Deliverable 4.4 | Jan. 2020

Infrastructure needs of an EU industrial transformation towards deep decarbonisation

Workshop report for the region of North-West Europe

Summary of the relevant background information, infrastructure storylines and their discussion at the workshop held on 3 Dec 2019 in Essen

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With support of Simon Heck and Philipp Hammelmann

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Climate-KIC is supported by the EIT, a body of the European Union

European Climate Foundation

Wuppertal Institut

This report is a result of the research project „Infrastructure needs of an EU industrial transformation towards deep decarbonisation“ and is funded by EIT Climate-KIC.
Task ID: TC_2.11.1_190229_P259-1B

The responsibility for the content of this publication lies with the authors.

Please quote the report as follows:
Wuppertal Institut / ECF (2020): „Workshop report for the region of North-West-Europe (Deliverable 4.4) – Infrastructure needs of an EU industrial transformation towards deep decarbonisation; research project funded by EIT Climate-KIC. Task ID: TC_2.11.1_190229_P259-1B, January 2020

Project duration: Jan– Dec 2019

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Imprint

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Date of report: January 2020

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1 Introduction

This workshop report has been developed in the course of the study[1] „Infrastructure Needs of an EU Industrial Transformation towards deep decarbonisation“ (Infra Needs). It summarises the main methodological steps as well as the main findings for decarbonised industrial clusters and related infrastructures in North-West-Europe 2050, as presented and discussed at the regional workshop held on 3 Dec 2019 in Essen (see Appendix for agenda).

The background is that the decarbonisation of core energy intensive industries in Europe, such as steel making, basic chemicals or cement, to a net-zero level of greenhouse gas emissions will need considerable additional amounts of renewable based electricity, gases and feedstocks. However, there will still remain significant process-related CO_2 emissions, e.g. from cement making, that need to be captured and stored or used (CCS/CCU). Therefore, achieving climate neutrality in basic industries will require massive transport and storage infrastructures for renewable energy and CO_2 as a prerequisite for a green industrial transformation.

This study aims to geographically localise industrial demands for power, gas and CCS in Europe 2050, which result from existing decarbonisation scenarios, and to explore which infrastructure solutions for electricity, hydrogen (H_2) and CO_2 would be necessary to meet these demands for three selected industrial regions. Figure 1 shows exemplarily the emerging huge and concentrated electricity demand regions in Europe 2050 for decarbonising steel, basic chemicals and cement making (left) based on (Material Economics, 2019) and the resulting electricity balances (right), if in addition the demands from the electrification of the other sectors from (e-Highway 2050, 2014) are considered.

[1] The study is gratefully funded by EIT Climate KIC (Task ID: TC_2.11.1_190229_P259-1B). Further information and deliverables of the study can be found here: https://wupperinst.org/en/p/wi/p/s/pd/818/

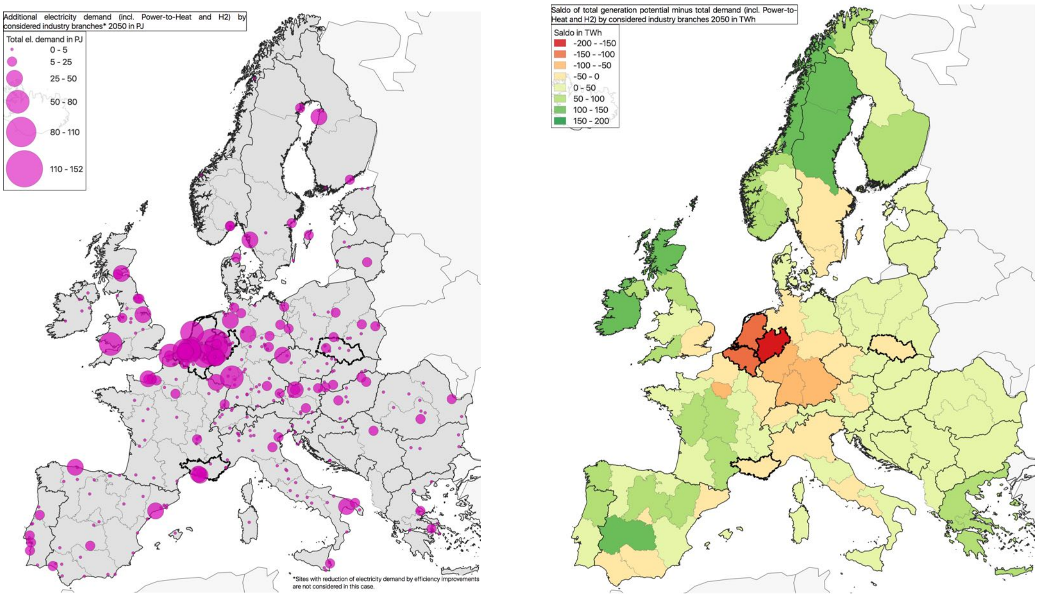


Figure 1: Regional distribution of electricity demand 2050 of three decarbonised core industries (left) and resulting electricity balances by considering electrification of other sectors

Source: own graphs based on own calculations and on (Material Economics, 2019), (e-Highway 2050, 2014)

According to the scenarios developed in the study “Industrial Transformation 2050” (e-Highway 2050, 2014), the additional industrial electricity demand compared to 2015 could sum up to about 450 to 750 billions of kWh_{el} in 2050. These values “only” apply to the three branches of basic chemicals, steel and cement and depend on the pathways and in particular the amount of hydrogen production via electrolysis (cf. chapter 2 and 3). This new industrial demand alone equals to an increase of up to 26% compared to the total electricity demand of appr. 2,900 billions of kWh_{el} in the EU 2015 (eurostat, 2019), which in itself requires a significant enhancement of the existing European power grid.

Within this "new processes" scenario, CCS plays only a relatively minor role, but nevertheless, annual emissions of 45 Mt remain from 2050 onwards, which must be captured and stored for full decarbonisation. If, however, an alternative, more CCS-intensive strategy was to be pursued (“carbon capture” pathway in (Material Economics, 2019)), this number drastically increases to 235 Mt CO_2/a from 2050 onwards. The latter demand for CCS and it’s spatial distribution across Europe is depicted in Figure 2.

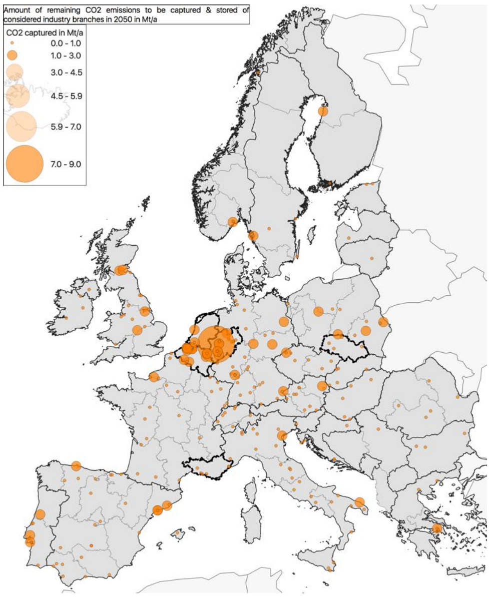


Figure 2: Remaining CO2 emissions from considered industry branches that need to be adressed by CCS in Mt/a from 2050 onwards

Source: own graphs based on own calculations and on (Material Economics, 2019)

Furthermore, Figure 1 shows that due to the existing spatial distribution of basic industries in the EU, the future demand will be largely concentrated in just a few regions with important industrial clusters. These are in particular the region of North-West Europe (BENELUX+NRW[2]), Mid-East England, Southern France, Southern Italy, Eastern Spain and Southern Poland. Thereof, the following three regions have been selected for an in-depth analysis based on their relevance and geographical distribution (cf. chapter 2):

- North-West Europe - as by far the largest industrial cluster in the EU (focus of this deliverable)
- Southern France - as a proxy for the Mediterranean Region (see deliverable WS 2 (Wuppertal Institut & ECF, 2020b))
- Southern Poland - as a proxy for central European industrial regions (see deliverable WS 3 (Wuppertal Institut & ECF, 2020c))

North-West Europe covers the industrial triangle between Antwerp, Rotterdam and Rhine-Ruhr, being the most important cluster of steel and chemical industry in Europe. Today, this region is home to appr. 50% of the petrochemical capacity in the EU, it's chemical parks are well connected to each other by feedstock and product pipelines and the river Rhine is a backbone of logistics. Within Europe, this region represents a unique "hot spot" of energy demand. The supply of the large quantities of electricity and hydrogen that will probably be needed as well as transport and storage of CO_2 imposes an enormous infrastructural challenge.

[2] North Rhine-Westphalia

The relevant qualitative and quantitative characteristics of this hot spot region, the decarbonisation strategies considered and the resulting new demand patterns are described more in detail in chapter 3 below. Chapter 0 to 6 then look also partly on the existing infrastructure and mainly discuss potential infrastructure solutions (depicted as storylines) for electricity, hydrogen and CCS, which have been discussed and individually evaluated by the regional experts during the interactive workshop part. The findings, which reflect the workshop results, are presented at the end of the respective chapters.

2 Methodological remarks

This chapter explains the study structure, the main reference studies used, the main methodological steps and the concept for the interactive WS part.

The study is structured into five different tasks illustrated in Figure 3, whereof the first four tasks are described below in more detail. The first two tasks T1 (industrial hot spots) and T2 (supply/storage sweet spots) lay down the basis for the analyses in core task T3 (infrastructure needs) and they altogether are the basis for the four different regional workshops (T4) and the dissemination of the results (T5).

It should be noted that the analyses about the hot and sweet spots are undertaken for both the European-wide level as well as for the regional level, while the exploration of infrastructure needs (and solutions) is performed only for the three selected hot spot regions as semi-quantitative case studies.

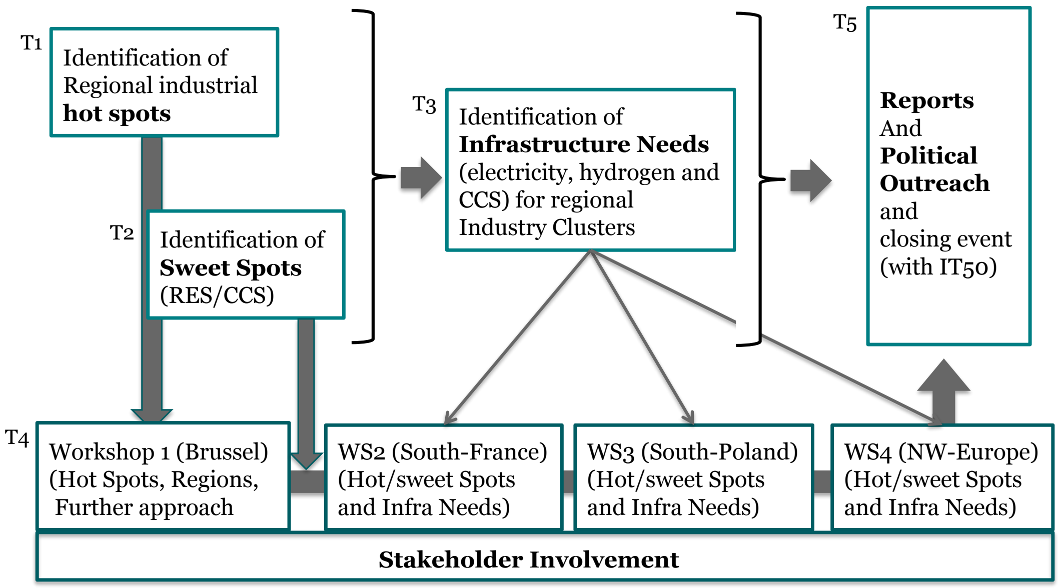


Figure 3: Structure of the study Infrastructure Needs

Source: own graph

The own analyses are mainly built on the following two studies and their data (cf. chapter 2.1 and 2.2), being used as references (see Figure 4):

1 | The study “Industry Transformation 2050” (Material Economics, 2019), which determines three different scenario strategies for the decarbonisation of three industry branches (chemicals, steel and cement) on EU-level and

2 | The study “e-HIHGWAY 2050” (e-Highway 2050, 2015), which assesses future transmission system structures for five different ambitious scenarios, in order to reach European climate targets (minus 80-95% of CO_2-emissions in 2050 vs. 1990). Of the five scenarios we choose the scenario X7, which represents an electricity supply system based to 100% on renewable energies, because it is the most ambitious one for the future power grid.

For the CCS analyses we have used a couple of different basic studies, described in chapter 2.3.

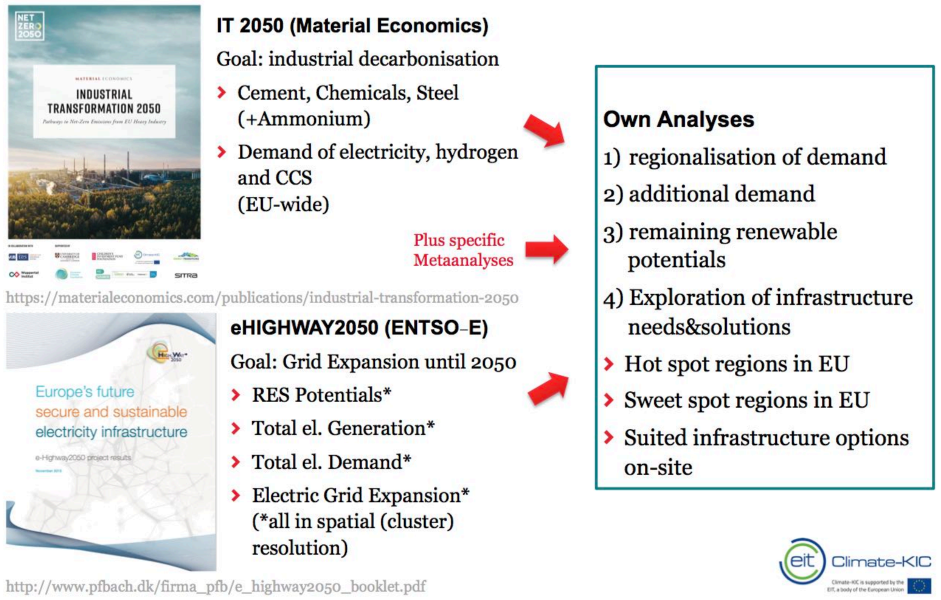


Figure 4: Reference scenarios used for own analyses

Source: own graph with front pages from (Material Economics, 2019; e-Highway 2050, 2015)

The first study (Industrial Transformation 2050 by Material Economics) gives us the aggregated demand data for the decarbonised industry branches differentiated by processes and decarbonisation strategies. These together with our own industry database and industry model (cf. Schneider et al., 2014) are used to determine both the total demand (electricity, hydrogen) as well as the additional demand (compared to 2015) in 2050 by the three considered branches on their production sites. The same is valid for the remaining GHG emissions.

The second study (eHIGHWAY2050 by ENTSOE-E) supports us with spatially resolved data of renewable energy generation and potentials, “conventional”[3] electric demand and NTC-expansion for the reference scenario X7 by clustering. These cluster data are geographically assigned with the on-site industrial demand data from above. This allows us first, to determine the additional electric demand caused by industry decarbonisation compared to the total conventional demand. Together with the known electricity generation of the reference scenario, we then calculate the resulting new electricity balance and the remaining potential for renewable electricity production in the cluster that belongs to the hot spot region.

These results build the main basis for the infrastructure and workshop analyses.

[3] In the sense, that it does not contain electric demand by the sophisticated decarbonisation strategies assumed in the first reference study of Material Economics.

2.1 Task 1: Localisation of relevant industrial cluster and their total as well as additional demands (industrial hot spots)

Task 1 (industrial hot spots) concentrate on the localisation and selection of industrial demand cluster by breaking down aggregated industrial demands on EU-level to the existing industrial production sites.

The future “hot spots” highlighted in the project have been derived by a thorough analysis of today’s production locations. Wuppertal Institute’s WISEE edm database includes all known production sites in Europe for primary steel making, steam cracking and cement clinker production with their geographical (GIS) coordinates and production capacities and was thus suited to locate possible future energy demands.

Another dimension is the technology routes used. The portfolio of technology routes used in the study by Material Economics (2019) is the same across all scenarios and includes:

- electrifying high-temperature heat supply in ovens
- electrifying steam supply
- higher shares of secondary production
- Carbon Capture and Storage (CCS)
- electrification of primary steel production by using H_2 as a reducing agent (DRI process)
- chemical recycling of plastic waste
- using biogenic feedstock for polymer production
- water electrolysis to supply hydrogen

However, the three scenarios differ in regard to the shares they attribute to certain strategies.

The “New Processes” scenario focuses on converting the production stock to electrified processes and electricity-derived chemical feedstock. As a result electricity demand in this scenario is the highest of all three amounting to 965 TWh in 2050. The major part is used for the production of hydrogen, only 226 TWh are direct electricity use (e.g. for mechanical energy or to produce heat).

The “Circular Economy” scenario tries to evaluate the contribution of ambitious circular measures in order to reduce energy requirements and costs as well as CCS. It thus ends up with the lowest electricity demand and low CO_2 volumes to be stored.

The Carbon Capture pathway shows a “world” where CCS is applied at a large scale - and not only for process-related emissions like CO_2 from cement or “CCS sweet spots”, like sites at a sea port close to potential storage sites.

In all following analyses we focus on the “New Processes” scenario to give an indication for future infrastructure requirements in an “Electrification” scenario and on the “Carbon Capture” scenario to indicate CO_2 infrastructure requirements.

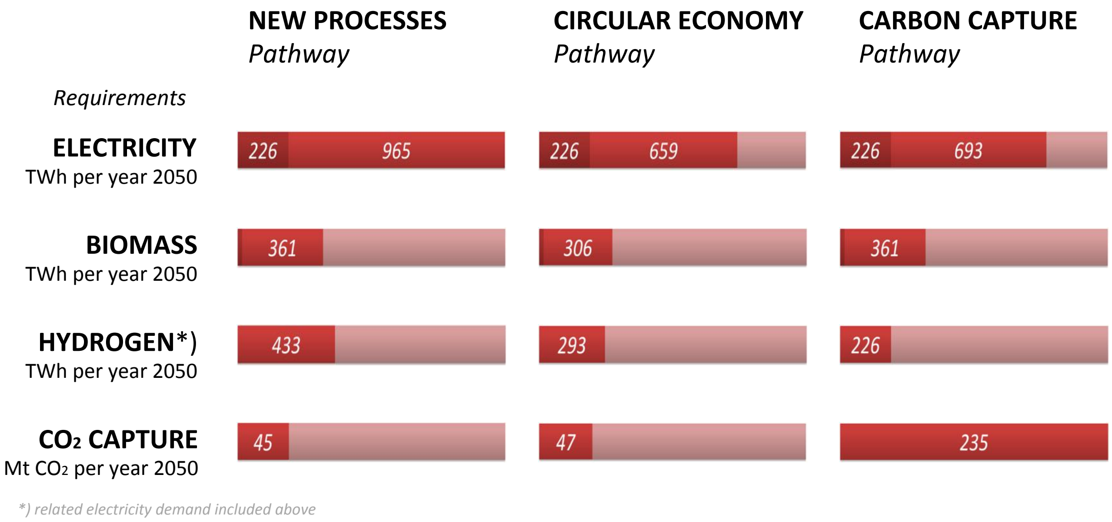


Figure 5: Energy Requirements in the three scenarios by Material Economics

Source: own graph based on (Material Economics, 2019)

The scenario results calculated by Material Economics for the EU as a whole were broken down to a production site level. We therefore also used the results of the Material Economics study and applied the technology mix for 2050 evenly for all production sites identified (see the following exemplary graph for steel industry).

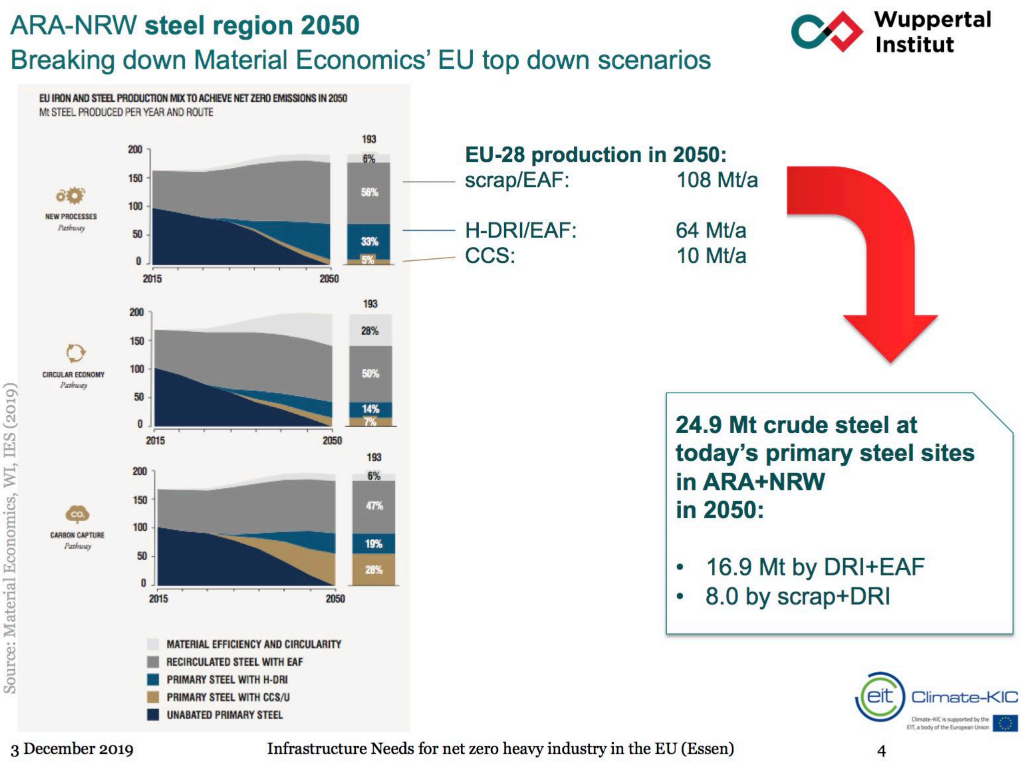


Figure 6: (Exemplary) scheme for breaking down the aggregated consumption values to industrial values according to strategies after (Material Economics, 2019)

Source: Slide from presentation held on 3rd of Dec. 2019 in Essen

The study "eHIGHWAYS2050" (see above) is used to estimate how large the additional electricity consumption of the decarbonized industries according to (e-Highway 2050, 2014) will be compared to the future total electricity consumption in 2050. It is suitable as a reference study for the entire electricity system because the focus for decarbonization is more on the other sectors. For the industrial sector, efficiency improvements as well as a moderate electrification of industrial process heat demand by power-to-heat and with renewable electricity are assumed. It is therefore supposed that the associated additional industrial electricity demand in scenario X7 will be negligible compared to that for the strategies of (e-Highway 2050, 2014) considered above. They therefore overlap little and are added to the total electricity consumption in 2050 for our analyses. Taking into account the three decarbonised industries, this is between 4750 and 5050 TWh_{el}/a.

For a better classification of this value, Figure 7 shows the total power consumption of X7 compared to "today" (average value over the years 2010-2015) and to other scenarios for the years 2040 and 2050. It is almost 50 % higher than today's total power consumption, which represents an average annual increase of almost 1 %/a. This corresponds relatively well with the assumption for electricity consumption in the DE scenario (0.9 %/a) for the year 2040 (ENTSO-E & ENTSO-G, 2019, 19f). Otherwise, the reference value of X7 is rather in the lower range of the other scenarios considered for the year 2050[4], so both this and our total electricity consumption derived from it, including the decarbonized industrial sectors, can therefore be regarded as conservative.

4 While Eurelectric's three scenarios place increasing emphasis on industrial electrification (≤60%), McKinsey's scenarios for industry rely heavily on CCS. Both studies pursue less ambitious decarbonisation strategies compared to our reference study.

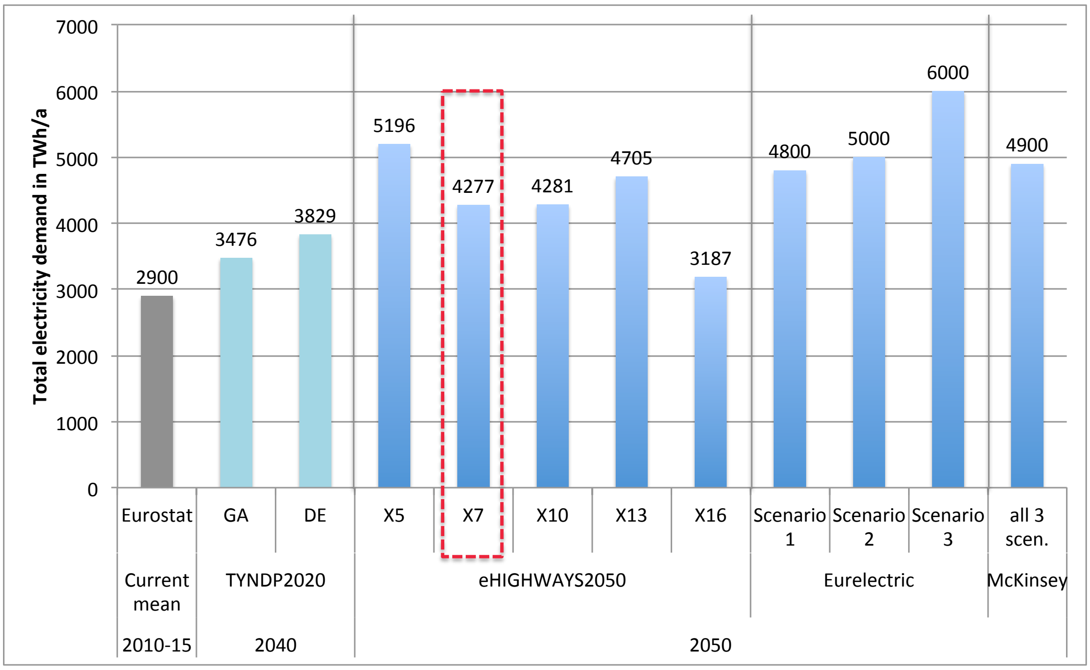


Figure 7: Total electricity demand of scenario X7 (red dotted rectangle) compared to today and to other scenarios

Source: own graph based on (e-Highway 2050, 2014; eurostat, 2019; Material Economics, 2019)

2.2 Task 2: Localisation of high-yield renewable energy potentials (sweet spots)

The goal of this task is to determine and localise spatial resolved technical potentials for renewable electricity production both in Europe and in the hot spot regions as well as to identify areas with high-yield renewable energy potentials (sweet spots).

First of all, we analysed whether the technical potential for renewable electricity production in Europe is (arithmetically) sufficient to cover the expected conventional electricity demand as well as the additional industrial demand due to decarbonisation in 2050. We have achieved this by a meta-analysis of relevant studies from which we have selected the following two studies (e-Highway 2050, 2015) and (LBST, 2017) as references.) and shown at the first workshop in June (cf. (Wuppertal Institut & ECF, 2020a)). The results indicate a broad range of generation potentials (from 4,500 TWh_{el} (e-Highway 2050, 2014) up to 14,000 TWh_{el} (LBST, 2017). This will be sufficient for the considered demand sizes, if the better assumptions about the permitted land use rates as well as the allowed water depths and coast distances for wind offshore power plants, which mainly influence the potential size, are taken into account.

In the next step, we used the technical generation potential data of the reference scenario X7 from (e-Highway 2050, 2014) to determine the renewable electricity production 2050 in the different European cluster regions needed for the supply of the conventional electricity demand. The result is shown on the left side of Figure 8. This gives the remaining solar and wind potential in the clusters after deducting the conventional power demand of X7 (see right side of Figure 8).

These spatially derived figures of the potential renewable electricity production in 2050 build the basis for the further assessment of electricity balances and remaining regional potentials when considering the additional industrial demands by decarbonisation. This helps to identify the infrastructural challenge and solution options in the hot spot regions and to prepare the interactive workshop parts by concrete background information.

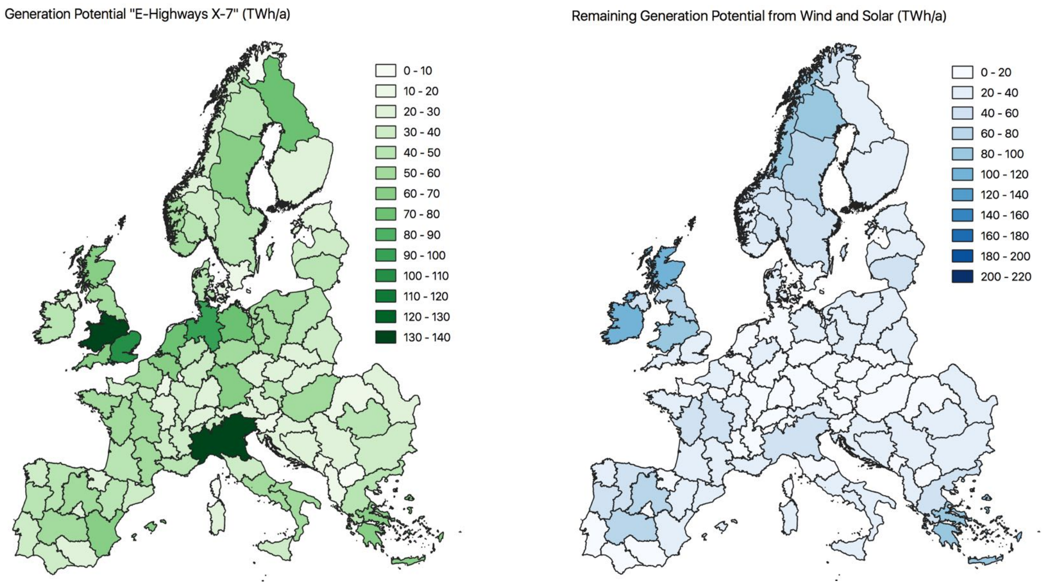


Figure 8: Yearly renewable generation potential in reference scenario X7 (left side); remaining technical wind and solar potentials after supply of conventional electricity demand 2050 (right side)

Source: own maps based on (Material Economics, 2019; e-Highway 2050, 2014)

2.3 Task 3: Localization of well suited carbon storage potentials

The main objective regarding the Carbon Capture and Storage (CCS) analysis is to roughly determine and localize the sweet spot regions for CCS in the EU by matching storage potentials, CO_2 sources and infrastructural considerations. Investigations are carried out both on the aggregated European level as well as more in detail for the respective focus regions. Primarily, meta-analyses of relevant scenario and potential studies for the EU and the selected regions are used while missing or inconsistent data are supplemented by expert judgements and own assumptions. However, neither model calculation/optimization nor complex infrastructure planning is conducted regarding CCS. Data at the European level are based mainly on the linkage of the comprehensive publications (Viebahn et al., 2010), (Neele, 2010) and (Christensen, 2009), from which the effective storage potentials are contrasted with the own determined storage requirements in Figure 9. As can be seen, the aggregated storage potentials seem to be sufficient for most countries on an aggregated level, but a closer examination will exclude many facilities due to their location, spread and geological characteristics. In order to conduct more specific regional analyses (especially as part of the storylines), a larger range of recent national level studies is used in addition, particularly (Norwegian Petroleum Directorate, 2019), (Pale Blue

Dot Energy, 2016), (MEDDE, 2015), (Ministerstwo Srodowiska, 2014), (Neele et al., 2013), (TNO, 2012) and further.

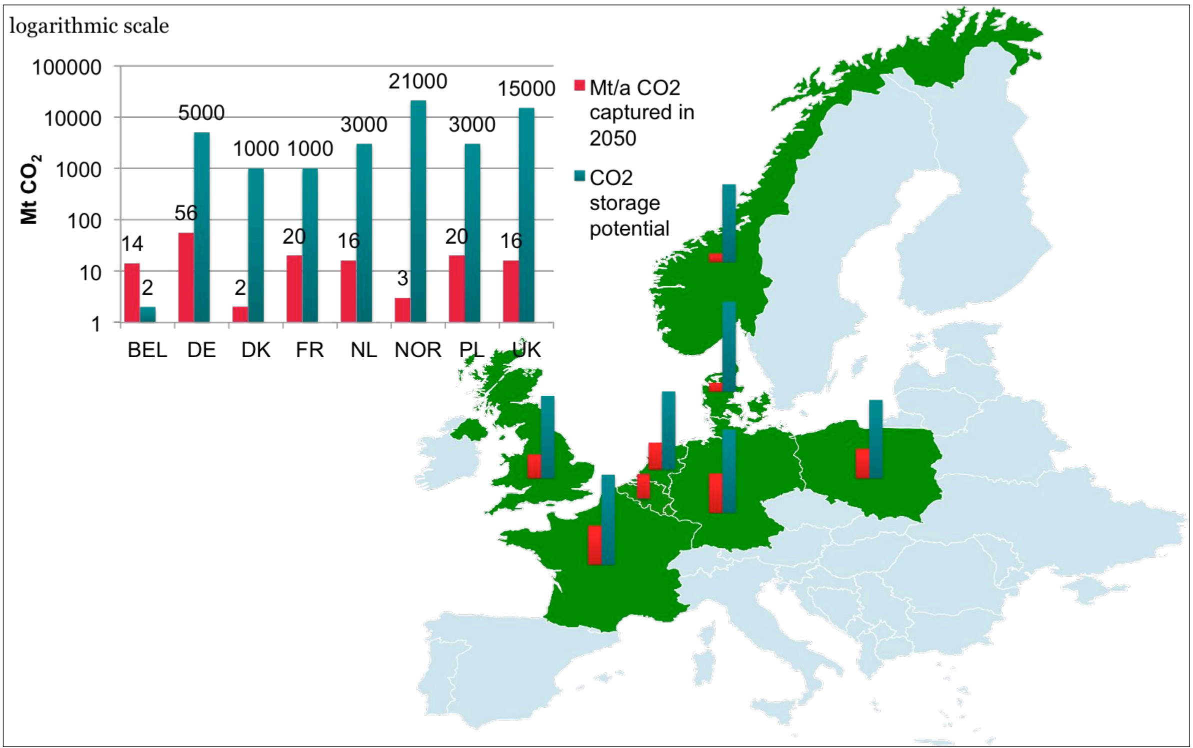


Figure 9: Storage demands and aggregated effective potentials according to Carbon Capture scenario

Source: own graph based on (Viebahn et al., 2010) and (Strategy Compass GmbH, 2020)

Regarding storage potentials, only effective storage capacities are used in this analysis in order to ensure realistic assumptions (see Figure 10). Furthermore, the focus lies on depleted oil and gas fields, as their capacity assessments refer to known hydrocarbon output volumes and are therefore assumed to be quite realistic. Coal seams are excluded from the analyses due to safety reasons. Regarding aquifers, only deep closed saline aquifers are considered and, as far as possible, the analysis is always based on the lower effective capacity limits mentioned in the literature.

For further insights into the general methodology, please see also Wuppertal Institut / ECF (2019): „Workshop evaluation report 01 (Deliverable 4.1) – Infrastructure needs of an EU industrial transformation towards deep decarbonisation, research project funded by EIT Climate-KIC.

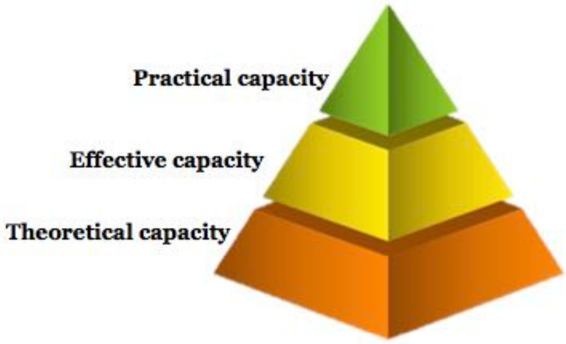


Figure 10: Capacity definitions for CO_2 storage in the literature, of which only effective storage capacities are used in this analysis in order to ensure realistic assumptions

Source: own graph

2.4 Task 3: Infrastructure analyses for selected hot spot regions

This task aims to indicate first the magnitude of the future infrastructural challenge for the selected regions and then to derive and describe possible suited solutions, which are used as input for the evaluations in the workshops (see Task 4).

The main idea behind the exploration of infrastructure needs and solutions is first to determine the size and regional pattern of the additional demands for electricity, hydrogen and CCS, in order to get a better understanding of the future challenge in the region. The next step is to determine the supply and storage capacities required in each case, assuming that the demand is for base loads with very high capacity utilization (8000 h/a). These capacities represent approximately the minimum challenge for adaptation and expansion of the infrastructures. They are then first compared with the corresponding potentials in the immediate vicinity of the region in order to assess the possibilities of decentralised solutions. In addition, it will be investigated in which more distant regions suitable potentials for the supply of demand can be found. For this purpose, imports from non-European countries, especially from North Africa, are also taken into account.

Based on these analyses and considerations, different semi-quantitative storylines for infrastructure solutions (see chapter 4-6) are developed for each region and the corresponding workshops. These are differentiated according to regional, national and European or international solutions, depending on the requirements and suitability. It is assumed that the infrastructure solutions are preferably spatially oriented between hot and sweet spots.

Figure 11 illustrates these relationships using electricity as an example. The majority of renewable electricity generation potentials are concentrated in a few countries, mainly in regions away from the demand centres. This applies in particular to the very large potentials in the North Sea, Great Britain, Spain and Scandinavia. In comparison, the majority of electricity demand is concentrated mainly in five countries and metropolitan areas.

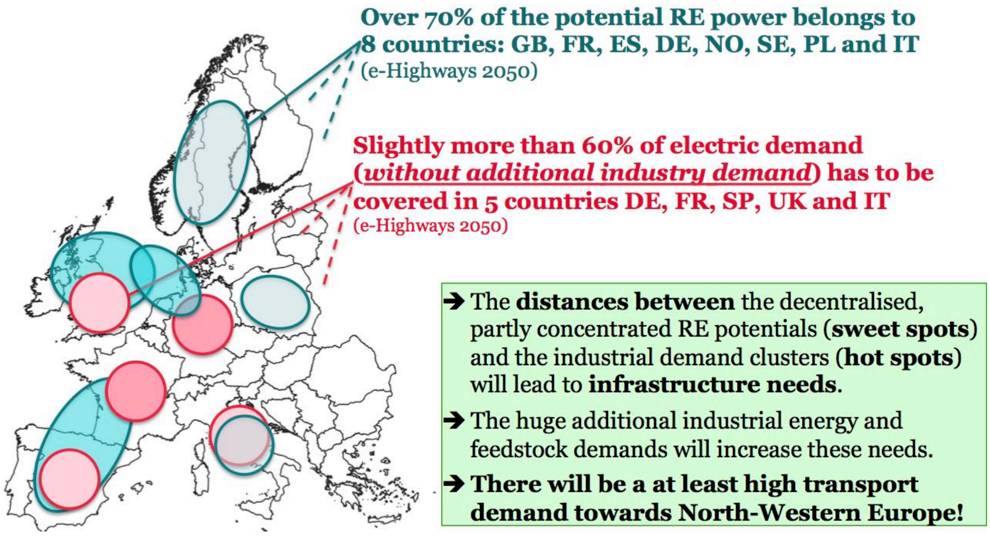


Figure 11: Overview of the major locations of renewable electricity potentials and electricity demand by European countries

Source: own graph based on information in (Material Economics, 2019; e-Highway 2050, 2014)

For the quantitative part of the analyses, new electricity balances for all clusters are calculated from the previously determined cluster data on conventional electricity demand and corresponding electricity generation as well as on the additional industrial electricity demand, and are presented as maps. These show very clearly where and to what extent the supply requirements are changing and in particular where they are becoming more acute. The new electricity balances are compared with the remaining, not yet fully exploited renewable generation potential on site and in Europe. The results are in turn corresponding maps which serve as a basis for the WS analyses (see chapter 4-6).

In addition, the selected hot spot regions tend to already have relatively powerful electricity and gas pipelines, which in principle offer good conditions for future challenges. For this reason, additional essential data is collected in order to be able to better assess the importance of the existing infrastructures, at least qualitatively.

Finally, it has to be noted that the infrastructure analyses have been done on the above mentioned semi-quantitative level, but not by modelling or economic optimisation.

2.5 Task 4: Interactive workshop parts for exploration and evaluation of infrastructure solutions

Only desktop research as outlined before cannot adequately adress and solve the infrastructure challenges of decarbonised industries in the regions. That is why we performed a total of four different workshops in order to involve relevant experts from practice with respect to the topics and the hot spot regions. This is intended to increase the awareness of the infrastructure needs of a future decarbonised industry and to critically and constructively review the results and possible solutions in order to improve them as far as possible.

The first workshop on 13 June 2019 in Brussels served initially to publicise the study and subsequent regional workshops and to present and reflect on the basic assumptions and approaches with regard to their suitability. There is a separate workshop report about the contents and findings (see (Wuppertal Institut & ECF, 2020a).

The three regional workshops, on the other hand, each focus on the selected regions in the context of their surroundings and Europe and follow the same concept and procedure to a large extent. This is exemplified in the agenda for the workshop on which this report is based in Figure 12.

First, the background, objectives, reference studies and basic assumptions are presented relatively briefly, followed by a detailed presentation of decarbonization strategies and resulting demands for the hot spot region. Since a good understanding of these strategies and results is particularly important for the following interactive parts, the participants are given the necessary time for further questions and initial discussions.

Depending on the number of participants, the main interactive parts of the workshop will then preferably take place separately for electricity, hydrogen and CCS. Each part starts with a short presentation of the background (i.e. additional industrial electricity demand by industry and location, resulting electricity balances for the clusters and existing infrastructures) and then leads to the required supply capacities and the derivation and description of possible infrastructure solutions as a storyline.

These storylines then form the basis for further joint discussion of the infrastructures. First of all, the participants collect topics and arguments to be seen as (essential) strengths and weaknesses for each storyline, by writing or sticking them on a large poster. The contributions are presented to each other and in some cases already discussed (more intensively). The result is an overview of individual strengths and weaknesses for each infrastructure option (cf. Figure 17 and Figure 29).

For more in-depth analyses, preferred solution options are selected next. This is done indirectly by identifying the overall least favoured storyline. For each storyline, the participants may assign resistance points between 0 (for no resistance) and 10 (for very high resistance), which express how strongly they themselves would reject this solution. The result is a set of (different) resistance points from which the average resistance is calculated for each option. The solution option with the highest resistance is then not considered further.

The in-depth analyses are then carried out differently for each workshop due to the different numbers of participants. For the underlying hot spot region North-West

Europe the following questions will be discussed for the remaining storylines together or divided into groups[5]:

- „Influencing factors on implementing necessary electricity infrastructure“ (group)
- „Important moments for the establishment of hydrogen infrastructure“ (group)
- „Which influencing factors do you see from today‘s situation for setting up a CCS infrastructure?“ (all)

As a result of the group work, the individual contributions of the participants to the questions are collected on a poster and clustered as far as possible (cf. Figure 20).

In the case of CCS, the group will also fill out a pre-fabricated diagram to show possible transformation paths for the CCS capacities required over the period until 2050 (cf. Figure 31).

At the end of the workshop, all participants come back together in the plenum and present to each other the results achieved and special features of the discussions.

Workshop schedule
Infrastructure needs for the decarbonisation of heavy industry up to 2050
3 Dec 2019 Essen, hdt congress center (Haus der Technik e.V.) , Hollestr. 1, 45127 Essen

Time	Duration	TOP		Persons
10:00	00:30	**Welcome & background information (aims & scope of project, basic approach and underlying scenarios)**		Stefan Lechtenböhmer, Frank Merten (WI) Rannveig van Iterson (ECF)
10:30	00:15	Overview of the study "Industrial Transformation 2050"		Clemens Schneider (WI)
10:45	00:30	Decarbonisation results for the industrial hot spot region between Antwerp, Rotterdam and North Rhine-Westphalia		Clemens Schneider (WI)
11:15	00:30	Questions & answers		
11:45	00:05	Distribution to **2** sessions		Christine Krüger (WI)
11:50	00:15	Coffee break		
12:05	01:10	Session 1: Infra needs for H2/gas and power system	Session 2: Infra needs for CCS	1: Christine Krüger, Arjuna Nebel, Frank Merten 2: Alexander Scholz, Ansgar Taubitz, Clemens Schneider
13:15	00:45	**Lunch**		
14:00	01:15	Session 1: Follow-up H2/gas and power system	Session 2: Follow-Up CCS	as before
15:15	00:15	Coffee break		
15:30	00:45	Resume of sessions 1 and 2		Representatives of session
16:15	00:15	Wrap-up of the day and outlook		
16:30		**Farewell**		

Figure 12: Agenda of the workshop for the hot spot region North-West Europe

[5] The two groups for electricity and hydrogen changed after half the time and then continued the group work based on the results of the previous group.

3 Regional demand characteristics 2050

The focal region “North-West Europe” at first consists of The Netherlands with a high density of heavy industry in the Southern province of South Holland around the Rotterdam harbour with refineries and petrochemical industry. Immediately connected is the Flemish heavy industry cluster around the port of Antwerp – another petrochemical cluster – and the steel plant at Ghent in Belgium. The third corner of this heavy industry cluster is the Rhine-Ruhr area, which is located in the West of the German federal state North Rhine Westphalia. The Rhine-Ruhr area comprises a petrochemical cluster around Cologne and another around Gelsenkirchen. Duisburg is the spot in Europe with the highest crude steel production.

In between these corners there are other major petrochemical sites e.g. at Beringen (Belgium) and Geleen (Netherlands). Taking that altogether the region is unique within the EU in regard to the density of heavy industry and the linking infrastructure as well as in regard to the energy requirements of industry. All in all this regions comprises almost 50% of the EU’s petrochemical production and about a quarter of European primary steel production.

The following maps indicate the results of breaking down the overall EU results for the “New Processes” (NP) scenario in the (Material Economics, 2019) study to single sites according to their share in European production capacity today.

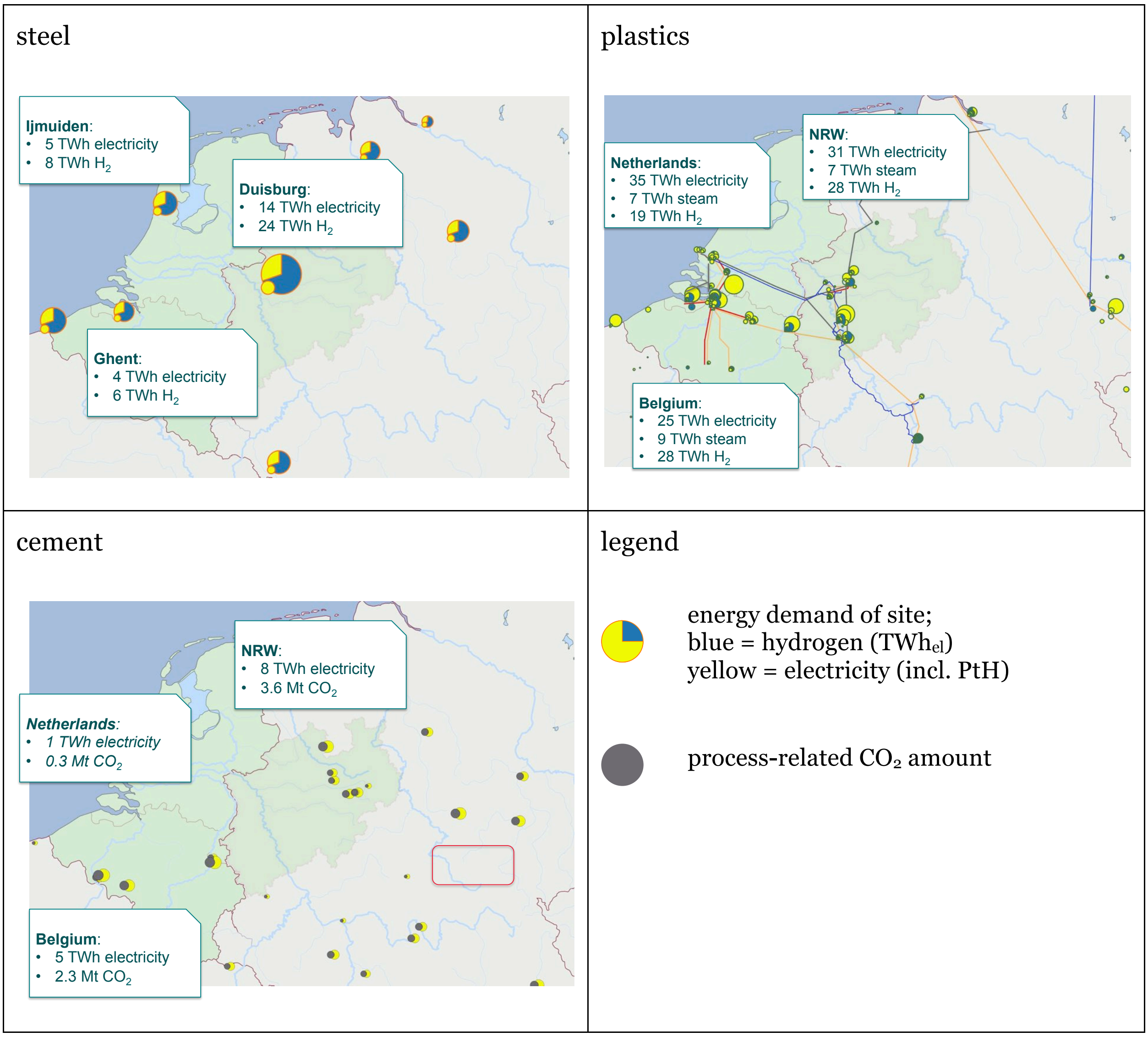


Figure 13: Energy demand and CO_2 flows in the region in 2050

Source: own graph based on (Material Economics, 2019)

It can be seen that steel industry represents the greatest single sinks, in particular for hydrogen: The steel site of Ijmuiden will require 8 TWh_{th}, Ghent 6 TWh_{th} per year and Duisburg with its three sites will have a demand of 24 TWh_{th}/a in the “New Processes” scenario 2050. The hydrogen demand of the plastics industry is even higher. It is a bit more scattered, but still clustered around a few major sites that are connected by a strong pipeline grid to exchange energy, feedstock and platform products (indicated by the lines drawn in the map). Cement production is located at the periphery of the core region. In total, however, its future electricity demand particular in Belgium and NRW will be considerable if cement clinker ovens are operated with electricity instead of fuels as assumed in the NP scenario. The remaining process-related CO_2 flows are another issue relevant for future infrastructure needs. The location of the cement plants – rather far away from other pipeline infrastructures – is a specific challenge for the application of CCS. Process-related CO_2 flows amount to six million per year in the region, that would have to be stored.

4 Storylines for electricity infrastructure solutions

North-West Europe is a region of a high energy demand due to a high population density and a strong industrial sector and will presumably remain so in the future. The decarbonisation of heavy industry sectors will lead to higher electricity demands, thereby intensify this load characteristic.

Figure 14 shows the industrial electricity demands in the considered sectors in 2050 (without electricity for hydrogen), which rises from 28 TWh/a to 147 TWh/a. These numbers result from analyses based on the scenario “new processes” (Material Economics, 2019), which is the scenario with the highest additional electricity demand. These demands result in an additional necessary electricity transport capacity of 15 GW, when this extra load is assumed to be close to baseload (8,000 full load hours).

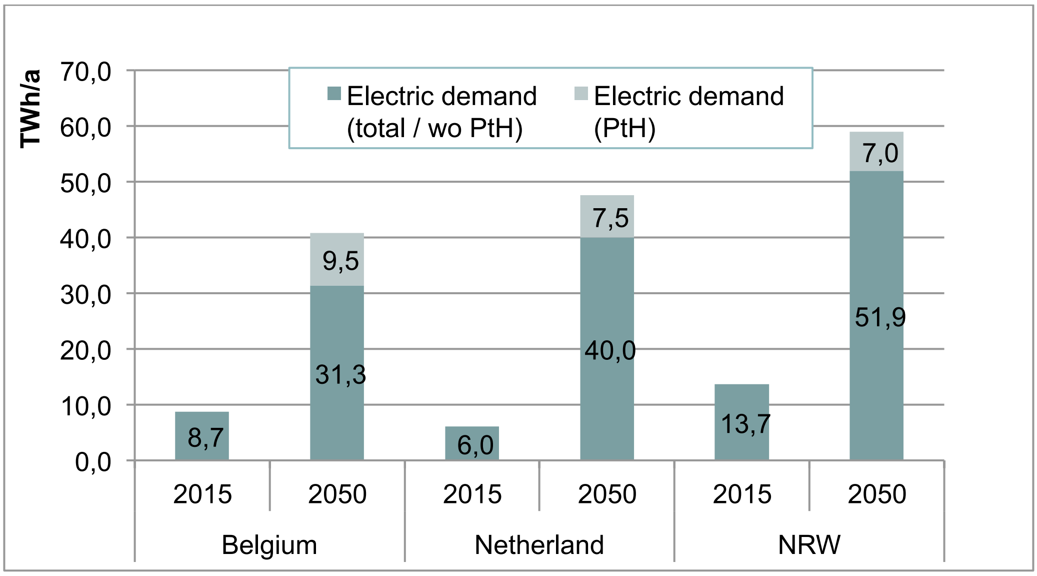
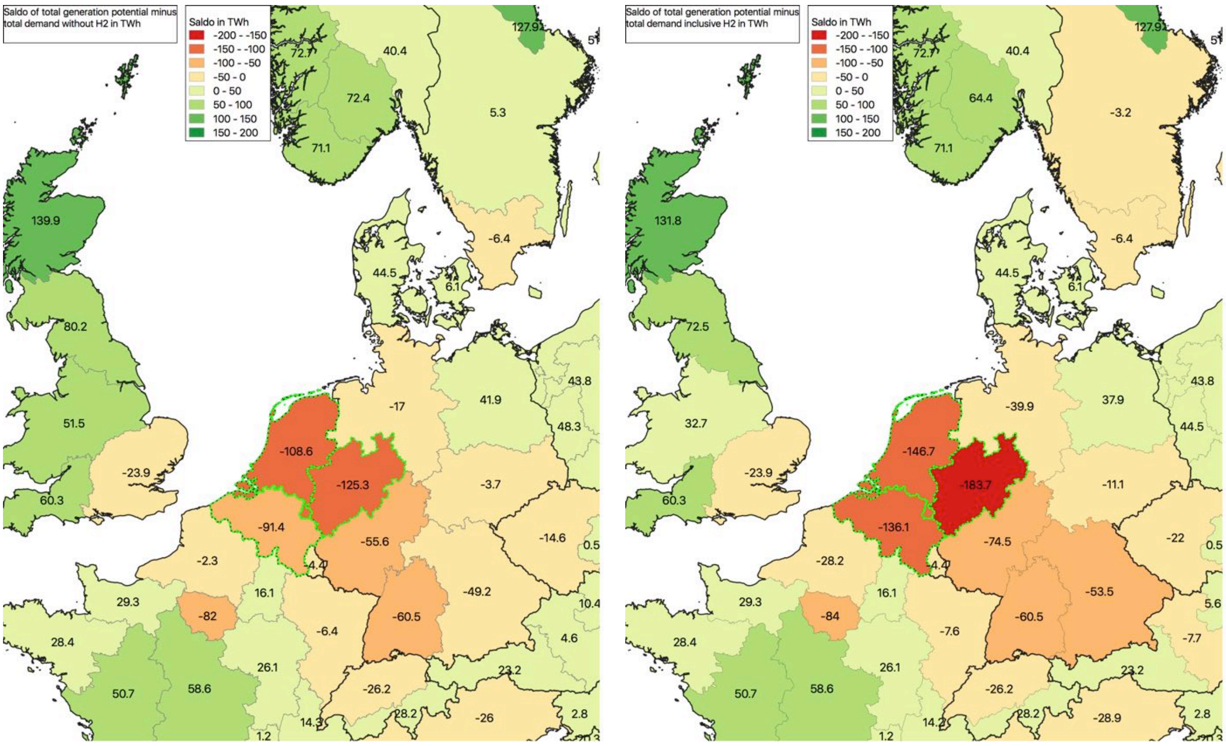


Figure 14: industrial electricity demand in 2015 and 2050

Source: own illustration and calculations based on (Material Economics, 2019)

These industrial demands strengthen a characteristic of disadvantageous spatial distribution of loads. Figure 15 shows the balance of the potential for generating renewable electricity based on (e-Highway 2050, 2014) scenario “100% RES” and the electricity demand (sum of demand from “100% RES” and additional electricity demand for decarbonised industry). Offshore wind potentials are included in the adjacent regions’ generation potentials. Regions coloured green are regions where the electricity generation potential is higher than the demand, red is indicating a higher demand than generation potentials. These maps show that even if all generation potentials were exhausted, the region of North-Western Europe would still have a strong deficit and be heavily dependent on imports.



(A) without electricity for H_2 (B) including electricity for H_2

Figure 15: Balance of generation potential and demand, (A): without electricity for hydrogen, (B): with electricity for hydrogen

Source: own illustration based on (Material Economics, 2019) and (e-Highway 2050, 2014)

Electricity would need to be generated in regions of high generation potentials and then imported into the regions of high demand. There are two main different storylines for these imports that can be distinguished:

- Storyline Electricity 1: import electricity from northern Europe (Scandinavia, United Kingdom)
- Storyline Electricity 2: import electricity from MENA

4.1 Storyline Electricity 1: Import from northern Europe (Scandinavia, UK)

Figure 16 shows the balance between generation potential and additional demand without hydrogen, and the grid that has been calculated in (e-Highway 2050, 2014) in grey colour. This depicted grid includes grid expansion to 2050 in order to fulfil the transmission needs foreseen in the eHighway scenario “100% RES”; this does not include transmission for additional electricity for decarbonised industry.

The blue lines indicate additional transmission needs for electricity imports to North-West Europe. The eHighway study already assumes an expansion of the capacities to Scandinavia and the United Kingdom. In addition, another 15 GW of transmission capacity are necessary for decarbonised industry. The blue lines indicate an example of where these additional connections could be made: strengthening the connection between North-Western Europe and Norway, connecting to offshore wind parks in the North Sea that belong to UK territory, and enhancing the connection between Germany, Netherlands and Belgium.

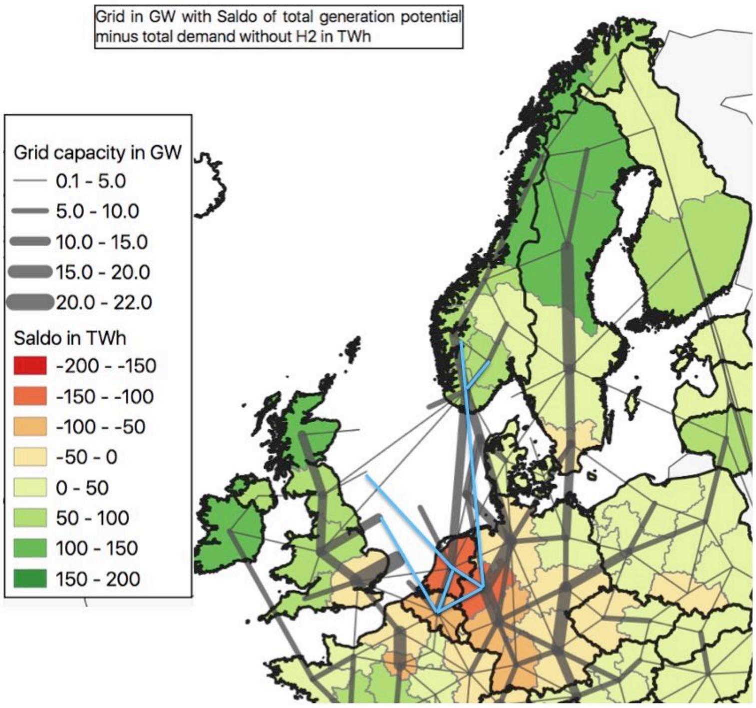


Figure 16: Electricity grid according to (e-Highway 2050, 2014) (grey), additional grid (blue) and balance between generation potentials and electricity demand (wo hydrogen)

Source: own illustration based on own calculations, (Material Economics, 2019) and (e-Highway 2050, 2014)

Evaluation of storyline E.1

Within the workshop, the storylines were evaluated in terms of their strengths and weaknesses (see Figure 17). For storyline E.1, the existing infrastructure and the existing political and economic relationships were identified as the most prominent strengths. An additional strength is the improvement of the European security of supply and the exploitation of the large hydropower potential in Scandinavia. According to the workshop participants, the weaknesses of this storyline lie in possible competition for energy exports with the United Kingdom, which will soon no longer be part of the EU and energy exchange could therefore be more complicated than expected today. The possibility of using the biomass potentials in Northern Europe in a sustainable and climate-neutral way has also been doubted.

The overall rating of this storyline by the participants of the workshop was 2.73, where 0 can be regarded as full agreement and 10 as full rejection.

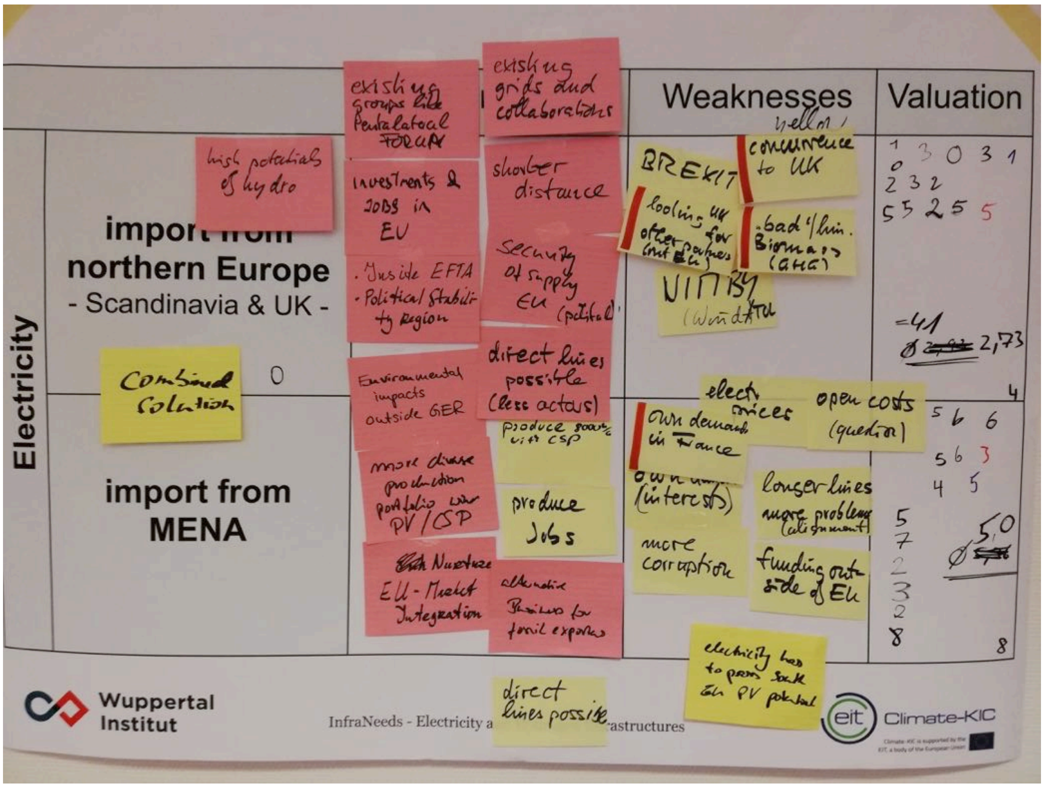
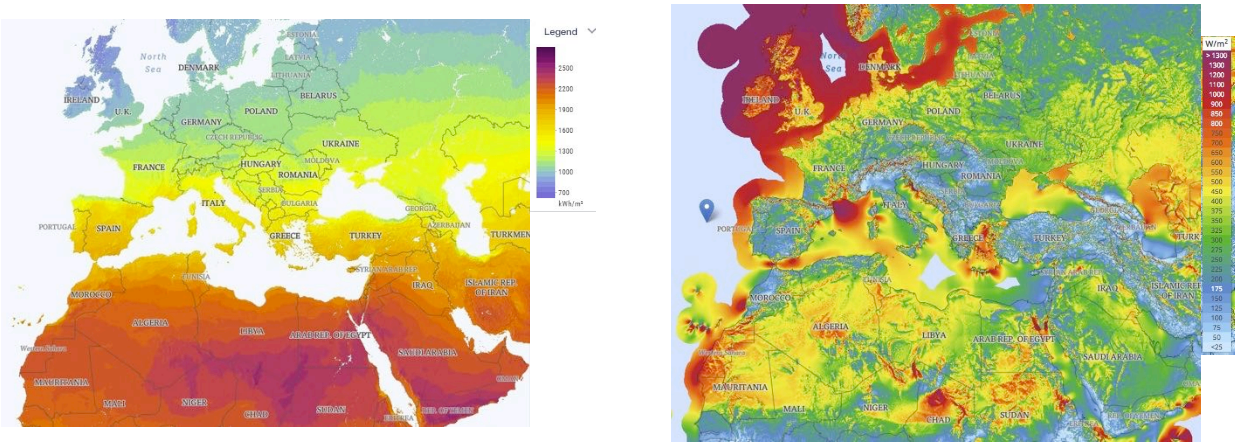


Figure 17: Workshop evaluations of the electricity storylines

Source: own photograph

4.2 Storyline Electricity 2: import from MENA

Another possible source of imports could be the MENA (Middle East North Africa) region. There are large renewable potentials, especially the resources of solar, but also of wind are very high (see Figure 18).



global horizontal radiation (kWh/m²) wind power density at 100 m (W/m²)

Figure 18: left: solar and wind resources according to Global Solar Atlas and Global Wind Atlas

Source: left: (World Bank Group, 2019), right: (World Bank Group & DTU Wind Energy, 2019)

If this potential is to be tapped for use in Europe, the local interests and needs of the MENA region must of course be taken into account. An exemplary import route is shown in Figure 19, where electricity generated in Algeria could be transported to North-West Europe via France.

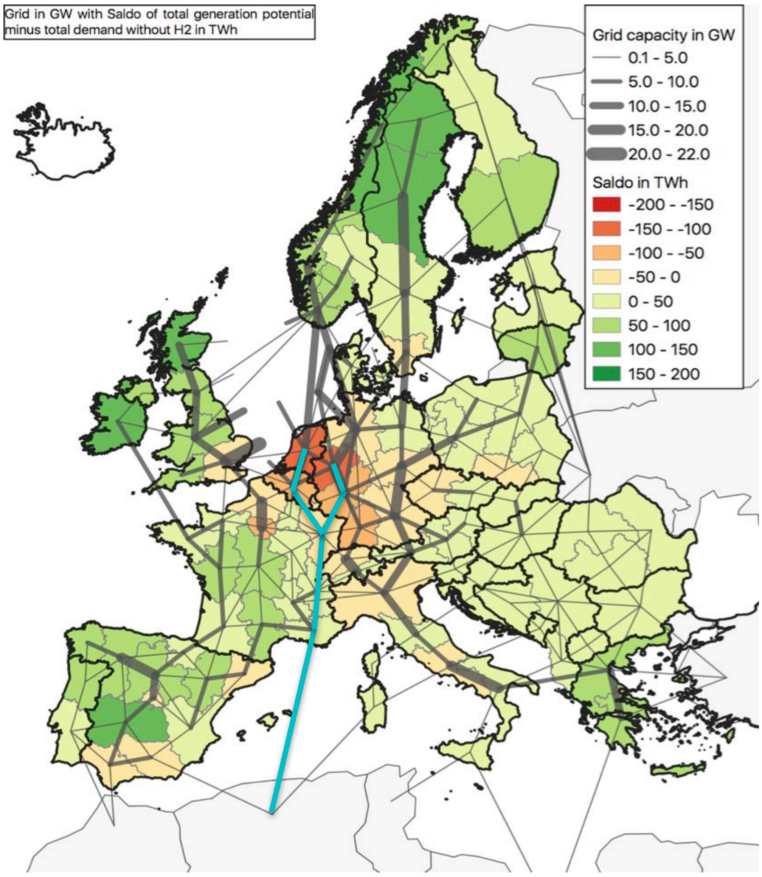


Figure 19: Exemplary electricity import route from MENA to North-West Europe

Source: own illustration based on own calculations after (Material Economics, 2019) and (e-Highway 2050, 2014)

Evaluation of storyline E.2

The diversification of the energy supply has been highlighted as the most important strength of storyline E.2. In the MENA region, electricity can be produced from wind, PV or CSP on a significant scale. This is also accompanied by an alternative business model for those countries, that still export fossil energy today. It is also seen as a strength that energy exports in the MENA region trigger development impulses and thus the greatest environmental impacts occur outside the EU. The higher political and economic risk for investments outside the EU as well as the greater distance to the load centres are seen as weaknesses. In the case of this storyline, the electricity would also have to be transported through France, although France would not benefit directly from the transport.

The overall rating of this storyline by the participants of the workshop was 5.00, where 0 can be regarded as full agreement and 10 as full rejection. The storyline, in which the electricity is imported from northern Europe is therefore preferred over this storyline.

4.3 Influencing factors on implementing necessary electricity infrastructure

As the storyline „Import from northern Europe" is the preferred one, it has been elaborated further (see Figure 20).

Great emphasis has been made on the financial options and opportunities. How the infrastructure and the energy exchange is financed has an important impact on the transformation speed and the design of the energy system. To decide these issues and to balance interests and needs of different stakeholders, the regulating authorities and political bodies are seen as major actors. If the European Green Deal will take the electrical infrastructures between northern and central Europe into consideration, this political project could speed up the development of the storyline.

Furthermore, the economic advantages and the contribution to emission reduction of wind offshore power generation have to be very clear, to get the acceptance for such a storyline.

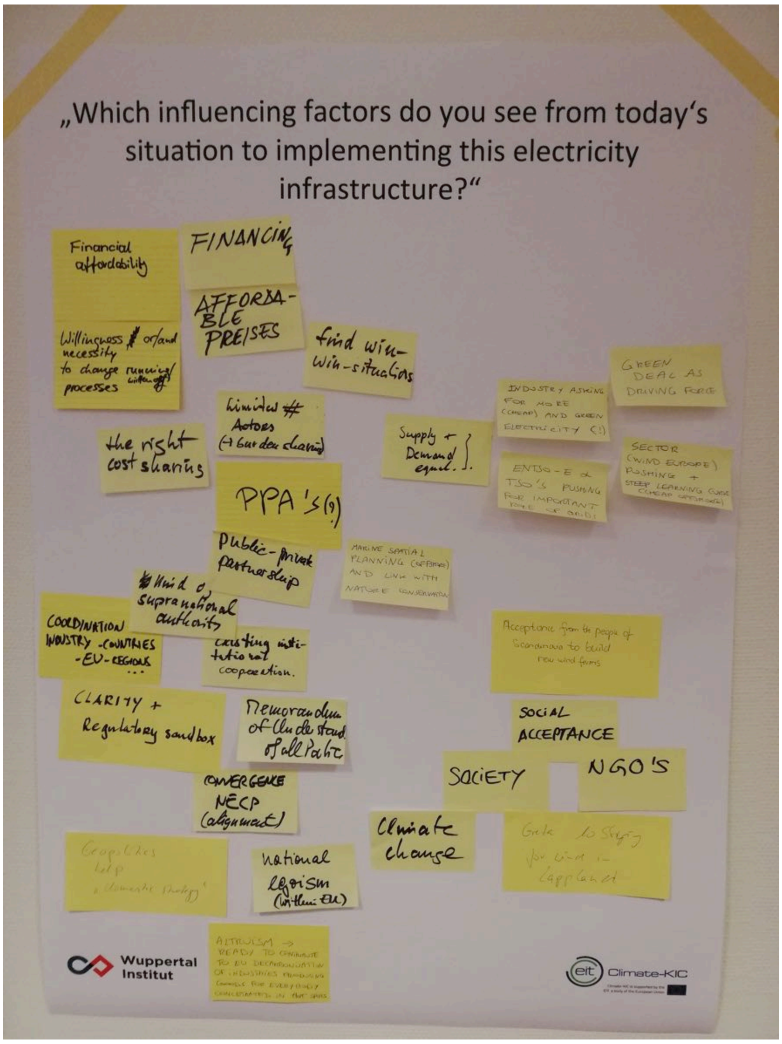


Figure 20: Influencing factors to the implementation of electricity exchange between central and northern Europe

Source: own photograph

5 Storylines for hydrogen infrastructure solutions

In addition to the industrial electricity demands described in the previous section, there is an expected hydrogen demand of 106 TWh/a in 2050 (again, these analyses are based on (Material Economics, 2019) scenario "new processes"). To produce this hydrogen, 141 TWh electricity are necessary (at an assumed electrolysers' efficiency of 75 %); this nearly doubles the amount of additional electricity demand due to decarbonised industry. Figure 21 shows the spatial distribution of these hydrogen demands.

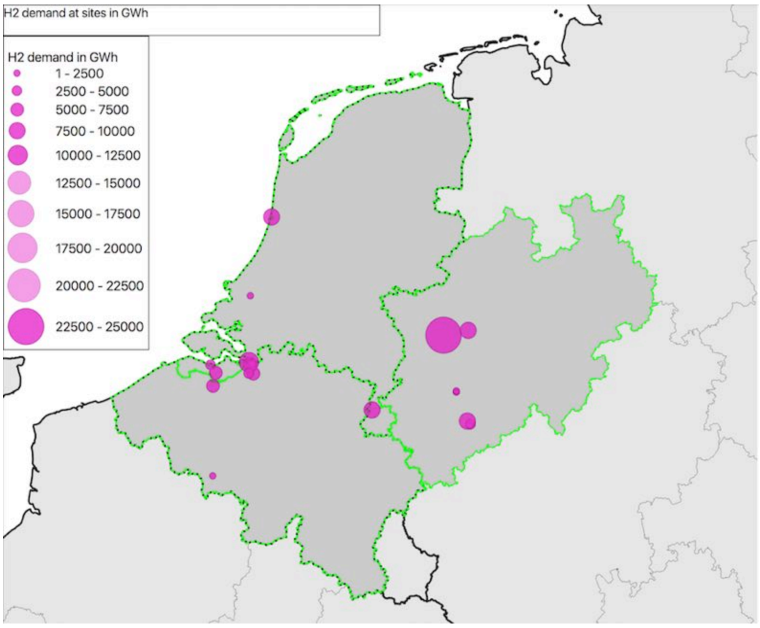


Figure 21: Hydrogen demand at sites in GWh per year

Source: own illustration based on own calculations and (Material Economics, 2019)

Electrolysers to produce that hydrogen would need to have a capacity of nearly 18 GW at 8,000 full load hours, for a baseload generation of hydrogen. A more flexible generation which could be adapted to regional load or feed-in would result in even higher necessary capacities and according storage facilities.

There are different possibilities to generate and/or transport the needed hydrogen, shown in Figure 22. Hydrogen can either be generated at each single site, or it can be distributed by a hydrogen grid. This grid could either be fed by a centralized electrolysis or with imported hydrogen. Import in turn could be from Northern Europe or MENA (see previous section, the same arguments as for electricity apply here). In the following, three distinguished storylines are described:

- Storyline Hydrogen 1: Generate hydrogen at site, transport electricity
- Storyline Hydrogen 2: Central electrolysis to supply Belgium, Netherlands and North Rhine-Westphalia
- Storyline Hydrogen 3: Import hydrogen

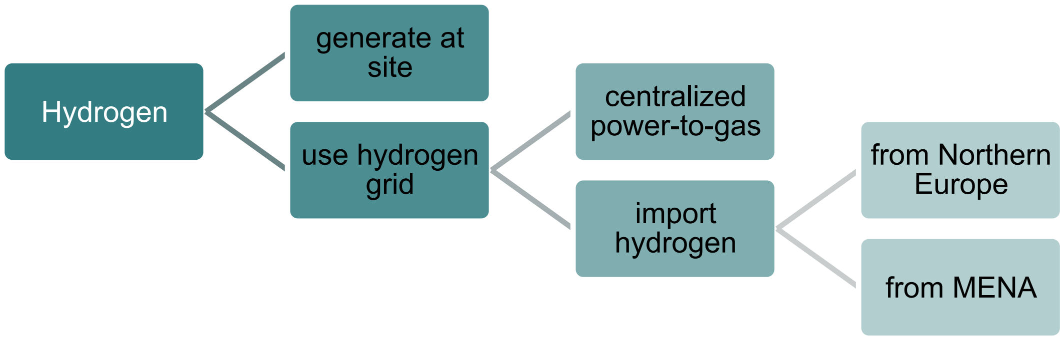


Figure 22: Possibilities to generate and/or transport hydrogen

Source: own graph

5.1 Storyline Hydrogen 1: generate hydrogen at site, transport electricity

There is a limited number of industrial sites which are assumed to have a need for hydrogen in the future (see Figure 21). These hydrogen demands could be covered locally, with electrolysers located directly at the sites. In this case, electricity would need to be transported there. The overall hydrogen demand for decarbonised industry is 106 TWh (33 TWh Belgium, 29 TWh Netherlands, 44 TWh NRW), which results in an overall electricity demand of 141 TWh. If these are assumed to be close to baseload (8,000 full load hours), this results in 18 GW of additional electricity transmission lines (6 GW to Belgium, 5 GW to the Netherlands, 7 GW to NRW).

Evaluation of storyline H.1

The main strength of storyline H.1 lies in its focus on infrastructure. Since hydrogen can be produced where it is needed, there is no need to build up a separate hydrogen infrastructure with its own challenges and losses. This enables a social, technical and political focus and thus, if necessary, faster implementation. However, the space and storage requirements at the respective industrial location are seen as a disadvantage. The additional infrastructure needs in the area of electricity grids have also been pointed out.

The overall rating of this storyline by the participants of the workshop was 6.79, where 0 can be regarded as full agreement and 10 as full rejection. This reflects, that the participants of the workshop rated the weaknesses of this storyline higher than the potential strengths.

5.2 Storyline Hydrogen 2: central electrolysis to supply Belgium, the Netherlands and North Rhine-Westphalia

Another possibility is to produce hydrogen in one suited spot instead of decentralised generation at site. That spot would need to be connected to a strong electricity grid (18 GW electrolysers' capacity in case of baseload hydrogen generation, even more if the electrolysers are to be used more flexibly). From there on, hydrogen could be transported via a hydrogen grid.

By now, there already are some hydrogen pipelines in the region. These are capable of transporting about 0.6 TWh of hydrogen per year, which is just a very small fraction of the necessary 106 TWh. So a new hydrogen grid would be necessary. This could either consist of newly built pipelines, parts of the natural gas grid could be repurposed (e.g. the grid for low-grade gas which will not be utilised in the future), or a combination of both strategies. In Figure 23 it can be seen that hydrogen demands occur near to large natural gas transport capacities.

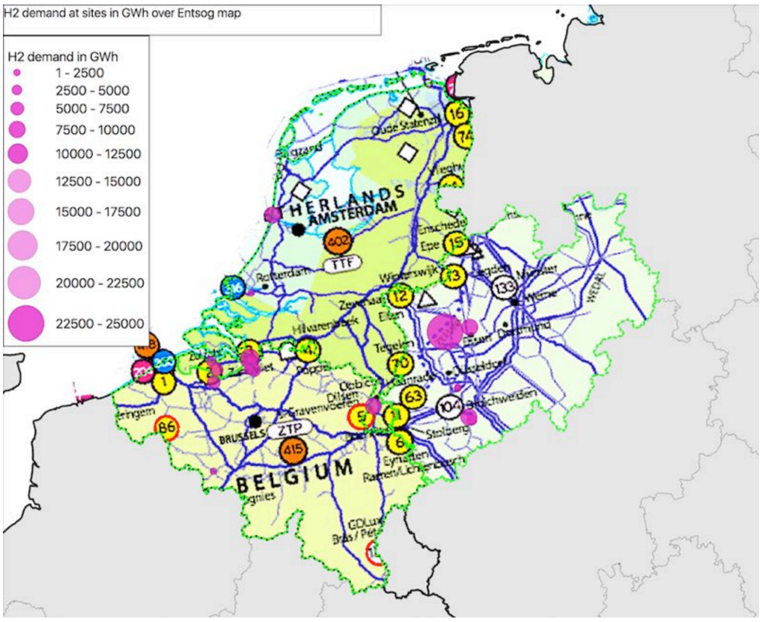


Figure 23: Hydrogen demand at sites and gas transport capacities

Source: own illustration based on own calculations, (ENTSOG, 2017) and (Material Economics, 2019)

Evaluation of storyline H.2

The reuse of existing natural gas pipelines and the possibility of buffering and storing energy in central locations have been mentioned as major strengths for the storyline H.2. But as the energy density of hydrogen is lower than the energy density of methane, the current gas pipeline capacities may have to be expanded when switched from natural gas to hydrogen[6].

The overall rating of this storyline by the participants of the workshop was 3.57, where 0 can be regarded as full agreement and 10 as full rejection.

5.3 Storyline Hydrogen 3: Import hydrogen

A possible future hydrogen grid could not only be fed by central electrolysers, but also by hydrogen imports. The region under consideration here (Belgium,

[6] This is a statement form the group discussion. However, this study does not consider the case that all natural gas is replaced by hydrogen, but instead only the additional industrial hydrogen demands.

Netherlands, NRW) is a hydrogen load focus, but there are further hydrogen demands in the surrounding areas (see Figure 24). The European hydrogen demand for decarbonising industry is about 296 TWh/a (1 065 PJ/a) in 2050, while more than 50 % of this demand (158 TWh/a, 567 PJ/a) occur in the observed region and its surrounding clusters.

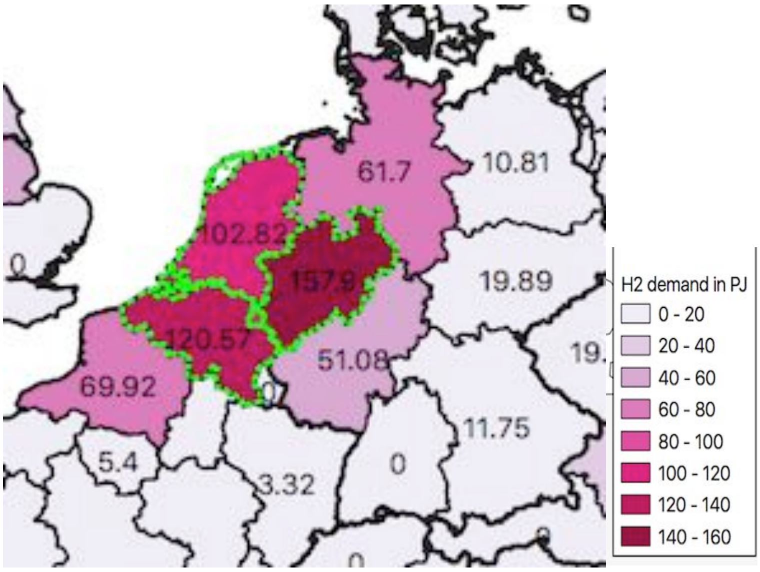


Figure 24: Hydrogen demand in the surrounding clusters (in PJ/a)

Source: own illustration based on own calculations and (Material Economics, 2019)

In addition, there are other hydrogen demands that can be expected in a decarbonized energy future (e.g. for mobility). Therefore, hydrogen imports even over long distances could be worthwhile. Hydrogen could be produced in regions with high potentials for renewable electricity, for example in Norway or North Africa (see section 0, where this has been discussed for electricity). Hydrogen could be transported via ship or via pipeline. A pipeline to cover the demand in the region of Belgium, Netherlands and NRW would need to have a diameter of 1.2 m; in case of transport by ship, about 320 shipments per year would be necessary[7]. To supply the region and the surrounding clusters, 1.5 m diameter or 475 shipments would be necessary.

Evaluation of storyline H.3

According to the participants of the workshop, the main strength of this storyline is the production of hydrogen in areas, where the electricity production is cheaper and thus the hydrogen could be less costly as well. But the political insecurities and the technical and economical challenges in transporting hydrogen via ship have been named as major weaknesses of this storyline.

The overall rating of this storyline by the participants of the workshop was 5.71, where 0 can be regarded as full agreement and 10 as full rejection.

[7] Assumptions: 10,000 t per shipment according to (Sonal Singh et al., 2015); pipeline pressure 100 bar, velocity 10 m/s

5.4 What are important moments for the establishment of the hydrogen infrastructure?

As the central electrolyser with a hydrogen distribution grid has been chosen as the preferred storyline, it has been analysed more in detail. The output of this analyses can be seen in Figure 25.

Pilot projects in place today, the high motivation to develop hydrogen solutions and "grey" hydrogen as an initializer of a hydrogen infrastructure are seen as current or very short term opportunities for the establishment of such a storyline. The switch from L- to H-gas is seen as an opportunity but as a risk at the same time. This switch seems to be a window of opportunity, but if this opportunity is missed, the establishment of a hydrogen infrastructure could be heavily delayed. As short term risks, the missing acceptance of an hydrogen infrastructure, the missing production capacity of electrolysers and the problems with the electrical grid and the capacity expansion of renewables have been named.

Mid to long term opportunities are the increased willingness of end consumers to pay for "green" products, a steady increase in the carbon price or a carbon tax and if there are green investment criteria fostering the use of electrolysers. The mid to long term risks are a competition with the CCS development and the limited feasibility of end use appliances to use hydrogen.

In the very long term, a supply with abundant renewable energy is seen as the major opportunity.

Figure 25: Important moments for the implementation of a centralised hydrogen production and a distribution via local and regional hydrogen grids

Source: own photograph

6 Storylines for CCS infrastructure solutions

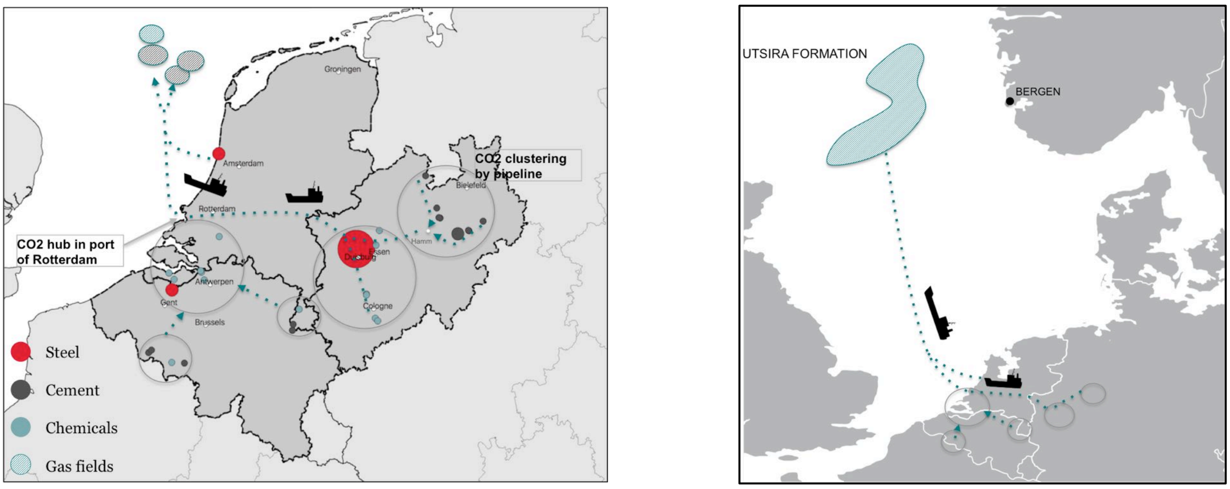
The CCS section is based on the “carbon capture” scenario (Material Economics, 2019), as this is where, in comparison to the other two scenarios, the largest installed carbon capture capacity is found and thus best illustrates the challenges in terms of capacities and CO_2 transport infrastructure. In this scenario, European heavy industry avoids 235 Mt of its total 545 Mt in the target year 2050 by CCS. Of this, North-West-Europe’s industries (steel, cement, basic chemicals) account for 32.1 Mt CO_2 captured annually (56.4 Mt if end-of-life emissions were included) from 2050 onwards.

In contrast to the previous workshops, the particular challenge for this focus region is not the identification of suitable CO_2 storage and transport options: Off the Dutch coast, there are numerous depleted gas fields whose suitability for carbon storage has been comparatively well investigated and - due to its accessibility via the river Rhine – the port of Rotterdam depicts a well-suited CCS hub. In this focus region, however, the industries and interests of three countries as well as the restriction of unilaterally distributed storage capacities had to be considered. Therefore, three different storylines were derived, which served as a basis for the subsequent discussion:

- joint strategy,
- semi-individual strategy,
- individual strategy.

6.1 Storyline 1: joint strategy – joint usage of the Dutch storage sites

The first storyline consists of a joint strategy in which industrial players from the Netherlands, Belgium and NRW jointly use the Dutch CO_2 storage capacities. The port of Rotterdam will become the central CCS hub, from where the CO_2 will be transported to the depleted gas fields off the Dutch coast. At some sites, the CO_2 will first have to be bundled via pipelines (especially necessary for the more scattered cement plants on the periphery) before it is transported to Rotterdam mainly via inland shipping (see Figure 26 A). This makes particular sense for the North Rhine-Westphalian sites, which can establish and use a common transport infrastructure for large parts of the route. As the effective capacities of the Dutch gas fields (~ 800 Mt CO_2) will suffice for around 20 - 25 years (if used by all three countries and considering the 2050 capture demand of 32.1 Mt/a, this is only a medium term solution. In the long term, there will be a joint move towards the large storage capacities (~ 21,000 Mt CO_2) in Norway, such as the Utsira Formation (see Figure 26 B).



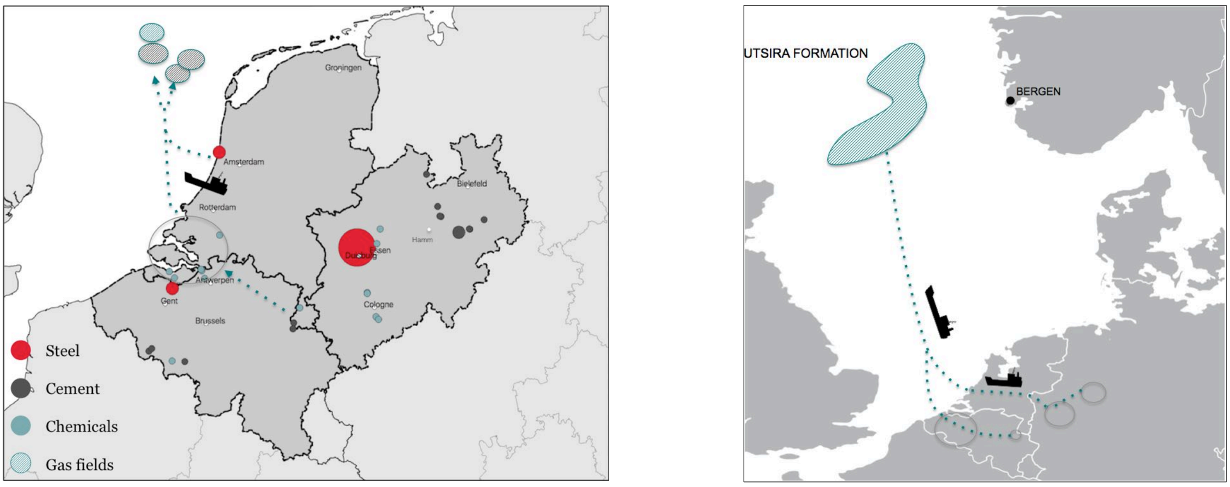
(A) (B)

Figure 26: joint strategy – (A) joint usage oft he Durch storage sites (medium term); (B) joint move to the Norwegian storage sites (long term)

Source: own graph

6.2 Storyline 2: semi-individual strategy – only the Netherlands uses the Dutch gas fields, Belgium and NRW move to Norway

The second storyline is a semi-individual strategy in which only the Netherlands uses the local hydrocarbon fields for CCS (see Figure 27 A). Belgium and North Rhine-Westphalia, on the other hand, transport their captured CO_2 to Norway right from the start (see Figure 27 B). There are still opportunities for cooperation between the two countries in the field of infrastructure development, as they both continue to use the port of Rotterdam as their joint CCS hub.



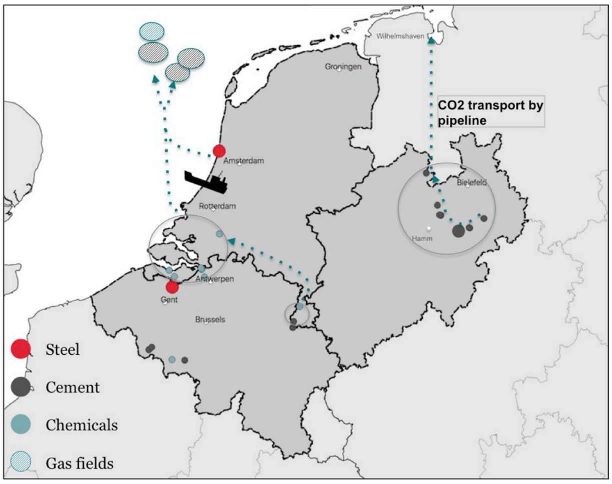
(A) (B)

Figure 27: semi-individual strategy – (A) only the Netherlands uses the local storage sites; (B) Belgium and NRW move jointly to Norway

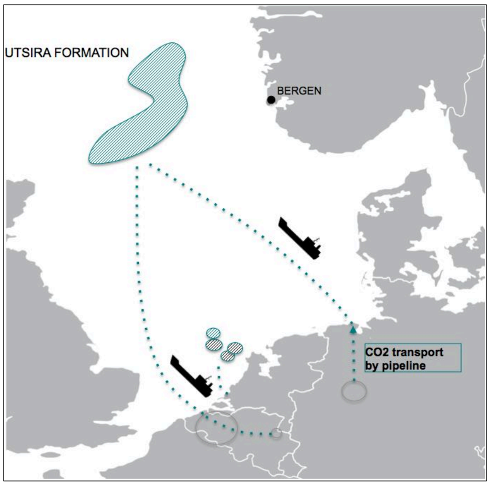
Source: own graph

6.3 Storyline 3: individual strategy

The third storyline is intended to illustrate possible effects if the steel and chemical sites in North Rhine-Westphalia decide against CCS. As the cement plants currently have no foreseeable technological alternative for their process-related CO_2 emissions, they continue to depend on CCS, but will now (e.g. in North Rhine-Westphalia) choose the shortest route to the coast by pipeline and set up their own CCS hub in Wilhelmshaven, from where the CO_2 is shipped to Norway (see Figure 28 A and B). Belgium also acts independently and transports the captured CO_2 to Norway via Antwerp. The Netherlands continues to use its local hydrocarbon fields. The individual strategy could also be seen as a more „national strategy“, as each of the three regions has its own approach with an individual CCS hub.



(A)



(B)

Figure 28: individual strategy – (A) NRW's steel and chemical sites do not follow CCS, the Netherlands uses local hydrocarbon fields; (B) Belgium and NRW (cement only) move separately to Norway

Source: own graph

6.4 Evaluation - strengths and weaknesses (interactive)

The subsequent discussion of the presented storylines was conducted interactively. The participants were asked to work out the core strengths and weaknesses of the respective strategies from their point of view and to record them in a prepared matrix (see Figure 29). The task opened up the debate especially on non-economic aspects, which were not assigned a leading role at the beginning and stimulated a lively discussion among the participants. The written results are presented in the appendix.

For the joint strategy, strengths are seen above all in the merger of the three regions (e.g. economies of scale in costs and central management). Weaknesses are the currently low social acceptance and the long time frame needed to unite all actors and to create a joint regulatory framework.

Regarding the semi-individual strategy, only a small benefit is seen for the transit corridor (Netherlands) which e.g. the actors from NRW would have to use to reach the Norwegian storage facilities. On the other hand, the dependence from the Netherlands is it's weakness.

The individual strategy is also not seen so positively, as there are 2 strengths opposed to 6 weaknesses. A high personal risk and higher costs are mentioned. In addition, there is a risk that a carbon border tax or an ETS top-up could be introduced to support domestic industry. On the other hand, there is a quick setup time with low dependencies and the fact that mainly the individual national regulatory framework applies.

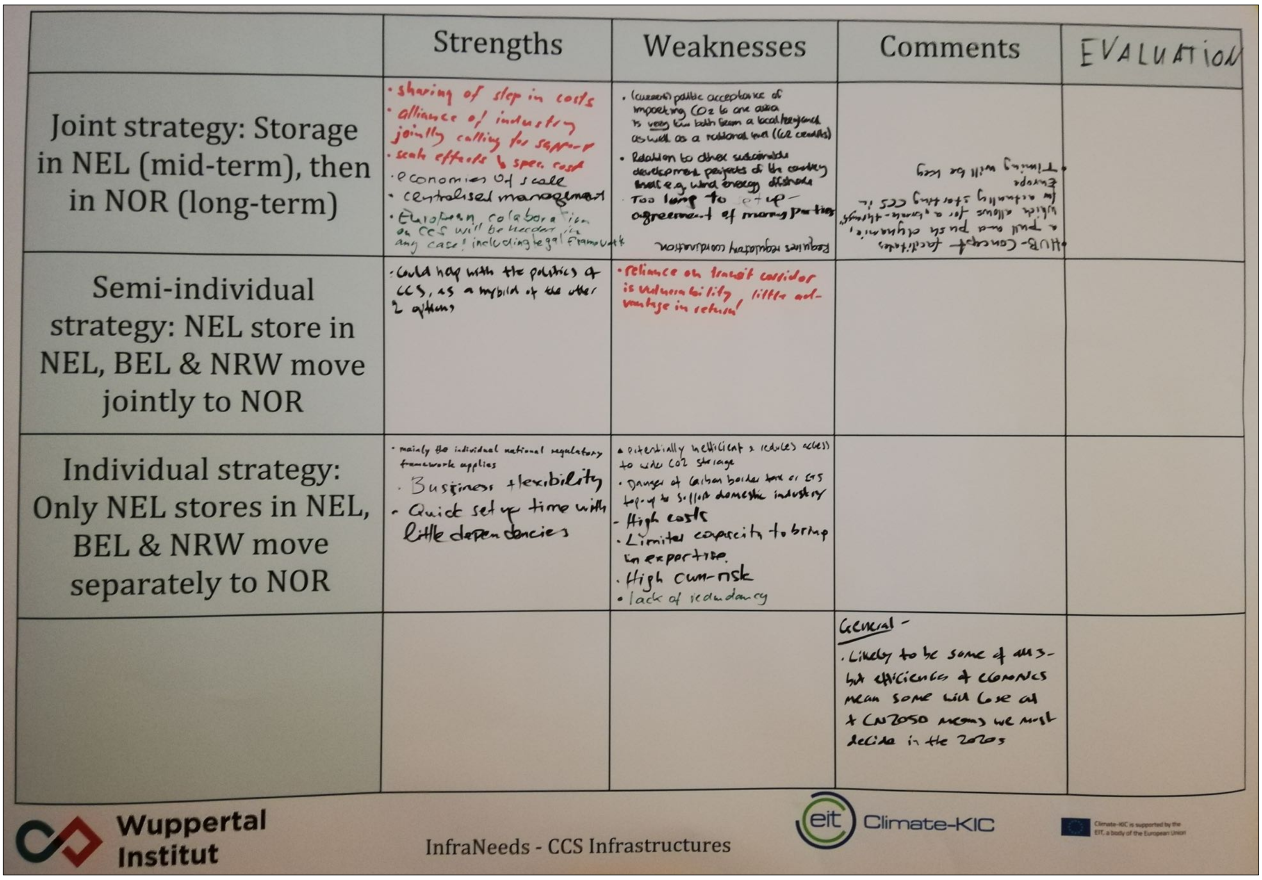


Figure 29: Strengths and weaknesses of storylines (results)

Source: own photograph

6.5 Influencing factors (interactive)

In this second interactive task, the participants were asked to identify the main influencing factors that need to be taken into account when setting up a CCS infrastructure from today's perspective. As thought-provoking impulses they were given the following guiding questions:

- What are the characteristics of the region for enabling or hindering those infrastructure developments?
- What are specific chances or risks in the region?

- Who are the relevant actors towards/against that development?
- Are there suited windows of opportunity ahead?
- Which role do current infrastructures play in that development?

Further, the participants were given stickers in different colors on which they could note down driving (green), neutral (yellow) as well as inhibiting (red) forces and attach them to a large poster. Figure 30 provides an overview of the results.

The driving role of successful demonstration projects was highlighted as particularly important. Some participants pointed out that CCS has a much lower overall societal cost than other decarbonization options. Regionally specific reference was made to the particular density of the CO_2-intensive industry, which creates synergy effects. The interface to regional innovation hubs such as universities and think tanks was also emphasised. In particular, the issue of social acceptance played a central inhibiting role for many participants and was mentioned very frequently. A complete list of results can be found in the appendix.

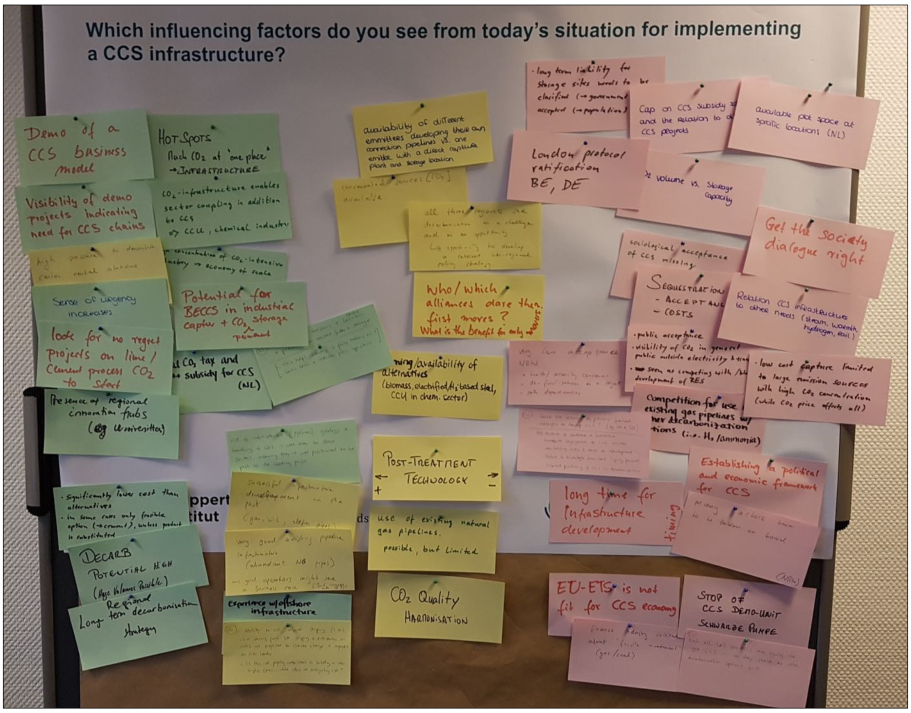


Figure 30: Influencing factors for a CCS infrastructure (results)

Source: own photograph

6.6 Transformation pathway (interactive)

As a third interactive workshop fragment, the participants were asked to think of possible development pathways for the CCS infrastructure required in the future for the three regions under consideration, starting from 2020 and extending into the target year 2050. The participants first had time to draw the pathway on a chart by themselves and were afterwards asked to present their results to the plenary on a large poster (see Figure 31).

It is striking that none of the participants believes that the CCS infrastructure required by 2050 will be fully implemented at that point in time. Two development paths with different levels of ambition are seen by the participants. This concerns both the start of CCS activities and the absolute installed CCS capacity in the region in 2050 (see Figure 30).

The more ambitious path starts in 2021 with the Final Investment Decision (FID) for the Porthos project (2 Mt/a installed capacity in 2025) and it's subsequent realization, as well as the Northern Lights Project (4 Mt/a installed capacity in 2027/2028). In 2030, the Athos and Acorn projects will lead to a strong leap in installed CCS capacity up to 10 Mt/a. In the early 2030s, the first reference units are developed and built, so that in 2035, with the expansion of Northern Lights and Porthos 2, the leap towards the 20 Mt/a mark is achieved. From this point on the development remains unclear. A range is emerging which either does not envisage any further CCS expansion by 2050 (stagnation at 20 Mt/a) or an expansion to 30 Mt/a installed capacity. A major influence is seen here in the development of the steel industry and how it's technological basis will look like in the future (strong entry into direct reduction technology or use of blast furnaces equipped with CCS).

The less ambitious curve shows only marginal CCS capacities from 2025 to 2030 (limited to pilot projects). The actual major entry into this technology is not seen before 2030, where a capacity of ~ 3 Mt/a is installed. In the course of infrastructure development (2040s), CCS capacity will reach 9 Mt/a (lower capacity limit) to 13 Mt/a (upper capacity limit) in 2050. This is only one third of the CCS capacity required for this region (32.1 Mt/a.) About two thirds of the installed capacity (7 to Mt/a) is attributed to the cement industry.

Overall, this exercise on developing the CCS transformation pathway led to a lively and intensive discussion among the participants.

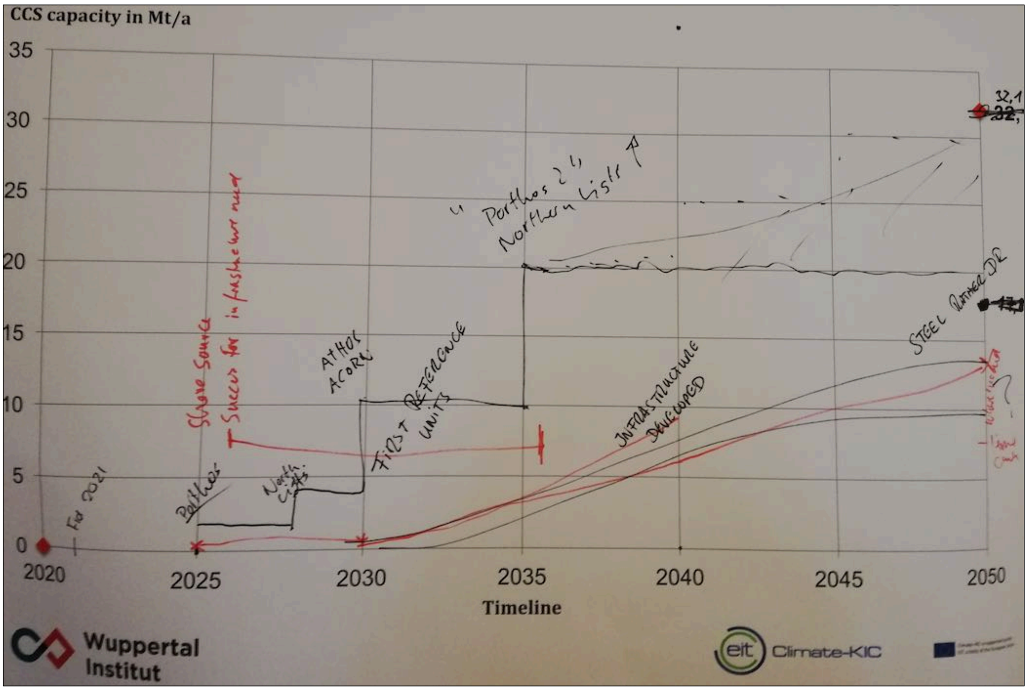


Figure 31: Assessment of some participants regarding the future CCS infrastructure development in the focus region

Source: own photograph

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8 Appendix

8.1 Workshop agenda

Workshop schedule Infrastructure needs for the decarbonisation of heavy industry up to 2050				
3 Dec 2019	**Essen, hdt congress center (Haus der Technik e.V.) , Hollestr. 1, 45127 Essen**			
Time	**Duration**	**TOP**		**Persons**
10:00	00:30	**Welcome & background information (aims & scope of project, basic approach and underlying scenarios)**		Stefan Lechtenböhmer, Frank Merten (WI) Rannveig van Iterson (ECF)
10:30	00:15	Overview of the study "Industrial Transformation 2050"		Clemens Schneider (WI)
10:45	00:30	Decarbonisation results for the industrial hot spot region between Antwerp, Rotterdam and North Rhine-Westphalia		Clemens Schneider (WI)
11:15	00:30	Questions & answers		
11:45	00:05	Distribution to **2** sessions		Christine Krüger (WI)
11:50	00:15	Coffee break		
12:05	01:10	Session 1: Infra needs for H2/gas and power system	Session 2: Infra needs for CCS	1: Christine Krüger, Arjuna Nebel, Frank Merten 2: Alexander Scholz, Ansgar Taubitz, Clemens Schneider
13:15	00:45	**Lunch**		
14:00	01:15	Session 1: Follow-up H2/gas and power system	Session 2: Follow-Up CCS	as before
15:15	00:15	Coffee break		
15:30	00:45	Resume of sessions 1 and 2		Representatives of session
16:15	00:15	Wrap-up of the day and outlook		
16:30		**Farewell**		