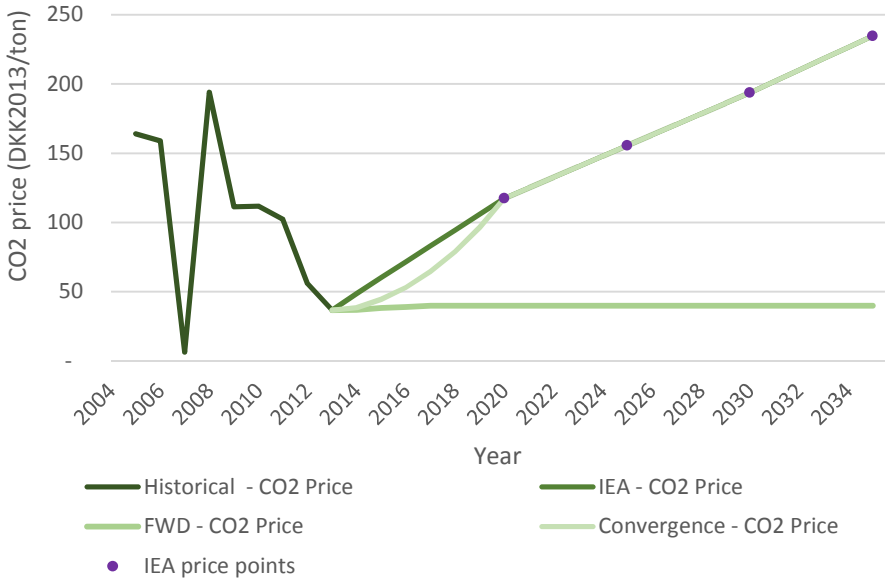

Figure 6: Historic prices of CO2 in real terms (DKK2013/ton) from 2005 to 2013 and the convergence prices until 2020. The CO2 Futures prices are given until 2017 and kept constant in real terms onwards. The IEA WEO New Policies price projection pathway is interpolated between the price point provided in the WEO publication (purple dots) and 2013 in order to illustrate the difference versus the convergence prices.

‘ETS-collapse’ CO2 price projection

In addition to the central price projection pathway, a ETS collapse scenario of the CO2 price development (as expressed by the EU Emission Allowance prices, EUA) over short- to-medium term future 2013 to 2020 is hereby put forward. The ETS collapse scenario presently is to be understood as the failure of the emission trading schemes (ETSs) to regain their role as an effective financial incentive of emission abatement.

The currently prevailing low price level (EUA Mar14 future contract traded at 5.1 EUR/ton as of January 22, 2014 on the ICE), as well as the similarly low short- to medium-term future price expectations (e.g. EUA Dec16 future contract traded at 5.64 EUR/ton as of January 22, 2014 on the ICE) are therefore to be regarded as constituting the ETS collapse CO2-price scenario price projection pathway. The period up to 2020 in the ETS collapse scenario pathway beyond the last price point set by the EUA Futures prices (2016 to 2020 in the current analysis) has been extrapolated maintaining the last available EUA Futures’ price point value constant in real terms up to 2020. The ETS collapse case is illustrated in Figure 6 (‘FWD – CO2 price’ line in the graph).

The reason the currently prevailing price level (and future expectations thereof) qualify as the constituents of the ETS collapse scenario is that the price of ca. 5 EUR2013/ton of CO2 is not sufficiently high in order to significantly affect investment and operation decisions in favor of CO2 abatement and as such are not significantly different from CO2 price of 0 (and effectively a collapse of the CO2 trading system altogether).

3.4 Sensitivity analysis

The goal of the sensitivity analysis is to demonstrate 2 alternative scenarios that would represent the ‘high’ and ‘low’ price development pathways, respectively, that would be *possible* yet *not extreme*. In the context of the current analysis it is deemed important to maintain the balance between the alternative scenarios illustrating price levels and pathways that would be significantly different from the central scenarios described above, and at the same time, providing ‘high’ and ‘low’ estimates that would be *possible* enough to still be informative and useful in real-life business plan analysis (as opposed to ‘extreme’ high and low price projections representing the boundaries of hypothetically achievable price developments).

The sensitivity analysis is applied to the Convergence pathway on a relative basis, linking the possible ‘high’ and ‘low’ price development pathways to the Forward/Future prices in the short- to medium-term (as expressed by the Convergence prices - see description of the approach in section Convergence prices).

Coal, oil and natural gas price sensitivity analysis

In order to reduce the complexity of the scenarios underlying the sensitivity analysis, two key price drivers/determinants are considered:

- Climate policies
- Market factors

Climate policies

IEA WEO Current Policies ('high' price) and 450 ('low' price) scenarios are the basis for the alternative development pathways in terms of climate policies alongside the central New Policies scenario. All of the WEO scenario projections operate under the assumption of long-term equilibrium subject to fundamental supply and demand dynamics, i.e. effects of short-term market volatility and fluctuations are not a part of the price pathways of the sensitivity analysis.

The IEA WEO 2013 Current Policies scenario only takes into account the policies and measures affecting the energy markets that have been formally enacted as of mid-2013 (i.e. no further policies or measures with regard to the energy markets are implemented above and beyond those active currently). As such, Current Policies places fewer limitations on the use of fossil fuels as compared to e.g. the central scenario, New Policies scenario) thereby increasing demand and consequently prices.

The 450 Scenario of the IEA WEO 2013 implies much lower use and demand (and consequently prices) of fossil fuels due to its assumption of full implementation of the 2010 UN Climate Change Conference commitments (a.k.a. the Cancun Agreements) in the period up to 2020. For the period after 2020, the 450 Scenario assumes that the OECD countries and other major economies are implementing emission reduction measures both within and outside of OECD.

Market factors

EIA Annual Energy Outlook (EIA, 2013) serves as the basis for input on the alternative development pathways in terms of market factors for crude oil and coal.

It should be noted that the EIA AEO scenarios have been chosen in such a way that they would only entail changes in the market factors whilst climate policy measures would remain unaltered.

A different approach has been applied in the case of natural gas because the natural gas markets are very regional - it would thus be inadequate to use the

US-focused EIA AEO scenarios to model the market factors for the European natural gas price projections.
For the 'low' price scenario, the Gas Price Convergence Case for Europe from the IEA WEO 2013 is used, whereas oil price-indexing is used for the 'high' price scenario.

Assumptions

Several important assumptions are being made:

1. The mechanisms employed and price effects brought about by climate policy scenarios and market factor scenarios have some commonalities, i.e. they are *not* fully complimentary to each other.
2. The quantification of the price effect of each individual factor underlying the climate policies or market developments modelled is beyond the scope of the current analysis. A straight-forward approach of equal 50-50 weighting will be used when combining price projections of different scenario development frameworks (e.g. IEA WEO and EIA AEO) to account both for climate policy effect and market factor impact, respectively. This is also done to make sure that the 'high' and 'low' scenarios hereby obtained would be representing possible yet not extreme potential price development pathways.

Oil

The oil price development pathways as per the IEA WEO Current Policies and 450 scenarios have been used as the point of departure for possible climate policy development courses and the price impacts thereof.
In order to account for the market factors and the price impacts thereof, the EIA AEO Low Oil Price and High Oil Price scenarios have been deployed. The market drivers therein modelled include:

- Petroleum demand in non-OECD countries
- Global supply
- OPEC market share
- Liquid fuel production technology costs

The assumptions stated earlier are applied: first, it is assumed the climate policy and market factor effects are not fully *complimentary* to each other and that the IEA WEO and EIA AEO respective scenarios will be combined in an equal 50-50 weighting.
Figure 7 presents the price development pathways as projected by the EIA AEO Low Oil Price and High Oil Price scenarios.

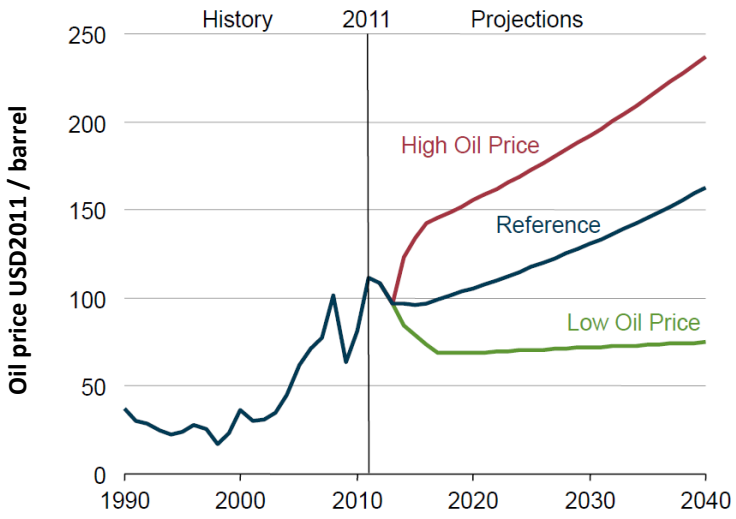

Figure 7: EIA AEO 2013 High Oil Price, Reference and Low Oil Price scenarios, development pathways for annual average spot price for Brent crude oil in 2011 USD/barrel. Source: (EIA, 2013)

Based on these assumptions, the 'low' price scenario is collated from the price development pathway as set forth by 50% of the relative price difference between the IEA WEO 450 and IEA WEO New Policies scenarios, and 50% of the relative price difference between the EIA AEO Reference and Low Oil Price scenarios, respectively.

The 'high' price scenario, in turn, is collated from the price development pathway as projected by 50% of the relative price difference between the IEA WEO Current Policies and IEA WEO New Policies scenarios, and 50% of the relative price difference between the EIA AEO Reference and Low Oil Price scenarios, respectively.

A formula illustrating the approach applied in the sensitivity analysis for crude oil (and also coal) in the case of 'high' price scenario for year ***t*** is provided below:

$$Crude\ oil(High)_t$$

$$= Crude\ oil(Convergence_{t<2020}; WEO\ New\ Policies_{t\geq 2020})_t$$

$$\times 0.5 \left[\frac{Crude\ oil(WEO\ Current\ Policies)_t}{Crude\ oil(WEO\ New\ Policies)_t}\right.$$

$$\left. + \frac{Crude\ oil(EIA\ AEO\ High\ Oil\ Price)_t}{Crude\ oil(EIA\ AEO\ Reference)_t}\right]$$

Coal

Alike oil, the coal price development pathways as per the IEA WEO Current Policies and 450 scenarios have been used as the point of departure for possible climate policy development courses and the price impacts thereof.
EIA AEO Low Coal Cost and High Coal Cost scenarios have been deployed to account for the impact of the following factors:

- Regional productivity growth rates for coal mining
- Coal mining wages, equipment, and transportation rates

Figure 8 presents the price development pathways as projected by the EIA AEO Low Coal Cost and High Coal Cost scenarios.

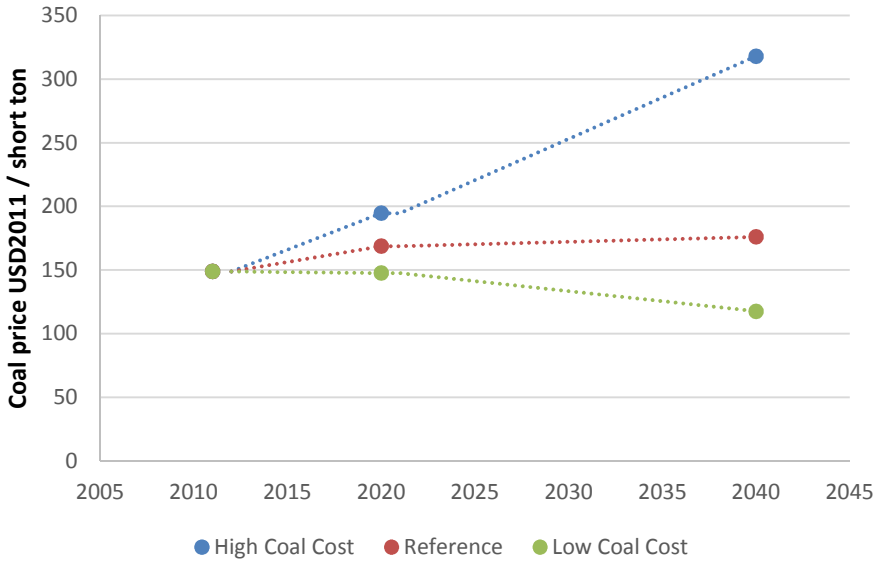

Figure 8: EIA AEO 2013 High Coal Cost, Reference and Low Coal Cost scenarios, development pathways for annual price of export coal in the US in 2011 USD/short ton. Own graph based on linear interpolation between price projections of 2011, 2020 and 2040. Data source: (EIA, 2013)

In order to make the price pathways more representative of the global situation (IEA WEO scenarios provide projections for OECD steam coal imports), the price of Exports is selected in the EIA AEO coal scenarios in order to avoid the price bias of local US coal for the domestic market. In addition, US-specific price factors are eliminated because the relative differences in between of the EIA AEO coal scenarios are used.

Based on the same assumptions (discussed earlier, see the section above), the 'low' price scenario is collated from the price development pathway as set forth by 50% of the relative price difference between the IEA WEO 450 and IEA WEO New Policies scenarios, and 50% of the relative price difference in

percentage terms between the EIA AEO Reference and Low Coal Cost scenarios, respectively.
The 'high' price scenario, in turn, is collated from the price development pathway as projected by 50% of the relative price difference between the IEA WEO Current Policies and IEA WEO New Policies scenarios, and half of the relative price difference in percentage terms between the EIA AEO Reference and High Coal Cost scenarios, respectively.

Natural gas

The price development pathways as per the IEA WEO Current Policies and 450 scenarios have been used as the point of departure for possible climate policy development courses and the price impacts thereof.
In terms of market factors, the natural gas markets are very regional. Therefore it would be less appropriate to use the US-focused EIA AEO scenarios to model the market factors for the European natural gas price projections.
For the 'low' price scenario, the Gas Price Convergence Case for Europe from the IEA WEO 2013 will instead be used. Since the Gas Price Convergence Case is an add-on to the IEA WEO New Policies scenario (under the same World Energy Model framework), no weighting of the price impacts will be done here:

- Larger volume of LNG exports from North America
- New supply contracts are hub-priced in Europe
- Reduction in liquefaction plant construction costs and LNG shipping costs

Figure 9 presents the price development pathways as projected by the IEA WEO 2013 Gas Price Convergence Case scenario scenarios.

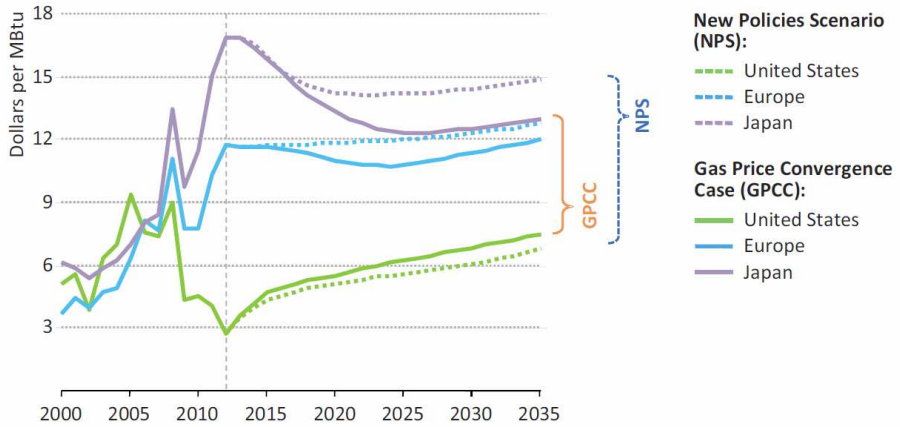

Figure 9: IEA WEO 2013 New Policies and Gas Price Convergence Case scenarios, development pathways for regional natural gas prices in 2011 USD/million Btu. Source: (IEA, 2013)

The 'low' price scenario is collated from the price development pathway as set forth by 100% of the relative price difference between the IEA WEO 450 and IEA WEO New Policies scenarios, and the negative real price difference (approximated to -1 USD2011 /MBtu, held constant in real terms 2020 onwards, and linearly interpolated from 0 to -1 USD2011/MBtu from 2015 to 2020) between the IEA WEO New Policies and IEA WEO Gas Price Convergence Case scenarios, respectively.
The approach applied for 'low' price scenario for natural gas for year ***t*** is illustrated below:

$$
\begin{aligned}
&Natural\ gas(Low)_t \\
&= Natural\ gas(Convergence_{t<2020}; WEO\ New\ Policies_{t\geq 2020})_t \\
&\times \frac{Natural\ gas(WEO\ 450)_t}{Natural\ gas(WEO\ New\ Policies)_t} \\
&- [Natural\ gas(WEO\ New\ Policies)_t \\
&- Natural\ gas(WEO\ Gas\ Price\ Convergence\ Case)_t]
\end{aligned}
$$

For the 'high' natural gas price scenario, oil price-indexing (coinciding and corresponding to the 'high' oil price scenario in the current analysis) is deemed to be the relevant market factor to model in the European context. This is due to the fact that up until recently oil price-indexing has been a very common gas contract pricing practice, and in the case of high oil prices (and generally high demand for fossil fuels as prescribed by the IEA WEO Current Policies scenario), the natural gas suppliers to Europe might be able to take advantage of the favorable market situation and return to the oil price-indexing pricing practice.
The 'high' natural gas price scenario is collated from the price development pathway as projected by 50% of the relative price difference between the IEA WEO Current Policies and IEA WEO New Policies scenarios, and 50% of the relative oil price difference between the 'high' oil price scenario developed within the current analysis and the Convergence oil price pathway (IEA WEO New Policies scenario 2020 onwards), respectively.
The approach applied for 'high' price scenario for natural gas for year ***t*** is illustrated below:

$$Natural\ gas(High)_t$$

$$= Natural\ gas(Convergence_{t<2020}; WEO\ New\ Policies_{t\geq 2020})_t$$

$$\times 0.5 \left[\frac{Natural\ gas(WEO\ Current\ Policies)_t}{Natural\ gas(WEO\ New\ Policies)_t}\right.$$

$$\left. + \frac{Crude\ oil(High)_t}{Crude\ oil(Convergence_{t<2020}; WEO\ New\ Policies_{t\geq 2020})_t}\right]$$

'High' and 'Low' scenarios for coal, crude oil and natural gas

An overview of the composition of the respective 'low' and 'high' price scenarios that are applied to the Convergence price pathway (IEA WEO New Policies price pathway in the long run) is presented in **Fejl! Henvisningskilde ikke fundet.**:

Table 1: Composition of the 'low' and 'high' price scenarios for crude oil, coal and gas

	Low	High
Crude oil	50% relative difference IEA WEO 450 vs IEA WEO New Policies & 50% relative difference EIA AEO Low Oil Price vs EIA AEO Reference	50% relative difference IEA WEO Current Policies vs IEA WEO New Policies & 50% relative difference EIA AEO High Oil Price vs EIA AEO Reference
Coal	50% relative difference IEA WEO 450 vs IEA WEO New Policies & 50% relative difference EIA AEO Reference vs EIA AEO Low Coal Cost	50% relative difference IEA WEO Current Policies vs IEA WEO New Policies & 50% relative difference EIA AEO Reference vs EIA AEO High Coal Cost
Natural gas	100% relative difference IEA WEO 450 vs IEA WEO New Policies & the negative absolute difference between the IEA WEO Gas Price Convergence Case vs IEA WEO New Policies	50% relative difference IEA WEO Current Policies vs IEA WEO New Policies & 50% relative oil price difference of the 'high' oil price scenario created in the current analysis vs Convergence price pathway (IEA WEO New Policies in the long term) created in the current analysis

The sensitivity analysis for all 3 fossil fuels' price projections in real terms (2013 DKK/GJ) is provided in Figure 10 below:

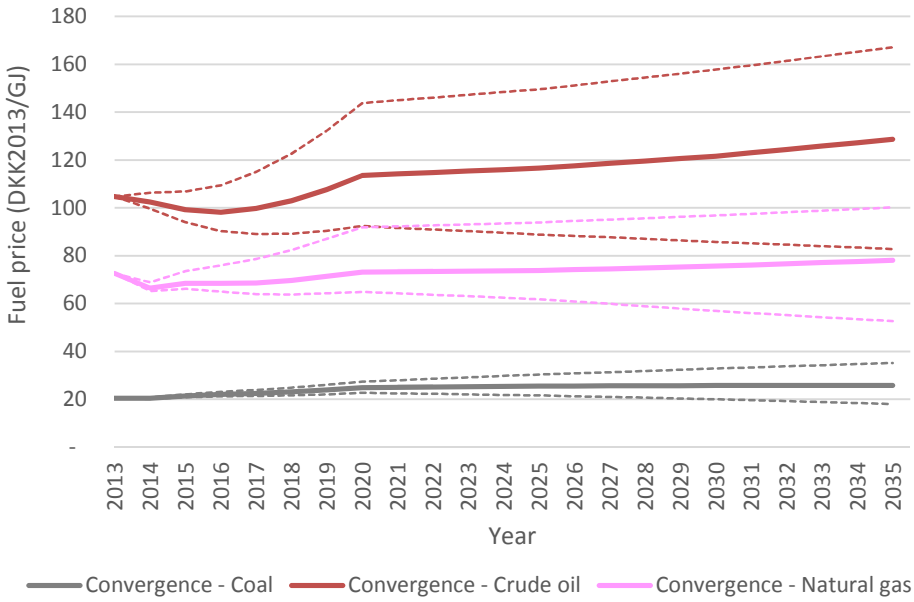

Figure 10: Price projections (including Convergence prices) in real prices, DKK2013/GJ, for coal, crude oil and natural gas for 2013 – 2035, with 'low' and 'high' sensitivities provided by the corresponding dotted lines

CO2 price sensitivity analysis

Since the CO2 price development (as opposed to that of fossil fuels) is almost exclusively dependent on the regulatory and climate policies imposed, it is deemed fitting to use the alternative scenarios put forward by the IEA WEO as the 'high price' (450) and 'low price' (Current Policies) scenarios, respectively.

- High price scenario (IEA WEO's 450): a CO2 price development pathway corresponding to of the global energy sector being on a course to "limiting the long-term increase in the average global temperature to 2°C" with near 50% chance. It can be regarded as a 'normative' pathway as the scenario assumes more active efforts towards full implementation of the Cancun Agreements (than in e.g. the Current Policies scenario).
- Low price scenario (IEA WEO's Current Policies): a CO2 price development pathway taking into account "only those policies and measures affecting energy markets that were formally enacted as of mid-2013"

The sensitivity analysis for CO2 price projections in real terms (2013 DKK/ton) is provided in Figure 11 below:

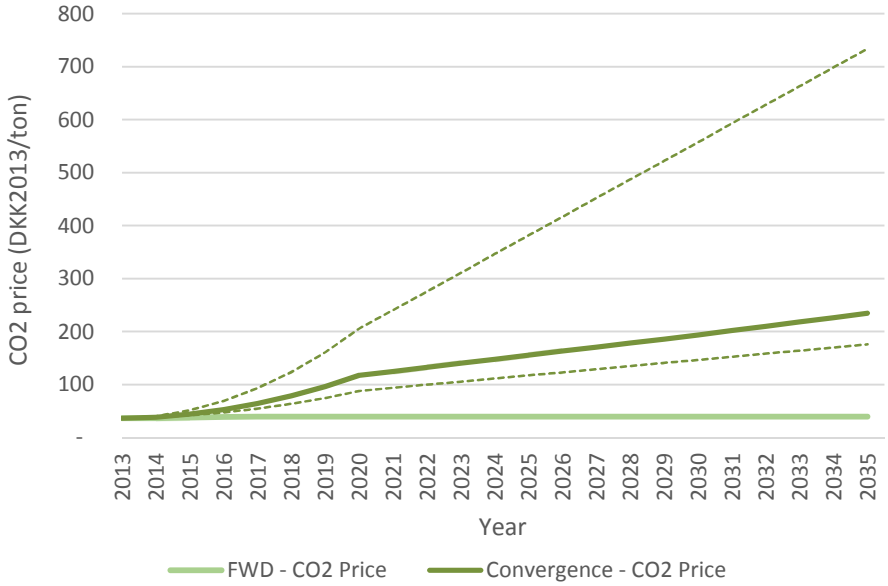

Figure 11: Price projections (including convergence prices) in real prices, DKK2013/ton, for CO2 for 2013 – 2035, with 'low' and 'high' sensitivities provided by the corresponding dotted lines. The 'FWD – CO2 Price' line represents the 'ETS collapse' CO2 price projection pathway

Bibliography

Argus. (2013, June 27). Coal Daily International.

CME-Group. (2013, December 8). Retrieved from http://www.cmegroup.com/trading/energy/crude-oil/brent-crude-oil-last-day.html

EEX. (2013, December 7). *European Energy Exchange.* Retrieved from Natural Gas Futures: http://www.eex.com/en/Market%20Data/Trading%20Data/Natural%20Gas/Natural%20Gas%20Futures%20%7C%20Derivatives

EEX. (2013, December 6). *European Energy Exchange*. Retrieved from Market Data - Coal Futures: http://www.eex.com/en/Market%20Data/Trading%20Data/Coal

EIA. (2013). *Annual Energy Outlook 2013.* Washington: EIA.

EIA. (2013, December 13). *EIA*. Retrieved from Energy Conversion Calculators: http://www.eia.gov/energyexplained/index.cfm?page=about_energy_conversion_calculator

EIA. (2013, December 8). *Short-Term Energy Outlook.* Retrieved from http://www.eia.gov/forecasts/steo/report/prices.cfm

Energistyrelsen. (2012). *Energistyrelsen*. Retrieved December 13, 2013, from Årlig energistatistik: http://www.ens.dk/sites/ens.dk/files/info/tal-kort/statistik-noegletal/aarlig-energistatistik/energistatistik2012.pdf

ENS. (2013, April). *ENS*. Retrieved from Samfundsøkonomiske beregningsforudsætninger.

ICE. (2013, December 9). Retrieved from http://www.iceendex.com/market-data/spot-markets/ttf-spot/dashboard/

ICE. (2013, December 6). *InterContinental Exchange*. Retrieved from EUA Futures: https://www.theice.com/productguide/ProductSpec.shtml?specId=197#data

ICE. (2014, February 18). Retrieved from ICE - Global Markets in Clear View: https://www.theice.com/marketdata/reports/ReportCenter.shtml#report/159

IEA. (2013). *World Energy Outlook 2013.* Paris: IEA.

NCG. (2014, February 18). Retrieved from http://www.net-connect-germany.de/cps/rde/xchg/SID-6A1DCC11-DCDE7601/ncg/hs.xsl/792.htm

Quandl. (2013, December 6). *Quandl*. Retrieved from EUA Futures, December 2013: http://www.quandl.com/ICE-Intercontinental-Exchange/CZ2013-EUA-Futures-December-2013-CZ2013

Verein der Kohlenimporteure. (2013, December 8). *MCIS Steam Coal Marker Prices.* Retrieved from http://www.verein-kohlenimporteure.de/download/2013/112013_Preise_engl.pdf?navid=5

Appendix

Appendix I: Historic prices

Table 2: Historic prices of coal, crude oil and natural gas in real terms (DKK2013/GJ) and CO2 (DKK2013/ton) from 1990 to 2013

	Coal	Crude oil	Natural gas	CO2
Year/unit	DKK2013/GJ	DKK2013/GJ	DKK2013/GJ	DKK2013/ton
1990	20.5	37.7	29.3	
1991	20.0	33.0	32.3	
1992	17.7	29.1	25.6	
1993	15.8	27.7	26.1	
1994	15.6	25.5	23.7	
1995	15.6	24.5	22.8	
1996	15.6	29.7	23.5	
1997	16.4	30.9	27.1	
1998	14.9	20.4	23.3	
1999	13.3	28.9	19.4	
2000	14.7	52.7	32.4	
2001	17.1	44.6	40.6	
2002	14.9	42.3	33.8	
2003	12.5	40.8	34.1	
2004	16.4	46.3	32.4	
2005	18.7	62.8	41.6	165.1
2006	17.7	74.2	53.4	159.9
2007	18.2	74.4	46.2	6.2
2008	26.9	93.2	61.0	195.1
2009	22.7	60.5	45.2	111.9
2010	22.8	74.8	43.9	112.3
2011	28.2	102.8	56.1	102.6
2012	23.9	109.6	68.3	55.9
2013	20.5	104.7	72.6	36.5

Appendix II: Price projections

Table 3: Price projections (including convergence prices) in real prices, DKK2013/GJ, for coal, crude oil and natural gas and CO2, DKK2013/ton, for 2014 – 2035, with 'low' and 'high' sensitivities provided

	Coal			Crudeoil			Naturalgas			CO2		
Year/unit	**DKK2013/GJ**			**DKK2013/GJ**			**DKK2013/GJ**			**DKK2013/ton**		
	Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High
2014	20.2	20.5	20.8	99.9	102.7	106.6	65.4	66.6	69.0	38.0	38.6	40.4
2015	20.8	21.4	22.0	93.9	99.3	106.9	66.2	68.5	73.5	42.2	44.6	51.8
2016	21.2	22.1	23.1	90.3	98.2	109.5	65.0	68.5	76.0	47.7	53.1	69.3
2017	21.3	22.5	23.9	89.0	99.7	114.9	63.9	68.5	78.6	55.1	64.7	93.5
2018	21.6	23.1	24.8	89.2	103.0	122.6	63.7	69.6	82.3	64.1	79.1	124.0
2019	22.1	23.8	26.0	90.4	107.7	132.3	64.3	71.4	87.1	75.1	96.7	161.4
2020	22.7	24.8	27.4	92.4	113.7	144.0	64.9	73.2	92.0	88.1	117.5	205.6
2021	22.4	24.9	28.0	91.7	114.3	145.1	64.3	73.4	92.4	94.0	125.1	240.9
2022	22.2	25.1	28.6	91.0	114.9	146.2	63.7	73.5	92.8	99.9	132.8	276.1
2023	22.0	25.2	29.2	90.3	115.5	147.4	63.1	73.6	93.2	105.7	140.4	311.4
2024	21.8	25.4	29.7	89.6	116.1	148.5	62.5	73.7	93.6	111.6	148.0	346.6
2025	21.6	25.5	30.3	88.9	116.7	149.7	61.9	73.8	94.0	117.5	155.7	381.9
2026	21.3	25.5	30.8	88.3	117.7	151.3	60.9	74.2	94.6	123.4	163.3	417.1
2027	21.0	25.6	31.3	87.7	118.7	153.0	59.9	74.6	95.2	129.2	171.0	452.3
2028	20.6	25.6	31.8	87.1	119.7	154.6	58.9	75.0	95.7	135.1	178.6	487.6
2029	20.3	25.7	32.3	86.5	120.7	156.3	57.9	75.3	96.3	141.0	186.2	522.8
2030	20.0	25.7	32.8	85.8	121.7	157.9	56.9	75.7	96.9	146.9	193.9	558.1
2031	19.6	25.7	33.3	85.3	123.1	159.8	56.1	76.2	97.6	152.7	202.1	593.3
2032	19.2	25.7	33.8	84.7	124.5	161.6	55.2	76.7	98.3	158.6	210.3	628.6
2033	18.8	25.7	34.2	84.1	125.9	163.5	54.4	77.2	98.9	164.5	218.5	663.8
2034	18.4	25.7	34.7	83.5	127.4	165.3	53.5	77.7	99.6	170.4	226.8	699.1
2035	18.0	25.7	35.2	82.9	128.8	167.2	52.6	78.2	100.3	176.2	235.0	734.3