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Financial incentives for climate neutral energy carriers

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ABSTRACT
The Dutch government is currently examining the possibilities to promote the production and use of climate neutral energy carriers. Climate neutral energy carriers are energy carriers from fossil fuels with a low level of associated emissions of greenhouse gases. To judge whether a project qualifies for financial support understanding must be obtained on additional costs and avoided emissions. A conceptual framework is developed and applied to five different case studies for the production and use of climate neutral energy carriers.
When taking the whole lifecycle of the energy carrier into account, the emission of the production and use of climate neutral *hydrogen* varies per project and ranges from 17 to 33 kg of carbon dioxide equivalent per gigajoule. The emission factor for climate neutral *electricity* for the examined projects amounts to 0.2 to 0.5 kg per kWh.

INTRODUCTION
Climate neutral energy carriers are defined as hydrogen and electricity produced by means of fossil fuels and by which (a substantial part of) the produced carbon dioxide is stored or put to good use. The term "climate neutrality" of an energy carrier refers to the share of the energy carrier that can be marked as climate neutral.
To judge whether a project qualifies for financial support the climate neutrality needs to be taken into account. All changes in the emissions of greenhouse gases in the production chain should therefore be determined. The emissions of production and application of an energy neutral energy carrier are compared to the emissions in a reference system. The results of the study are used to develop a calculation methodology which should be used for project developers to submit an application for financial support. In addition, the production costs of climate neutral hydrogen and electricity are compared to the current prices of natural gas and electricity for small consumers.

STARTING CONDITIONS CLIMATE NEUTRAL ENERGY CARRIERS
The production and application of climate neutral energy carriers should fulfil a number of conditions in order to qualify for possible financial support:

- the climate neutral energy carriers should be produced from fossil energy carriers in addition to which the carbon dioxide is stored or put to good use,
- the produced climate neutral energy carriers should be electricity or hydrogen, and
- the reduction of carbon dioxide emissions may not be used to fulfil existing obligations or agreements.

It was expected that production technologies and application of climate neutral energy carriers might considerably differ in terms of greenhouse gas emissions and (additional) costs compared to fossil fuel energy carriers. To examine these variations systematically, we introduce two concepts: the system boundaries and the reference system. At the hand of five case studies the climate neutrality and additional costs are assessed.

In this study we restrict the system boundaries to seven different elements which form the total chain of production and application of (climate neutral) energy carriers. The different chain elements are displayed in Figure 1. The production chain includes:

1. Extraction and production of the fossil energy carrier.
2. Transport of the fossil energy carrier.
3a. Production of the climate neutral energy carrier (e.g. hydrogen or electricity) and CO_2 or carbon.
3b Compression of the CO_2.
4. Transport and/or distribution of the CO_2 or carbon.
5. Storage of the CO_2 or carbon. In this step the CO_2 is stored or put to good use.
6. Transport and distribution of the climate neutral energy carrier.
7. End-use of the climate neutral energy carrier. This means the use of the climate neutral energy carrier by the end-user.

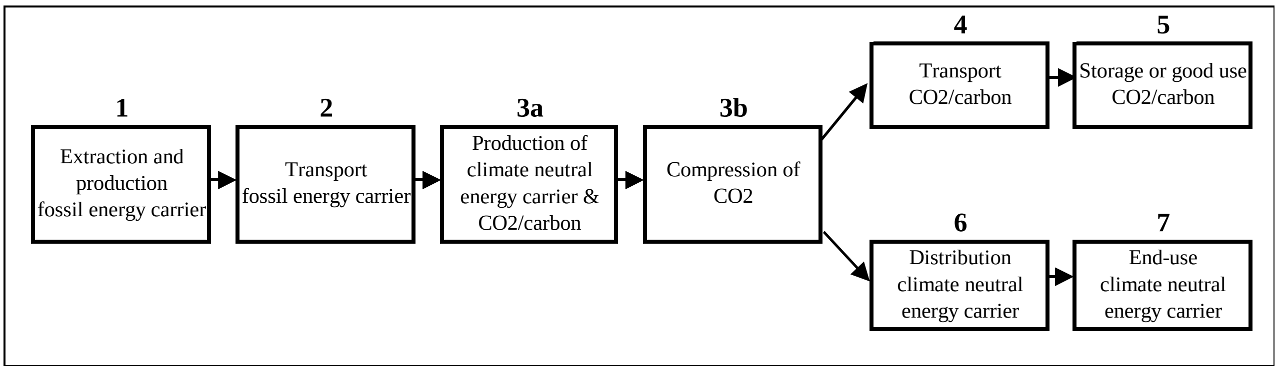

Figure 1: Chain elements in a production chain for climate neutral energy carriers

The 'reference system' is defined as the amount of greenhouse gases that would have been emitted and the costs that would have been made in the absence of the project. The reduction of greenhouse gas emissions and additional costs due to the implementation of a production chain can be calculated by comparing the emission and costs of the production chain with the emission and costs in the reference system.

In principle two different approaches can be applied to determine the emissions and costs in the reference systems.

1. In the multi-project approach generic emissions factors and cost figures for a certain activity are used to calculate the emission and generated costs in the reference systems. These generic emission and cost factors are project independent and can e.g. be derived from benchmarks.
2. In the project specific approach the emissions and costs in the reference system are calculated with project specific assumptions or measurements for all important project parameters. E.g. emission factors of one specific electricity production plant are used because it can be argued that the project replaces electricity generated by that specific plant.

Applying different approaches

For the production of climate neutral electricity by means of a coal-fired power plant and storage of the CO_2 in empty gas fields roughly three different approaches can be applied to calculate the emissions in the reference system:

1. The electricity generated with the project replaces the average produced electricity in the grid (e.g. the Dutch grid or the European grid);
2. The electricity generated with the project replaces electricity produced by a specific technology mix (e.g. the average public mix, industrial power or a specific technology e.g. a combined cycle unit);

3. The electricity generated by the project replaces electricity generated by a specifically defined plant (e.g. due to the implementation of the project another (specific) power plant is closed down or not erected).
When applying the different approaches to a zero emission power plant (i.e. PC3 characterised in Table 1) the amount of achieved CO_2 emission reduction per kWh is:

- 0.2 kg CO_2-eq per kWh when using the combined cycle as a reference system,
- 0.4 kg CO_2-eq per kWh when using the average production mix in the Netherlands,
- 0.7 kg CO_2-eq/kWh when applying the project specific approach.

For the production of climate neutral hydrogen the reference system is defined as the use of natural gas. The emissions in the reference system can be calculated by taking the emissions of greenhouse gases for the production of natural gas in the Netherlands. In this case only a multi-project approach can be applied and the emission reduction per GJ hydrogen ranges from 43 kg CO_2-eq /GJ H_2 for PC1 to 27 kg CO_2-eq /GJ H_2 for PC2 (for comparison natural gas has an emission factor of 60 kg CO_2-eq /GJ).

CASE STUDIES

This conceptual framework has been applied to five different case studies, which are listed in Table 1. The case studies represent the variation in the different elements in the production for a climate neutral energy carrier. The elements in the case studies were selected on basis of maturity for technology available, and whether it has a substantial emission reduction potential in the Netherlands.

Table 1: Characterisation of five examined production chains

Code	**Production facility**	**Storage/use of CO_2/Carbon**	**Climate neutral Energy carrier**
PC1	Natural Gas Reforming + fuel gas recovery	Storage in coal layers by ECBM	Hydrogen
PC2	Coal gasification + fuel gas recovery	Storage in empty NG field	Hydrogen
PC3	Coal combustion with pure O_2 (1)	CO_2 used in production of methanol	Electricity
PC4a	Flue gas recovery of coal-fired power plant	CO_2 used in greenhouses + storage	Electricity
PC4b	Flue gas recovery of natural fired power plant	CO_2 used in greenhouses + storage	Electricity
PC5	Natural processing (recovery of abundant CO_2)	Storage in aquifer	Natural gas

(1) this facility is based on a zero emission plant concept which is still in an early stage of development.

EXAMPLE OF CASE STUDY

In this paragraph we give a short description on one of the examined case studies. In production chain PC4b annually five petajoule of climate neutral electricity is produced by a conventional gas-fired power plant. The electricity is added to the grid. An amine process separates the carbon dioxide from the flue gases of the power plant. The recovered carbon dioxide is compressed and transported over 100 km. On average 25% of the recovered carbon dioxide is used in greenhouses, the remaining 75% is stored underground in empty natural gas field. In this example it is assumed that the electricity in the project replaces electricity produced by the 'average park' in the Netherlands. In the reference case gas engines locally produce the carbon dioxide for the greenhouses. In periods that carbon dioxide is not required for fertilising or co-incidence with heat demand, the carbon dioxide is stored into an empty natural gas field. Table 2 presents the comparison of the emissions in the project and the reference case for each chain element.

Table 2. Emissions of carbon dioxide (Gg/y) for each chain element from the annual production of 5 PJe of production chain PC4b compared to emissions from the reference case (electricity from "average park")

#	Production chain element	Reference	Project	Comment
1	Extraction fuel	50.1	6.0	Average fuel emissions is higher than for natural gas
2	Transport fuel	4.9	21.0	
3a	Production energy carrier	609.1	70	Gas engine with power efficiency (38%) and heat efficiency (38%)
3b	Compression carbon dioxide	0.0	46.9	Compression energy: 430 kJe/kg CO_2
4	Transport carbon dioxide	0.0	0.0	No recompression required
5	Storage/use carbon dioxide	157.5	157.5	Annual use of CO_2 in greenhouses
6	Distribution energy carrier	0.0	0.0	No emissions occur during transport of electricity
7	Application energy carrier	0.0	0.0	No emissions occur during use of electricity
	Total CO_2-eq emission	**822**	**301**	
	Emission reduction	78%	63%	

RESULTS

Per case study, for each chain element the contribution to the total emission is determined. Figure 2 and Figure 3 show that the climate neutrality of the energy carriers lies in the range of 7% to 77% (black bars in the figure). The figures show that the largest changes in emissions take place either at the end user (chain element 7) in cases where hydrogen is produced or in the production stage (chain element 3) for projects where electricity is produced.

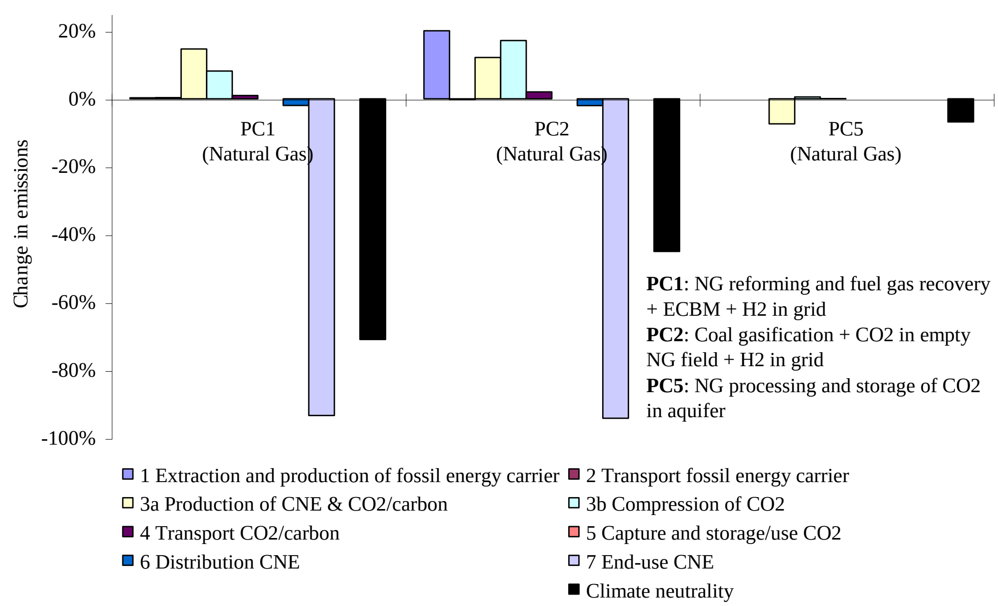

Figure 2: Changes in emission in each of the chain elements for the hydrogen production chain (the reference system for each production chain is included in brackets)

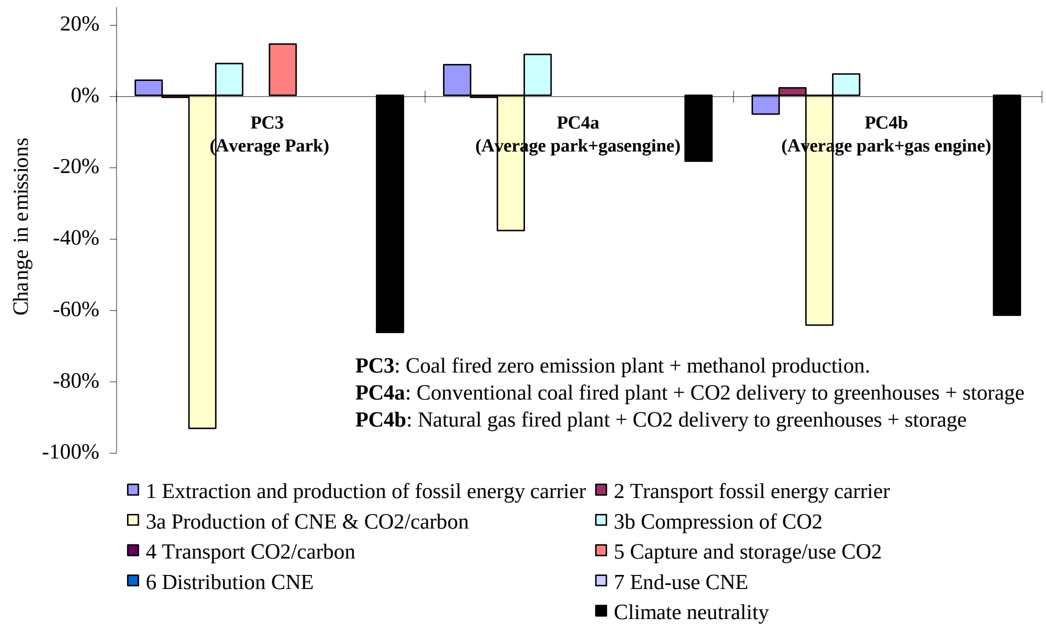

Figure 3: Changes in emission in each of the chain elements for the electricity production chain (the reference system for each production chain is included in brackets)

The main results per case study on costs and climate neutrality of the energy carrier are summarised in Table 3.

Table 3 Summary of the main results for the five examined production chains

Code	Emission Factor	Costs[a]	Reference	Climate neutrality[c]
PC1	17 $kgCO_2$/GJ H_2	13.5-16.2 euro/GJ H_2	Natural gas	71%
PC2	33 $kgCO_2$/GJ H_2	15 euro/GJ H_2	Natural gas	46%
PC3	0.2 $kgCO_2$/kWh	0.08 euro/kWh	Average park	77%
PC4a	0.5 $kgCO_2$/kWh	0.11 euro/kWh	Average park/gas engine[b]	21%
PC4b	0.2 $kgCO_2$/kWh	0.09 euro/kWh	Average park/gas engine[b]	63%
PC5	59 $kgCO_2$/GJ NG	6.0 euro/GJ NG	Natural gas	7%

a) 15% discount rate.
For comparison: prices for small consumers excluding energy tax and VAT: natural gas 5.9 euro/GJ; electricity 0.08 euro/kWh.
b) 25% of the recovered CO_2 is used in greenhouses; 75% is stored underground in empty natural gas fields.
c) Climate neutrality compared to the reference in the former column.

Our analysis shows that the emissions from the total production chain of climate neutral hydrogen range from 17 and 33 kg of carbon dioxide equivalents per gigajoule. For comparison the emissions of natural gas for the whole production chain amount to 60 kg CO_2-eq/GJ. The climate neutrality of the hydrogen amounts to about 71% when natural gas is used as feedstock, and to about 46% when coal is used.

The emissions from the total production chain of climate neutral electricity amount to between 0.2 and 0.5 kg of carbon dioxide equivalents per kWh. For comparison, the emissions of electricity production facilities currently in operation range from about 0.4 to 1.1 $kgCO_2$-eq/kWh. The climate neutrality ranges from 21% to 75%, depending on the application/storage of the recovered CO_2 and the electricity production reference used.

The calculated production costs for hydrogen ranges from 13 to 16 euro/GJ of hydrogen, whereas the current price for natural gas for end-users (excluding energy tax and VAT) is approximately 6 euro/GJ.

The calculated production costs for electricity ranges from 8 to 11 euroct/kWh in the situation where the producer of the electricity delivers the CO_2 for free to the customer (either a methanol producer or a greenhouse grower). The eight cents per kWh reflects the production costs of a new concepts for a zero emission plant in the USA, which is still in an early stage of development. However, in case the customer of the CO_2 is willing to pay a price for the CO_2, equalling the marginal costs of the energy saved by the customer, the electricity price could drop to 5 to 9 euroct/kWh. For comparison the current price for electricity for end-consumers (excluding energy tax and VAT) is approximately 8 euroct/kWh.

The specific reduction costs for climate neutral hydrogen (using a discount rate of 5%) ranges from 150-250 euro/Mg of CO_2. In the examined production chains the specific reduction costs for climate neutral electricity is very sensitive to the assumptions with regard to the energy price. The costs range from less than zero to 30 euro/Mg of CO_2 avoided.

SENSITIVITY OF RESULTS

In the case of hydrogen production, generally only emission changes in chain element 3 (production of the climate neutral energy carrier and compression of the CO_2) are substantial, and contribute up to 80% of the total emissions of the whole chain. In the case of electricity, generally only changes in emission in chain element 7 (end use of energy carrier) are substantial.

Emission changes in element 1 (extraction and production of the fossil energy carrier) are only relevant when the (methane) emission factor of the fossil fuel used for the production of the climate neutral energy carrier differs substantially from the (methane) emission factor of the fossil fuel used in the reference system. Emission changes due to storage are negligible. However, in cases where the CO_2 is applied in other production processes, e.g. in greenhouses, it has to be carefully analysed which part of the CO_2 is stored in the product and which part of the CO_2 is emitted to the atmosphere.

The costs for climate neutral energy carriers are sensitive to the scale of production. In our analysis we assumed an annual production of 5 million gigajoule of hydrogen or electricity. A production unit twice as large as assumed in this study, might lead to a cost reduction of 10 to 15%.

CONCLUSIONS

Climate neutral electricity can be produced in the Netherlands at about 11 euroct/kWh, which is about 3 euroct/kWh higher than current electricity prices. To be competitive, financial support of about 3 euroct/kWh will be required. The climate neutrality of electricity in the examined cases varied between about 20 and 75% depending on the technology and reference used. When the financial support is applied to 100% climate neutral energy carriers only, the financial support should be about 4 and 12 euroct per 100%-climate neutral electricity in order to be competitive. This financial support can be lower, when end-user of carbon dioxide (e.g. greenhouse growers) are willing to pay a price for the recovered carbon dioxide.

The production of hydrogen to replace natural gas in the grid is currently expensive. Climate neutral hydrogen production costs ranges from 13 to 16 euro/GJ, while climate neutrality ranges from 50% (coal gas as feedstock) to 70% (natural gas as feedstock). Current natural gas price is 6 euro/GJ. To cover the additional production costs (of the examined production chains), financial support between about 20 and 30 euro per 100%-climate neutral hydrogen will be required.

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