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ñThe next Generation of Carbon for the Process Industryò

Coordination and Support Action

Theme [SPIRE 5] ï Potential use of CO_2 and non-conventional fossil natural resources in Europe as feedstock for the process industry

Deliverable *4.1*:
Methodology to assess the business case and economic potential of CCU

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CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Introduction

This deliverable presents the framework and methodology to assess the CO/CO_2 resources and the identified CCU pathways in Work Package 2. The aim is to provide a comparative economic analysis of the different pathways, assessing the CCU business model. It is important to clarify that this deliverable will focus only on profitability and that it is to be complemented by an LCA screening which accounts for environmental impacts. Other issues such as technical feasibility, potential CO/CO_2 uptake and (environmental) impacts are addressed by other deliverables under the CarbonNext project:

- Deliverable 1.1 highlights the availability of CO/CO_2 sources and characterises them
- Deliverable 2.3 defines the CCU pathways to be assessed with this methodology, including their technical feasibility
- Deliverable 3.1 analyses at what market conditions it becomes attractive to capture and transport CO/CO_2, which can be used for CCU
- Deliverable 4.2 provides the methodology to assess the environmental impacts of the CCU pathways

This deliverable first defines the scope of the CCU business case and provides a general framework for the methodology, identifying and briefly describing the key market conditions which are required for a successful CCU business case. Then, it defines three (climate policy) scenarios and related assumptions which have an impact on the business case assessment. Finally, we detail the methodology which will be used to assess each of the CCU pathways.

The draft version of the methodology has been validated in a webinar held on 08 March 2018 with selected experts.[1] Based on their comments, we have slightly adapted and finalised the methodology.

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2. Business Case Framework

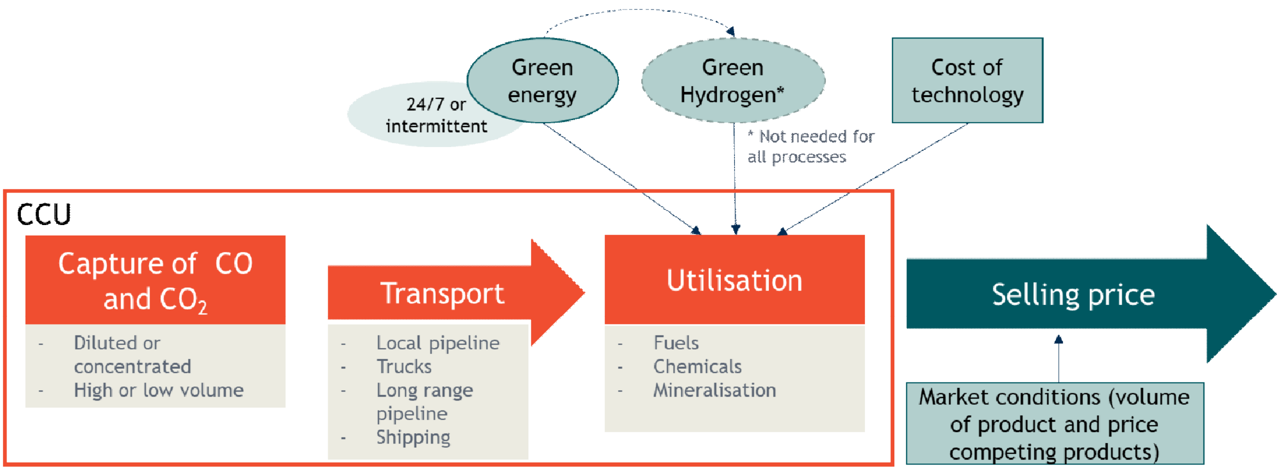
2.1 Scope of the business case

The first step to define a methodology for the assessment of the CCU business case is to define the limits of the business case and the key components that play a role in CCU.

There are three main steps in the process: The capture, transport and utilisation of CO or CO_2. Each of these steps can be characterised further, though the utilisation aspect may strongly depend on the selected CCU pathway. The capture and transport, on the other hand, will often be independent of or less impacted by the selected CCU pathway but depend on other variables, such as the source of the CO/CO_2 (which will define if there is a high or low volume available, if it is diluted or concentrated and if it pollutes or not) and the distance it has to be transported (which will define the transport method and related cost).

The general macroeconomic aspects that are relevant for any business case, such as interest rates and GDP growth are left out of scope for this comparative exercise as they are too similar between all business cases to make any distinction.

Figure 2-1 Scope of the CCU business case



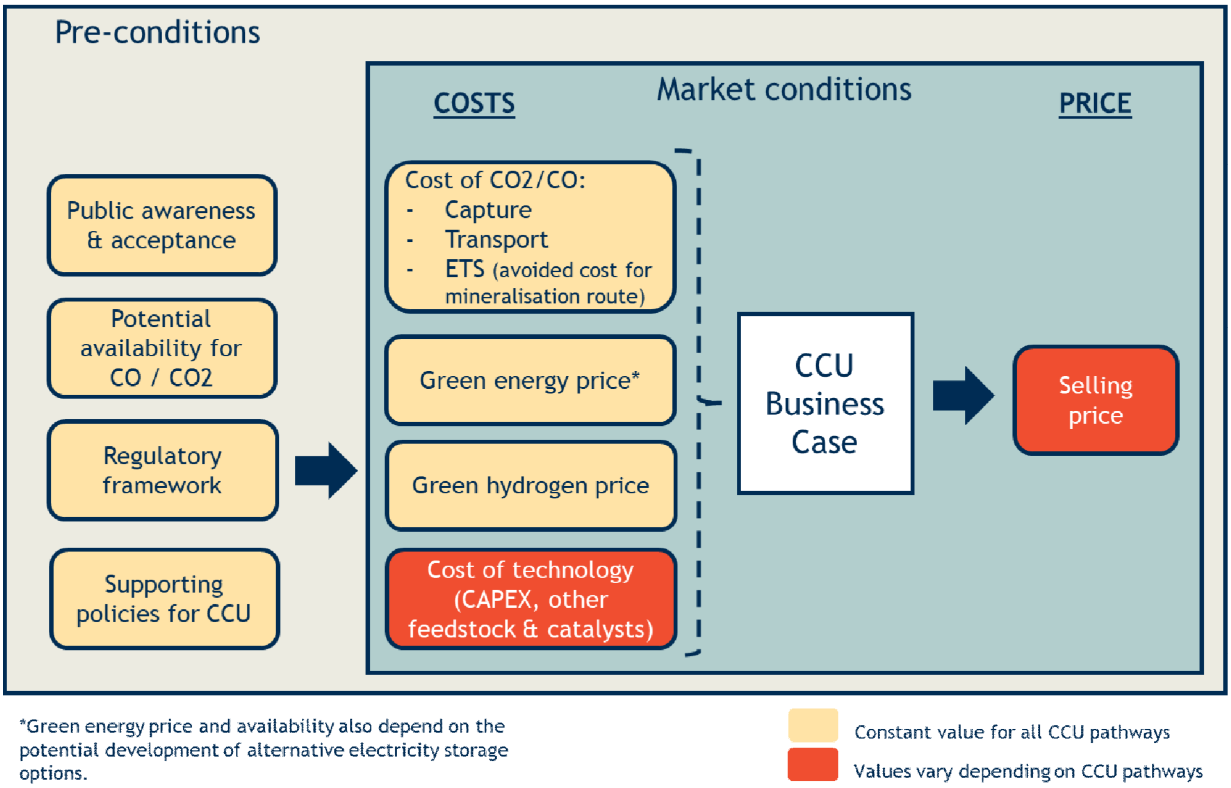
Besides the three core steps of CCU, there are other (external) aspects which affect its business case. The most important ones are the availability and price of green energy; the cost of the technology itself (including for example the catalysts and their effectiveness); and the selling price of the product (related to the volume available and the price of competing traditional products). For some pathways, there are specific factors which may come into play and have a considerable impact on their business case (while they are not relevant for other pathways). For example, the ETS price is relevant for mineralisation pathways, while the availability/price of green hydrogen is highly relevant for the hydrocarbon (fuel) pathways.

2.2 Framework for the methodology

Once the scope is clear, we can define the framework which will be used to assess the business case of CCU. The figure below aims to identify the different conditions which have an impact on the CCU case. These conditions have been split into pre-conditions and market conditions. Pre-conditions are those which need to be in place for CCU to be a feasible option, and are further discussed in other reports within this project.

Market conditions, on the other hand, are those which have an impact on the CCU costs and the CCU product price. These market conditions can be dependent or not on the selected pathways. This diagram aims to be comprehensive, therefore, certain conditions may not be relevant for certain pathways.

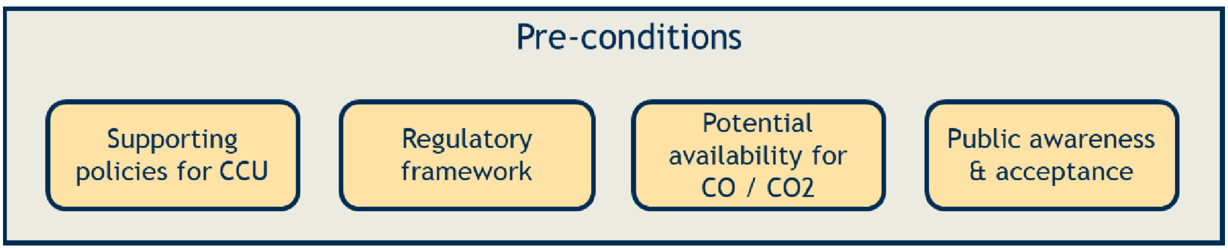
Figure 2-2 Framework to assess the CCU business case



The sections below provide more details on each of the (pre-)conditions.

2.2.1 Preconditions required for the CCU business case

The following are the four main pre-conditions for the development of a CCU business case:



These are introduced below shortly, as they have been further developed in other Work Packages within the CarbonNext project.

Supporting policies for CCU

This refers to the policies (at EU and MS level) which may support CCU. In a scenario where there is a strong climate policy and the EU implements powerful instruments to reach carbon neutrality and oil independence, this aspect may act as a driver for CCU. It is reasonable to expect, that without these supporting policies, CCU will not become widespread in the medium term as the fossil alternative is still too cheap.

Examples of how to improve the business case for CCU via supporting policies:[2]

- Increase government and industry support for R&D
- Provide an adequate carbon price / ensure long term storage utilisation benefits from ETS
- Provide credits under regulatory and voluntary programmes tied to the use of CCU products
- Government procurement to provide early demand
- Government mandates to use CO_2 in certain products to spur market

Relevant regulatory framework

These are policies which have an impact in different market conditions, such as:

- **EU Emissions Trading System (EU ETS)[3]** – Defines the CO_2 (emission) price in Europe;
- **Renewable energy directive[4]** (and other supporting instruments for RES) - Has an impact on green energy availability and prices and could indirectly also have an impact on hydrogen price and availability;
- **Biofuels directive[5]** – Proposed amendment can have an impact on the business case for CCU-based synthetic fuels, which will then be allowed in the mix of biofuels;
- **Car emission regulations[6]** to push quicker for full electric or hydrogen cars; and
- **Research, development and innovation support** (via e.g. Horizon 2020).

Potential availability for CO/CO_2

This aspect refers to the availability (volume) of CO/CO_2 to be used for CCU. Scenarios where there is no CO/CO_2 availability would impede the development of CCU. It is likely that there will be more than enough availability of CO_2 whereas the availability of CO is more restricted as CO (especially from the steel-industry) is currently often used for energy-production (and thus emitting CO_2). CO_2 is by nature less 'valuable' as it has no energy content left, whereas CO is more reactive and thus more valuable. Deliverable 1.1 under the CarbonNext project provides an overview of the CO and CO_2 sources in the EU.

Public awareness and acceptance

This aspect refers to the public awareness and understanding regarding CCU. In a scenario of strong climate policies, for example, there will be increased awareness and acceptance of CCU and decarbonisation, to the extent that consumers may be willing to accept higher prices for carbon neutral products. On the other hand, some will consider CCS/CCU as an excuse to continue polluting industries. Deliverable 3.2 explores the guidelines for acceptance and awareness of CCU.

2.2.2 Market conditions with an impact on the CCU business case

There are several conditions affecting the CCU business case, which can be grouped as cost or price related. These are explained below.

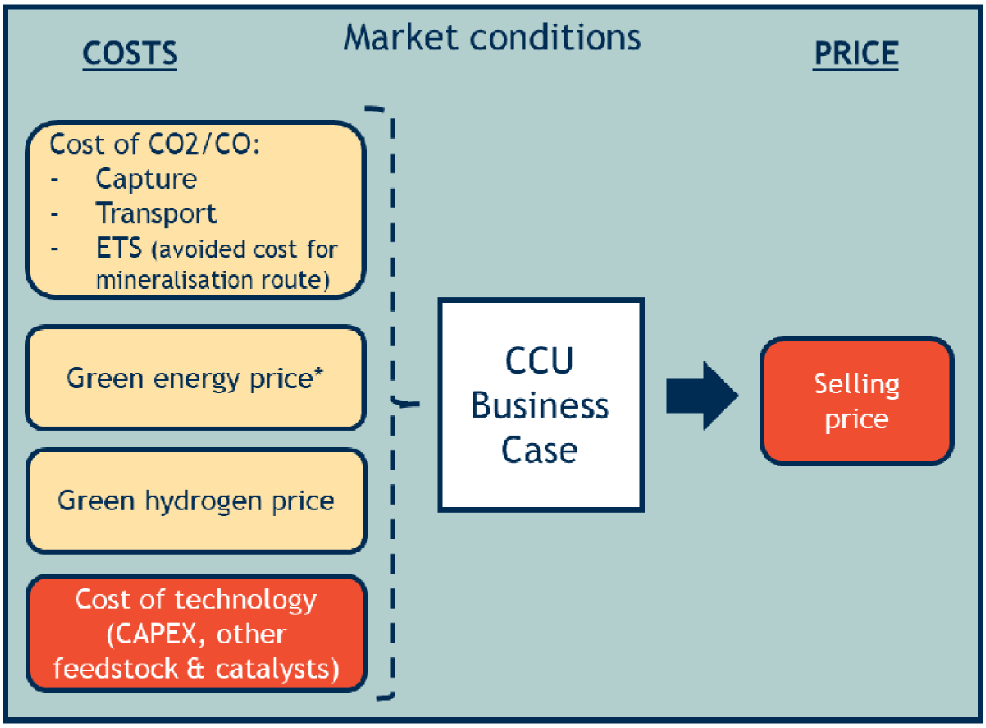
[2] ICEF (2016), Carbon dioxide utilization (CO2U) – ICEF Roadmap 1.0.

[3] Directive 2003/87/EC (Consolidated version), http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02003L0087-20140430

[4] Directive 2009/28/EC, http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028

[5] Directive 2003/30/EC, http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32003L0030

[6] Regulation (EC) No 443/2009, http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32009R0443 and Commission Regulation (EU) No 459/2012, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012R0459



Cost of carbon

The main costs of carbon include cost of capture and cost of transport. Avoided costs can potentially also play a role if the ETS would be amended. These costs are further detailed below.

We expect the cost of capture and transport of carbon to be a relatively minor cost component in the overall business cases for CCU.[7] We will base our estimates on the results of WP3.1. The costs will have the same impact for all CCU pathways, as long as certain conditions (e.g. location of industry and source of carbon) remain the same. However, the impact may vary depending on the scenarios.

Potential indicators to support the analysis are:

- Cost to transport carbon per km (for different transportation options)
- Threshold for the switch in type of transport (e.g. from trucks to pipeline) in volume and amount of kilometres
- Cost of carbon capture per tonne (distinguishing between high and low concentration sources, and the implications in the process)

More information on the analysis of these costs is given in WP3.1.

Regarding ETS, currently, utilising CO_2 falls outside the accounting scope of the European Union Emission Trading System (EU-ETS), except when used for longer-term geological storage.[8] A reform, acknowledging CCU, has been debated on several occasions. A legislative proposal to revise the EU-ETS was presented in 2015[9] extending the scope of the EU-ETS Directive by including (1) low-carbon technologies and processes in industry; and (2) allowances will not need to be surrendered for CO2 emissions which are ópermanently stored or avoidedô which potentially makes room for CCU.

[7] CE Delft (2017) óCCU market options in the Rotterdam Harbour Industrial Complexô

[8] The EU-ETS Monitoring and Reporting Regulation (MRR Regulation) states that the transfer of inherent or pure CO_2 shall only be allowed for the purpose of long-term geological storage. Utilising the CO_2 for any other purpose would require the emitter to surrender emission allowances for the utilised CO_2 and is therefore not financially encouraged under the EU-ETS. Source: Article 49 of the EU-ETS Monitoring and Reporting Regulation 601/2012

[9] COM(2015) 337 - Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low carbon investments

However, assuming this amendment will come into force, the actual meaning and interpretation of these two concepts still requires some clarification. It is argued that those forms of CCU which lead to permanent storage of CO2 (such as mineralisation routes) should be included in the EU-ETS reporting framework.[10] If this were the case in the future, the ETS price would have an impact on these business cases. No mineralisation pathways are included in our analysis, therefore there would be no consequences for the CCU business cases we will analyse. We will however include a short analysis on what the impact would be if the EU-ETS Directive would include "CO_2 avoided" in the future, in which case all CCU business cases would improve by getting a monetary benefit for using the CO_2.

Green energy price and availability

Energy will be a major cost component for most CCU pathways, and the impact will vary depending on the scenario. Given the high energy penalty of almost all CCU pathways, it is likely they are employed at times of low energy prices (which equals low demand). If electricity storage is available, the price is likely to be more equally spread. Therefore, we will assess qualitatively the availability of storage and the effect of intermittent RES on electricity prices.

Further, the lack of 24/7 green energy availability may also have an impact on the CCU business case. We assume that industry investments are usually made with the expectation of constant product output; however, if green energy is only available intermittently, this would have a very strong impact on the business case. If the same CAPEX is invested but the plant is only operational 50% of the time, the return on investment would be roughly half as low as well. Also the OPEX will increase strongly if a plant has to switch on and off repeatedly.

In both EU and IEA scenarios for 2030 nuclear power is playing a strong role. Nuclear power is CO_2 neutral and available 24/7, therefore (from a climate perspective) an efficient and suitable source of energy for CCU. We will not further investigate this option in our analysis. In our scenarios, we will base the share of nuclear power in the energy mix on existing scenarios by the EU and IEA.

Green hydrogen price and availability (limited routes)

Hydrogen price will be a major cost component for those CCU pathways producing hydrocarbons (like Methane or Methanol). Only hydrogen coming from green sources will result in sufficient CO_2 reduction and thus the hydrogen needs to be produced without emitting CO_2. Electrolysers using green electricity is a source of green hydrogen (see below). Predictions on the price development of hydrogen come with high uncertainties. The scaling of the production of electrolysers could reduce their price substantially. Also, direct use of hydrogen (e.g. for energy or for transport) could have a major impact. Alternative demand could push up the price as well as the availability.

Cost of technology (incl. catalysts)

This aspect refers to the technologies for carbon utilisation. We expect that cost of technology will be a considerable cost component for most CCU pathways. The role of catalysts may be especially important here, as they cause the essential and thermodynamically minimal energy expenditure in endothermic reactions for CO_2 utilisation. The catalyst reduces the activation energy and accelerates the reaction. This market condition will focus on assessing the following:

- Cost reduction potential, linked to innovation and future timeline
- CAPEX – related to the capital expenditures, mostly for the production plant equipment required
- Catalysts:
  - Cost
  - Recuperation factor
  - Increased efficiency / Reduction in energy needs

[10] Zero Emissions Platform (2016), ZEP Policy Brief: CCU in the EU-ETS; SCOT project. Briefing paper: EU-ETS to incentivise CO2 utilisation?

Note that the operation and maintenance costs (O&M) will not be addressed here; as they are strongly linked to the use of intermittent energy this is hence addressed under the green energy price and availability condition.

Selling price

The demand-side of the business case is also very relevant. In our analysis, the cost elements will be quantified (ú per ton of product) and compared to the selling price of fossil-based alternatives. Our main point of comparison will be the current (fossil-based) market price of the different products generated by each pathway (and recent trends, if relevant). We will complement this with looking at different qualitative aspects, including the price of other green alternatives and the price elasticity: If the market is big enough and there is a relatively small CCU production, there will be little impact on the selling price. On the contrary, in a smaller market that is flooded with CCU products, the price will drop, unless demand grows and the market is expanded. Aspects such as product substitution will be explored qualitatively as well.

3. Scenarios

3.1 Introduction

In the previous chapter we have indicated the different key elements that can be relevant for the different CCU pathways. In order to estimate the (cost) developments for these key elements we have developed four different scenarios. In these scenarios we try to sketch a variety of internally coherent options. Whenever possible we will refer to existing scenarios of EC and IEA. The scenarios are all taking 2030 as point of reference.

Linking the market conditions to future scenarios

Availability of green electricity

It is clear that the future energy mix for Europe will contain a much higher percentage of electricity and that RES will provide a substantial part of this electricity. EU is estimating that by 2030 some 42% of all electricity will be from RES (mainly wind and hydro). IEA is expecting that 49% RES is required in 2030 to achieve 450ppm/2 degree. We have therefore chosen for a scenario with high and a scenario with medium percentage of RES. How much of this electricity is available for CCU (or electrification of chemical industry in general) is unclear as also low temperature heating (heat pumps in houses) and transport are strongly depending on this same green electricity.

Intermittence of green electricity

For industrial production like CCU it makes a significant difference if the green electricity is available 24/7 or only in off-peak hours. The increase in CAPEX and OPEX for almost all CCU options is substantial if only intermittent green electricity is available. We have therefore differentiated between 24/7 or intermittent availability in the scenarios. With relatively low RES penetration grades (<25%) the grid is likely flexible enough. On the other end of the spectrum, if abundant (>100%) RES is available this is not a major issue either. But in getting there the intermittence will be a strong element in the overall picture (linked to the point below).

Available large-scale options for storing green electricity

If the green electricity produced by intermittent sources like wind and solar can be stored in a relatively easy/cheap manner, this will immediately impact the price and intermittent character of the green electricity. It is unclear if these storage options will become available or not, it could even be that CCU is part of the storage solution, for instance by making methanol or aviation fuels. We have therefore included a scenario where this large-scale storage is available (combined with 24/7 availability and higher prices) and not available (combined with intermittency and lower prices).

Price of green energy

In the end this translates into prices for green energy, and in particular green electricity. Today electricity prices are strongly fluctuating and the market is deteriorated due to the many policy interventions and subsidies. A high electricity price will have a negative impact on both the production of hydrogen (required for hydrocarbons; mainly for synthetic fuels) as well as all other CCU routes where green electricity is required to upgrade the CO_2 to high-value products. Only for mineralisation (exothermal reaction) the E-price is less relevant. It is not fully clear what the effect will be of availability of large storage capacity on the E-price. We assume that large storage potential will have an upward pressure on the E-prices. We do not anticipate on very low or negative electricity prices: as soon as there is an alternative demand (CCU) there will be a price that is related to the cost of production.

Price of hydrogen

As mentioned before hydrogen is crucial when making hydrocarbons from CO_2. The price of hydrogen depends on three elements that are all difficult to predict: 1. technological innovation 2. large ćscaling upôof the production of electrolysers 3. the electricity cost. As hydrogen can also be used as a direct electricity storage option this is linked in our scenarios: Cheap hydrogen is combined with high storage potential. Even as the high storage potential will likely induce a higher E price (and thus higher price for Hydrogen).

Price of CO_2

We have explained previously that the price of CO_2 is relatively small and irrelevant for most CCU routes. Only for mineralisation the price of CO_2 makes a bigger impact as here it can be (likely) related to the ETS. We have therefore included a high and low CO_2 price according to EC estimates.

CO as potential resource (instead of CO_2) can be used for almost each pathway but at a lower energy penalty level. We have concluded in chapter 1 that CO is mainly to be sourced from steel production. Here the CO emission is intertwined with CO_2 emission and the separation cost for the CO for this specific pathway will likely be a relevant cost in CO pathways. For CO pathways selected we will look into this in more detail.

Development of CCS

We have not included the development of CCS as a crucial element in the scenarios. First of all because all existing scenarios do not predict massive CCS around 2030. Secondly because we expect that for most CCU routes the amounts of CO_2 required are limited and will be more άacross the fenceô industrial symbioses (regional at best) and less dependent on large-scale CO_2 infrastructure. Only for large volume CCU options (especially transport fuels) CO_2 availability becomes an issue, but they can be directly linked to remaining plants for steel, concrete and maybe refineries.

3.2 Overview of scenarios

There are 4 scenarios:

1. **Reference scenario**
2. **Low electricity price**
3. **Good electricity storage options**
4. **Low electricity price, low hydrogen price**

Table 3-1 gives an overview of the elements in each scenario. They are described further below.

Table 3-1 Overview of the selected scenarios

2030	Scenario 1 Reference	Scenario 2 Low e-price	Scenario 3 E-storage	Scenario 4 Low e-price, low H2-price
Share of RES in electricity generation	**Moderate**[11]	**High**[12]	**High**	**High**
Alternative options for electricity storage	**No**	**No**	**Yes**	**Yes**
Intermittency	**Yes**	**Yes**	**No**	**No**
Average electricity price **(ú/MWh)**	**High** 140 [13]	**Low** 59 [14]	**High** 140	**Low** 59

[11] Moderate share of RES (42.9%), of which 25% intermittent (18% by wind and 7% by PV). Nuclear 22%. Based on EU Reference Scenario (2016)

[12] High share of RES (49%), of which 28% intermittent (21% by wind, 6% by PV and 1% by CSP). Nuclear 27%. Based on the 450 scenario in IEA (2016) World Energy Outlook 2015.

[13] Based on EU Reference Scenario (2016) average electricity prices before taxes by 2030

[14] Based on EU Reference Scenario (2016) and historical industrial electricity price without taxes for the highest consumption band (Eurostat)

2030	Scenario 1 Reference	Scenario 2 Low e-price	Scenario 3 E-storage	Scenario 4 Low e-price, low H2-price
Hydrogen price **(ú/kg)**	**High** 6 [15]	**High** 6	**Low** 2 [16]	**Low** 2

Scenario 1: Reference scenario

The reference scenario is partially based on the EU reference scenario 2016[17]:

- The share of renewable energy sources (RES) in the total electricity production is moderate at 42.9%, of which 25% intermittent.
- The average electricity price will be high, around ú140/MWh.

There are no viable large-scale alternative options for electricity storage, therefore the availability of green electricity will be intermittent. Linked to intermittency and the electricity price is the hydrogen price, which is expected to remain high.

We estimate the intermittency leads to an average availability of green electricity for 50% of the day. This is based on the full load hours for wind and solar PV, and the assumption that energy from solar PV overlaps with half of the load hours for wind energy. However, assessing impacts of intermittency in the business case will be done mostly in a qualitative manner, as other aspects (such as buying green certificates and self-generation, as well as the lifetime of the plants) may also play a role.

Table 3-2 Full load hours of wind and solar PV

Source	Full load hours[18]	% of total hours in one year
Onshore wind	1800-2500	21-40%
Offshore wind	4000-5000	46-57%
Solar PV	800 (Northern Europe) 1300 (Southern Europe)	9% 15%

Scenario 2: Low electricity price

The share of RES is higher in scenario 2, 3 and 4, at 49% of the total electricity production, of which 28% intermittent. This leads to lower electricity prices of ú59/MWh. Other elements are the same as in the reference scenario.

Scenario 3: Electricity storage

In this scenario, there are viable, large-scale alternative options for electricity storage, which leads to 24/7 availability of green electricity. Off-peak electricity prices are higher than in scenario 2 and 4, because it can now be stored for later use, improving the demand and business case for alternative uses of off-peak green electricity.

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[15] High end of benchmark estimated production costs of water electrolysis using renewable electricity by 2030. Based on Fuel Cells and Hydrogen Joint Undertaking (2015), Study on Hydrogen from Renewable Resources in the EU. http://www.fch.europa.eu/sites/default/files/GHyP-Final-Report_2015-07-08_5%20%28ID%202849171%29.pdf

[16] Based on SET-plan target 2020-2030 for alkaline and PEM technology. EASE and EERA 2017, Joint Recommendations for a European Energy Storage Technology Development Roadmap.

[17] 18% by wind and 7% by PV. Based on EU Reference Scenario (2016)

[18] Based on: Graaback and Korpas 2016, Variability Characteristics of European Wind and Solar Power Resourcesð A Review

Scenario 4: Low electricity price, low hydrogen price

This scenario has the most favourable conditions for CCU applications, with low electricity prices, a low hydrogen price, and no intermittency. This is the only scenario that combines low electricity prices and no intermittent electricity (and availability of storage options). This implies continued decreased of technology costs for both intermittent RES and storage options, and increased use of distributed energy along with demand response and local storage.

Cost of carbon and the CO_2 price

The cost of carbon capture and transport (hereafter: cost of carbon) can vary largely and is context-specific. Deliverable 3.1 shows this in detail. In all scenarios, we will work with an average cost figure, based on capturing CO/CO_2 with a high concentration level and transport through pipelines. This cost will be the same for all pathways. In our report, the illustrations of the results for each pathway and scenario will visually show the rough share of the cost of carbon in each business case. In our report, we will make note of the pathways where the cost of carbon plays a significant role in the business case (e.g. more than 25% of the total costs). For these pathways (if applicable), we will do a brief sensitivity analysis to show how a higher or lower cost of carbon affects these particular business cases.

Cost		Value	Unit
Capture of CO_2	Capture from high purity sources	~ 30	**EUR/tCO_2**
	Capture from diluted sources[19]	~ 34 to 99	**EUR/tCO_2**
Transport of CO_2	Onshore pipe, < 180 km (capacity: 2.5Mt per year)	~ 5.4	**EUR/tCO_2**
	Offshore pipe[20]	~ 9.3 ï 51.7	**EUR/tCO_2**
	Ship (including liquification)[21]	~ 13.5 ï 19.8	**EUR/tCO_2**
ETS	Emissions price (2030 forecast, range)	~ 32-75	**EUR/tCO_2**

The CO_2 price does not affect the CCU business case under the current ETS (except for mineralisation routes, which are not included in the selection of pathways that we will assess). There is however a (small) possibility that óCO_2 avoidedô will be included in the ETS in the future. Therefore, we will briefly look at the impacts on the CCU business cases if this would happen. We will base this assessment on the CO_2-prices that are described in deliverable 3.1 (and presented in the summary table above).

[19] Naims, H. (2016). Economics of carbon dioxide capture and utilization ï a supply and demand perspective. Environmental Science and Pollution Research, 23(22), 22226-22241. https://link.springer.com/article/10.1007%2Fs11356-016-6810-2

[20] Price depends on the distance (i.e. 180km ï 9.3EUR/tCO_2; 1500km ï 51.7EUR/tCO_2)

[21] Price depends on the distance (i.e. 180km ï 13.5EUR/tCO_2; 1500km ï 19.8EUR/tCO_2)

4. Methodology for the assessment of the business case

In this section, we describe the methodology to assess the business case for the different pathways. It will consist of three main steps:

- Identifying the relevant market conditions for the pathway;
- Estimating the OPEX;
- Estimating the CAPEX;
- Comparing the total costs to current market prices;
- Validating results with key experts;
- Report on final results and visual summaries.

Overall, we expect that in many cases there will only be limited or imperfect information available to perform a quantitative assessment (e.g. on the CAPEX and OPEX). While we expect this quantitative data to be often inexact, it will allow for a comparison across pathways. The steps are described below.

4.1 Identifying the market conditions

The first step is to identify which of the market conditions are relevant under the selected pathway. We will provide a descriptive explanation of the role of each market condition for each of the selected CCU pathways. Where available, supporting quantitative data will be provided. Based on the technological assessment, we will be able to determine which components and how much of each one goes into the process (i.e. how much electricity, heat, CO/CO2, and hydrogen) to produce a unit of the product.

4.2 Estimating the OPEX

HB we could say: Although OPEX is made up by a wide variety of cost, we expect that to differentiate between the different CCU pathways, especially green energy prices, hydrogen costs and the cost of carbon will be useful in comparing the business cases of the selected CCU pathways. The amounts estimated will be multiplied by the cost of each element (as defined in our scenarios) to arrive at the total OPEX of the pathway. The costs will differ per scenario. In cases where information on other OPEX costs is available (such as other feedstock and catalysts, which are part of the cost of technology), it will also be taken into account.

4.3 Estimating the CAPEX

The CAPEX is more difficult to determine. Currently, there is no information available on the CAPEX for the different CCU pathways as this requires detailed chemical engineering and calculations, but the technology used in the pathways is often similar to the technology used for existing (fossil-based) processes. We will base our assessment on estimates of the CAPEX of these existing processes and conduct interviews with experts to determine to what extent the CAPEX would be higher or lower for the CCU pathway (using percentages, such that we can quantify the difference), compared to this existing process. This way, we will arrive at a rough estimate of the CAPEX for the CCU pathway.

The impact of the scenarios on the CAPEX is linked to the availability of green energy. If only intermittent green energy is available, this will have an impact on the output that can be achieved with the CAPEX. Hence leading to a higher CAPEX per unit produced. The impact will be based on the estimated load factor in each scenario. The load factor will be high in the scenarios with 24/7 availability of green energy, and low in case of high intermittency.

4.4 Comparing to market prices

The production cost (estimated as OPEX + CAPEX per unit produced) of the pathway will be compared to the price of the fossil-based alternative that is already in the market. The selling price is calculated based on the market value and volumes which are available in the PRODCOM database. A simple trend analysis will be performed based on the last 10 years, along with a qualitative assessment to account for future developments. As the fossil-based products also benefit from lower energy prices, we will assume the same energy-related cost reduction for these products as for the CCU products. The production cost can be substantially lower than the selling price: some of the products can have margins of up to 25%. The comparison is therefore meant to be informative only: it will show how much higher or lower the CCU pathway production costs are compared to the selling price of fossil-based alternatives, which will give an indication of how competitive the pathway would be under each scenario.

Table 4-1 Estimated prices for selected products (EUR/tonne). Source: PRODCOM database

Product	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Ethylene (and polyethylene)[22]	883	948	702	811	912	980	996	961	908	873
Propylene (and polypropylene)[23]	-	-	-	914	1021	1030	1074	1076	1012	902
1,3-butadiene	483	776	1 213	1 083	793	655	496	473	483	776
Benzene	666	637	403	600	693	862	867	855	568	531
Xylene[24]	601	651	511	648	863	973	901	752	610	551
Ethanol[25]	636	557	544	597	687	696	681	590	602	573
Methanol	255	284	165	205	247	272	319	285	269	187

Note: ‘Ethylene carbonate’, ‘Dimethyl carbonate’ and ‘Dimethyl ether’ are not on PRODCOM database. Fuels are also not on the database.

4.5 Validating results with key experts

Given the large range of uncertainties in the different aspects to be assessed, we will validate our results with key experts via interviews.

[22] Includes values for code 20141130: Ethylene; 20161039: Polyethylene having a specific gravity < 0.94, in primary forms (excl. linear); 20161050: Polyethylene having a specific gravity >= 0.94, in primary form; 20161090: Polymers of ethylene, in primary forms (excluding polyethylene and ethyl vinyl acetate)

[23] Includes values for code 20141140: Propene (propylene); 20165130: Polypropylene, in primary forms; 20165150: Polymers of propylene or of other olefins, in primary forms (excl. polypropylene); 20601150: Polypropylene synthetic tow and staple not carded, combed or otherwise processed for spinning; 20601340: Polypropylene filament yarn, n.p.r.s. (excluding sewing thread); 20601420: Polypropylene monofilament of >= 67 decitex and with a cross sectional dimension of <= 1mm (excluding elastomers); 22212155: Rigid tubes, pipes and hoses of polymers of propylene; 22213021: Other platesé , of biaxially orientated polymers of propylene, thickness <= 0.10 mm.; 22213023: Other platesé , of polymers of propylene, thickness <= 0.10 mm, others; 22213026: Other platesé , of non-cellular polymers of propylene, thickness >= 0.10 mm, n.e.c.

[24] Includes values for code 20141243: o-Xylene; 20141245: p-Xylene and 20141247: m-Xylene and mixed xylene isomers

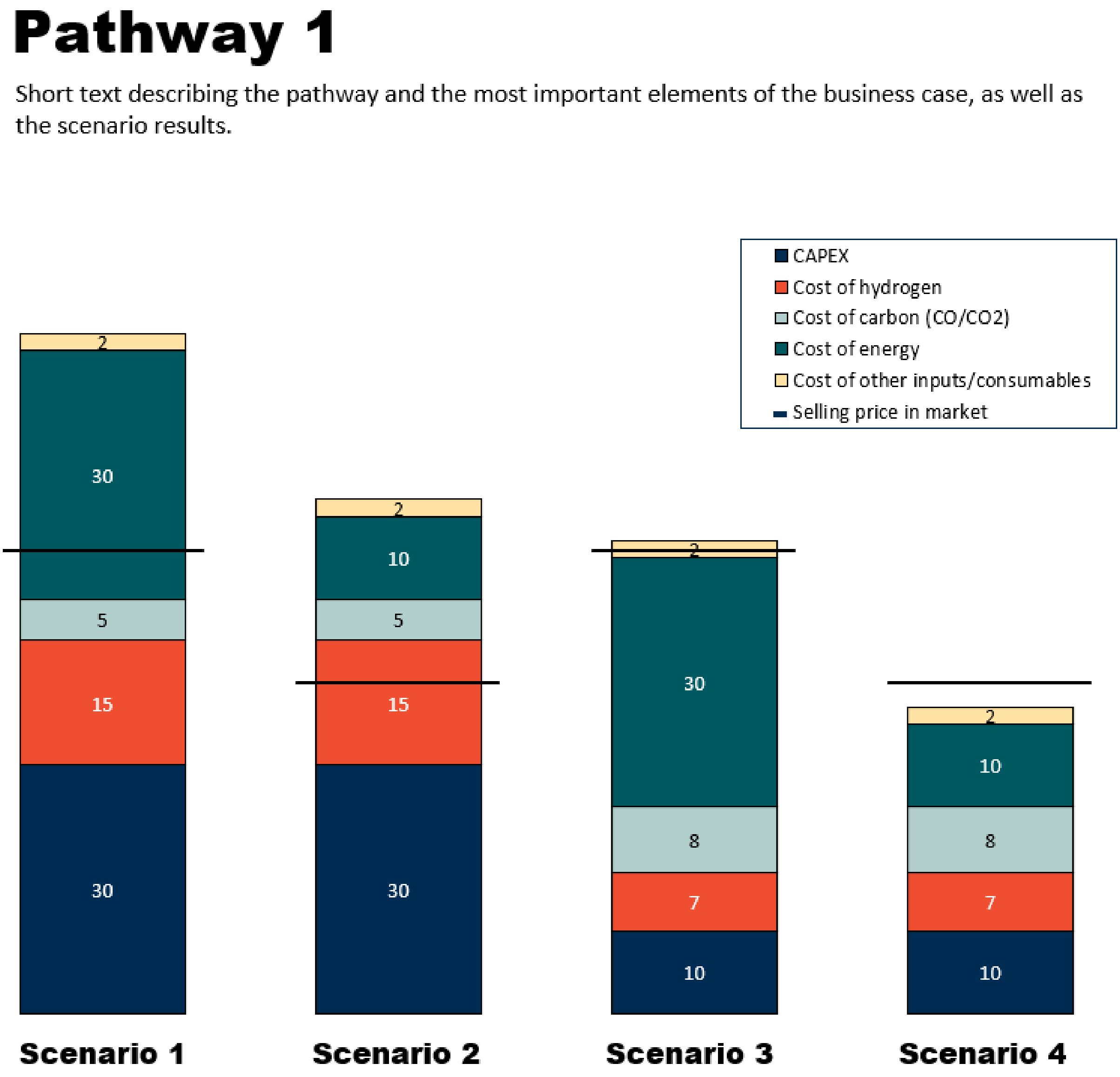
[25] Includes values for code 20147400: Undenatured ethyl alcohol of an alcoholic strength by volume >= 80 % (important: excluding alcohol duty) and 20147500: Denatured ethyl alcohol and other denatured spirits; of any strength

4.6 Final assessment overview

We will prepare an Excel-based overview table for each pathway, where we include the estimated OPEX and CAPEX under each scenario. The Excel-file will include an interactive feature: the file will allow the user to change the market conditions and costs in a fifth scenario. The results of these changes will automatically show in the overview table in a separate column.

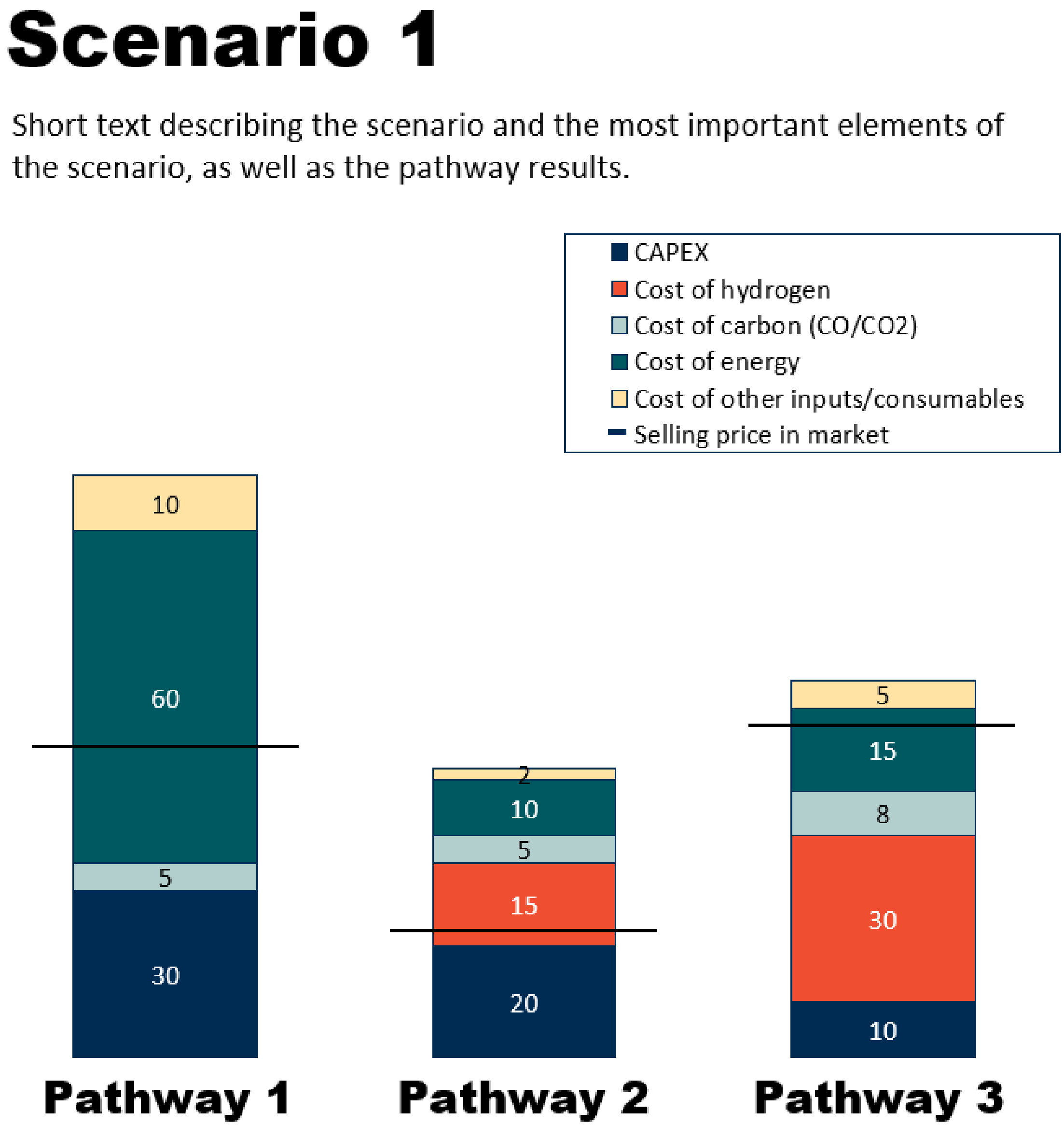
The results of our assessment will be reported in deliverable 4.3. The tables of all the pathways in each scenario will be translated into visual results, which will allow stakeholders to have a combined visual summary of these results which may facilitate comparison and decision making. The visual results will be included in the deliverable 4.3. Illustrative examples are given in Figure 4-1 and Figure 4-2.

Figure 4-1 Example of the illustration of results for one pathway



The results will also be presented by scenario for all the pathways, providing an overall ranking of the pathways in each scenario. An example is given in Figure 4-2. This will allow us to conclude which pathways are likely to have a positive business case under each scenario.

Figure 4-2 Example of the illustration of results for one scenario



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