Contribution to the discussion: Green Steel Definition – A Labelling System for Green Lead Markets

Technical background paper on the proposal of the steel industry in Germany

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1. Executive Summary

This report describes the technical background to the proposal "Green Steel Definition - A Labelling System for Green Lead Markets" of the steel industry in Germany[1]. In particular, the methodological derivation of the reference values for the ambition levels of the **classification system for green steel**, including the curve for the **"sliding scale"**, which classifies emissions as a function of the scrap used in production, is presented in detail. The classification system provides the basis for political governance of green lead markets by using it to define how the use of green steel in different uses can be counted towards climate neutrality.

Instead of starting from a specification of target values to be achieved (top-down), a **bottom-up methodology** was used:

- Based on the work that already exists in the sector and in intense discussion with experts from the steel industry, virtual reference plants and associated reference alloy grades were defined, as well as
- the process steps included in the assessment and direct, indirect and upstream emission sources.
- This enables the determination of reference classification values for virtual plants on basis of what is technically feasible, and derived from these,
- the determination of classification levels.

During the development, particularly important conclusions regarding balancing rules could be reached, and the focal areas for further, more detailed specification could be developed ("rulebook"). In the course of this rulebook process, in which precise calculation rules are to be formulated, adjustments to the threshold values may still be necessary.

Classification system

Calculations were made for different virtual reference plants, which facilitate a classification. These indicate the suitability and realisability of the classification system and also provide information about particularly important aspects. The system can be used for a range of different technologies and is also suitable for supporting partial transformations of production sites. It is also compatible with other initiatives, such as the recommendation by the International Energy Agency (IEA) and develops it further.

[1] The term "green steel" (and variations thereof) is used in this report exclusively in a policy context in the sense of its use in a political classification system.

The recommended classification system is as a result specified as follows:

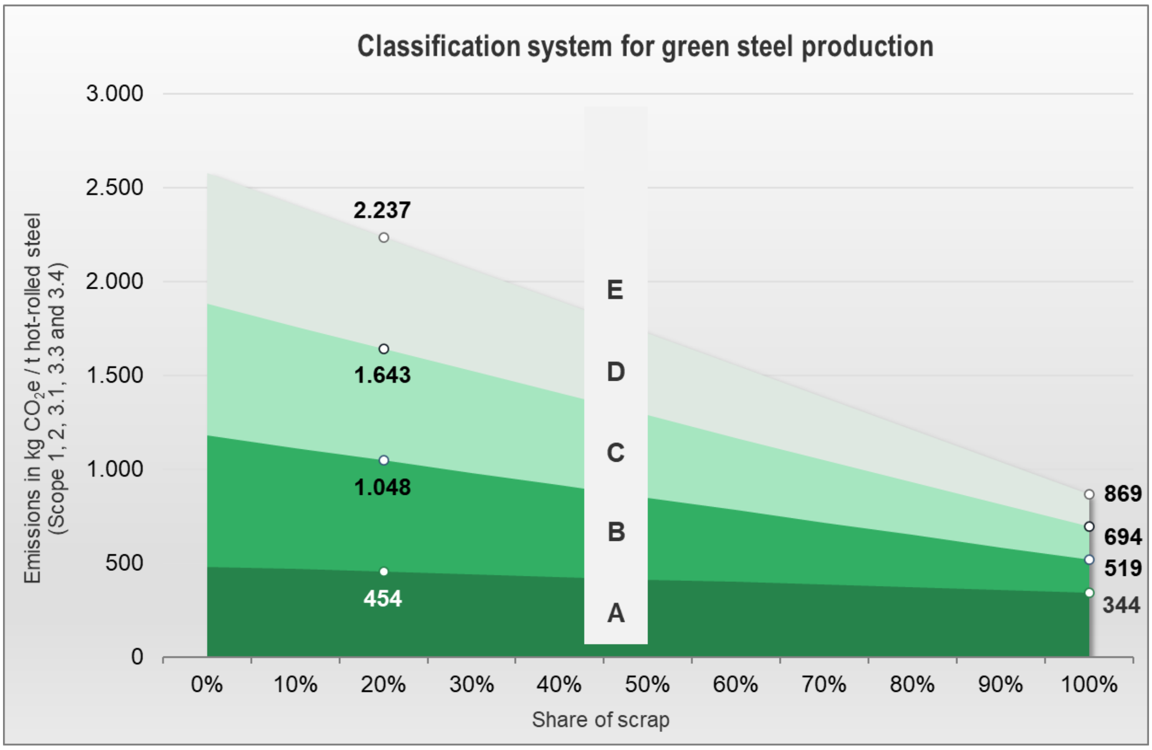

Figure 1: Recommended levels and reference values for the classification system for green steel production

Conclusions:

- **The classification system supports the goal of transformation in clearly identifiable steps**: Key transformation steps and challenges are illustrated. In both routes, particularly ambitious classification levels, level A for instance, cannot be achieved without considerable effort. Conversely, it is ensured that partial transformation steps also lead to products being better classified in the system. At the same time, it is ensured that the standards set in political regulatory framework regarding the environmental performance of products can increase stepwise over time in defined steps.
- **Ambitions**: The recommended classification system is ambitious. The transfer in level D already requires state-of-the-art technology with corresponding operational management. Level A requires extensive transformative activities and can only be achieved with 100 percent renewable produced hydrogen and renewable produced electricity. As a result, this classification level, which leads to green steel, is only practicable when the corresponding requirements have been fulfilled.
- **Fairness**: Regardless of the route, the starting point is ambitious, but achievable. In addition, the fact that scrap metal usage and the use of slags is taken into account ensures that no disadvantages arise for individual routes from the classification system, and also not with regard to certain aspects of the circular economy.
- **Connectivity**: The method leads to similar results compared to other initiatives. Differences compared to the IEA are understandable and result in particular from the selected scope and bottom-up method. The approach developed here is thus also a further development and due to its application with different plant configurations, a more specific realisation of the IEA approach.

- **Transparency**: The specifications made provide the basis for a rulebook for the classification system, which in turn creates a prerequisite for certification and a specific classification of products. The determination of specific values should be presented to an assessor, while the reference values themselves are derived in a clear and understandable way.
- **Potential for development:** The system has the potential for development in the sense that partial transformations can be depicted at a location, and in addition, regular reviews are planned, which shall reflect the changes in external framework conditions.
- **Expandability:** The limit values developed apply to base steel grades[2] from the blast furnace and the electric arc furnace route. Based on these values, a "**rulebook**" will be developed in a next step, with which corresponding **limit values for all existing steel grades** can be determined by correction factors.

[2] Blast furnace route: grade C22, electric arc route: grade C45

2. The starting point and goal for the Green Steel Classification System

The overriding goal of the system is to create a basis for political instruments. This does not necessarily mean creating a general valid basis for calculating a Product Carbon Footprint (PCF), even though parts of the working results are of key importance and could be used for a PCF. The classification system should reflect the **increasing demand** for an emission intensity reduction over time, which is why different **classification levels** are defined. The starting point is the state-of-the-art of the **relevant** production routes for steel products. In order to achieve higher classification levels, individual efforts are required to reduce emissions within the respective routes.

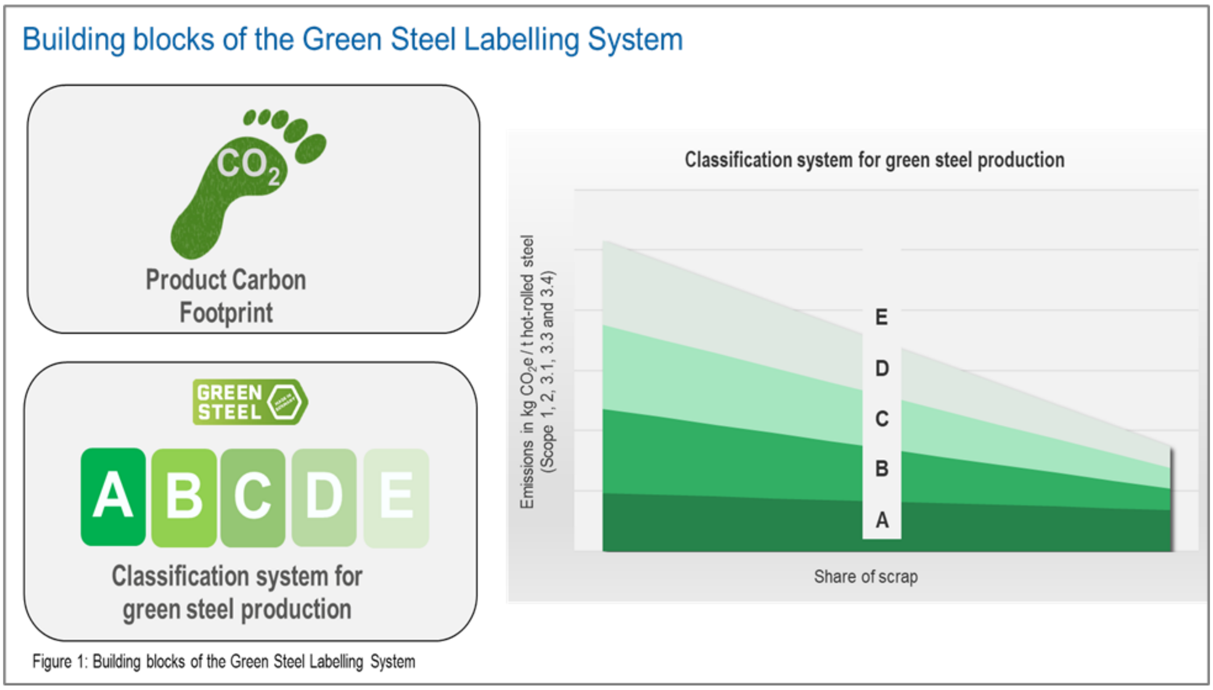

Figure 2: Building blocks of the Green Steel Labelling System

The goal of the present work is to initially define **virtual reference plants** and future **reference technologies** for low-level CO_2 steel production. On this basis, threshold values for the classification system will be determined and from these, a corresponding curve progression will be derived. The project focuses on the following aspects:

- Virtual reference plants must be unequivocally and clearly defined.
- Relevant balancing rules must be determined in a clear and understandable way, and through these, the first basic principles for the development of a **rulebook** must be created which enables producers to use the classification system. This rulebook ensures comparability between the information provided by different manufacturers and is thus a prerequisite for the application of the classification system in its practical implementation.
- The progress of the D/E level reference value must be determined.
- The progress of the A/B level reference value must be determined.
- A recommendation for other classification levels must be derived.

Compromises are necessary in order to handle the following conflicting goals:

- Ambition level vs. fair/ feasible starting point.
- Necessary standards re. precision vs. feasibility in practice and derivation.
- Transparency and acceptance in the sector vs. protection of operational secrets.
- Constant reference point vs. opportunities for adaptation.

3. The classification system for green steel production: specifications, reference values and levels

The system classifies the emissions of plants depending on their use of scrap. The specific emission for each level is decreasing according to a sliding scale as the use of scrap increases (see Figure 1: Recommended levels and reference values for the classification system for green steel production).

When reference values are determined for specific CO_2-eq emissions for relevant production routes, both a status quo and the ongoing transformatory development in the steel industry can clearly be represented with the necessary degree of differentiation.

For this purpose, virtual reference plants are first defined (subchapter 3.1) and the related balance range is determined for the greenhouse gas emissions (subchapter 3.2). On this basis, the reference values can be derived using predetermined calculation models (subchapter 3.3) and set in relation to the defined production routes (subchapter 3.4). From this, the curve progressions of the classification levels can be derived, depending on the amount of scrap used (subchapter 3.5). As an interim step, the specific values are calculated for further virtual plants (subchapter 3.6) before finally, different virtual reference plants are classified in the system (subchapter 3.7).

3.1 The virtual reference plants

The virtual reference plants form the basis for deriving the reference classification values and **thus determine the starting points for the curve progression of the system**.

At the start of the process, six possible reference plants were discussed:

- Integrated coal-based steelworks
- Integrated natural gas-based steelworks
- Electric steelworks for stainless steel
- Electric steelworks for quality steel - QST
- Electric steelworks for reinforced steel
- Iron direct reduction plant (Direct Reduced Iron - DRI plant) natural gas basis

The integrated natural gas-based steelworks was deleted from the list of reference plants for classification level D/E. It represents a lower emission alternative to coal-based production but does not provide a new point on the scrap use axis. The standard case worldwide is the coal-based production. The corresponding reference value is thus determined on the basis of coal (blowing in of PCI - pulverised coal injection). The variant with natural gas offers a first opportunity for supplementary measures in order to classify the D/E reference value **below** (subchapter 3.4). However, a DRI plant is used to calculate the reference value for level A on the primary side, with the use of largely “green” energy sources.

Steelworks producing quality and reinforcement steel are currently working with similar scrap levels, but the emissions they cause differ widely, due to their differing qualities and the resulting deviations in the production process. **It is therefore not sufficient overall to define threshold values for the classification system alone, depending on the quota of scrap used**. An adaptation for the **steel grade** actually produced is required. Necessary grade-dependent adaptations are a key item of the rulebook which has yet to be completed.

A virtual **quality steelwork** is used for the curve progression of the classification system.

For the first development of the classification system, it was decided to ignore the production of high-alloyed grades and stainless steel, since these are not suitable for deriving reference values. This is due to the wide variety of product variations and their direct impact on scope 3 upstream emissions. While developing the rulebook, however, suitable adaptation rules should be developed for higher grades through to stainless steel.

In order to create comparability along the curve for scrap use, two reference qualities were determined for both ends of the spectrum. These are the **steel grades** C22 for the integrated and C45 for the EAF route.

3.2 Definition of the balance scope

Definitions regarding the scope of the classification system form further cornerstones for the consideration. This also relates to the **production depth**. In order to take the opportunities for reducing emissions in both production routes into account, the classification system does not relate to crude steel, but to a **hot-rolled product** (single heating) without further treatment, such as a further heat treatment.

Thus, with respect to the primary route, the following process steps are directly covered by the classification system:

- Coking facility
- Sintering plant
- Furnace
- Steelworks process (converter)
- Secondary metallurgy
- Strand casting / block casting
- Hot rolling mill
- Power plant

For threshold value at the barrier A/B, the picture changes for the primary route by conversion to DRI. Here, the following are essentially covered:

- Direct reduction plant - DR
- Steelworks processes – Electric Arc Furnace – EAF or Submerged Arc Furnace – SAF and Basic Oxygen Furnace - BOF
- Secondary metallurgy
- Strand casting / block casting
- Hot rolling mill

With respect to the secondary route, there is no difference in terms of the process steps covered between the reference value consideration for level D/E and A/B. In any case, the following processes are covered:

- Steelworks process with EAF
- Secondary metallurgy with
  - Ladle Furnace – LF
  - Vacuum Degassing plant – VD
  - Rinsing unit
- Strand casting / block casting
- Hot rolling mill

As well as considering the type of process, it is of key importance which **emission sources** need to be considered for the classification. Scope 1 and scope 2 emissions, from the process steps, must be considered in all cases. This also applies to all emissions from the considered processes which are reported in the European Emission Trading (ETS). Further scope 1 and scope 2 emissions which are directly connected to these must also be taken into account for evaluation.

With regard to the scope 3 emissions, the classification system pursues the cradle-to-gate approach. Accordingly, none of the downstream emissions are considered. Upstream, the focus is on the essential drivers of the emissions. These comprise the following:

- Upstream energy chain (also de facto greenhouse gases other than CO_2, e.g. for natural gas and biogas)
- Materials (raw materials) that flow **directly** into steel production, or which are essential (scrap, ore, alloy materials, slag formers, refractories, technical gases, and other consumables)
- Transportation of the above materials to the required site

These emission sources cover an essential portion of upstream emissions from steel production. The sources not considered are of significantly less importance. Similar to the commonly used standards (in particular ISO, GHG protocol) within the specified system limits, a cut-off criterion of 10% is applied in order to limit the amount of time and effort involved in data preparation, both for the virtual reference plants and for application with real-life production plants. In other words: the emission sources included comprise 90% of the total emissions, including scope 3 upstream.

Figure 3 shows the relevant system boundaries of the reference plants.

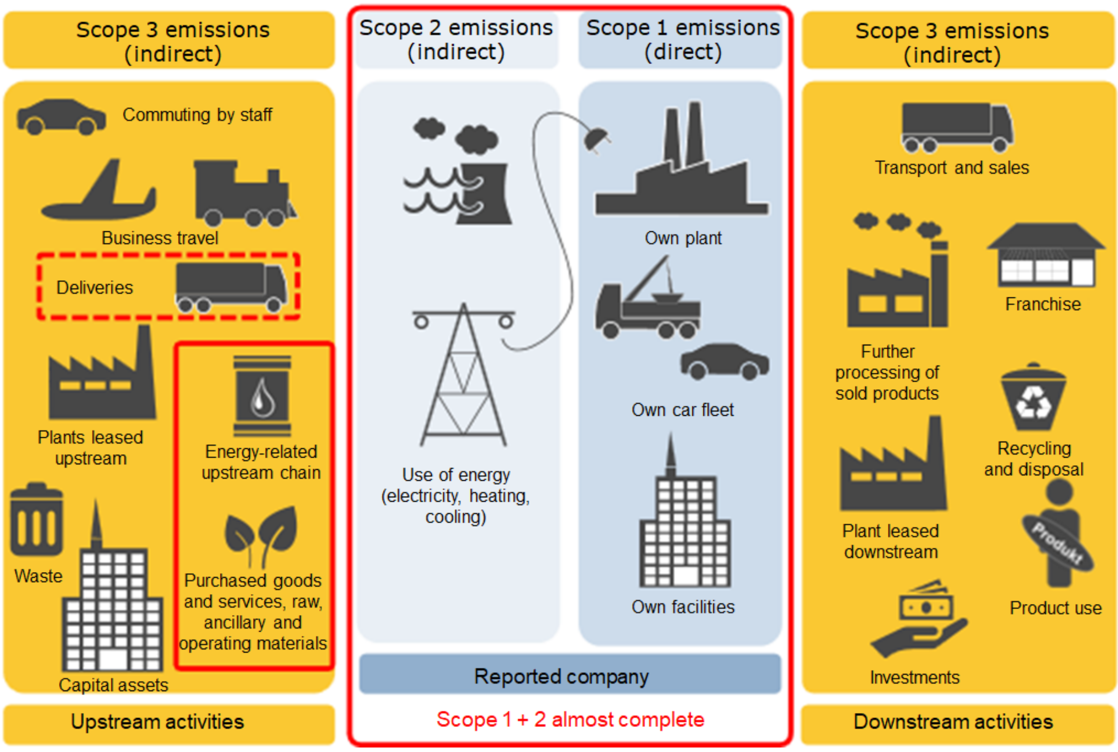

Figure 3: Emissions included for the classification system

Activities that are contracted out are treated separately. If process steps which, according to the definition above, are covered by the virtual reference plants, but are not an integral part of a real plant, these emissions should be **taken into account** in another scope (e.g. scope 3 instead of scope 1).

As this example illustrates: the broad scope also ensures that a simple relocation of emissions beyond the system boundary does not lead to a more ambitious classification. At the same time, the producers have a broader range of action options available as a result, for example with a view to their upstream activities. This requires clear calculation rules in order to be able to guarantee comparability.

The classification system allows the consideration of credits for materials and energies that are emitted beyond the balance boundaries only for:

1- slag sand (granulated blast furnace slag) which is sold as clinker replacement for cement production, and

2- the use of blast furnace gases for the generation of electricity or heat (similar to ETS), which are consumed outside the plants.

The credit can be awarded only when these materials and energies are really used. The credit for electricity is awarded with the **emission factor** published by the **German Environment Agency** (Umweltbundesamt) for the German electricity mix from previous year (which is also used as a reference when determining the electricity-related emissions for the virtual reference plants, value 485 g CO_2eq/kWh). For slag sand, a credit is awarded as cement (clinker) replacement in accordance with Portland cement (CEM I) with a factor to be ultimately determined in the rulebook. The credit for heat is awarded on the basis of natural gas. For other auxiliary products, credits are not awarded.

3.3 Determination of the reference values

Starting with the virtual plants, reference values are determined which form the basis for the progression of the curves in the classification system. Here, the reference values represent the transfer to the more ambitious level in each case. The D/E transfer should therefore be assigned to D, for example. It is not entirely sufficient to create virtual reference plants that reflect the current state-of-the-art (D/E). For higher classification levels such as C and A, the reference values should also be derived from assumptions regarding changes in existing production methods and using new technologies.

3.3.1 Presentation of the calculation models

In order to derive the level reference values, a differentiation must be made between primary and secondary route due to the data availability.

With respect to the primary route, a calculation model had already existed for the emissions from a virtually integrated steelworks. Which is based on the final report "Waste heat usage potential in plants of integrated steelworks in the steel industry"[3]. In order to determine the emissions, corresponding emission factors were used for both direct and indirect emissions. The calculation model is subordinated into individual process steps and therefore enables conclusions about the emissions from the individual process steps.

Based on this model, two variants were derived for DRI plants, a DRI-EAF and a DRI-SAF, in order to guarantee openness for other technologies. The fundamental data for the newly considered process steps are essentially taken from public available sources[4]. In order to be able to ensure vertical comparability with the reference model of the virtual, integrated steelworks, a scrap usage level of 20% is assumed for DRI plants. In individual cases, necessary adaptations with certain usage quantities were made by experts.

No comparable calculation model existed for the secondary route which was suitable to support the determination of the reference values. A new calculation model was created and the data required for the purpose was collected per data query with FutureCamp in the role as an independent third party[5]. In addition, this data was supplemented by research of publicly accessible sources. Here, particularly with the narrow timescale in mind, the collection focused on the essential drivers of emissions within the secondary route. This is congruent also with the cut-off criterion of 10% defined above.

3.3.2 Adaptations for level A

In order to determine the level reference values for the transition from B to A, specifications were made that applied in equal measure to both routes. This relates in particular to energy sources. In level A, only CO_2-neutral energy sources were used.

For the calculations, this means the following: The electricity used is renewable produced and therefore only entails scope 3 emissions. The level of scope 2 emissions is zero. Consequently, the oxygen used is therefore also lower in emissions, since it has to be produced using renewable produced electricity. Natural gas is replaced by hydrogen produced in a CO_2-neutral manner. This entails scope 3 emissions that must be taken into

[3] Marten Sprecher, Dr. Ing. Hans Bodo Lüngen, Dr. Ing. Bernhart Stranzinger, Dr. Ing. Holger Rosemann, Dr. Ing. Wolfgang Adler (2019), "Abwärmenutzungspotenziale in Anlagen integrierter Hüttenwerke der Stahlindustrie".

[4] Pasquale Cavaliere, Angelo Perrone, Alessio Silvello, Paolo Stagnoli and Pablo Duarte (2022), "Integration of Open Slag Bath Furnace with Direct Reduction Reactors for New-Generation Steelmaking" in Metals 2022, 12, 203

[5] Feedback from the companies was used by FutureCamp to determine average values. In some cases, these are quantity weighted. An identification or back calculation to actual values from individual companies was thus securely prevented.

account, which arise through transport and the upstream production activities. During production itself, however, no specific emissions occur, since production involves only the use of renewable energies. For the calculation, transportation from Qatar was foreseen on a conservative basis, since it can be assumed that the need cannot be covered by local production alone in the short term. This also applies to CO_2 neutral coal, such as biogenic pyrolysis coal from sustainable production sources. Here, transport from Latin America is assumed.

Further emission reductions are not considered for the derivation of the level reference value for A, since from the point of view of the specialists involved, in particular, no availability of climate-friendly alternatives is provided. Developments in this area, such as with alloy materials, pellets or burnt lime, should be taken into account in regular updates of the rulebook, and may then lead to the adaptation of the predetermined emission factors or possibly also the level reference values.

3.4 Results of the level reference values

3.4.1 D/E level reference values

The D/E reference threshold should reflect the state-of-the-art level. The starting point for the integrated steelworks and the secondary route are thus an ambitious emissions level, but also one that is achievable using current available technologies.

Integrated steelworks

The level reference value for the integrated steelworks is 2.237 kg CO_2e/t hot-rolled steel with a scrap usage of 20%. This contains credits from 275 kg CO_2e/t hot-rolled steel for the export of electricity and the sale of slag sand as a replacement for cement clinker. From the emissions of the defined virtual reference plant, around 88% are occurring in scope 1 (considering the credits from scope 3). The rest is allocated to scope 3. Scope 2 emissions do not occur, since the entire electricity demand can be covered by own production from blast furnace gases.

EAF QST

This calculation is the basis for all other calculations relating to EAF QST. Here, the emissions in the D/E level reference value is 869 kg CO_2e/t hot-rolled steel. All calculations of the secondary route are made with a scrap usage of 100%.

3.4.2 A/B level reference values

All values below the A/B reference threshold should be subsequently defined as “green steel”. Achieving these values requires maximum effort from the producers.

DRI-EAF under level A conditions

For this purpose, all reductions as described in Chapter 3.3.2 are implemented. Under these conditions, emissions of 454 kg CO_2e/t hot-rolled steel were determined (level reference value A/B for primary route). These originate mainly from the upstream chain of the pellets, hydrogen, dolomite lime and aluminium used[6]. Direct emissions are created above all from the carbon content of the pellets and electrodes.

[6] Use for killing steel

EAF QST under level A conditions

Under the conditions described in Chapter 3.3.2, there are emissions of 344 kg CO_2e/t hot-rolled steel. This is the A/B reference value for the secondary route. The remaining emissions largely also originate from the upstream chain, in particular from burnt lime and alloy materials. The highest direct emission is caused by graphite electrodes.

Table 1: Emissions level reference values divided according to scope in kg CO_2e/t hot-rolled steel

Annex	Scope 1	Scope 2	Scope 3	Total 1-3[7]
Integrated steelworks	1,974	0[8]	263[9]	2,237
EAF QST	205	295	369	869
DRI-EAF under level A conditions	18	0	435	454
EAF QST under level A conditions	15	0	329	344

3.5 Definition of the curve progressions

On the primary side, the value of the integrated steelworks is a fixed point for the D/E level reference threshold, at 20% scrap use. With the secondary route, the virtual QST reference plant was used for deriving the curve progressions. [10]

The D/E level reference curve is thus characterised by the values of the integrated steelworks (with 20% scrap use) and EAF QST (with 100% scrap use) virtual reference plant.

For the A/B transition, the same logic is consequently applied. DRI-EAF and EAF QST are now of decisive importance for the progression. The scrap quotas should be set in the same way as for D/E.

No separate values were calculated for the threshold values between the two curves described. These are derived solely from the A/B and D/E curves. The curves are laid such that with the defined scrap quota, the distance from one level to the next is always the same. The two additional straight lines thus divide the space between A/B and D/E into thirds for any scrap quota. The B and C levels are thus precisely defined and open for different technologies.

This results in the recommendation shown in the following Figure for steps and reference values for the classification system for green steel production as "sliding scale", depending on the scrap use.

[7] The values of the individual scopes are rounded off to the next kilogramme. The total is calculated from the precise values and is then also rounded off to the next kilogramme. As a result, deviations may arise from the total of the individual values.

[8] The integrated steelworks cover its electricity requirement by converting blast furnace gases into electricity in its own power station, and therefore does not draw electricity, and has no scope 2 emissions.

[9] Taking the credits into account.

[10] Different steel grades deliver considerably different emissions with the same level of scrap use. An adaptation starting from the specified level reference values is therefore urgently required in order to avoid creating an advantage or disadvantage for a plant type. The precise determination of the adaptations and specific applications must be clearly specified in the rulebook.

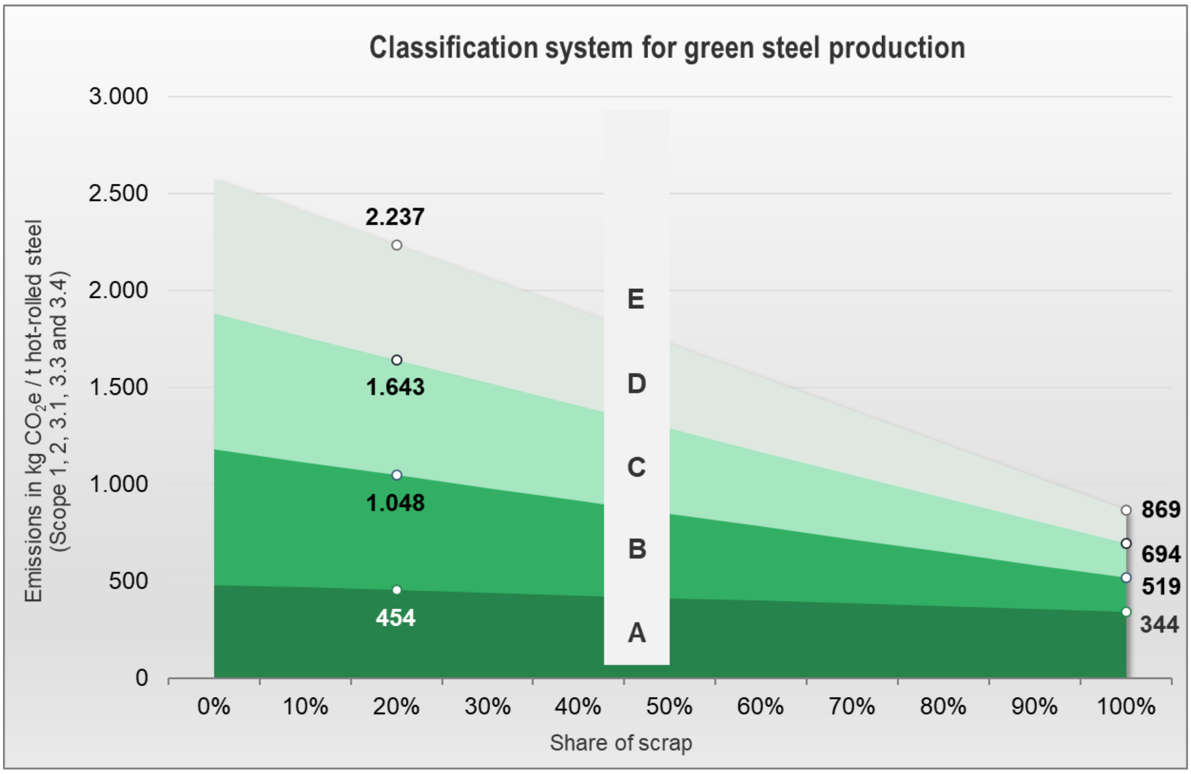

Figure 4: Proposal for a classification system for green steel production

Intensive discussions were held during the course of the project as to whether results from the DRI model are suitable for modelling the progression in the average scrap use range. Ultimately, this would have led to a curve progression with a steep increase with a low scrap quota and a gradual increase with a high scrap quota.

During the discussion, these considerations were discarded, however. Direct reduction is already a technology that has far lower emissions than the classical primary route. With a scrap usage of 20%, the DRI routes are significantly lower than the level reference value of the integrated route. Consequently, these should also not represent the D/E transition with an average scrap quota but should instead be better positioned.

With the secondary route, the use of DRI is also a significant improvement and is therefore also not assessed as being a suitable choice for the D/E progression there. If raw iron instead of DRI is assumed for the secondary route, the increases at both ends of the spectrum.

On this basis, the straight line contained in Figure 4 arises for the curve progression. This sufficiently represents the progression without excessively placing certain production plants or modes of operation at an advantage or disadvantage. The International Energy Agency and Responsible Steel also use straight lines in their systems. This progression therefore also ensures connectivity to their initiatives.

Finally, it should again be noted that the above level reference values relate to virtual reference plants and defined steel grades.

3.6 The calculation of further virtual reference plants to illustrate possible transformation steps

The following values serve to classify possible plant configurations into the classification system. Unlike the level reference values, they do not have a normative effect for the system. They are used solely to **clarify and illustrate feasible (partial) transformations**. The virtual reference plants should not be equated with real-life plants with a comparable transformation status. Depending on the actual levels of energy and material use, their emissions can be higher or lower than the values calculated here.

3.6.1 DRI-EAF

All DRI-EAF values are calculated in the same way as for the integrated steelworks with a scrap quota of 20%.

DRI-EAF based on natural gas

The starting point for the calculation is a DRI plant based on natural gas. This production route already means a significant reduction in emissions compared to the furnace route. Here, emissions are at 1.585 kg CO_2e/t hot-rolled steel.

DRI-EAF with renewable produced hydrogen for direct reduction

For this calculation, starting from the basic model, only natural gas was substituted in the direct reduction by renewable produced hydrogen. As a result of this step, emissions of 943 kg CO_2e/t hot-rolled steel are determined.

3.6.2 DRI-SAF

All values are calculated with a scrap usage level of 20%. The values contain a credit of 135 kg CO_2e/t hot-rolled steel for ancillary products from SAF. Here, it is assumed that the slag created has similar properties to slag sand and can therefore be similarly used as a replacement for cement.

DRI-SAF based on natural gas

In the SAF variant, a significant reduction in emissions can be achieved compared to the integrated steelworks. Here, emissions are still 1.630 kg CO_2e/t hot-rolled steel. Compared to DRI-EAF, this value is higher, which is almost entirely due to the greater importance of scope 2 emissions relating to electricity (see Table 2 below).

DRI-SAF with renewable produced hydrogen for direct reduction

In accordance with the EAF variant, only the natural gas usage for direct reduction is substituted by hydrogen. The emissions decrease to 932 kg CO_2e/t hot-rolled steel and are somewhat lower than for DRI-EAF.

DRI-SAF under level A conditions

In the same way as for the EAF variant, all items from Chapter 3.3.2 are implemented in the calculation. The emissions thus add up to 423 kg CO_2e/t hot-rolled steel.

These calculations show that with both DRI-EAF and DRI-SAF, very similar values can be achieved, and the classification system can function for different production routes.

3.6.3 EAF quality steel

The secondary route is calculated with a scrap quota of 100%.

EAF QST with 50% renewable electricity

With a coverage of 50% of the electricity requirement from renewable energies, in the model 705 kg CO_2e/t hot-rolled steel are emitted.

EAF QST with 100% renewable electricity

If the entire electricity requirement is covered by renewables, an emission of 547 kg CO_2e/t hot-rolled steel is resulting.

EAF QST with 100% renewable electricity and hydrogen

If the natural gas is also substituted by renewable produced hydrogen, alongside the use of green electricity, the virtual plant still creates 434 kg CO_2e/t hot-rolled steel.

The table below shows an overview of all related calculations.

Table 2: Emissions from virtual reference plants divided according to scopes in kg CO_2e/t hot-rolled steel

Annex	Scope 1	Scope 2	Scope 3	Total 1-3[11]
DRI-EAF based on natural gas	740	324	521	1.585
DRI-EAF with renewable produced hydrogen for direct reduction	127	324	492	943
DRI-SAF based on natural gas	731	373	526	1.630
DRI-SAF with renewable produced electricity	731	0	499	1.230
DRI-SAF with renewable produced hydrogen for direct reduction	70	373	489	932
DRI-SAF under level A conditions	7	0	416	423
EAF QST 50% renewable electricity	205	147	358	711
EAF QST 100% renewable electricity	205	0	348	553
EAF QST 100% renewable electricity + hydrogen	89	0	345	434

3.7 Classification of calculated virtual reference plants into the system

It is of particular interest how the reference values calculated in Chapter 3.6 should be classified in the system. The plants named in 3.4 are situated on the D/E or A/B dividing lines and should thus be assigned to the level D or A respectively.

It should be clearly stressed that this report contains the values for virtual reference plants. It is therefore always possible that real-life products from existing plants have lower or higher emissions, depending on the type of operation by the producing company. [12]

With respect to the primary route, both DRI-EAF and DRI-SAF based on natural gas are in the level C range.

DRI-SAF based on natural gas may be slightly higher than DRI-EAF, but it is still clearly in the C range.

The classification system thus gives clear incentives for investing in direct reduction plants, since only they make it possible to achieve level C on the primary route. This ensures that the achievement of a higher classification is possible, regardless of the technology used.

When the direct reduction is based on hydrogen produced in a climate-neutral way, with both DRI variants – without further changes – it results in a B classification. Here, too,

[11] The values of the individual scopes are rounded off to the next kilogramme. The total is calculated from the precise values and is then also rounded off to the next kilogramme. As a result, deviations may arise from the total of the individual values.

[12] Particularly obvious starting points can for example be a targeted use (physically or with regard to balance) of renewable produced electricity or the (partial) use of hydrogen. The anticipated development in the German electricity mix by 2030 is likely to relieve the burden here.

incentives are created to make greater efforts to reduce emissions, without having to compromise with the type of technology used.

With the secondary route, as expected, the emissions factor of the electricity used plays a significant role for the classification. This is also the greatest lever that can be directly influenced by the producers. If, instead of the German electricity mix, with 50% of renewable produced electricity is used, the virtual plant already comes very close to the threshold for level C. With a slight additional effort, level C can be achieved. If however only renewable produced electricity is used, the transition to level B is already approached. In order to achieve this, further efforts are required, such as the use of hydrogen or biogenic coal.

The following figure classifies the above-mentioned virtual reference plants in the classification system.

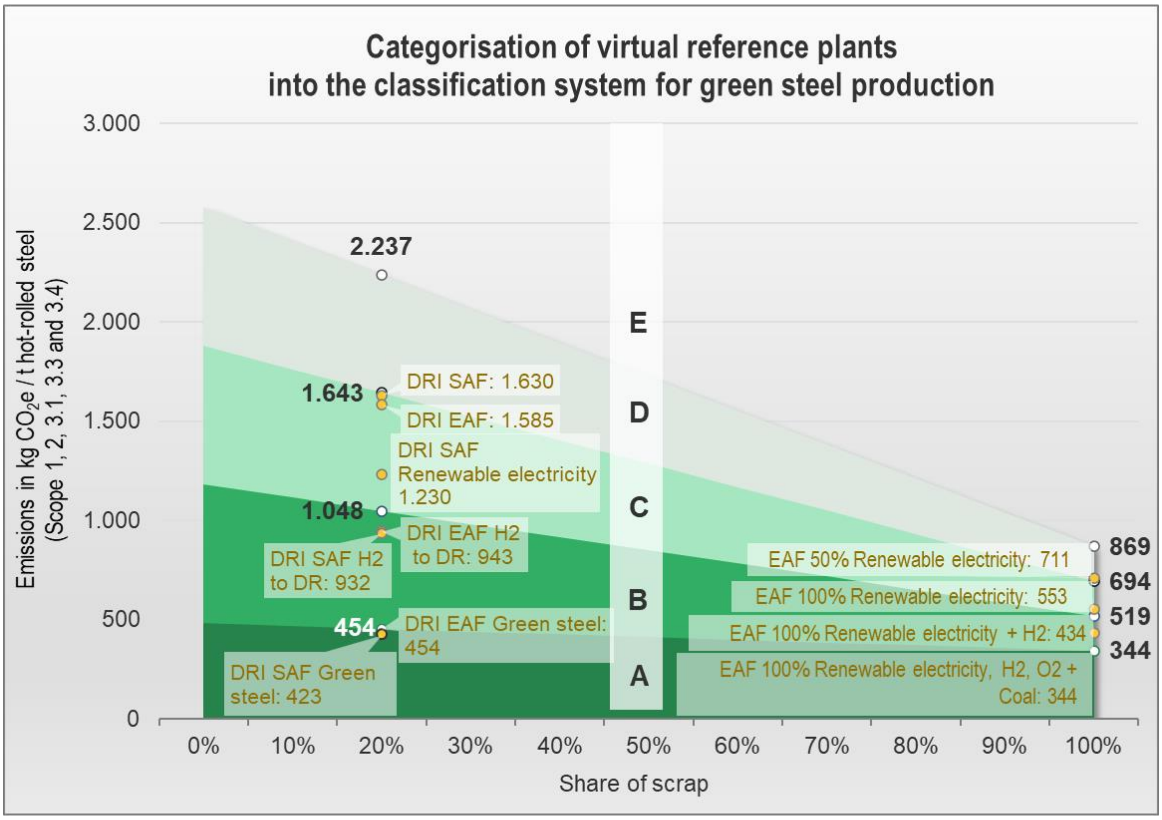

Figure 5: Categorisation of virtual reference plants into the classification system for green steel production

The derived results permit the conclusion that with the aid of the classification system recommended here, the stepwise transformation of the steel industry to become climate neutral can be illustrated in a practicable way, and key basic requirements for a classification system, as described in the introduction to this report, are fulfilled.

4. Comparison with similar initiatives

Comparing the present approach with global discussed models, a similar classification of reference values emerges, depending on the use of scrap. Therefore, common features and differences will be considered below, with a focus on the recommendation issued by IEA. In general, the Responsible Steel initiative describes a similar route to the certification of comprehensively sustainable products.

A direct and precise comparison between the values of the classification system and the values of the IEA is not possible, however. The reasons for this are as follows:

The boundaries for this classification system are much broader than the recommendation issued by the IEA. There, the values relate to the production of crude steel. The use of alloying elements, the preparation of scrap materials and the production of graphite electrodes used are **not taken into account** by the IEA. The hot rolling process is also not included. Alongside the energy-related emissions from the hot rolling process per se, in this consideration, the emissions from the steelworks increase, since cut-offs and other losses in the hot rolling mill have to be taken into account. Furthermore, the approach of the IEA draws narrower boundaries when it comes to scope 3 emissions.

With respect to the primary route, in addition to the differences described, the IEA approach does not take any credits into account. If, to a plausible degree, the model of the integrated steelworks virtual reference plant is adapted to the conditions of the IEA and the cut-off criterion of 10% is subtracted, the values deviate from each other by approx. 1%. Here, an important adaptation is the conversion of the calculation model described with a scrap quota of 20% to 0%. Furthermore, the scope 3 limits were adapted in line with the IEA and the hot rolling mill was deleted from the calculation. Since following these changes, the difference is reduced to the order of 1 percent, a compatibility with an overall higher level of precision can be determined.

If the above items are subtracted from the model for the classification system with respect to the secondary route in order to make a comparative assessment, values arise on a comparable scale of 420 kg CO_2e/t crude steel (classification system) compared to 285 kg CO_2e /t crude steel (IEA). The remaining differences can mainly be traced back to the weighting of the emissions from the use of (burnt) lime (approx. 50 kg CO_2e /t) and different assumptions regarding the use of coal (approx. 70 kg CO_2e /t). Regarding lime, the IEA pursues an approach taking the use of lime and the calculation of the emissions arising during use into account, while this model assumes the dominant use of burnt lime in practice. Different usage quantities are assumed in the models with regard to the use of coal. **Without publication of the database used in the IEA approach, no more precise statements are possible.** Here, it should also be noted that the IEA approach assumes a **generalised value** for the secondary route, which tends to be in the area between reinforced and quality steel, while the model described here explicitly considers quality steel.

While the IEA derives the "near zero threshold" **top down** from external specifications, in the present case, the comparable A/B reference threshold is derived **bottom up** on the basis of possible plant configurations and the information available in the industry. This makes it easier to take real-life operation steelworks into account. As a result of the intended cyclical updates of the emission values (see also following chapter), the opportunity arises of achieving level A earlier, regardless of parts of the upstream chain. For this purpose, the standards are increased when the corresponding reductions are achieved in upstream processes.

The biggest differences between the systems can therefore be plausibly resolved. Even when certain differences remain, the systems are fundamentally comparable and compatible. The approach taken by the IEA offers a first basis for discussion and important food for thoughts. It should also be regarded as such. It therefore makes an important contribution to generating awareness of the necessity to create such a classification and offers points of reference for similar initiatives – such as that of WV Stahl. Thanks to the disclosure of the bases for calculation and the extended balancing scope, the model presented here also enables a more detailed discussion and illustrates a way of further developing of the classification system, taking into account real-life conditions.

With a view to practical implementation – in which it will be necessary to assign individual products to a certain level – it can therefore be ascertained that the approach for the system recommended here is not only comparable with that of the IEA but is also its further development. Due to the subsequent rulebook process, a solid basis is created for the implementation of the classification system, which guarantees the comparability of the classification of different products. The here developed approach prevents both a route-related and a grade-related discrimination of individual products.

5. Further specifications for the rulebook

The work shows that a rulebook must be developed which regulates the implementation of the classification system in practice. Here, the comparability of the results of different producers must be the top priority, and greenwashing must be prevented. In this project, key specifications for the rulebook have already been made, some of which have already been described in the chapters above. Furthermore, additional items were already specified, which must then be formulated in the rulebook with the relevant precision.

The assignment of real-life products in the classification system must be certified by an **independent assessor**. Precise standards with regard to the assessor and the certification must be specified in the rulebook.

For higher alloyed grades than the reference grades defined, a correction system will be established which takes the higher emissions caused by the use of additional alloy materials into account. Due to the correction, a value is determined which can be classified as an "**equivalent**" in the system, without moving the characteristic curves, i.e. the stages. The precise procedure must be defined in the rulebook process. Evidence of the corresponding corrections and additional emissions must be given to the assessor. For this purpose, during the development of the rulebook, a procedure must be defined and supported by examples as to what measures should be taken in each individual case in order to determine "equivalent values" for the reference values, which result in a classification e.g. of a product of a higher grade (possibly also a lower grade, as with reinforced steel above) into a (higher or possibly also lower) level – even in cases when the determined equivalent value is higher (or possibly lower) than the reference value to be used in each case. It can possibly also be specified that these equivalent values should only be determined or used when a relevance threshold is achieved, and when evidence of this is presented to the assessor. Corrections for the secondary route resulting from the use of energy should be clarified in the rulebook process. These are evaluated as irrelevant for the primary route.

The procedure for adaptation to **specific plant configuration** (e.g. no separate coking plant or no hot rolling mill) must be described. Such an adaptation is absolutely necessary when the real-life plant deviates from the scope of the virtual reference plant. For this purpose, specifications have already been made, in particular for the primary route (e.g. consideration of externally purchased electricity in cases of a lack of own use of blast furnace gas to produce energy, consideration of use of coke in scope 3 when no own coking plant is available).

The rulebook should contain a list of **emission factors to be applied** for the used materials. Currently, the values are used in the calculations that are itemised in greater detail in the documents named in Annex 8. Ideally, the rulebook should contain a list of relevant emission factors. If this is not possible, possibly for licensing reasons, it must at least be clearly defined which factors should be used in order to guarantee comparability. The basic principle applies that primary data takes priority over secondary data. Certified Product Carbon Footprints according to the common standards take priority over the listed emission factors, particularly in the upstream chain. However, the relevant evidence must be provided. This creates an incentive for activities in the sector to reduce emissions, including in companies' own upstream chains. By selecting correspondingly emission-friendly upstream products, the company's own classification can be improved.

A **partial transformation** may be depicted by the classification system. This means that if a producer replaces e.g. a furnace with a direct reduction plant, they may only set direct reduction emissions for this part of the production process, while setting the emissions from the furnaces for the rest of the production. A producer thus offers products with different classifications. The relevant quantities must then be presented to the assessor in a clear and understandable manner. The depiction of a partial transformation in this way means that the remaining production must be balanced with the actual emissions from the remaining (conventional) production process. Under no circumstances a double offsetting of reductions may occur.

In order to ensure that the system is up to date, and where necessary to take generalisable developments in the upstream chain of the materials used, such as alloy elements into account, a regular review of the system should be conducted (e.g. every three to five years). Relevant specifications should be made during the rulebook process. The D/E reference curve should not be adapted. From the point of view of the authors in order to be able to uphold the company’s own ambition standard, adaptations for level A should be enforced in future, in particular when the aim is to significantly reduce upstream emissions that can generally be included, e.g. for lime.

6. List of abbreviations, figures and tables

List of abbreviations

BOF	Basic Oxygen Furnace
CEM I	Portland cement
DR	Direct reduction
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
IEA	International Energy Agency
LF	Ladle Furnace
PCI	Pulverised Coal Injection
SAF	Submerged Arc Furnace
QST	Quality Steel
VD	Vacuum Degassing

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