Models and tools for the CO_2 emissions assessment and forecast in iron and steel sector

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Abstract: The first step to set out the measures requested for the mitingation and the reduction of the CO_2 emissions in the iron and steel sector is the assessment and the forecast of the amounts released into atmosphere in a certain period of time, both at the overall sector and for the iron and steel plants.
Hence, on the international level a series of assessment and forecast models for CO_2 emissions has been developped. These models takes into consideration a variety of economical and technological parameters.
In Romania, the drawing up of such models is in the inception phase, but the need to have accurate tools for the assessment and the forecast of CO_2 emissions which were or will be allocate to the iron and steel plants included in the EU- Emission Trading Scheme (EU-ETS), did in the last period to a supplementary attention to such models.
This paper presents the achivements of the autors in this field and the benefic effects of such approach for the iron and steel plants, doing to a adequate allocation and planning both of human resources and of the possible profits obtained by the CO_2 trading.

Key-Words: CO_2 forecast model, iron and steel sector, CO_2 emissions forecast and assessment, activity data

1. Introduction

CO_2 emissions released by iron and steel industry represent an important part (7% as percentage) from the total amount of global emissions [5]. The reduction of these is a major challenge, especially in the last years, due to the fight against adverse effects of the climate change and in accordance with the provisions and the commitments foreseen by the Kyoto Protocol.
An adequate assessment of the CO_2 emissions released at the national, sectoral or industrial plants level, gives the first indications for the localisation and the amplitude of the actions route to be used, in order to control and to reduce these emissions. Also, to know the evolution of the emissions amounts in a certain period, such information could be obtained through the elaboration of adequate technical-economical forecasts.

Starting from these issues, on the international level has been developped, especially in the last decade, a series of models for the assessment and the forecast of the CO_2 emissions, taking into consideration production parameters (quantities of steel, coke, pig iron), process parameters (emission factors, energy consumption) and development parameters (growth rate, the structure of the planned technical upgradings, gas and energy prices).
For Romania, the development of such performed models, became stringent, especially in the context of EU accesion starting with 1st of January 2007, and, as effect, the participation to EU-ETS. The iron and steel sector is one among industrial sectors with important weight in the total of emissions allocated in the National Allocation Plan (NAP). This NAP foresees the amounts of CO_2 emissions for each Romanian instalation and plant included in EU-ETS.

Hence, the weight of allocated emission certificates (t CO_2) to iron and steel plants within NAP is about 17 % from the overall quantity of CO_2 national emissions alocated in 2007, and about 19 % in the period 2008-2012, [10]. For that reason, within national research programs or within special agreements with big iron and steel polluters, models for assessment and forecast of CO_2 emissions has been developped. The results obtained after modelling are usefully both to the authorities in the field with responsabilities in NAP elaboration, and for Romanian iron and steel plants included in EU-ETS.
Within paper [1], the basis elements of models has been presented, both on the national and on the iron and steel sector levels. The model for iron and steel was conceived based on production factors and CO_2 emission factors trends.
In this paper, the results presented in [2] at the level of iron and steel sector and plants has been developped, after an in depth analysis of a number of types of models for CO_2 assessment and forecast, followed by a systematization of these. Finally, the utility and benefic effects of the use of each model for specific applications, has been added.
Also, a clear relationship between the results obtained after the use of the assessment models for the calculation of CO_2 historical data and forecast models for the period 2007-2012 has been established. Therefore, the output data of assessment models are input data for forecast models.

2. The assessment and forecast models for CO_2 emissions released in iron and steel sector

The macro-economic forecast model for CO_2 emissions at the national level [1], and set using an “top-down” approach, has to be completed with sectoral models, at the industrial branches level, in which Greenhouse Gas (GHG) emissions are produced, among iron and steel. In this case, we discuss about a “bottom-up”approach, wich allows to stress better the effects of the technological and energetical upgradings over GHG emissions reduction.
The development and the completion of the general macro-economic model for Romania, was made by elaboration of specific models for CO_2 emission assessment and forecast.
A systematization of these by types of assessment models and forecast models used for CO_2 projections set-up and for monitoring of these in the forecast period, is shown in Fig. 1.

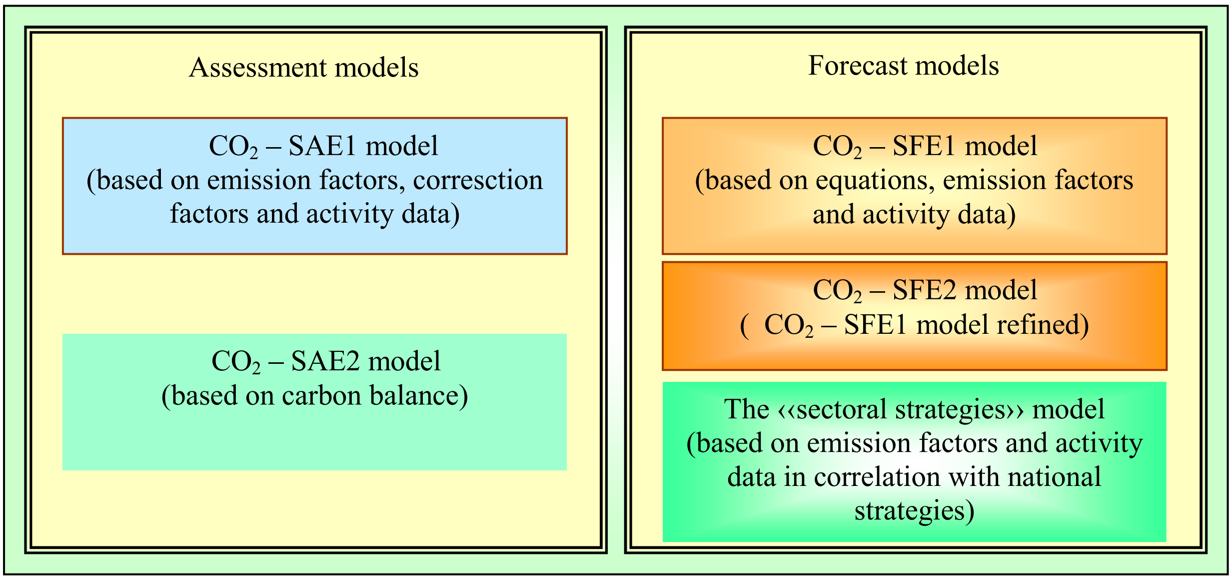

Fig. 1 The systematization of the developped models, by types of assessment models and forecast models

The assessment models for CO_2 emissions from iron and steel sector, could be classified on two types:

- a model based on emission factors, correction factors and activity data (CO_2-SAE1 as abreviation);
- a model based on carbon balance (CO_2-SAE2)

The first model could be used both for evaluation at the plant level and for iron and steel sector level. In this case, the analysis made is not for each tehnological process who is producing CO_2, these analysis and the model is for the overall plant or sector. The inputs (raw materials and other materials wich is producing CO_2) are taking into account indirectly and aggregates for the whole sector (through the production and emission factors). The emission factors are taking into account as average amounts, either are national factors, or are recommended by Intergovernmental Panel on Climate Change (IPCC).

The second one gives the most rigorous results in the case of the assessment of historical data used by forecast models at the sector level (by aggregation of the data obtained for each iron and steel plant). Besides, this model could be used for the calculation of the emissions during the forecast and monitoring period foreseen by EU-ETS.

The forecast models for CO_2 emissions produced in iron and steel sector, could be divided in three categories:

- a forecast model based on equations, emission factors (national or recommended by IPCC) and activity data-steel, coke and pig iron productions (CO_2-SFE1 as abreviation);
- a forecast model, wich adjusts and refines the CO_2 – SFE1 model, by taking into consideration of some relations of dependence among pig iron and coke production the one hand and Basic Oxygen Furnace (BOF) steel production on the other hand. The BOF steel production is in this case a reference amount;
- a forecast model, based on emission factors and activity data, conceived based on correlation with the national strategiei, significant for the estimation of CO_2 emissions in iron and steel.

Between these models, in the next sections of the paper, the two basic models developped are presented: the assessment model CO_2 –SAE1 and the forecast model CO_2 – SFE2. Both models are conceived based on activity data (steel, pig iron and coke productions) and CO_2 emission factors and could be used for plants or iron and steel sector.

3. The forecast model based on activity data and emission factors

The forecast of the CO_2 emissions from iron and steel industry for the period 2007-2012, obtained with the forecast model CO_2-SFE1, based on the evolution of steel, pig iron and coke productions for a certain period of time and emission factors (nationals or IPCC) has been issued in three scenarios, each off them having various hypothesis.

Using this forecast model, it is remarked that level of CO_2 emissions produced in iron and steel processes, increase from around 14.8 Mt in 2004 (supposed the same for the all 3 scenarios), to 15.8 Mt in 2007 (an amount less with around 0.1 Mt compared to first scenario, but the same compared with the second one). Also, the level of CO_2 emissions increase to about 20 Mt in 2012 (an amount less with around 2 Mt compared to second scenario, and about 2.5 Mt compared to the first one). Therefore, the calculated emissions amount in third scenario are more realistic compared to the both first two scenarios, what is normal, as long as the third scenario is the only one who takes into consideration the variations in time, both for Romanian iron and steel production structure, and the decreasing of CO_2 emission factor caused by the technological upgradings.

The forecast model CO_2-SFE1, based on plant projections, has been adjusted and completed, in order to have a new model, namely CO_2-SFE2. Therefore, to increase the accuracy of the production amounts (steel, pig iron, coke), used to estimate the CO_2 emission amounts in the same period, the relations of dependency between pig iron and coke production, on the one hand, and BOF production on the other hand have been established.

For instance, between the amount of natural gas consumed and the quantity of steel produced in BOF, the next dependency has been obtained:

$$Gn = 104{,}56 \times OC \qquad (1)$$

Where: Gn- the quantity of natural gas used, m^3

OC – The quantity of BOF steel, t

For the residual gases produced and used by Mittal Steel SA Galati (MSG) the bigest Romanian steel producer (70 % from overall Romanian iron and steel production), namely coke oven gas (COG) and blast furnace gas (BFG), the analysis was made in depth. So, the dependencies between COG and BFG quantities on one hand, and coke and pig iron quantities, on the other hand, have been achieved. The reason of such dependencies could be find in technological causes (process causes), namely the manufacture of coke in the same time with COG coke making process, or pig iron manufacture in the same time with BFG within pig iron meking process.

For instance, between the quantity of coke produced and the quantity of COG obtained in coke making process, the following relation of statistical dependency has been obtained:

$$Gc = 411{,}1975 \times coke \qquad (2)$$

where Gc- the quantity of COG produced, m^3

coke – the quantity of coke produced, t

The CO_2-SFE2 forecast model is based on the equations (3) as follows:

$$E= E_1+E_2+E_3 \quad (3)$$

where:

E – CO_2 annual emissions for iron and steel sector,t

E_1- CO_2 annual emissions issued from technological processes, t

E_2 – CO_2 annual emissions issued from burning processes,t

E_3 – CO_2 annual emissions issued by fluctuations of coke stock, t

Are defined as follows:

$$E_1 = a+b\times x+c\times y+d\times z \quad (4)$$

a,b,c,d – constant values;

x – annual quantity of steel produced, t

y – annual quantity of pig iron produced,t

z – annual quantity of coke produced, t

$$E_2 = E_{21}+E_{22} \quad (5)$$

where:

E_{21} – CO_2 annual emissions issued from burning processes on integrated route,t

E_{22} – CO_2 annual emissions issued from burning processes on electric route, t

Are defined as follows:

$$E_{21} = f_1\times p_1\times G_n+f_2\times p_2\times G_c+f_3\times p_3\times G_f \quad (6)$$

$$E_{22} = f_4\times OE \quad (7)$$

f_1,f_2, f_3, f_4 – emission factors

p_1,p_2,p_3 – net calorific value, GJ/m^3

G_n – annual quantity of natural gas consumed, m^3

G_f – annual quantity of BFG consumed, m^3

G_c – annual quantity of COG consumed, m^3

OE – annual quantity of electric steel produced, t

$$E_3 = f_5\times (Q_{coke\ import}- Q_{coke\ saled}) \quad (8)$$

f_5 – emission factors

$Q_{coke\ import}$ – annual quantity of imported coke, t

$Q_{coke\ saled}$ - annual quantity of saled coke, t

Taking into consideration the dependency, relations between the quantities of pig iron, coke and gas fuel, on the one hand, and the BOF steel annual production, on the other hand, it is obtained

$$x = OE + OC$$
$$y = c_1\times OC$$
$$z = d_1\times OC \quad (9)$$
$$G_n = n_1\times OC$$
$$G_c = n_2\times z = n_2\times d_1\times OC$$
$$G_f = n_3\times y = n_3\times c_1\times OC$$

where

c_1, d_1, n_1, n_2, n_3 – constant values obtained from statistical dependencies;

OC – annual quantity of BOF steel produced, t

After substitutions and calculations, it is obtained the equations describing CO_2 emissions issued from Romanian iron and steel sector. This below equation (10) is associated to the CO_2-SFE2 model:

$$E = a + (b + f_4) \times OE + (b + c\times c_1 + d\times d_1 + f_1\times p_1\times n_1 + f_2\times p_2\times n_2\times d_1 +f_3\times p_3\times n_3\times c_1) \times OC +f_5\times (Q_{coke\ import}- Q_{coke\ saled}) \quad (10)$$

The amounts of calculated parameters are presented in the Table 1 and those of the emission factor and of the net calorific value in the Table 2, respectively in the Table 3.

Table 1 The amounts of calculated parameters used in model

Calculated parameters	Measure unit	Amount
a	-	2872
b	t CO_2/ t steel	0.016109
c	t CO_2/ t pig iron	0.252486
d	t CO_2/t coke	3.100
c_1	t pig iron/t BOF steel	0.891
d_1	t coke produced / t BOF steel	0.380
n_1	m^3 natural gas / t BOF steel	104.5600
n_2	m^3 COG / t coke produced	411.1975
n_3	m^3 BFG / t pig iron	1652.7400

Table 2 The amounts of emission factors used in model

Emission factor	Source	Measure unit	Amount
f_1	IPCC	tCO_2/GJ	0.0561
f_2	IPCC	tCO_2/GJ	0.0471
f_3	IPCC	tCO_2/GJ	0.2418
f_4	calculated *	tCO_2/t electric steel	0.75
f_5	IPCC	tCO_2/t coke	3.10

* Value established in the reference [2]

Table 3 The net calorific values used in model

Type of gas	Notation	Net calorific value GJ/m^3
Natural gas	p_1	0.033689
Coke oven gas	p_2	0.016740
Blas furnace gas	p_3	0.003306

The comparative analysis of the results obtained through the both models (CO_2-SFE1 and CO_2-SFE2) shown in Fig. 2, gives the existence of some differencies for the projections of calculated emissions for the period 2007-2012. There are abbatment from 252 kt CO_2 for the year 2007, until 1913 kt for the year 2012.

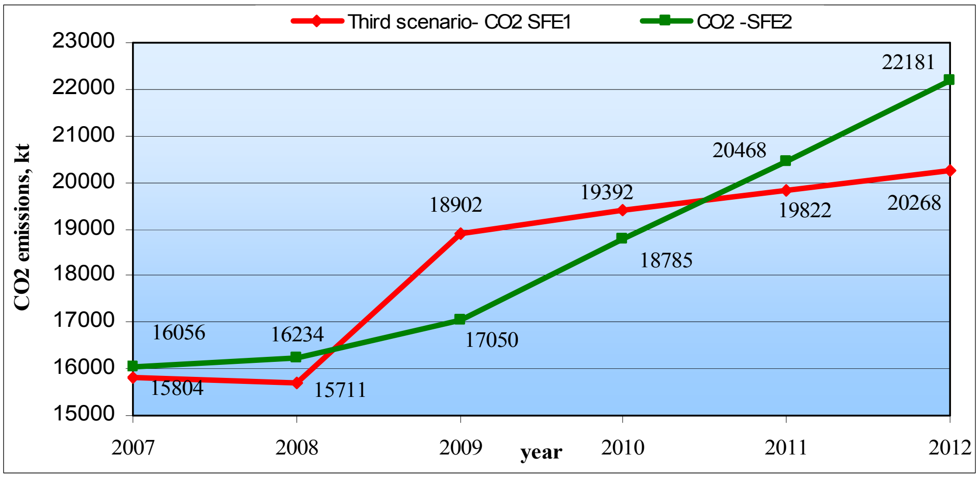

Fig. 2 The comparative analysis of the results obtained with the models CO_2-SFE1 and CO_2-SFE2

4. The assessment model based on activity data and emission factors

The input and the output parameters in the case of the assessment model of CO_2 emissions based on activity data and emission factors (CO_2-SAE1) are:

Input parameters

a) Productions achieved (kt) for:
- Electric steel;
- BOF steel;
- Pig iron;
- Coke.

b) Burning processes – for the electric route:
- Emission factor (kt CO_2/kt electric steel);
- Correction factor (with value between 0 and 1);

c) Burning processes – for the integrated route:
- Type of consumed gas (natural, COG or BFG);
- The consumtion for each type of gas (m^3);
- The net calorific value for each type of gas (GJ/m^3);
- CO_2 emission factor (t CO_2/TJ).

Output parameters

a) Burning processes – for the electric route:
- Updated emission factor (kt CO_2/kt electric steel);

b) Burning processes – for the integrated route:
- CO_2 emissions (kt) for each type of gas fuel;

c) CO_2 emissions (kt) issued by iron and steel sector:
- Emissions issued from burning processes on the electric route;
- Emissions issued from burning processes on the integrated route;
- Emissions issued from technological iron and steel processes;
- The aggregated emissions.

d) Iron and steel sector emission factor (kt CO_2/ kt steel)

The updated emission factor (kt CO_2/kt electric steel) represents the emission factor established for the burning processes on electric route [2], adjusted with a correction factor. This can be estimated depending on the modernizations achieved.

The CO_2 emissions (kt) issued from burning processes on the electric route is obtaining by the multiplication of steel production achieved on electric route and of the corrected emission factor.

The CO_2 emissions (kt) issued from burning processes on the integrated route represents the sum of the CO_2 emissions for each type of gas fuel used .

The CO_2 emissions (kt) issued from technological processes is computing based on the equation (4) for the E_1, and specific emission factor for Romanian iron and steel sector is equal with the ratio between the total CO_2 emissions and the total steel production at the national level. Emission factor value has a refference indicator role and allows to make comparaisons between the Romanian iron and steel performances and of the other countries.

5. Conclusions

In the context in which the iron and steel sector is one of the branches included in EU-ETS, for the Romanian iron and steel plants became very important the use of the assessment and forecast models with high accuracy for CO_2 emissions.

For this reason, CO_2–SFE1 forecast model developped before and presented in [1] , was adjusted and refined, in order to obtain the forecast model CO_2-SFE2. This model takes into account rigurously the dependencies between coke and BFG quantities, on the one hand, and coke and pig iron productions, on the other hand.

Also, the utility of the proposed models, so as the software developped based on these models is emphasized by the applications at Romanian iron and steel plants.

Hence, Mittal Steel Galati used the software for CO_2 emissions for the years 2001-2004 to elaborate the questionnaire asked by the Regional Environmental Agency. This questionnaire was used by the Agency to compute the number of emission certificates (equivalent t CO_2) allocated to MSG within NAP. The software was elaborated based on the assessment model CO_2 - SAE1.

The model CO_2 – SAE2, based on the carbon balance, will be used by MSG for the calculation of annual CO_2 emissions as well. The calculation will be made during the EU-ETS monitoring period (2008 – 2013). Besides, the forecast models CO_2 – SFE1 and CO_2 - SFE2 are very usefully to the iron and steel plants (as well as to the entire sector) in these period, for the evaluation of the CO_2 quantities allocated, in the periods included in EU-ETS (2007, respectivelly 2008 – 2012 for Romania).

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