INSTITUTE OF COMMUNICATION, INFORMATION AND PERCEPTION TECHNOLOGIES

Scuola Superiore Sant'Anna

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

RIVA

EVALUATION OF INTERNAL SLAG REUSE IN AN ELECTRIC STEELMAKING ROUTE: SIMULATION ANALYSES THROUGH THE EIRES MONITORING TOOL

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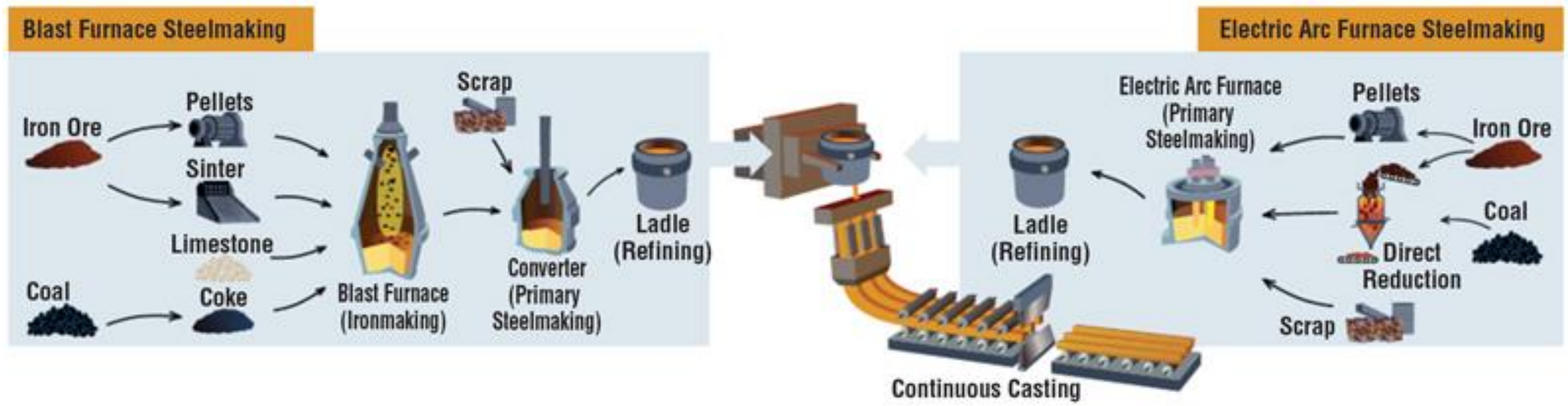
Content

Introduction

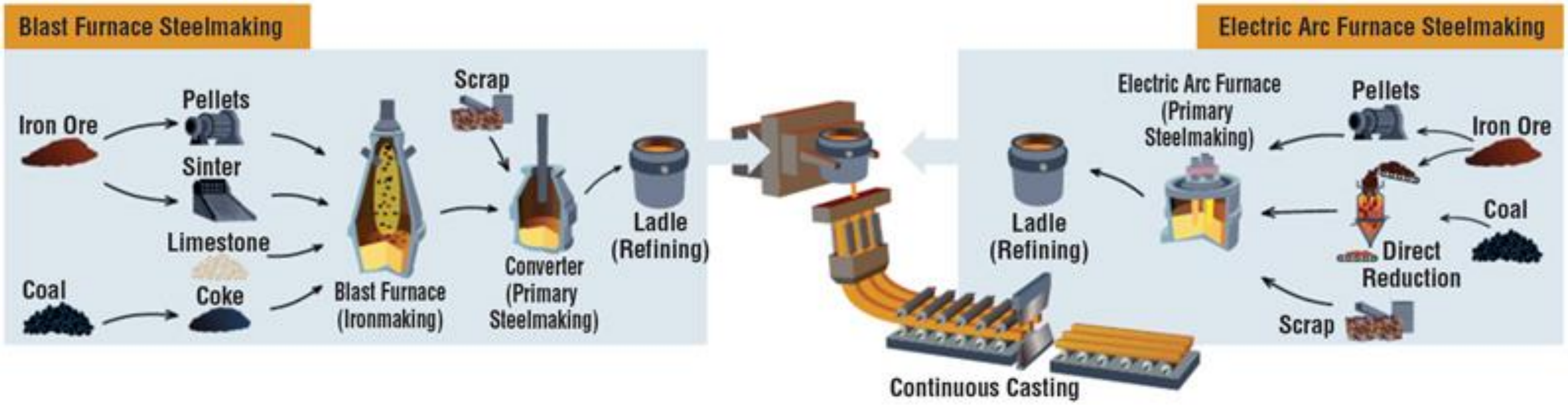


70% **World Steel Production** **30%**

Main Feed

- **Steel Scrap →** the **main raw material** (an end of life product) **→** in line with circular economy
- **Electricity → to melt** the scraps
- **Scoryfing agents →** lime, dolime, silica sand **→ to remove** scrap **contaminants**
- **Iron Alloys → to achieve** the desired **steel composition**

Introduction



70% **World Steel Production** 30%

Main By-Products and Wastes

- **Slags →** Electric Arc Furnace (EAF) and Ladle Furnace (LF) Slags → most important by-products in quantitative terms
- **Off-gases**
- **Sludges**

Introduction

EAF Slag

Main Components:
Iron and Calcium Oxides

LF Slag

Main Components:
Calcium, Silicum, Aluminium and Magnesium Oxides

Sources of valuable raw materials

−

- Only in some cases this products are reused in the steelworks as raw material substitutes
  - Variability of their composition
    - **Not perfectly known effects on process behaviour, product yield and quality**

\+

- **Internal reuse** can allow obtaining a lot of advantages
  - **Economic Advantages**
    - Reduction of raw material exploitation
    - Reduction of waste disposal costs
  - **Environmental Advantages**
    - Reduction of waste disposal
    - Compliance with ever more stringent environmental regulations

The slag (or other by-products/waste) reuse could improve the Plant Sustainability and its Competitiveness following the Strategic Research Agenda of the European Steel Technology Platform

Introduction

Purpose of the work

Analysis of the process behavior, performance and steel composition when slags are reused in an Italian Steelworks

Case Studies

Replacement of lime and dolime by total LF Slag recovery (CS 1)	Replacement of lime and dolime by total LF Slag recovery and partial recovery of EAF slag (CS 2)

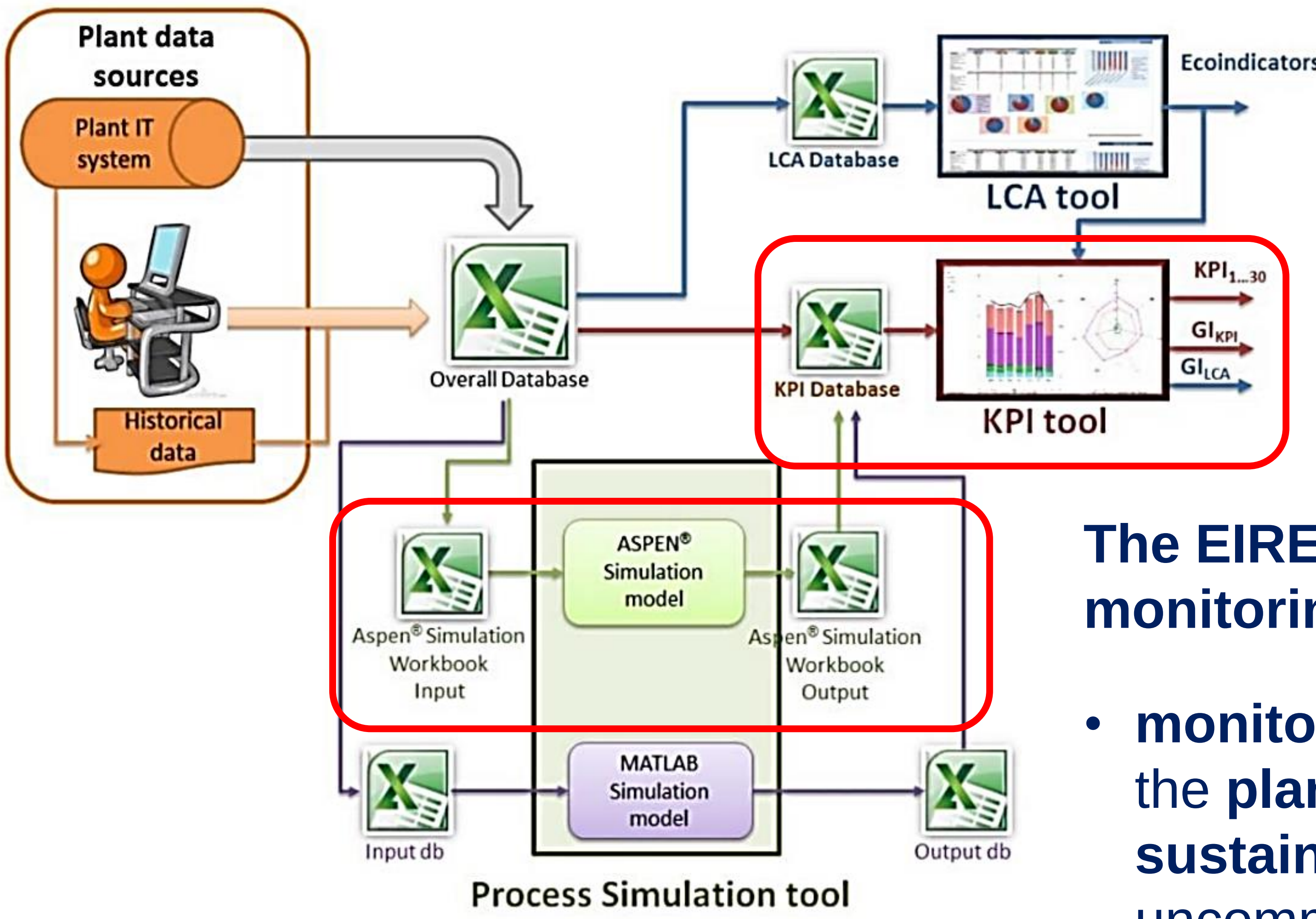
Two modules of the EIRES general purpose monitoring tool were used

KPI tool	Process Simulation tool

Evaluation of process modification on

production route	environmental impact	energy impact	steel quality	product yield

EIRES General Purpose Monitoring Tool

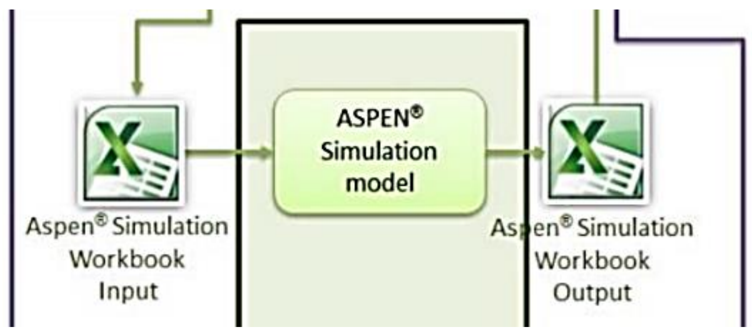


Only ASPEN® based-Simulation Tool and KPI tool were exploited in this work

The EIRES general purpose monitoring tool allows:

- **monitoring** the behaviour of the **plant** in terms of **sustainability** in common and uncommon scenarios
- making online evaluations or offline simulations
- **monitoring product quality** in terms of steel composition

EIRES Tool - Aspen®-based Simulation Tool



Aspen®-based Simulation Tool → three sub-modules:

- a production process model (the only one used in this work)
- a fumes network model
- a water network model

Production process model

- It was **validated for 11 steel families** that include steel grades with similar features
- **Prediction error** lies **below the 2%** for some parameters (e.g. EAF electric energy, steel quality and amount, temperatures during the process)
- For other parameters (e.g. amount of dust) the error is bigger but still lower than a threshold value
- it allows:
  - **simulating the different steps of a real electric steel production route**
    1. Electric Arc Furnace
       Charge, Melting, Oxygen addition, Furnace opening, De-Slagging, Refining
    2. Ladle Furnace
       Refining, De-Slagging
    3. Degassing (VD) if required and composition refining
    4. Continuous Casting (CC)
  - **monitoring each mass and energy streams and transformations**
  - **controlling production yield and product composition**

EIRES Tool - Aspen®-based Simulation Tool

Production process model

INPUTS

EAF
Scrap Charge (different scrap types)
Non-Scrap Charge (e.g. lime, anthracite)
Burners (natural gas, oxygen)
Other additions (blowing graphite, oxygen)
Fe-Alloys during tapping
Temperature after melting (or EAF electric power)
Time of EAF Power ON
LF
Fe-Alloys
Argon Volume Flow
Temperature input in VD/CC (or LF electric power)
Time of LF Power ON
VD
VD Pressure
Argon Volume Flow
CC
Fe-Alloys after VD and before CC
T before starting casting

OUTPUTS

Unit Operation	Output for KPIs	Other Output
EAF	Electric Energy (or Temperature after melting)	Mass of Steel Temperature of Steel Composition of Steel (also H_2 content) Composition of Slags Mass and Composition of Fumes and Dusts before the fumes treatment
	Chemical Energy	
	Energy from Burners	
	EAF slag	
	Metallic Charge	
	Non-Metallic Charge	
LF	Electric Energy (or Temperature input in VD/CC)	
	LF slag	
	Metallic Charge	
	Non-Metallic Charge	
VD		
CC	Desired Steel	
	Output for KPIs	

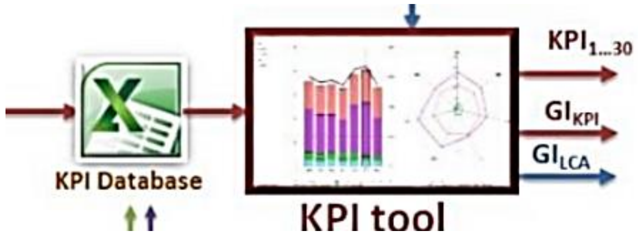
Simple **MS Excel® sheets** linked to the model by Aspen Simulation Workbook® represent the human machine interface (**HMI**) of the model

EIRES Tool – KPI Tool

KPI tool allows:

- **providing the values of** some defined Key Process Indicators (**KPIs**) → evolution of the environmental, energy and resources performance of the steelworks during common process or in case of modifications

- **obtaining global indexes** → global view of the sustainability of the steelworks



KPIs computed in this study:

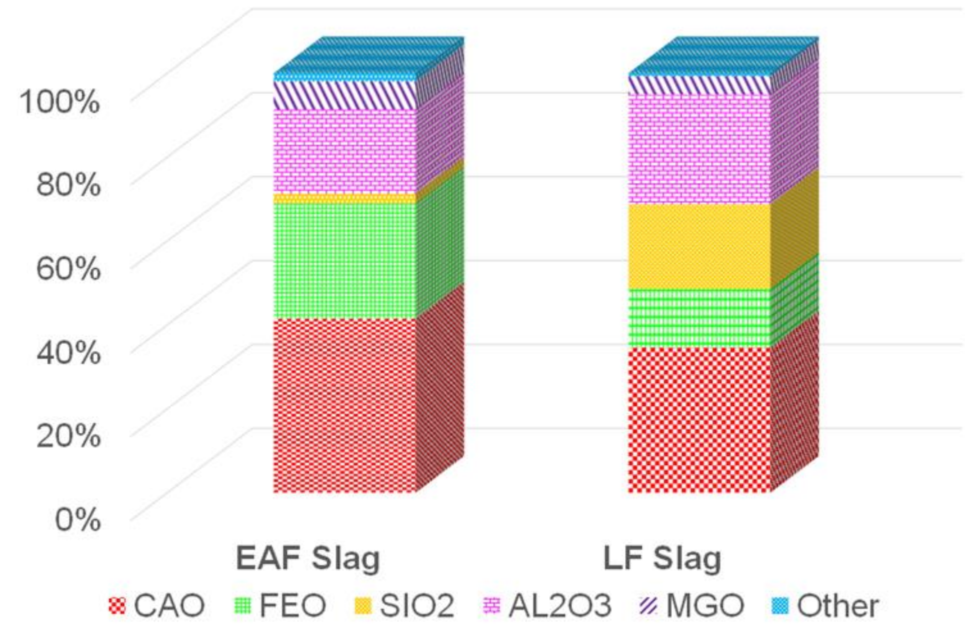
- **KPI_2 required electric energy** (ratio between the electric energy consumed in steel production and the amount of produced steel);
- **KPI_{12} specific non-metallic charge materials** (ratio between weight of non-metallic charge materials and the amount of produced steel);
- **KPI_{14} metallic yield** (percentage ratio between produced steel and the amount of metallic charge);
- **KPI_{15} specific EAF slag** (ratio between the amount of EAF slag and the amount of produced steel);
- **KPI_{18} specific LF slag** (ratio between the amount of LF slag and the amount of produced steel);
- **KPI_{21} total amount of slag** (ratio between the total amount of produced slags and the amount of produced steel).

Simulation of internal reuse of slags

Simulations were carried considering **one of the most produced steel family** in the considered steel plant

Steel Alloy Content [wt %]					
C	Si	Mn	Cr	Ni	B
0.12÷0.25	≤0.5	0.9÷1.6	≤0.25	≤0.25	≤0.0008

Simulations provided related **EAF and LF slags' compositions**



Slags appear **valid substitutes for some raw materials**

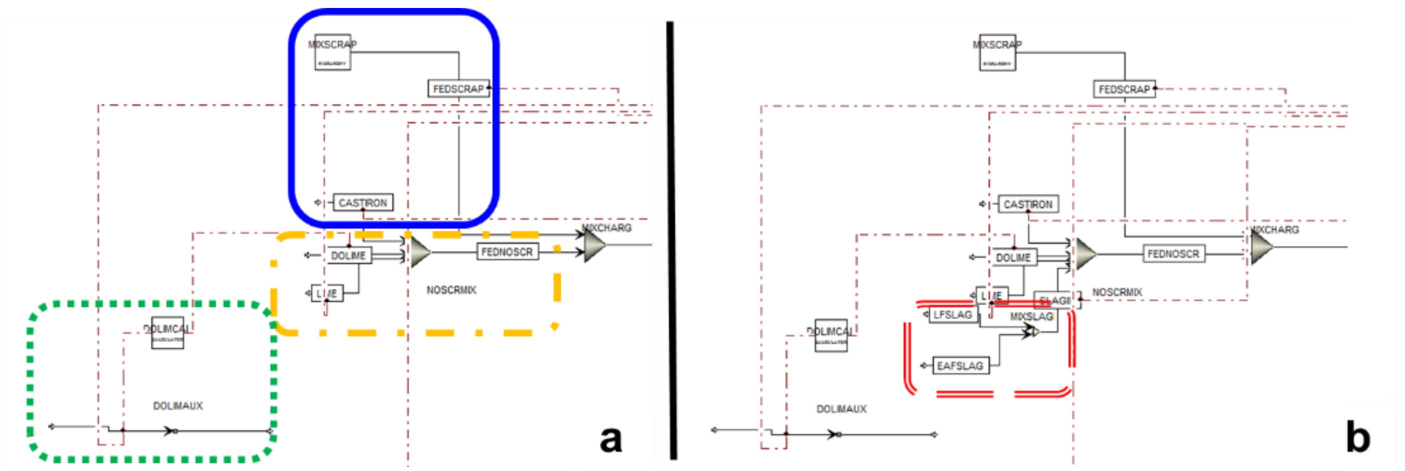
Simulation of internal reuse of slags

Replacement of lime and dolime by total LF slag recovery (CS 1)

- LF was completely reused in the process but only a **part of lime/dolime was replaced**

Replacement of lime and dolime by total LF slag recovery and partial recovery of EAF slags (CS 2)

- EAF slag was added to LF slag in order to **completely replace the lime/dolime**



EAF charge phase

a. standard route

b. modified route

Metallic Charge | Non-Metallic Charge | Auxiliary Calculator | Slag Charge

Simulation of internal reuse of slags

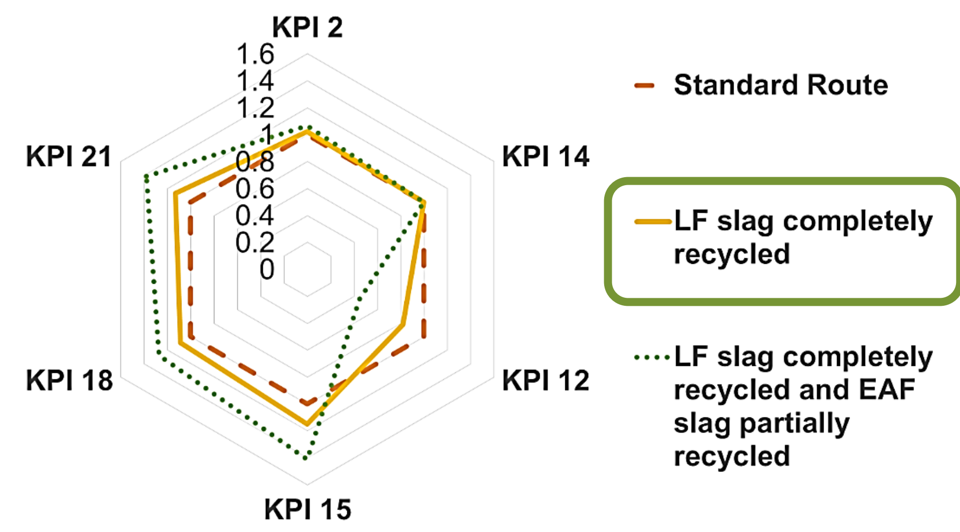
Replacement of lime and dolime by total LF slag recovery (CS 1)

Positive effects

- Reduction of non-metallic raw material feed (KPI_{12}) → -18%
- no effect on metallic yield (KPI_{14})
- no effect on steel composition

Negative effects

- Slight increase of required electric energy (KPI_2) → +2.5%
- Increase of produced slags (KPI_{21}), especially of EAF slags (KPI_{15})



This scenario appears to be a good compromise between process efficiency and increased by product reuse

Simulation of internal reuse of slags

Replacement of lime and dolime by total LF slag recovery and partial recovery of EAF slags (CS 2)

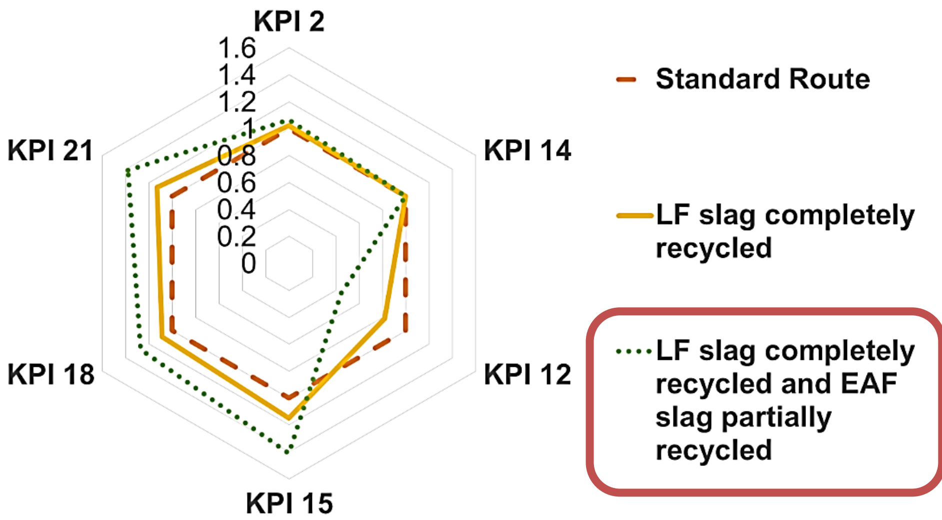
Positive effects

Negative effects

Significant increase of required electric energy (KPI_2) → **+ 7 %** ← bigger amount of matter to be melted

Reduction of non-metallic raw material feed (KPI_{12}) → **-55%** ← complete replacement of lime/dolime

Significant Increase of produced slags (KPI_{21}) → increment of related management costs



This scenario appears not economically and environmentally viable

Conclusions

Simulation studies were carried out **through a general-purpose monitoring tool**

For one of the most produced steel family, **simulated slags appear having high amount of valuable compounds** (e.g. CaO, MgO)

The **replacement of lime/dolime** was **evaluated by reusing LF slag with or withouth EAF slag**

LF slag could be a good material to replace partially lime and dolime, while maintaining a good steel quality and yield

EAF slags addition into the process appears a not economically and environmentally solution

Conclusions

The **followed approach provides useful indications and information** on non-standard scenarios preliminary to real plant implementation

An **early identification of most promising solutions** is possible

Risky and economically cumbersome plant trials related to non-viable options **can be avoided**

Conclusions

- This study is the **starting point for deeper studies and real experimentations**
- **Maximization of the internal reuse of by products and wastes** in the electric steel cycle
- **Increasing the environmental sustainability of the production process**
- **Increasing the electric steelworks competitiveness**

Acknowledgments

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