WHITEPAPER

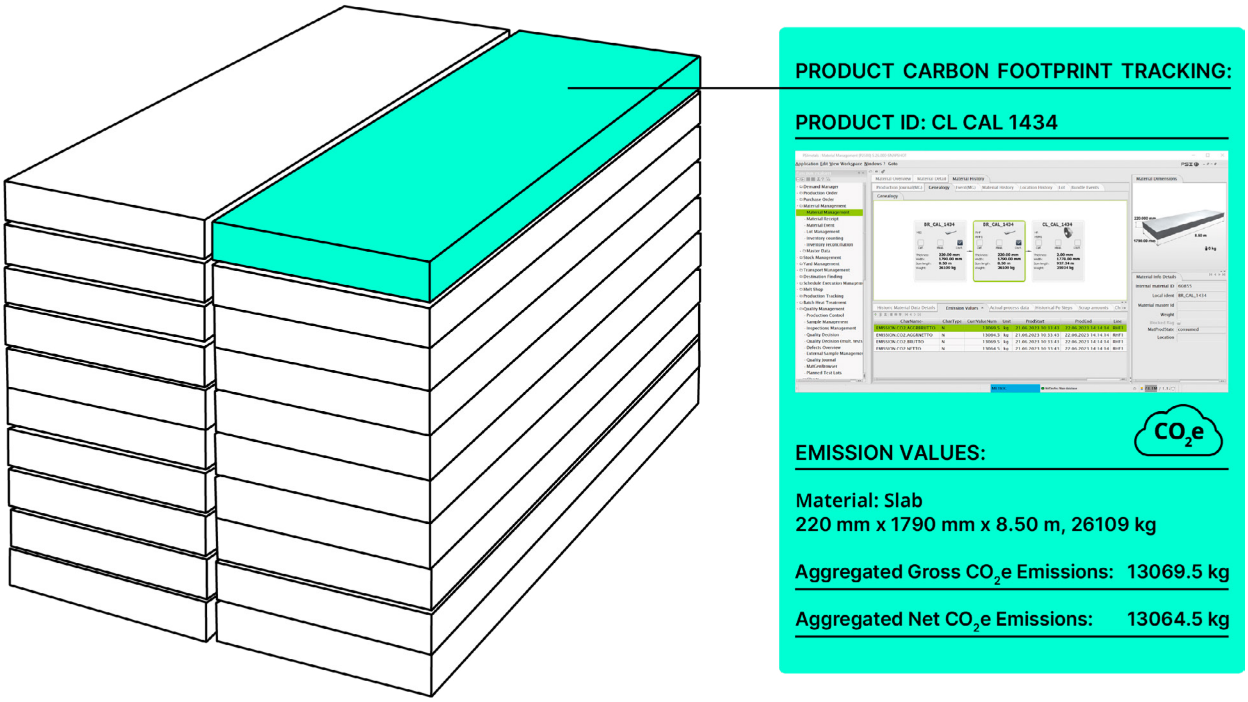
# Detailed tracking of product $CO_2$ footprint in the steel industry

PSI

# Take the first step on your green digital transformation journey with PSImetals

Decarbonization and digitalization are the current and future drivers of the transformation of the steel industry. Reliable carbon footprint calculations and certificates for the various steel products are being increasingly demanded by the market. In many industries, reporting $CO_2$ emissions is still not broken down to single products, but based on yearly production tonnage and average $CO_2$ equivalents for different plant areas.

A modern production management system like PSImetals supports customers to overcome this lack. It transparently calculates and tracks emissions on a piece and product level, along the entire production chain, from iron and steelmaking, hot and cold rolling to finishing lines.



# Contents

# Introduction

CHAPTER 1

# [ Introduction ]

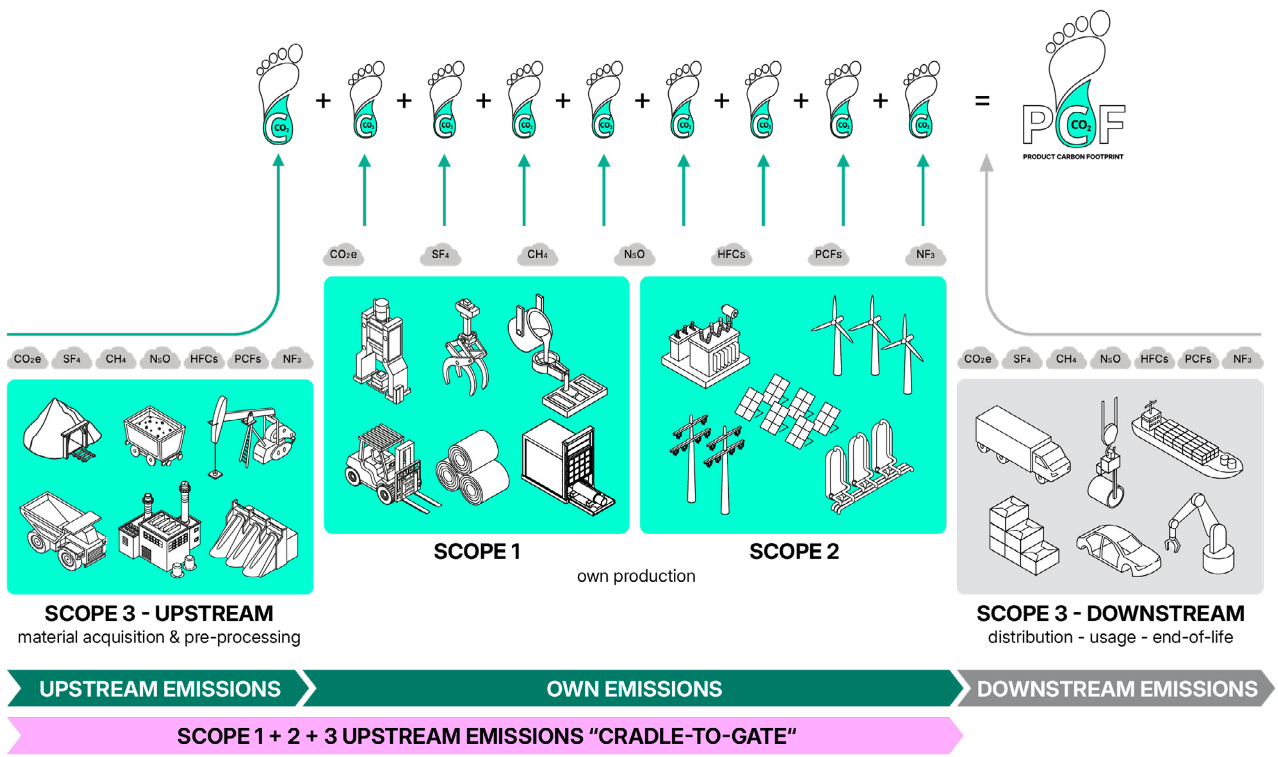
In the past years, there has been an increasing need for a modern production management system with functionalities that support the decarbonization journey of metals producers. This is because detailed production tracking is the basis for all other functions dealing with decarbonization. Steel producers need to transparently calculate and track greenhouse gas (GHG) emissions on a piece and product level, along the whole production chain. That is to say from preparation and charging of raw materials via the different production steps to the commissioning of the final products for shipment, i.e. from cradle to gate. In this paper, a new technology integrated within a quality management component of a manufacturing execution system (MES) is presented. It provides metals producers all the required information on their product carbon footprint (PCF), both per production step and aggregated over all steps until shipment. Such a system is able to overcome the shortage of current mass based $CO_2$ reporting aggregated on the company level, which is the corporate carbon footprint (CCF).

Although there are currently no mandatory legal regulations, the Greenhouse Gas Protocol Corporate Standard and the international norm ISO 14067 define requirements and guidelines to quantify greenhouse gas emissions at product level. Three scopes have been defined for the tracking of these emissions:

- Scope 1 comprises of emissions directly produced by processes in an organization
- Scope 2 includes indirect emissions from consumed energy provided by an external supplier
- Scope 3 contains emissions related to any other indirect upstream emissions from purchased goods as well as downstream emissions from distribution, usage and disposal of sold products.

PSImetals Product Carbon Footprint Tracking is the basis for:

- green key performance indicators (KPIs) to be used to optimize production planning, scheduling and execution through weighted trade-offs with classical economic KPIs (like throughput, costs and meeting delivery dates)
- green lead markets fostering the decarbonization journey of the industry through dedicated increase in demands for green steel.

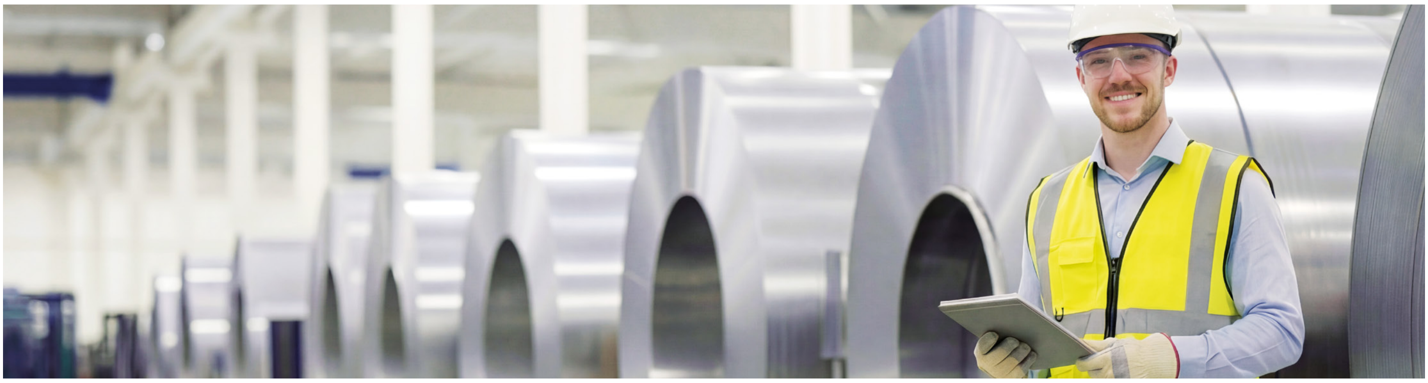



**FROM "CRADLE-TO-GATE":** PCF tracks all emission-relevant process data in real-time along the material's entire production chain, calculating Scope 1, 2, and upstream Scope 3 emissions for each individual product.

# Optimize production with MES production tracking

CHAPTER 2

# [ Optimize production with MES production tracking ]

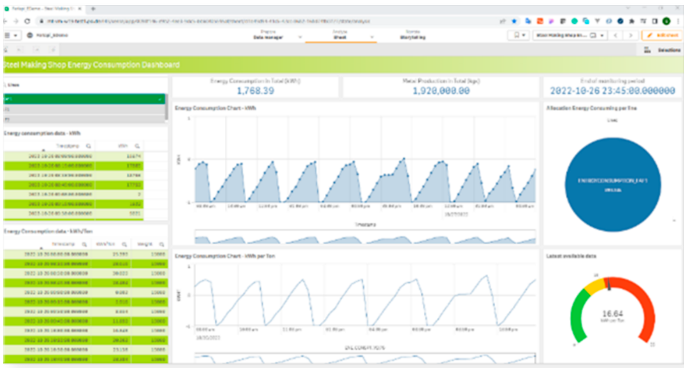


Comprehensive manufacturing execution systems for steel production, supervise and track all events during production of a certain product. It stores all:

- related process data, like consumed raw materials, electrical energy, chemical energy carriers (e.g. solid carbon carriers, liquid fuels, natural gas, hydrogen), oxygen, nitrogen, inert gas and other auxiliaries as well as durations and conditional parameters of each process step (e.g. heating with electrical power, deep vacuum treatment with vessel pressure, stirring with inert gas flow rate)
- relevant product quality data, e.g. chemistry, hardness, tensile strength, geometry, flatness, etc.

These data are received based on related events or cyclically along the time axis. The cyclic data are typically measured or calculated by level 1 and 2 process control systems and reported to the MES. This enables the monitoring of the information in real time and creation of performance reports or evaluations based on historic data. Examples given in Figure 1 show graphical user interfaces (GUIs) for monitoring electrical energy consumption at an Electric Arc Furnace (EAF) and a performance evaluation on total energy consumption.

This MES tracking functionality is the basis for optimized production in regards to adjustment of targeted product quality with minimum material and energy consumption (i.e. costs) and/or maximum productivity (in terms of yield and production time). The transformation of production towards decarbonization of all involved processes also requires tracking of GHG or $CO_2$ equivalent ($CO_2e$) emissions related to the different process steps and their energy and material consumptions per piece of product, i.e. Product Carbon Footprint (PCF) tracking.



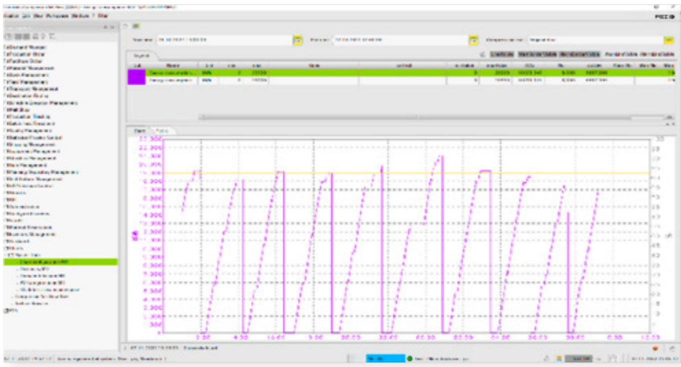



Figure 1. GUIs with electrical energy consumption at EAF and evaluation of total energy consumption in a melt shop

# PSImetals Product Carbon Footprint Tracking

CHAPTER 3

# [ PSImetals Product Carbon Footprint Tracking ]

Product Carbon Footprint data will be treated in the future like todays quality data. It will be part of the product certificate and will also be checked against tolerances during the production process. Hence why technologies developed for quality management within production management systems are ideally suited. An example is the “Quality Process Snapshot” within PSImetals which collects and stores, in real time:

- all process and material data relevant for the carbon footprint of a material piece at a certain production step (like material, electrical energy and process gas consumptions, offgas volume and analysis, slagged material, cut scrap parts) as provided by standard production report messages,
- as well as the derived product carbon footprint from this step and aggregated over all steps so far( Figure 2).

The stored data is linked to the “material genealogy” nodes related to the respective production steps. The material genealogy is used by various functions within PSImetals quality management with the main purpose, which is rather evident in the name, being to answer questions like:

- How is a material composed of materials of a former production step?
- Which materials include parts of a former material?
- What are the material characteristics of a former material piece?
- Which material defects exist from a former material piece?
- Where was a material defect located within a material of a former production step?

## PSImetals Quality Process Snapshot (QPS)

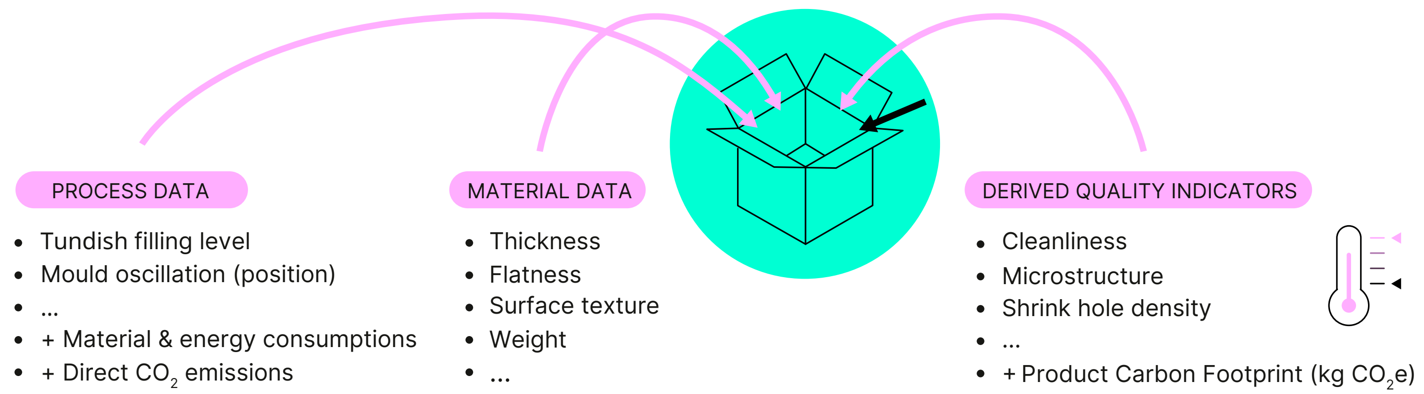



Figure 2. PSImetals Quality Process Snapshot

# [ PSImetals Product Carbon Footprint Tracking ]

Another question in the context of decarbonization to be answered by the material genealogy is:

- How is the PCF of a material evolving along the history of its production, i.e. along its material genealogy?

Enabling the answers to such questions requires the tracking of all processes and related data which influence the materials genealogy (melting, refining, casting, rolling, welding and cutting processes, scrap cuts, sample cuts, number of passes, as well as coiling processes changing coil orientation). PSImetals does this and keeps track of the related geometric, physical and chemical material characteristic changes – including related $CO_2$e emissions - across all production stages. Information stored for the material genealogy allows mapping geometrical areas of a given production stage to any other production stage. This information can, for example, map a defect area of a hot rolled coil to any other production stage. This permits quality related evaluations covering the whole production chain.

The material genealogy is implemented as a graph consisting of nodes and directed edges. Each node describes a material at a specific production stage. Each edge describes a material transformation with respect to geometric, physical and chemical characteristics, i.e. a performed production step. A user interface is available to visualize the material specific genealogy graph and to obtain process related information for a material's production history.

For determination of the PCFs (as "Quality Indicators") along the production route, master data with GHG emission factors for different material, electrical energy and process gas consumptions as well as related process input data and calculation rules have to be configured within dedicated process specification dialogues (Figure 3). Thus, different PCFs can be configured,

- per production step and over all performed steps,
- with distinction between gross and net emissions, i.e. with and without by-side products and scrap cuts,
- as well as total emissions containing all idle times and preparations of production campaigns as lumpsum contributions from the related production area.

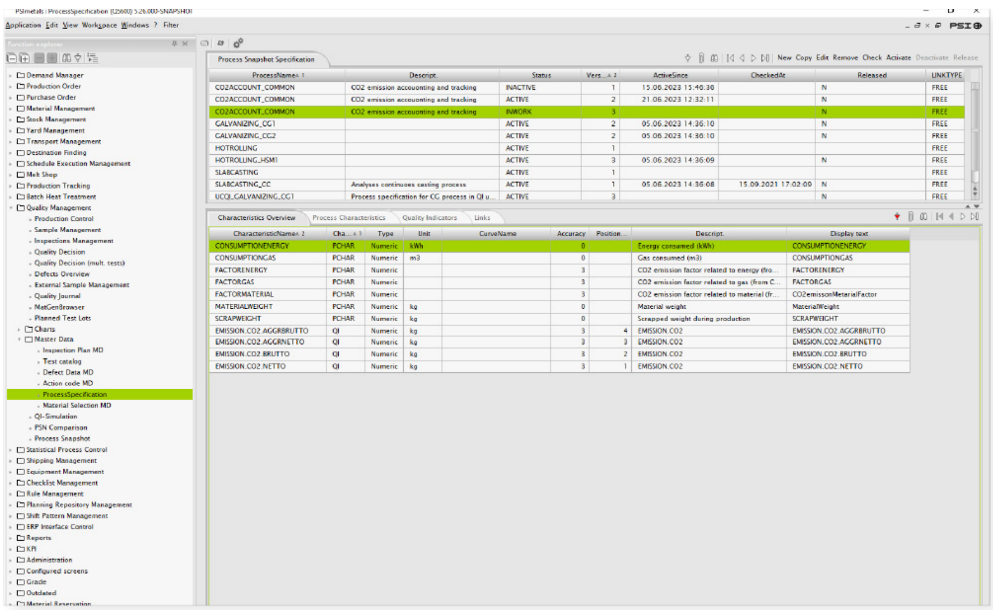


Figure 3. PSImetals Dialogue for Quality Process Snapshot definition with specification of PCF output variable

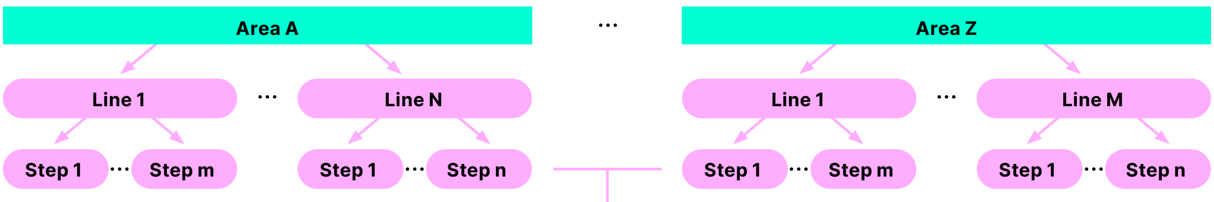
This is supported by a hierarchical definition of GHG emission factors ( Figure 4). Emissions related to raw material additions (scope 3), electrical energy (scope 2) and chemical energy (e.g. natural gas, scope 1) inputs for heating, as well as metallurgical reactions (like oxide reductions or decarburization, scope 1) can be calculated on the level of :

- individual production steps,
- individual production lines (aggregates)
- or areas of production lines.

This is with the possibility to distinguish these emissions (i.e. the respective emission factors) for different steel grades and products.

The scope 3 emissions of raw material additions have to be determined from their master data, i.e. their specific PCF provided by the supplier (which can also be another plant of own steel production, e.g. for scrap from solid production lines delivered to the melt shop). GHG emission factors for the calculation of scope 2 emissions given in kg $CO_2e$ / kWh electricity have to consider the mix of primary energy used to generate the consumed electrical energy. Scope 1 emissions related to fossil fuel (e.g. natural gas) or carbon carrier (e.g. injection coal) combustions are calculated from the associated emission factors, e.g. given in kg $CO_2e$ / $m^3$ gas or kg $CO_2e$ / kg coal, respectively. The other group of scope 1 emissions in steel production result from metallurgical reactions which are mainly a reduction of oxides by carbon or carbon monoxide and decarburization of liquid steel, e.g. by BOF, RH, VD/VOD or AOD treatments. The reduction reactions can be treated like chemical heating with GHG emission factors given in kg $CO_2e$ / $m^3$ gas, kg $CO_2e$ / kg coal or kg $CO_2e$ / kg coke. For the decarburization reactions, a mass balance of carbon before and after decarburization can be used to calculate the amount of emitted $CO_2$. The higher levels in the accounting hierarchy consider emissions that are not taken into account in the lower levels.

For example, emissions from idle times or preparations of next production campaigns, which cannot be assigned to a single product after its treatment in a specific production step, must be configured on the area level as a kind of lump-sum contribution per kg of produced steel. Thus, the total PCF results from the sum of all levels of the hierarchy. Area factors are processed only once per product, line factors once per line cycle, each with the first related production step. The PCF calculations are triggered by production reports after each production step is completed. With splitting of a material, the $CO_2e$ emissions of the mother piece are distributed to the children pieces, according to their weights. On the other hand, the joining of materials results in an aggregation of the involved $CO_2e$ emissions to the new piece.




| Table GHG Emission Factors | | | |
|---|---|---|---|
| **Column Name** | **Data Type** | **Constraints** | **Description** |
| **Factorid** | VARCHAR2 (32) | PK | Unique Id of factors |
| **Area** | VARCHAR2 (30) | FK | Production area defined in own table |
| **Line** | VARCHAR2 (10) | FK | Production line defined in own table |
| **Step** | VARCHAR2 (10) | FK | Production step defined in own table |
| **Grade** | VARCHAR2 (10) | | Steel grade according to own table, wildcard using * possible |
| **Product** | VARCHAR2 (10) | | Product according to own table, wildcard using * are possible |
| **Emissiontype** | VARCHAR2 (20) | | Specific type of emissions, e.g. CO2, CH4, N20, ... |
| **Factorname** | VARCHAR2 (100) | | Name of the conversion factor, e.g. MATERIAL, GAS, ELECTRICITY, ... |
| **Factorvalue** | NUMBER | | CO2 emission in kg for 1 unit related to factor |
| **UOM** | VARCHAR2 (30) | | Unit of measurement related to factor: pc, kg, $m^3$, kWh, ... |

Figure 4. Hierarchically defined GHG emission factors

# [ PSImetals Product Carbon Footprint Tracking ]

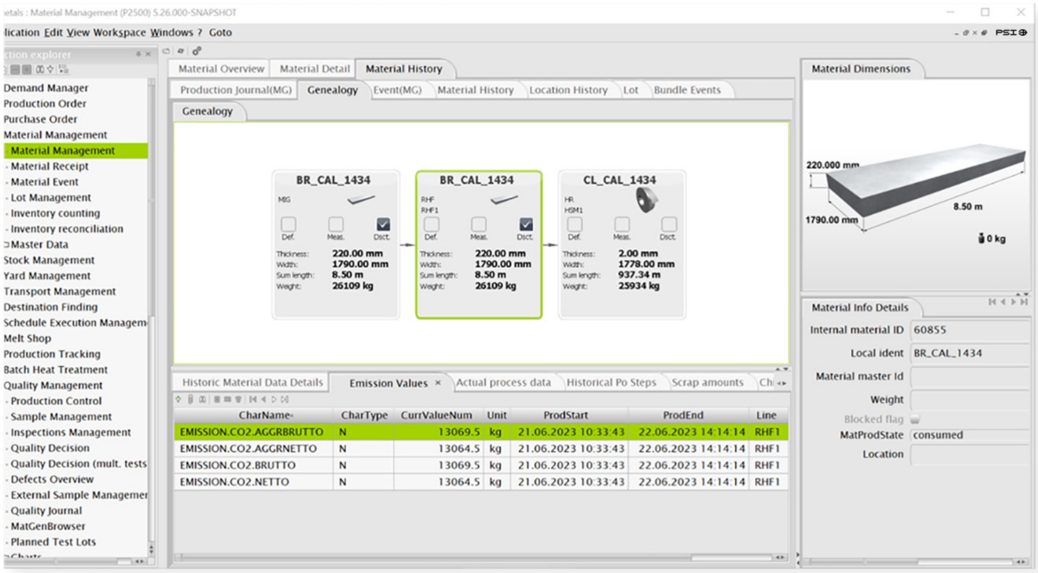
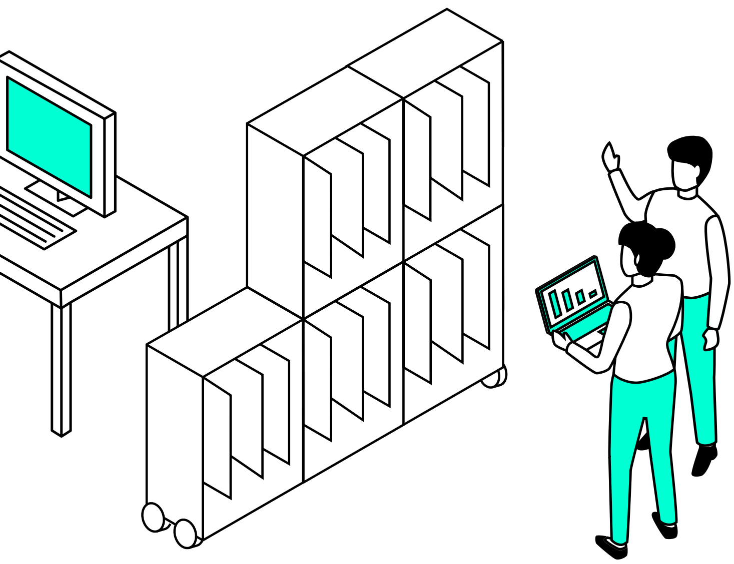



Figure 5. Visualization of PCF tracking in PSImetals material genealogy

There are valuable databases with material and energy consumptions, as well as related GHG emissions for steel production which can be used as a basis for the configuration of the PCF tracking rules and master data. An example of these databases are those from worldsteel life cycle inventory (LCI) study.

Figure 5 shows a visualization of the calculated and tracked PCFs along the whole production chain, as well as a detailed tab displaying the $CO_2e$ emissions from the individual process steps and their aggregated values for the respective product piece. Additionally, an embedded business intelligence (EBI) dashboard enables the evaluation of all information about PCFs of products, product groups, certain lines and areas including their evolution over the past weeks, months and years. This allows the detailed tracking of the improvements regarding decarbonization of steel production.



## Meeting the net zero target requires 24/7 team work

In the ecosystem of production planning and scheduling with energy trading and procurement, the key stakeholders must collaborate to manage material production and related energy consumption efficiently.

# Planning, scheduling and control of green steel production

CHAPTER 4

# [ Planning, scheduling and control of green steel production ]

The tracking and storage of material and energy consumptions, $CO_2$ emissions, as well as treatment and transport durations also allows for their statistical or even more sophisticated AI evaluation. This is in order to adapt related parameters used for corresponding forecasts in production planning, scheduling and control components of the production management system.

A classical model for optimized determination of charge input and alloy material additions in melt shops is based on linear programming, taking into account all kinds of configurable linear constraints and target specifications. Based on the specific melting energy and specific $CO_2$ footprint of the raw materials, the heat's total energy costs and carbon footprint can respectively be calculated and minimized by an appropriately enhanced charge and alloying model. Moreover, even for optimized scrap and alloy material procurement, the hybrid charge and alloy optimization model can be used based on the heats planned on a long-term horizon.

This supports:

- holistic scrap management with planning of scrap demands,
- procurement of scraps and alloys,
- management of external and internal scrap batches stored at scrap yard,
- optimized scrap mix and alloy materials charging,
- tracking of scrap consumptions and scrap generations

along the whole steel production chain. This assists with the minimizing of its energy consumptions and product carbon footprint.

Algorithms for optimized production planning and scheduling use properly elaborated production orders (POs) which contain technical information on all involved production steps.

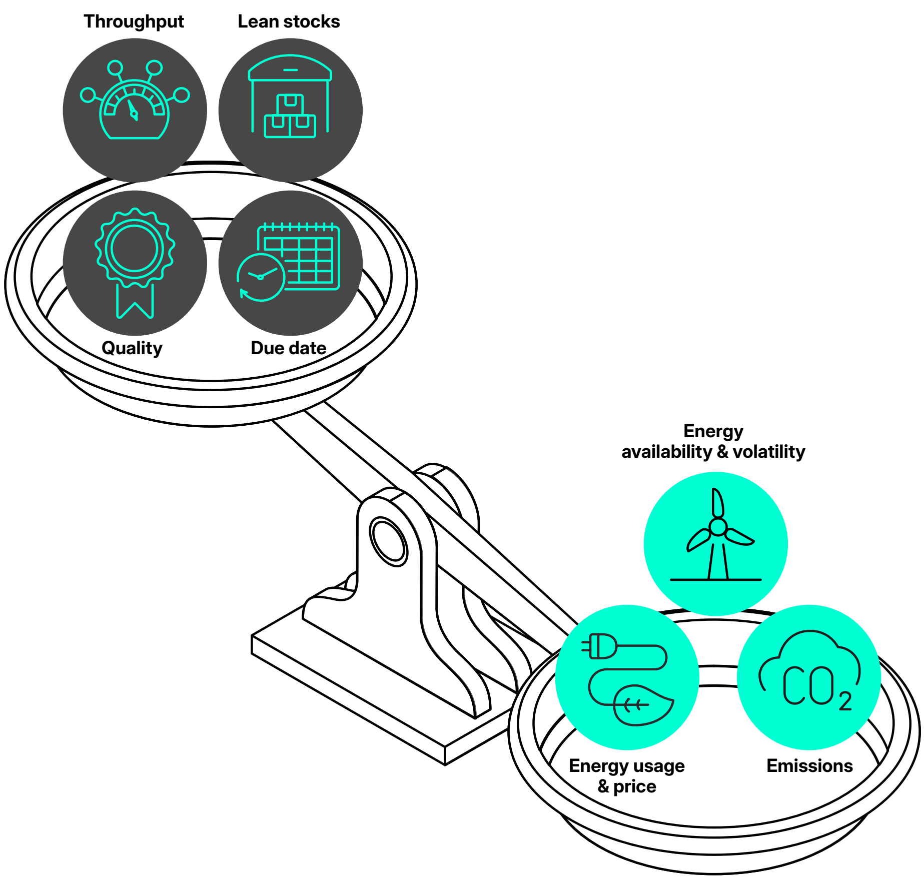



Figure 6. Smart management of conflicting targets is more essential now than ever

# [ Planning, scheduling and control of green steel production ]

For maximum efficient green steel production processes, this has to include minimization of material and energy resources, as well as product carbon footprint. Thus, the rules for technical elaboration of production orders have to consider energy consumptions and greenhouse gas (GHG) emissions related to the assigned input materials and production order steps used for planning, scheduling, execution, and quality control in order to fulfil the order demands, including customer specific requirements. The specific demands for input materials and energy input with their resulting GHG emissions, as well as additional specific GHG emissions (e.g. from decarburization reactions), are parameters of the rule based PO elaboration. They can be continuously adapted by simple statistical evaluation, linear regression or other machine learning methods applied on stored production data. The PO elaboration, including green key performance indicators (KPIs) like GHG emissions and energy consumptions, enables an optimized production planning, scheduling and execution through weighted trade-offs with classical economic KPIs (like throughput, quality, costs and due dates, cf. Figure 6). Moreover, it allows an energy management with

- prediction of overall energy demand based on specific energy demands by products, production steps and resources
- procurement of energy on long, medium and short term – including day ahead and intraday energy trading
- comparison of projected energy demand with availability, costs and possible limits of green and grey energy to adjust the scheduled production accordingly
- reaction on actual production deviations with transparency of impact on energy consumption.

# Standards, regulations and verification of PCF Tracking

CHAPTER 5

# [ Standards, regulations and verification of PCF Tracking ]

The PCF calculations in PSImetals are in accordance with the definitions of scope 1, 2 and 3 given in GHG Protocol Corporate Accounting and Reporting Standard. There are various further standards for accounting and reporting of GHG emissions at corporate and product level (cf. Figure 7). The most prominent international norms for corporate carbon footprint (CCF) tracking are ISO 14064-series and for product carbon footprint (PCF) tracking ISO 14067-2018, respectively. Especially for the steel industry, there are also ISO 20915:2018 for life cycle inventory (LCI) analysis and ISO 14404-series for $CO_2$ calculation methods related to different steelmaking routes (BF-BOF, Scrap-EAF and DRI-EAF). The more comprehensive ResponsibleSteel™ International Standard covers environmental, social and governance issues, which were identified and agreed upon with members and stakeholders of this not-for-profit standard and certification initiative.

Legal regulations based on these standards are still under development by the governments and parliaments in the various regions of the world. Nevertheless, there are many certification bodies that offer services for third party verification of implemented carbon footprint tracking methodologies according to the defined standards, e.g. TÜV Süd or auditors approved by ResponsibleSteel™. Such a third party verification of the presented PSImetals PCF calculation and tracking approach is in progress.

| | |
|---|---|
| **Product LCA/EPD/PCR Standards** | |
| ISO 14044:2006 | General LCA |
| ISO 14021:2017 | Labels Type II |
| ISO 14025:2006 | Labels Type III |
| ISO 14026:2017 | Principles, requirements and guidelines for communication of footprint information |
| ISO 21930:2017 | LCA for building products Super PCR |
| EN 15804:2012+A2:2019 | LCA for building products Super PCR |
| prEN 17662 | LCA for steel and aluminium c-PCR under EN15804 |
| ISO 20915:2018 | LCI for steel |
| ISO 14067:2018 | Carbon footprint of products |
| EN 45557:2020 | Recycled content in energy related products |
| **Organisation or site greenhouse gas, GHG, Quantification and Reporting** | |
| ISO 14064-1:2018 | Quantification and reporting org |
| ISO/TR 14069:2013 | Guidance to ISO 14064-1 |
| ISO 14064-2:2019 | Quantification and reporting project |
| ISO 14064-3:2019 | Verification and validating statements |
| ISO 14694:1:2021 | Stationary emissions GHG in energy intensive industries |
| SS-EN 19694-1:2016 | GHG Energy intensive industries general |
| SS-EN 19694-2:2016 | GHG Energy intensive industries, iron and steel industry |
| ISO 14404-1:2013 | $CO_2$ Calculation method Steel complimentary calculation rules BF-BOF |
| ISO 14404-2:2013 | $CO_2$ Calculation method Steel complimentary calculation rules EAF |
| ISO 14404-3:2013 | $CO_2$ Calculation method Steel complimentary calculation rules DR-EAF |
| ISO 14404-4:2013 | $CO_2$ Calculation method Guidance on 14404 |
| **General standards supporting decarbonisation** | |
| ISO 14097:2021 | GHG mgmt. incl. investments and financing |
| ISO 14080:2018 | Climate action |
| ISO/DIS 14068 | Carbon Neutrality |
| ISO/DIS 14030-3 | Green debt instruments, part 3 Taxonomy |
| ISO NWIP 2023 | Requirements and guidelines for sectoral transition plans |
| IWA 42:2022 | Net Zero Guidelines |

Figure 7. Relevant standards for the transition to near zero steel production (not exhaustive, source: Wei et. al. 2023.[1])

[1] W. Wei, R. Gyllenram, K. Östman, " Initiatives and Standards for the Transition to Near-zero Steel Production", URSTARK Project Report Final Version (Commissioned by Jernkontoret), 2023, Initiatives and Standards for the Transition to Near-zero Steel Production (jernkontoret.se)

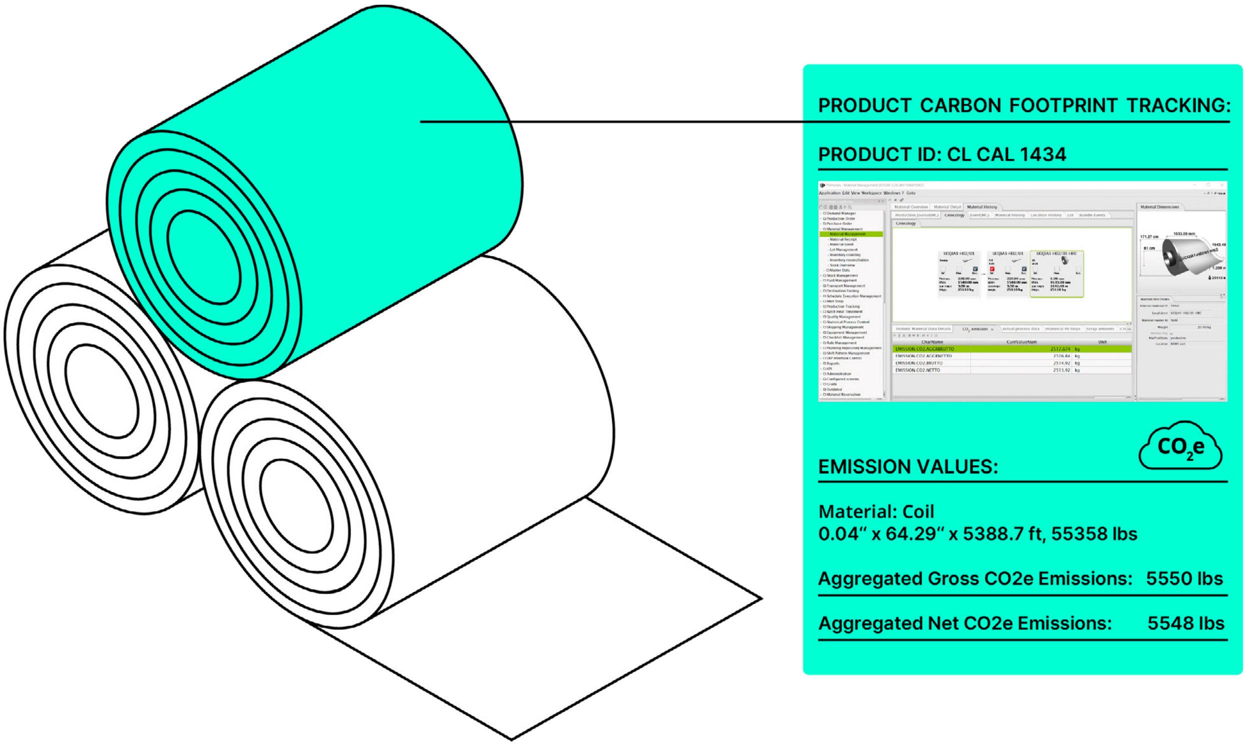
# Conclusions

CHAPTER 6

# [ Conclusions ]

A manufacturing execution system with quality management based on process snapshots along all production steps provides an ideal framework for product carbon footprint (PCF) tracking.

PSImetals has implemented this type of PCF approach using hierarchically defined GHG emission factors on levels of production area, production line and production step. Thus, $CO_2e$ emissions can be calculated and tracked in real time at piece and product level along the complete chain of production steps and the results are stored on the related material genealogy nodes. This also includes lump-sum contributions to GHG emission from idle or preparation times of production lines that can be configured by appropriate area emission factors given in kg $CO_2e$ / kg steel. Furthermore, PCF tracking and forecasting provides essential input for optimized production planning, scheduling and execution with a weighted trade-off between economic and ecological KPIs. Finally, products with labels from certified PCF tracking methodologies allow the establishment of green lead markets fostering an increase in demands for green steel.




#StepOnIt

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Martin started his career in the field of Metals Production as a Software Engineer, Project Manager and Consultant for level 2 and level 3 automation systems.

This was followed by a period of 16,5 years as Project Group Leader and Deputy Head of the Measurement and Automation Steelmaking department. There, he was responsible for the area of model based monitoring, simulation, optimization and control of liquid steelmaking processes from primary steelmaking via secondary metallurgical ladle treatment to continuous casting of the various semi-finished products.

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