Synopsis report of consultation activities (WP1) (Deliverable D1.6)

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Table of contents

List of figures

List of tables

List of acronyms and abbreviations

BF	Blast furnace
BOF	Basic oxygen furnace
CAPEX	Capital expenditure
CCU	Carbon capture and usage
CCUS	Carbon capture and usage or storage
ER	Energy recovery and re-use
ETS	Emission Trading System
EU	European Union
GREENSTEEL	Green Steel for Europe
H_2-DR	Hydrogen-based direct reduction
HPSR	Hydrogen plasma smelting reduction
IBRSR	Iron bath reactor smelting reduction
M	Month
MOE	Molten oxide electrolysis
NG-DR	Natural gas direct reduction
NGO	Non-governmental organisation
OPEX	Operational expenditure
TGR-BF	Top gas recycling blast furnace
TRL	Technology readiness level
WP	Work package

Executive Summary

This report presents the outcomes of the targeted stakeholder consultations conducted within work package 1 (WP1) of the Green Steel for Europe project. The consultation activities in WP1 were comprised of four steps:

1. **Scoping Interviews** (in April – May 2020)
2. **First In-Depth Interviews** (in August 2020)
3. **Second In-Depth Interviews** (in March 2021)
4. **Validation Workshop** (23 March 2021)

In each step, the consultation activities aimed to engage large **EU steelmakers** (covering >80% of CO_2 emissions by the sector) as well as **key technology providers**. These stakeholders were complemented by the members of the **Steering Committee** (composed of leading EU steelmakers and independent academic experts) and members of the **Advisory Board** (featuring technology providers, representatives of energy-intensive sectors and the energy sector, think tanks, research institutes, NGOs, the civil society and representatives of the EU and national institutions). This group of consultations ensured the **open and transparent consultation approach** of Green Steel for Europe.

In the first step, through **scoping interviews,** primary data and information about the relevance of specific **decarbonisation technologies** and feedback about the elaborated **decarbonisation drivers and barriers** were gathered**.** For that purpose, the scoping interviews relied on a **structured questionnaire**, which was mainly based on closed-ended questions. 34 stakeholders were contacted, of which 26 replied in any form and 15 (representing an estimated 71% of CO_2 emissions) provided a comprehensively filled questionnaire.

As **decarbonisation technologies envisaged for implementation** most answers covered measures of energy recovery, hydrogen-based direct reduction, carbon capture and usage and increased biomass utilisation. The most relevant **decarbonisation driver** was identified to be avoiding or reducing **costs stemming from EU or national rules** (e.g. EU ETS costs), followed by **entering new markets (e.g. green value chains).**

The stakeholders were furthermore asked to assess the 20 **decarbonisation barriers** identified beforehand by desk research. These barriers were categorised into four groups: financial barriers, policy/social barriers, technical barriers and organisational barriers. The provided stakeholder feedback shows that the group of **financial barriers** are **most relevant** by far**,** with **investments for industrial deployment**, **increase in OPEX** due to energy costs and **unknown market conditions of clean steel** being the highest rated answers.

The second step of stakeholder consultations in WP1 consisted of **first in-depth interviews** to gather feedback on preliminary key findings of "Green Steel for Europe". The interviews were based on a **structured questionnaire with open questions**, which was filled during **virtual interview sessions** of one to two hours each. Twelve stakeholders were contacted, of which ten stakeholders conducted a virtual interview. These first in-depth interviews were exploited to identify relevant promising **decarbonisation technology routes:** Four basic routes with a total of seven sub-routes were identified and categorised.

1A. Blast furnace (BF) and basic oxygen furnace (BOF) with alternative carbon sources;

1B. Blast furnace (BF) and basic oxygen furnace (BOF) with carbon capture and usage or storage (CCUS);
1C. Blast furnace (BF) and basic oxygen furnace (BOF) with other actions;
2A. Hydrogen-based direct reduction (H_2-DR) and electric arc furnace (EAF);
2B. Natural gas direct reduction (NG-DR) and electric arc furnace (EAF);
3. Iron bath reactor smelting reduction (IBRSR), basic oxygen furnace (BOF) and carbon capture and usage or storage (CCUS); and
4. other technologies.

The accompanying detailed discussions were fused with the results of desk research and exploited in Deliverable 1.2 ("Technology assessment and roadmapping"). Additionally, the pre-selected **decarbonisation barriers** and their assessment were validated during the first in-depth interviews with **general agreement** and no further additions required.

As third step of stakeholder consultations in WP1, a **second round of in-depth interviews** was conducted. These were structured similarly to the first round, utilising a different questionnaire accompanied by presentation slides introducing the project work-in-progress. These interviews were focussing on gathering feedback on the **assumptions and scenarios regarding the decarbonisation pathways for 2030 and 2050**. Twelve stakeholders were contacted, of which seven stakeholders conducted a virtual interview and four provided a written statement.

The overall feedback regarding the preliminary decarbonisation pathways was positive. The industrial deployment of **alternative carbon source utilisation and/or CCUS (route 1 A/B) or direct reduction plants (route 2 A/B) on 39 – 44% of primary steel production capacities by 2030 was rated as very ambitious** with respect the current European framework conditions. Additional core feedback was that **measures on the secondary steel production route should not be neglected** while focussing on measures within the primary steel production route may seem reasonable (based on absolute CO_2 mitigation potential). Strong feedback was also received regarding **the assumed CO_2 mitigation potentials** for the direct reduction routes. **Blast furnace relining dates were indicated as very relevant parameters** in case of technology switches towards other technology routes. Several stakeholders reported **significant limitations to the availability of biomass** for the steel industry.

The stakeholder consultations were concluded by a fourth step of holding a half-day virtual **validation workshop** to present and discuss the main findings of WP1 with all members of the Steering Committee and Advisory Board. A total of 62 participants was registered. The agenda covered four presentations of the WP1 findings obtained followed by extensive Q&A sessions for open discussions. As the participants had no objections to the content of the findings or the methodologies used, more detailed issues were discussed. Both **the methodologies** and the **preliminary results** were therefore considered as **successfully validated**.

1. Introduction

This deliverable report "Synopsis report of consultation activities (WP1)" (D1.6) summarises the technical results of the stakeholder consultations done within the Green Steel for Europe (GREENSTEEL) project. The overall objective of the consultations was to support the desk research done in work package 1 Technology roadmapping (WP1), in particular with a view on decarbonisation technologies development and industrial deployment by steel producing companies.

Focusing on the technological aspects of the GREENSTEEL project, this report complements the overall consultation strategy in deliverable D4.1.

The operational objectives of the consultations were consistent with the grant agreement:

- ensuring industrial commitment and uptake of project results; and
- engaging the stakeholders in consultation activities.

From a technical perspective, WP1-related consultation activities aimed at:

- collecting data and information on technologies, barriers and industrial deployment for low-carbon steelmaking;
- gathering feedback on draft deliverables from relevant stakeholders (e.g. producers, suppliers); and
- validating key findings during an interactive workshop.

The consultations were structured and performed in a four-step approach:

1. scoping interviews, based on questionnaires (distributed in May 2020);
2. first in-depth interviews, based on questionnaires (distributed in August 2020);
3. second in-depth Interviews, based on questionnaires (distributed in March 2021); and
4. validation workshop, based on presentations and discussions (in March 2021).

The first two consultation steps combined technical and financial questions in order to coordinate WP1 and WP2 consultations in the most effective way. The data provided in this report are in aggregated form to ensure confidentiality.

2. Scoping interviews

As a first step in the stakeholder consultation process, targeted scoping interviews were conducted. These scoping interviews relied upon a scoping questionnaire, mainly based on closed-ended questions. The interviews were conducted within a timespan of two months (M) from M4 to M5 (April-May 2020). The scoping questionnaires combined technical and financial questions in order to coordinate WP1 and WP2 consultations in the most effective way. In their technical (WP1) part, the interviews focussed on the assessment of decarbonisation technologies, the identification of drivers and barriers to the decarbonisation of the EU steel industry and the envisaged industrial deployment of decarbonisation technologies.

In that context, stakeholders were requested to provide their feedback regarding available and upcoming decarbonisation technologies and the expected timeline to further develop their readiness. The results were later utilised to select the most important decarbonisation technology routes and to produce a technology (development) roadmap. Additionally, the scoping interviews aimed at gathering preliminary feedback on important framework conditions considered as barriers to the decarbonisation of the EU steel industry. A preliminary list of barriers was prepared and utilised to be validated and/or expanded via stakeholder consultation.

Overall, 34 stakeholders among steel producers and technology providers were consulted, distributed throughout the European Union (EU) (Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Poland, Romania, Slovakia, Spain, Sweden). The aggregate corresponds to more than 80% of the estimated CO_2 emission in EU-27 from steel industry.

Table 1: Scoping interview participation

Status	Total	Share (of contacted)	Estimated CO_2 share (of EU-27 steel production)
Contacted	34	100%	83.5%
Replied to contact (in any form)	26	76.5%	83.1%
Provided filled questionnaire	15	44.1%	71.1%

Source: authors' own composition.

The share of CO_2 emissions generated by the stakeholders involved in the consultations was calculated based on the 2020 allocations within the EU Emission Trading System (EU ETS). For that approach, data on CO_2 emission were achieved by performing a data analysis of publicly available 2020 EU ETS allocations (via EU Transaction Log, https://ec.europa.eu/clima/ets/). The allocated CO_2 emissions for iron and steel industry stakeholders were extracted and the specific share of EU-27 steel industry CO_2 emissions was calculated for each stakeholder. This approach is based on the assumption that the allocated CO_2 allowances reflect the current CO_2 emissions more accurately than the stakeholders' production capacity, as they likely operate at varying (not full) capacity.

15 stakeholders answered the questionnaire in detail, corresponding to 71% of CO_2 emissions by the EU-27 steel industry. Additionally, three producers provided general, qualitative statements from which limited information could be derived.

2.1 Decarbonisation technologies

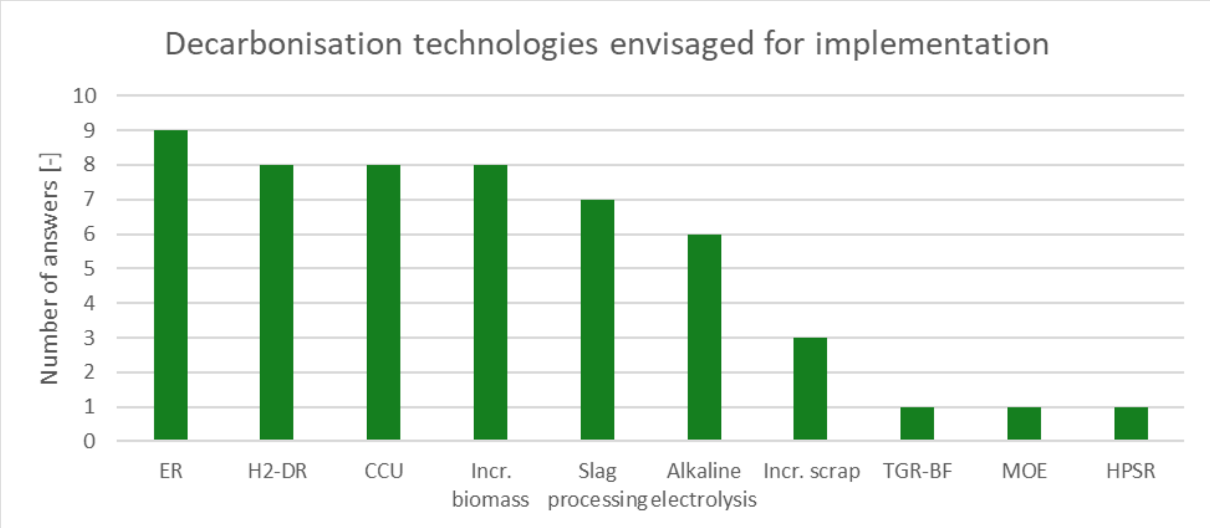
The scoping questionnaire allowed to assess specific decarbonisation technologies by asking the stakeholders which decarbonisation technologies they currently envisage to be relevant in the short-term (2030) and the long-term (2050). A selection of twelve possibly relevant technologies was prepared by the project consortium and included in the scoping questionnaire. This selection comprised of:

- hydrogen-direct reduction (H_2-DR);
- iron bath reactor smelting reduction (IBRSR);
- top gas recycling blast furnace (TGR-BF);
- chemical carbon capture and usage (chem. CCU);
- biological carbon capture and usage (biol. CCU);
- alkaline iron ore electrolysis (Alkaline electrolysis);
- hydrogen plasma smelting reduction (HPSR);
- molten oxide electrolysis (MOE);
- increased substitution of fossil fuels by biomass (Incr. biomass);
- increased scrap input (Incr. scrap);
- energy recovery and re-use (ER); and
- processing of steel plant slags (Slag processing).

Additionally, the questionnaire specifically probed the relevance of various combinations of different decarbonisation technologies, with respect to industrial implementation in the stakeholders' plants. Overall, the stakeholders provided a total of 18 different technology combinations. Most combinations included energy recovery and re-use (ER) (9 out of 15 answers). Almost just as often mentioned were hydrogen-based direct reduction (H_2-DR), carbon capture and usage (CCU) or increased substitution of fossil fuels by biomass (incr. Biomass) (8 out of 15 answers each). Processing of steel plant slags (slag processing) appeared in seven among the different combinations mentioned. Alkaline iron ore electrolysis appeared six times and was envisaged as a possible relevant option in the long term (2050). The other options were mentioned in less than five answers each. These outcomes are visualised in Figure 1 on the following page.

As this figure only provides the number of answers concerning the technologies, their specific relevance cannot be directly deducted. One technology may be of high relevance to a stakeholder in correlation with high production volumes and a high amount of CO_2 emissions, while other technologies may contribute to CO_2 mitigation to a lesser extent but be broadly applicable. Nevertheless, it can be identified that the full range of decarbonisation technologies is assessed as relevant to the stakeholders.

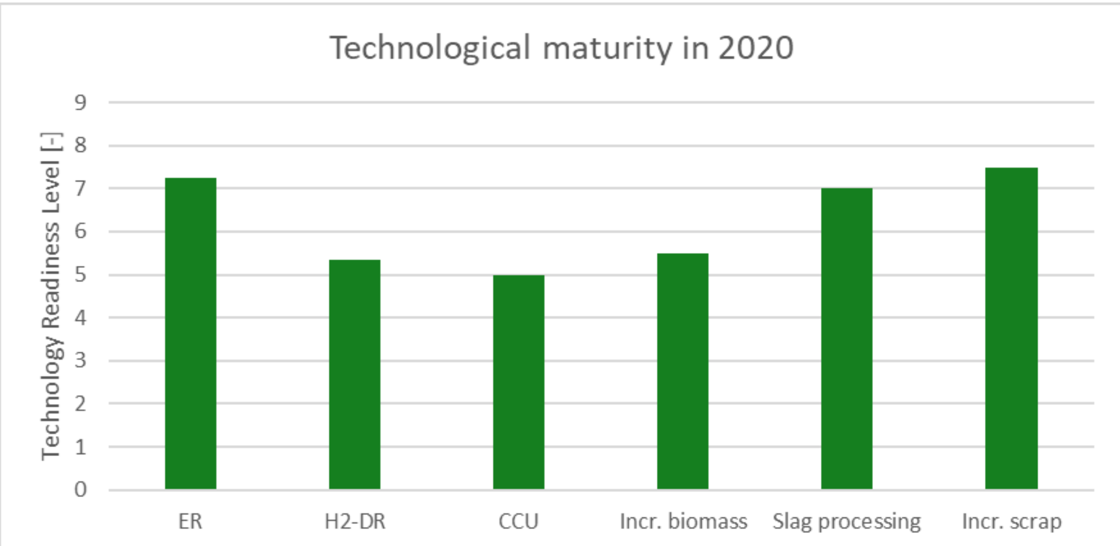
Figure 1: Relevance of combined technologies for industrial implementation as estimated by the stakeholders within the scoping interviews



Source: authors' own composition.

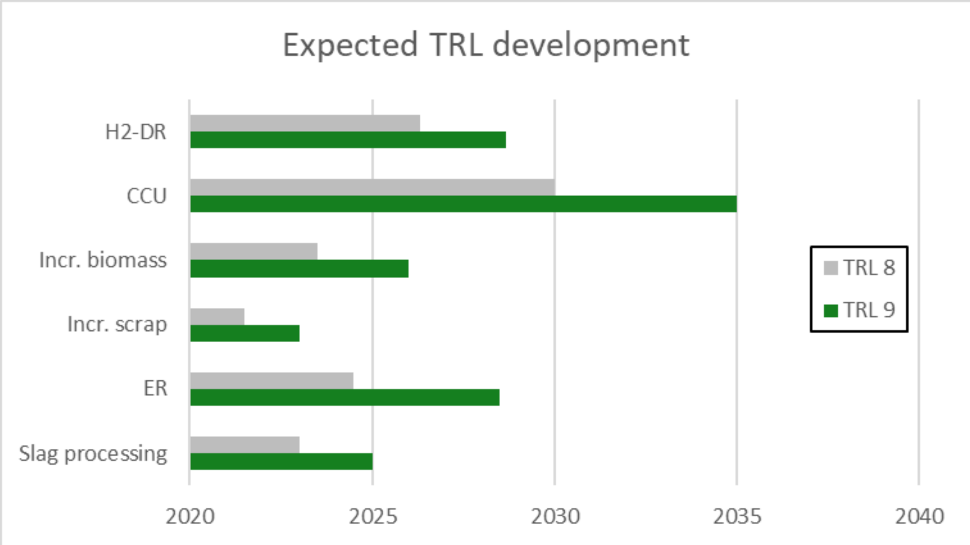
Besides assessing the relevance of decarbonisation technologies in the envisaged implementations by the stakeholders, the current state and estimated development of their technological maturity was assessed by the scoping questionnaire. The average estimated technological maturity in terms of technology readiness level (TRL) is provided in Figure 2 and the expected future development of these technologies to TRL 8 and TRL 9 respectively, is visualised in Figure 3 on the following page.

Figure 2: Technological maturity as estimated by the stakeholders within the scoping interviews



Source: authors' own composition.

Figure 3: Development of technological maturity as estimated by the consulted stakeholders



Source: authors' own composition.

2.2 Decarbonisation drivers

The scoping questionnaire asked the stakeholders about the relevance of specific decarbonisation drivers. Five main drivers, previously elaborated by the project consortium, were included in the questionnaire. These are summarised in Table 2. This table also provides the abbreviations for these decarbonisation drivers as they will be used in the following figures. Furthermore, the questionnaire provided the respondents with an option to report further drivers.

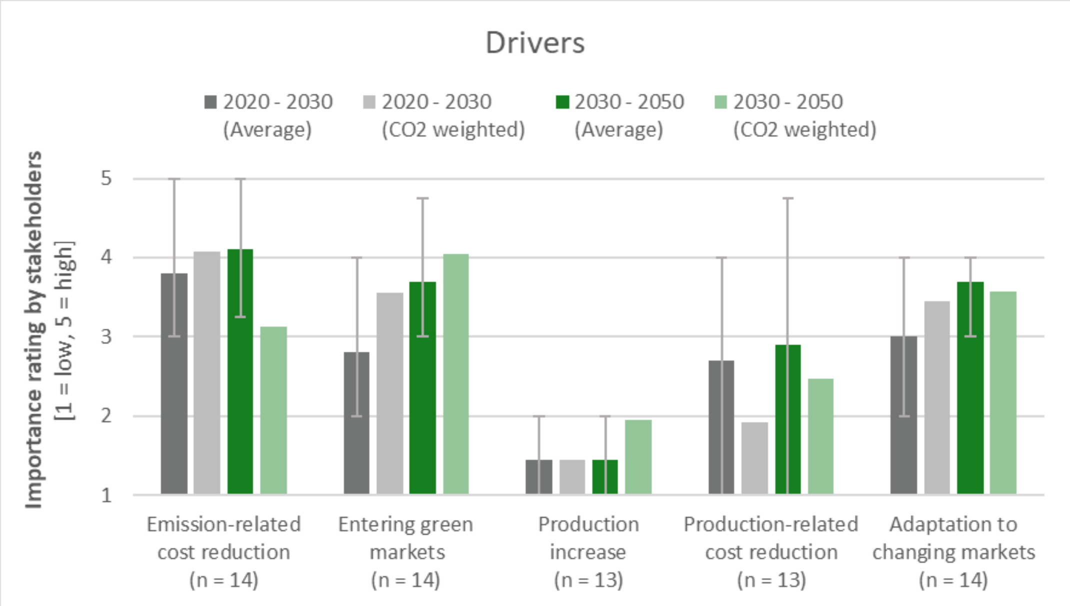
Table 2: List of decarbonisation drivers and their abbreviations for further use

Decarbonisation driver	Abbreviation
Avoiding or reducing costs stemming from EU or national rules (e.g. EU ETS costs)	Emission-related cost reduction
Entering new markets (e.g. green value chains)	Entering green markets
Increasing production levels	Production increase
Reducing production costs (e.g. via intensive use of circular economy actions)	Production-related cost reduction
Adapting the production processes to changing energy markets	Adaptation to changing markets

Source: authors' own composition.

The responses in terms of importance ratings by the stakeholders were evaluated utilising a linear importance rating scale from 1 (not important) to 5 (very important). Based on these ratings, two specific metrics (simple averages & weighted averages based on estimated CO_2 emissions) were used. Furthermore, two time periods (2030 and 2050) were assessed, leading to four values for each assessed decarbonisation driver. The results are provided in Figure 4 on the following page.

Figure 4: Importance of decarbonisation drivers as rated by the stakeholders



Source: authors' own composition.

The results in the short-term perspective (2020-2030) are displayed in grey, whereas those in the long-term perspective (2030-2050) are in green. Darker colours represent simple averages of the importance ratings as expressed by the stakeholders, light colours represent CO_2-weighted averages. The error bars display the area in which at least 50% of the answers were located, representing the borders of the 1st and 4th quartile. Thus, the error bars indicate the scattering of responses.

Overall, the assessed results show that avoidance or reduction of emission-related costs stemming from EU or national rules is the most important driver (i.e. rated between “relevant to some extent” and “relevant to a high extent”) for decarbonising the steel industry, both in the short- (2030) and long-term (2050). Moreover, adapting the production to enter new markets is a relevant aspect mainly in the long-term. Production-related cost reduction shows a wide scattering of responses, showing that the stakeholders differ on their understanding or opinion on that driver. The ranking of decarbonisation drivers based on their average rated importance as reported by the stakeholders is summarised in

Table 3.

Table 3: Ranking of decarbonisation drivers (sorted by 2030 average rating)

#	Decarbonisation driver	2020-2030		2030-2050	
		Avg.	**CO_2**	**Avg.**	**CO_2**
1	Avoiding or reducing costs stemming from EU or national rules (e.g. EU ETS costs)	3.8	4.1	4.1	3.1
2	Adapting the production processes to changing energy markets	3.0	3.7	3.4	3.6
3	Entering new markets (e.g. green value chains)	2.8	3.7	3.5	4.0
4	Reducing production costs (e.g. via intensive use of circular economy actions)	2.7	2.9	1.9	2.5
5	Increasing production levels	1.4	1.4	1.4	1.9

Source: authors’ own composition.

2.3 Decarbonisation barriers

The scoping questionnaire also asked about the relevance ratings of 20 decarbonisation barriers previously selected by the project consortium. This selection is summarised in Table 4.

Table 4: List of possible decarbonisation barriers (as included in the scoping questionnaire)

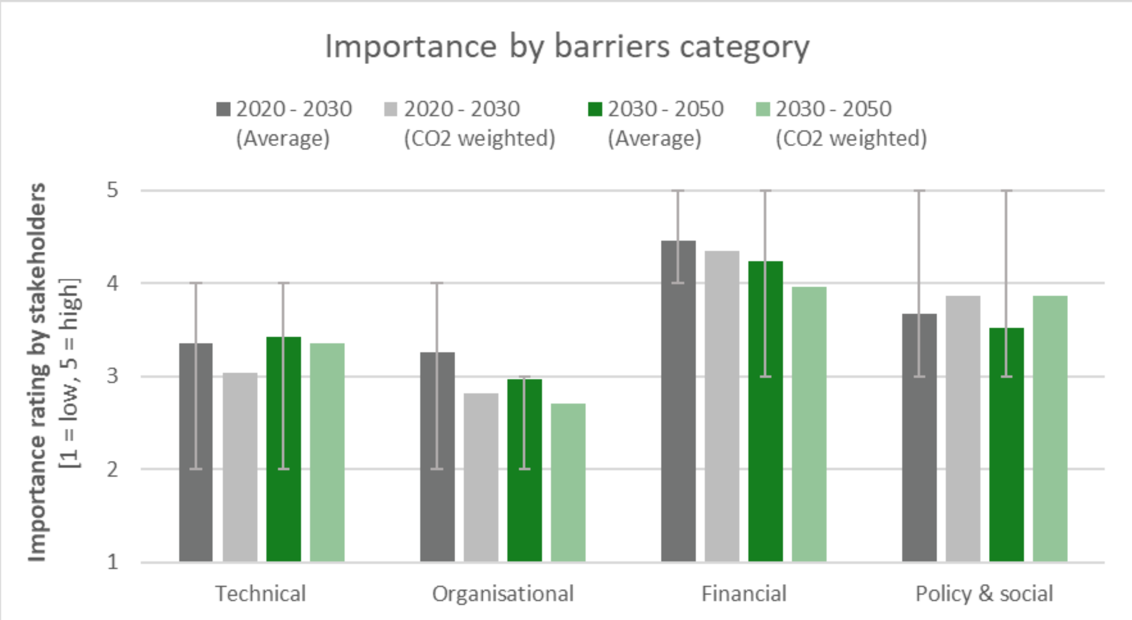
Decarbonisation barrier	Abbreviation
Technical barriers	
Risk of unsuccessful deployment	Unsuccessful deployment
Limited technical integration possibilities into existing plants	Integration possibilities
Limited availability of raw materials	Raw materials
Limited availability of renewable energy	Renewable energy
Organisational barriers	
Availability of qualified staff (for both development and operation)	Qualified staff
Bureaucracy (external) and other administrative burdens	Bureaucracy
Management of industrial transformation	Transformation management
Information exchange with other parties, collaborative research	Information exchange
Intellectual property management	IPM
Financial barriers	
Investments for demonstration plants	CAPEX Demo
Investments for industrial deployment	CAPEX Deployment
Limited access to funding opportunities	Funding access
Increase in OPEX (costs of energy/renewable energy)	OPEX Energy
Other increase in OPEX (costs of materials, CCS, CCU, etc.)	OPEX Other
Unknown market conditions of clean steel	Market conditions
Policy/social barriers	
Issuing of CO_2 storage permits for CCS	CO_2 Storage
Emission-related legislation (e.g. EU ETS)	Emission legislation
Social acceptance of certain technologies (CCS, plants, infrastructure for H_2/electricity)	Social acceptance
Local taxes and fees (e.g. German EEG)	Taxes & Fees
National implementation of other framework conditions (e.g. “contract for difference”)	National framework

Source: authors’ own composition.

The decarbonisation barriers were assessed both in the short-term (2030) and long-term (2050) perspective. For a more detailed assessment, the selected decarbonisation barriers were categorised into four groups: technical barriers, organisational barriers, financial barriers and policy & social barriers. Besides asking for the relevance of the pre-selected barriers, the questionnaire also gave the option of adding further barriers and their relevance rating.

Much like the evaluation of decarbonisation drivers, the evaluation of decarbonisation barriers utilised two different metrics. The basic average importance rating of specific barriers is presented in dark colours in the following figures. The CO_2-weighted assessment is provided in light colours. The results regarding the short-term perspective (2030) are displayed in grey, whereas the results in the long-term perspective (2050) are displayed in green. The importance rating is based on a scale from 1 (not important) to 5 (very important). The average relevance ratings for the barriers within each category is provided in ***Figure 5***.

Figure 5: Importance of decarbonization categories as rated by the stakeholders



Source: authors' own composition.

The financial barriers have the highest average importance rating as expressed by the stakeholders both in short-term and long-term perspective. Policy/social barriers come second, followed by technical decarbonisation barriers. The lowest average importance rating was given to organisational barriers. This ranking is summarised in Table 5.

Table 5: Ranking of decarbonisation barriers categories (sorted by 2030 average rating)

#	Decarbonisation barrier category	2030		2050	
		Avg.	CO_2	Avg.	CO_2
1	Financial barriers	4.5	4.2	4.3	4.0
2	Policy/social barriers	3.7	3.5	3.9	3.9
3	Technical barriers	3.4	3.4	3.0	3.4
4	Organisational barriers	3.3	3.0	2.8	2.7

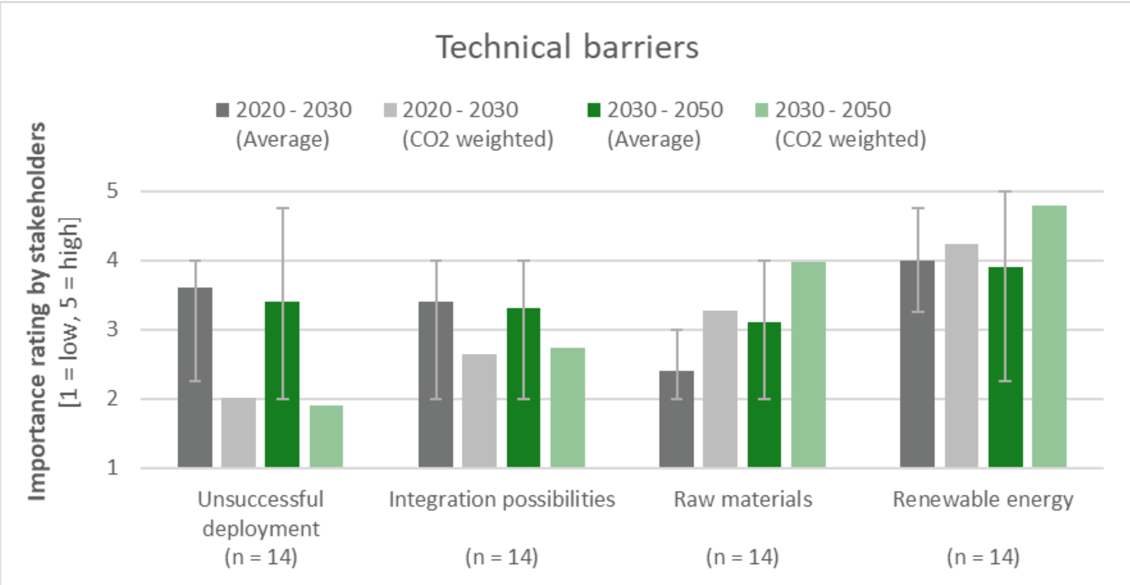
Source: authors' own composition.

Each category of barriers is assessed and presented separately below. For visualisation purposes, the decarbonisation barriers in the following figures are in the abbreviated form. The abbreviations in use are provided for each selected barrier in Table 4. In their assessment, error lines were used to display the spread of ratings of at least 50% of the stakeholders (upper and lower point representing the 1st and 4th quartile, respectively).

2.3.1 Technical barriers

The assessed relevance of technical barriers is displayed in Figure 6.

Figure 6: Importance of technical barriers as rated by the stakeholders



Source: authors' own composition.

The most important technical barrier is the availability of renewable energy sources. Its relevance rating increases further if assessed with the CO_2-weighted approach. This underlines the barrier relevance, especially for stakeholders generating higher volumes of CO_2 emissions. The availability of raw materials appears to be less of an issue in the short-term, though it has increasing relevance in the long-term. The risk of unsuccessful deployment and integration possibilities into existing plants reaches medium average importance rating and is of minor relevance to larger stakeholders. The assessed ratings are summarised and arranged by average short-term importance in Table 6**Error! Reference source not found.**.

Table 6: Ranking of technical barriers (sorted by 2030 average rating)

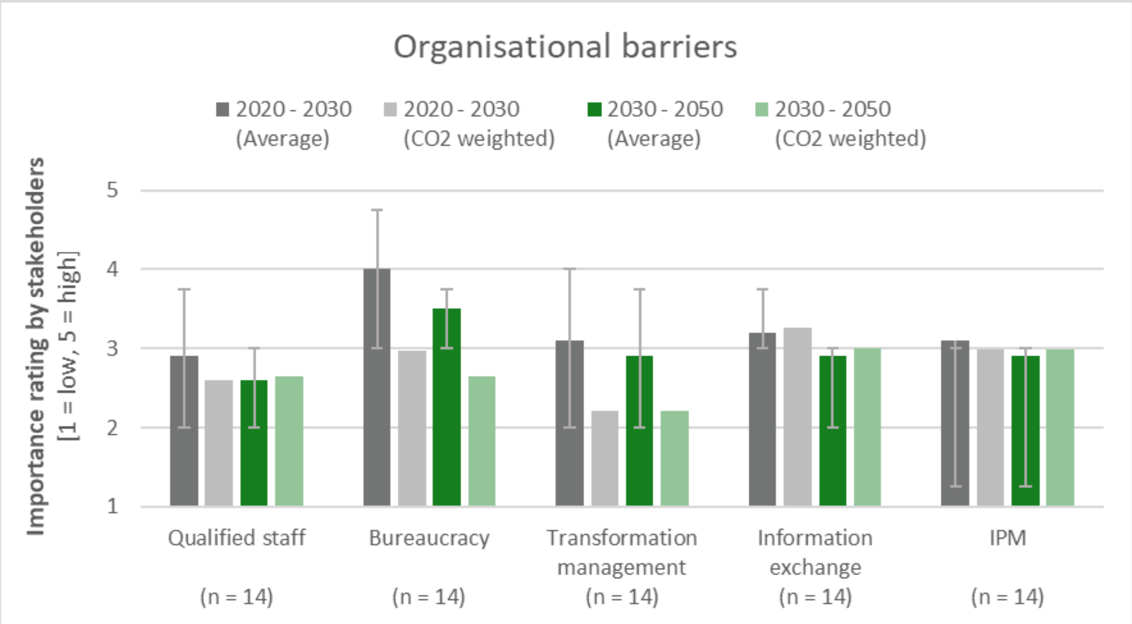
#	Decarbonisation barrier	2030		2050	
		Avg.	CO_2	Avg.	CO_2
1	Availability of renewable energy	4.0	4.2	3.9	4.8
2	Risk of unsuccessful deployment	3.6	2.0	3.4	1.9
3	Integration of new technologies in existing plants	3.4	2.6	3.3	2.7
4	Availability of raw materials (primary or secondary)	2.4	3.3	3.1	4.0

Source: authors' own composition.

2.3.2 Organisational barriers

The elaborated results regarding organisational barriers are displayed in Figure 7.

Figure 7: Importance of organisational barriers as rated by the stakeholders



Source: authors' own composition.

Based on the evaluation of the scoping questionnaire, bureaucracy is currently the most relevant organisational decarbonisation barrier with a ranking between "relevant to some extent" and "relevant to a high extent". Such topics as information exchange and intellectual property management (IPM) are of medium relevance with a significant scattering of the rating. The importance of this topic is ranked differently by the stakeholders. The relevance of management of industrial transformation does not change from the short-term to the long-term (3.1->2.9; 2.2->2.2). However, there is a reasonable lower relevance of this barrier for larger stakeholders (3.1->2.2; 2.9->2.2). The availability of qualified staff is of lower importance to the stakeholders than other organisational barriers. The organisational barrier specific evaluation results are summarised and arranged by short-term importance in Table 7.

Table 7: Ranking of organisational barriers (sorted by 2030 average rating)

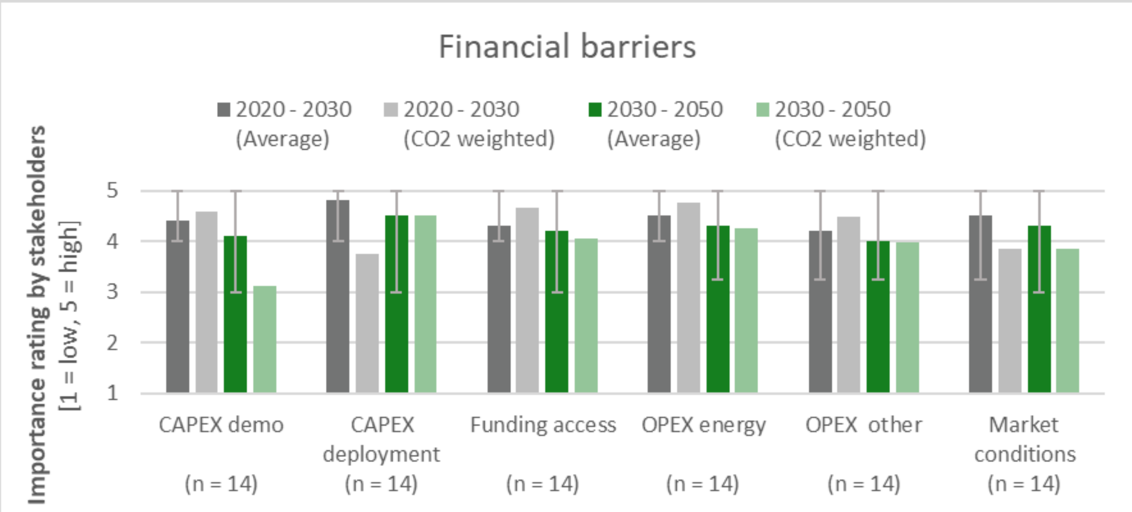
#	Decarbonisation barrier	2030		2050	
		Avg.	CO_2	Avg.	CO_2
1	Bureaucracy (external) and other administrative burdens	4.0	3.0	3.5	2.7
2	Information exchange with other parties, collaborative research	3.2	3.3	2.9	3.0
3	Intellectual property management	3.1	3.0	2.9	3.0
4	Management of industrial transformation	3.1	2.2	2.9	2.2
5	Availability of qualified staff (for both development and operation)	2.9	2.6	2.6	2.7

Source: authors' own composition.

2.3.3 Financial barriers

The relevance ratings of financial barriers assessed are visualised in Figure 8.

Figure 8: Importance of financial barriers as rated by the stakeholders



Source: authors' own composition.

Overall, all financial barriers were identified to have higher relevance to the stakeholders compared to other barrier categories. All of them are rated to be "relevant to a high extent" or even "relevant to the fullest extent". The respondents agree on the high short-term importance of CAPEX requirements for both demonstration plants and industrial deployment. This can be deduced from the low scattering of the 2020-2030 importance ratings expressed (between 4 and 5). This also applies for access to funding and the influence of operational expenditure (OPEX) caused by renewable energy requirements. The scattering increases if asked for the long-term perspective as well as for the influence of unknown market conditions, though the relevance level remains high. The medium relevance for CAPEX-Demo for the larger stakeholders in contrast to the high relevance for CAPEX-Deployment leads to the conclusion that the larger stakeholders anticipate to have the demo phases realised on long term and the major challenge after 2030 lies in the deployment. The results in regard to financial barriers are summarised in Table 8 and arranged by their 2030 average rating.

Table 8: Ranking of financial barriers (sorted by 2030 average rating)

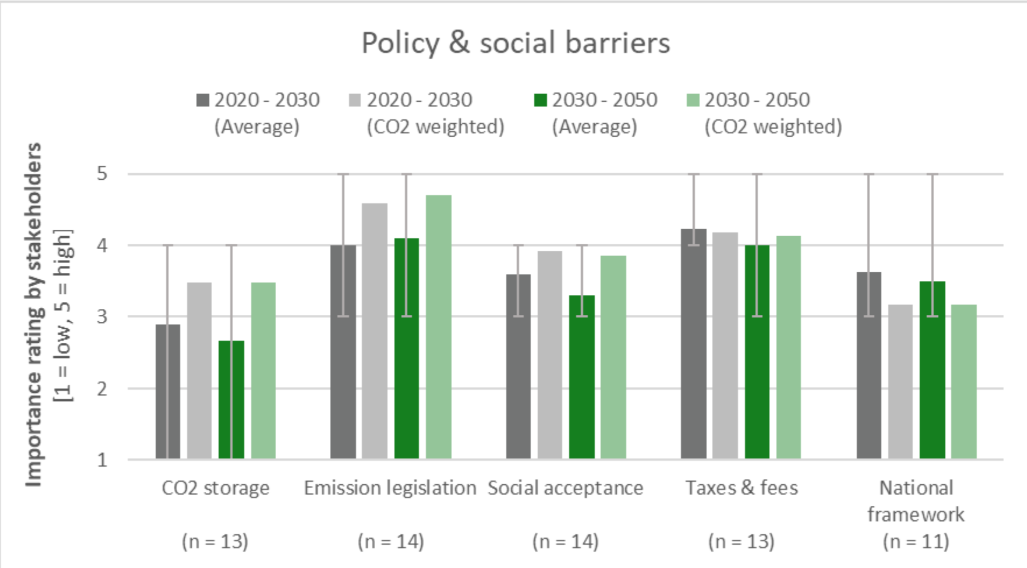
#	Decarbonisation barrier	2030		2050	
		Avg.	CO_2	Avg.	CO_2
1	Investments for industrial deployment	4.8	3.8	4.5	4.5
2	Increase in OPEX (costs of energy/renewable energy)	4.5	4.8	4.3	4.3
3	Unknown market conditions of clean steel	4.5	3.9	4.3	3.8
4	Investments for demonstration plants	4.4	4.6	4.1	3.1
5	Limited access to funding opportunities	4.3	4.7	4.2	4.1
6	Other increase in OPEX (costs of materials, CCS, CCU, etc.)	4.2	4.5	4.0	4.0

Source: authors' own composition.

2.3.4 Policy/social barriers

The results regarding the importance of policy and social barriers are displayed in Figure 9.

Figure 9: Importance of policy & social barriers as rated by the stakeholders



Source: authors' own composition.

The number of responses to the policy and social barriers chapter is lower compared to the other barriers. The barriers additional taxes and fees and emission-related legislation (e.g. in terms of the EU ETS) are identified as the most important policy and social barriers. As both barriers clearly relate to financial impacts, this underlines again the high relevance of financial decarbonisation barriers. National implementations of framework conditions and social acceptance were identified as being relevant on a medium level.

The importance of CO_2 storage conditions, containing e.g. legal national permission, are rated with lower average relevance. The results for CO_2 storage permits differ significantly, so it can be inferred to be relevant to some stakeholders (e.g. those intending to utilise it) and less so to other stakeholders. The barriers addressing legislation and regulation (2, 4, 5) received from at least 25% of the responds the highest relevance for the short- and long-term (upper point of scatter line equals 5). The simple average and CO_2-weighted results for policy and social barriers are summarised and ranked (based on their 2030 average values) in Table 9.

Table 9: Ranking of policy & social barriers (sorted by 2030 average rating)

#	Decarbonisation barrier	2030		2050	
		Avg.	**CO_2**	**Avg.**	**CO_2**
1	Local taxes and fees (e.g. German EEG)	4.2	4.2	4.0	4.1
2	Emission-related legislation (e.g. EU ETS)	4.0	4.6	4.1	4.7
3	National implementation of other framework conditions (e.g. “contract for difference”)	3.6	3.2	3.5	3.2
4	Social acceptance of certain technologies (CCS, plants, infrastructure for H_2/electricity)	3.6	3.9	3.3	3.9
5	Issuing of CO_2 storage permits for CCS	2.9	3.5	2.7	3.5

Source: authors’ own composition.

3. First in-depth interviews

The second step of the stakeholder consultation process consisted of targeted in-depth interviews with stakeholders volunteering to follow up on the scoping questionnaire. These in-depth interviews were designed to gather feedback on preliminary key findings within the GREENSTEEL project from relevant stakeholders, thus validating these preliminary key findings.

This first in-depth interview step consisted of a questionnaire with open questions (compared to the scoping questionnaire). In addition, instead of simply sending out questionnaires asking to be filled (as during the previous scoping stage), the in-depth questionnaire was filled during a virtual interview setting with representatives of the corresponding stakeholder. After the one-to-two hours interview, the filled questionnaire was distributed to the stakeholder for a final validation, to fill any remaining gaps and to ensure the written responses in the questionnaires were in the correct wording.

The interviews were conducted in M8 (August 2020). The first in-depth questionnaires fused technical and financial questions in order to coordinate WP1 and WP2 consultations in the most effective way. In their technical (WP1) part they were focussing on validating the selected technology routes in the short-term (2030) and long-term (2050) perspective and to gather feedback on the preliminary technology route roadmap visualisations. An additional focus was on discussing the outcomes of relevant framework conditions from the scoping stage. Besides that, stakeholder-specific deployment scenarios were discussed in more detail, focussing on correlated demands and requirements. Finally, the classification of steel production sites currently operating on the BF-BOF route based on the structure of the plants was discussed and assessed.

Within the in-depth, interviews twelve stakeholders among steel producers and technology providers who had expressed their availability and interest during the scoping stage were consulted. These stakeholders aggregate to 78% of the estimated CO_2 emission in EU-27 from the steel industry. Eleven stakeholders answered to the invitation to the first in-depth interviews, whereas ten stakeholders were available to participate in such an interview. Table 10 provides an overview of the first in-depth interview participation statistics.

Table 10: First in-depth interview participation

Status	Total	Share (of contacted)	Estimated CO_2 share (of EU-27 steel production)
Contacted	12	100%	77.6%
Replied to contact (in any form)	11	91.7%	70.7%
Provided in-depth interview	10	83.3%	35.2%

Source: authors' own composition.

Regarding the validation of technology routes which were predefined within the GREENSTEEL project, the stakeholders were asked to provide a feedback to the initial selection. This initial selection comprised of three separate technology routes, which correspond to complete process chains for decarbonised steel production considering the most relevant mitigation techniques.

In the questionnaire, the selected technology routes consisted of:

1. Blast furnace (BF) and basic oxygen furnace (BOF) with smart carbon usage (SCU);
2. Hydrogen-based direct reduction (H_2-DR) and electric arc furnace (EAF);
3. Iron bath reactor smelting reduction (IBRSR), basic oxygen furnace (BOF) and carbon capture and usage (CCU).

The in-depth discussion with stakeholders led to significant adjustments in this selection, both regarding the pre-selected technology routes and the envisaged deployment scenarios. It became clear that a further differentiation of the BF-BOF route was necessary to contribute for specific CO_2 mitigation potential, technological maturities and investment needs. Additionally, the in-depth discussion on the Direct reduction route made clear that multiple large steel producers are investigating the short-term implementation of natural gas direct reduction (NG-DR). In the mid- to long-term perspective, these implemented NG-DR plants could then gradually replace natural gas with hydrogen, guaranteeing high CO_2 mitigation in the long-term while at the same time exploiting the high technological maturity in the short-term with significant CO_2 emission reduction. Thus, the H_2-DR route was complemented by a NG-DR variant after conducting the in-depth interviews. Regarding the third route, namely IBRSR-BOF-CCU, the stakeholders emphasized on Carbon capture and storage (CCS) as an additional option. Consequently, the route was further assessed by considering both options (CCU and CCS) to the IBRSR-BOF-CCUS route.

Overall, based on the detailed discussions within the first in-depth interviews, the technology routes to be further assessed regarding the scenario development were adjusted to:

- 1A. Blast furnace (BF) and basic oxygen furnace (BOF) with alternative carbon sources;
- 1B. Blast furnace (BF) and basic oxygen furnace (BOF) with carbon capture and usage or storage (CCUS);
- 1C. Blast furnace (BF) and basic oxygen furnace (BOF) with other actions;
- 2A. Hydrogen-based direct reduction (H_2-DR) and electric arc furnace (EAF);
- 2B. Natural gas direct reduction (NG-DR) and electric arc furnace (EAF);
- 3. Iron bath reactor smelting reduction (IBRSR), basic oxygen furnace (BOF) and carbon capture and usage or storage (CCUS); and
- 4. other technologies.

The draft technology and investment roadmap provided in Deliverable 1.1 ("Draft technology assessment and roadmapping") was openly and directly discussed with the stakeholders. These very detailed discussions lead to updated versions of the roadmap figures, filling missing gaps and reflecting the data more accurately. Ultimately these discussions led to the e.g., numbers utilised in Deliverable 1.2 ("Technology assessment and roadmapping").

The decarbonisation barriers as assessed within Deliverable 1.5 ("Draft collection of possible decarbonisation barriers") were discussed during the in-depth interviews. The stakeholders generally agreed on this being a comprehensive list with no further additions required. The assessed decarbonisation barriers represent external framework conditions. They were complemented with site-specific conditions discussed during the in-depth interviews. Different stakeholders have independently stressed the necessity of having suitable connections to both power and gas grids. The majority of steel producing site representatives expressed their request of a stable and cheap supply of electricity, natural gas and/or hydrogen, even at higher demand, to be able to accomplish significant CO_2 mitigation in the future.

Besides these infrastructural demands, the decarbonisation process appears to be limited in connection to the site-specific condition of investment cycles. The realisation of transformation steps is intended to be coupled to the expiry of plant-specific lifespans to minimise investment costs and downtimes. As such, relining dates of BFs were especially mentioned by multiple stakeholders. The stakeholders also mentioned some additional site-specific conditions affecting the decarbonisation process: limited space to build additional plants, the need of different technologies and infrastructures operating in parallel during a transition phase, local scrap availability in sufficient quality, and the local availability of qualified staff.

As a groundwork for the following scenario development, the classification of steel production sites operating on the BF-BOF route was iterated in the first in-depth interviews. It turned out that the structure and the investment cycles of existing plants are relevant for the timing of specific steps along the decarbonisation process. Thus, the project consortium prepared a classification scheme based on the operation of sinter plants and coking plants as well as on the number of BFs in operation within the BF-BOF steel production sites. In the first in-depth interviews multiple stakeholders confirmed the relevance of those aspects and the proposed plant classification.

In the overall assessment, 76% of steel production on the BF-BOF route is produced in sites operating both coking and sinter plants, whereas 12% is being produced in sites operating a coking plant but no sinter plant. 8% of production occurs in sites operating a sinter plant but no coking plant and 4% of production originates from sites that rely on an external pellet/sinter supply. 4% of steel production on the BF-BOF route stems from sites that contain only one single BF, whereas 96% of primary steel production occurs in sites with multiple BFs available.

4. Second in-depth interviews

The first in-depth interviews conducted in August 2020 were followed up by a second round of in-depth interviews in March 2021. These were designed to gather feedback from the stakeholders on further WP1 key findings within the GREENSTEEL project, focussing especially on the assumptions and scenarios regarding the industrial implementation pathways for 2030 and 2050.

In the second round of in-depth interviews, a questionnaire containing mainly open-ended questions was prepared. It was complemented by a collection of presentation slides depicting the approaches and first key findings regarding the decarbonisation pathways for 2030 and 2050. Similar to the first in-depth interviews, this second round was also conducted in a virtual setting with representatives of a stakeholder for a duration of 1 to 2 hours. At first, the presentation slides were used to introduce the project work-in-progress, followed by an open interview in which the questionnaire was filled. After the interview, the pre-filled questionnaire was distributed to the stakeholder for a final validation in order to avoid any misunderstandings and add further information, if required.

The second round of in-depth interviews was targeted at the same twelve stakeholders among large steel producers and technology providers that were assessed for the first in-depth interviews. Eleven stakeholders answered to the contact initiated by the project consortium and seven stakeholders were available to take part in the interview. Four stakeholders sent a written statement answering a selection of prepared questions. The acquired responses reflect an aggregate of 71% of CO_2 emissions by EU-27 steel production (based on EU ETS). Table 11 provides an overview of the second in-depth interview participation statistics.

Table 11: Second in-depth interview participation

Status	Total	Share (of contacted)	Estimated CO_2 share (of EU-27 steel production)
Contacted	12	100.0%	77.6%
Replied to contact (in any form)	11	91.7%	70.7%
Provided in-depth interview	7	58.3%	70.5%
Provided written statement	4	33.3%	0.2%

Source: authors' own composition.

The main purpose of the second in-depth interviews was the initial discussion and validation of the assessed national framework conditions, scenario assumptions and approaches, and preliminary scenario results. A three-section questionnaire was used: CO_2 mitigation potential of technology routes, transformation process for implementation of decarbonisation technologies and assessment of decarbonisation pathways and industrial scenarios.

A core feedback regarding the CO_2 mitigation potential of technology routes was that while focussing on measures within the primary steel production route regarding absolute CO_2 mitigation numbers may seem reasonable, measures on the secondary steel production route should not be neglected. As such, especially the integration of renewable electricity production is working directly towards reaching CO_2 mitigation in secondary steel production, requiring lower mitigation costs and technical risks compared to measures required on the primary steel production route.

This is basically confirmed by the stakeholders operating plants on the secondary steel production route. They envisage a CO_2 mitigation potential of 30-50% in scope 2 emissions by 2030. On a long-term perspective, a value of 40-50 kg CO_2/t crude steel contributing for scope 1 and scope 2 emissions is envisaged for secondary steel production in 2050. The potential to replace primary by secondary steel production is limited especially by the availability of steel scrap in sufficient quality classes. In that regard, an increased availability in the range of +1% per year by 2050 is estimated by the secondary steel producers, which is in line with a study prepared by EUROFER (EUROFER, 2019). This would limit the share of secondary steel production on overall steel production within EU-27 to 50-55% in 2050, which is in line with a study prepared by IEA (IEA, 2020).

A strong feedback was also received regarding the assumed CO_2 mitigation potentials for the direct reduction routes: in that light, the estimated 35% CO_2 mitigation generated by implementing the NG-DR road was considered too low. Higher CO_2 emissions reduction by 66% for NG-DR with H_2 enrichment can be found in the literature (Agora Energiewende and Wuppertal Institut, 2019). In that context, the adjustment of the pure natural gas-based route towards hydrogen-enriched natural gas was suggested. Additionally, the CO_2 mitigation potential of H_2-DR was discussed. An assumed value of 95% CO_2 mitigation for both 2030 and 2050 does not reflect any limitations in reaching that potential already by 2030, nor does it reflect further improvement to reach 100% (or higher) CO_2 mitigation if biomass or other spent carbon streams were to be added in the mix. It was emphasized by some stakeholders that the scope 2 shares of 2030 CO_2 mitigation potentials should be assessed based on the estimated CO_2 intensity of electricity production for 2030. The stakeholders agreed that overall an increase of the CO_2 mitigation potential in H_2-DR should be assumed from 2030 to 2050.

Regarding the timing of technology deployment, the BFs relining dates were indicated as relevant parameters in case of technology switches towards other technology routes. The implementation of CCUS measures was regarded as independent from investment cycles correlated to BF and coke oven plants. Besides plant-specific investment cycles, infrastructure availability (e.g. regarding low carbon gas and electricity, hydrogen, transport and storage capacities) is especially regarded as highly relevant to deployment timing.

Several stakeholders reported significant limitations to the availability of biomass for the steel industry, which could limit the large-scale implementation of biomass-based CO_2 mitigation measures. They emphasised the need to investigate the availability of biomass in a comprehensive way, also with respect to its quality, pre-processing effort and utilisation for other purposes than the steel industry. The technical feasibility of using biomass and spent carbon streams in the magnitude of 100 kg/t hot metal as a replacement for pulverised coal injection until 2030 was deemed ambitious. Additionally, the stakeholders agreed that a CO_2 mitigation potential of 10% by other actions may reflect a realistic upper limit by 2030. In order to ensure an average value over all European plants, a lower number was suggested.

The overall feedback regarding the preliminary decarbonisation scenarios developed for 2030 and 2050 was positive. There was no opposition to the approaches used, although some scenarios were rated as very ambitious with respect to the industrial deployment and the current framework conditions of the European steel industry. Overall, the stakeholders are optimistic that the 2030 CO_2 mitigation target can be reached. Several stakeholders also encouraged the project consortium to consider the risks correlated to the decarbonisation process with regard to economic and social risks and carbon leakage.

5. Validation workshop

A half-day validation workshop was held on 23 March 2021 to present and discuss the main findings of WP1 up to that date. Due to the health and safety implications of the COVID-19 crisis, this workshop was held virtually. The validation workshop was interactive and focused on engaging stakeholders to share their feedback to the WP1 findings. All members of the Steering committee and Advisory board were invited to guarantee broad participation. Aside from Consortium partners who joined the session, there were 62 participants registered to the event through a dedicated registration system. These consisted of 29 members of the Advisory board, 16 members of the Steering committee and 17 other members (e.g. observers to the Advisory Board). The registration numbers are summarised in Table 12.

Table 12: WP1 validation workshop participation (based on registration)

Status	Total	Share (of contacted)
Advisory board	29	46.8%
Steering committee	16	25.8%
Others	17	27.4%
Total	62	100.0%

Source: authors' own composition.

The agenda covered four separate presentations of the WP1 findings obtained that far:

- decarbonisation technologies: assessment and roadmapping (contents of D1.2);
- decarbonisation barriers (contents of D1.5);
- decarbonisation pathways: framework conditions (preliminary contents of D1.7); and
- decarbonisation pathways: scenarios for 2030 & 2050 (preliminary contents of D1.7).

The presentations were followed by extensive Q&A sessions for open discussions. During these, the participating stakeholders gave insights on specific aspects of the research. Detailed issues were discussed, such as the assumed CO_2 intensity of electricity production, details of assessed technologies, resulting overall electricity demand, possible economic decrease, German EEG, infrastructure needs, biomass availability, nuclear power and its consideration for CO_2-free electricity, natural gas and its potential utilisation in bridge technologies, potential geopolitical dependencies, scrap availability and capital expenditure (CAPEX) needs.

Overall, the participants had no objections to the content of the findings or the methodologies used. Both the methodologies and the preliminary results were therefore considered as successfully validated. The project consortium will follow-up on the developed methodologies to finalise the results during the remaining project period.

6. Concluding remarks

The stakeholder consultations within the GREENSTEEL project proved to be a valuable tool to support the technology roadmapping of the project's WP1. This enabled to integrate the view of experts from steel producing companies. First, the experts provided input for the assessment of decarbonisation technologies, respectively on their prioritisation, their current maturity state and the expected further maturity progress and their combination to complete steel production chains. Second, the experts shared their view on the relevant framework conditions and their importance for industrial deployment.

This report summarises the main results of these consultations. The inputs complemented the project results derived from the desk research performed within the project. Thus, the consultations served not only to validate the results but also to ensure the industrial commitment, which was a special objective of the GREENSTEEL project. In particular, the intensive communication with the steel producers enabled to check the consistency of the technology assumptions and linked framework conditions derived by the consortium's desk research with the assumptions made by the steel producers. In this regard, the consistency was already on a high level initially and was further increased by the stakeholder consultations, which supplied important additional information as discussed in this report.

The consultations confirmed once again that the speed and the success of the industrial decarbonisation process strongly depends on external framework conditions. Thus, the consistency of the assumptions is important to develop deployment scenarios which are also consistent to the roadmaps and commitments of the steel producers. So, this combined input helps to define industrial deployment scenarios which are plausible and consistent with all information available for 2030 and 2050 in the respective tasks decarbonisation pathways 2030/2050 (Task 1.4/1.5). In this sense, the scenarios being developed within the project are 'what-if' cases ensuring transparency to the influences of different framework conditions on the CO_2 mitigation in the steel industry.

In the final technology roadmapping parts in WP1, the information gathered by the combined input from desk research and stakeholder consultations will be synthesised into a model. This model will perform a qualitative assessment of mitigation for the selected scenarios in order to provide decarbonisation pathways for 2030 and 2050, which are the main project objective from a technical perspective.

Moreover, the set of respective framework conditions and corresponding mitigation scenarios will provide the basis for the impact analyses of WP3 of the GREENSTEEL project. This supports the selection and assessment of the most important policy options, which are the main project objectives from a political perspective.

7. Bibliography

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