Romanian CO_2 emissions forecast: national and steel sector approach

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Abstract: In the period 1989-2004 Romania passed through a process of transition to a market economy and by restructuring of these. The emissions have started to increase after 1999, because of the economy revitalization. The paper reflects the CO_2 emissions forecast in accordance with the main trends in the economic development of the country, based on an in-house model at the national level.

To the national approach we add a sectoral forecast for CO_2 emissions released in iron and steel industry, for the period 2007-2012, based on 1989- 2004 time series data. This sector is one of the biggest industrial contributors to the total CO_2 emissions of Romania. Three scenarios has been analysed and compared and the most appropriate and realistic option was pointed out. The sectoral approach takes into consideration the trends of production structure and CO_2 emissions factor. The weight (%) of the iron and steel sector from the national CO_2 emissions forecast has been calculated for the period 2007-2012, as well.

Key-Words: climate change, CO_2 emissions forecast, CO_2 emissions national model, iron and steel sector CO_2 forecast model

1. Introduction

In 1994, Romania ratified the United Nations Framework Convention on Climate Change (UNFCCC). Romania signed the Kyoto Protocol in 1999 and ratified it in January 2001, being the first Annex I Party that ratified it. Within Kyoto Protocol, the Parties to the Convention assumed the obligation to reduce the Greenhouse Gas (GHG) emissions with a certain rate comparing with the base year. Romania committed itself to reduce the greenhouse gas emissions by 8% from base year (1989) level in the first commitment period 2008 - 2012.

Besides UNFCCC requirements, the EU Countries (Romania being a future EU member state, starting with first of January 2007) have to fulfil also the requirements of EU Directive 2003/ 87/EC, concerning the emissions trade in accordance to EU Emission Trading Scheme (EU - ETS). The essential element in EU - ETS is the preparation of a plan to allocate the emissions that can be trade. In order to elaborate the National Allocation Plan, a CO_2 emissions assessment and the forecasting for the period 2007- 2012 has to be achieved.

CO_2 emissions released by iron and steel industry represent an important part (7% as percentage) from the total amount of global emissions. Moreover, energy intensity is one of the lowest between of all industrial sectors, having a negative indirect impact, with consequences in the release of a supplementary amount of CO_2 / tone of steel as final product. 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.

On an international level, there are general macro-economic models, which help to underline the trends of the economic, social and environmental indicators relates to GHG emissions at the country level, and specific models, witch show these trends at sectoral level (industrial branches, transport, agriculture).

The general macro-economic forecast model for CO_2 emissions at national level, proposed by the authors, and set using an approach "top-down", has been completed with a sectoral model, for iron and steel. In this case, we discussed about a "bottom-up" approach, which allows to stress better the effects of the technological and energetically modernizations over GHG emissions reductions. In this regard, the sectoral model completes and refines the general model, for such goals as assessments or forecasting with high precision (i.e. the calculation of the GHG emissions amounts allocate to some industrial sectors or installation, within EU- ETS).

2. National approach

In the context of the Romanian's evolution in the last 20 years, the missing of a growing unchanging trend, can be observed The important economic parameters, such GDP, the total energy production, the population have fluctuations due to the complexes socio-economics events taking place in this period. Besides, the annual aggregation of these parameters does the inclusion in annual amounts of the seasonal behavior elements. In this context, it can be possible to achieve socio-economic elements and development planning tools using the trends of the above parameters.

The case of non-linearity of data series from the last two decades drives to the idea to use forecasting models that reflect specific periodicities for the evolution of the CO_2 emissions result series, such Fourier regression. Opposite, the planning specific trends (i.e. in the National Development Plan- NDP) are linear for the above mentioned parameters (even the GDP evolution and Energy Production are positive, but the population evolution are negative)

It is normal that in the second above case to considered a multi-linear regression to be the most suitable and adaptive to the forecast development evolution. Discussing about NDP evolution it can be possible to calculate CO_2 emissions in close correlation with total energy produced, that mean we live inside a society based on carbon to generate the energy needed to create GDP.

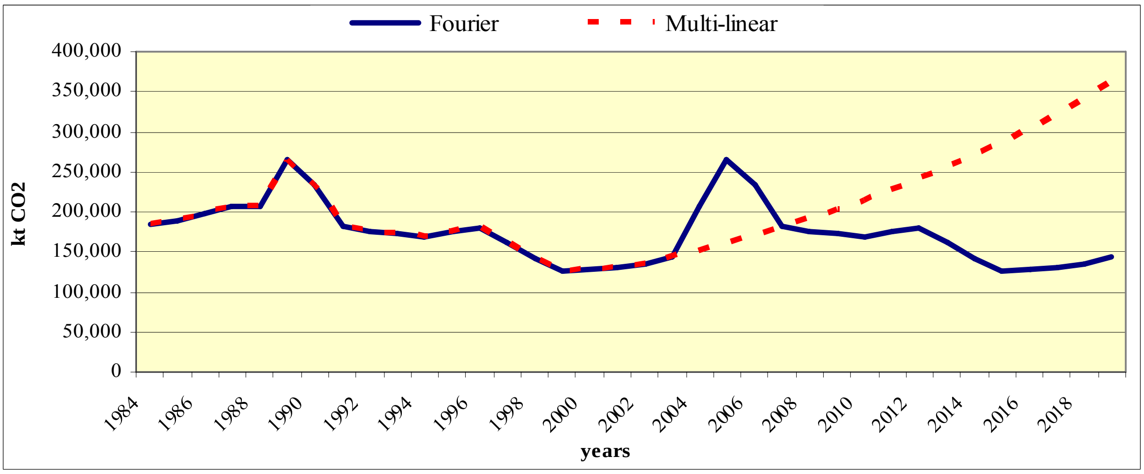

Fig. 1 The evolution curves "Fourier type" respective multi-linear

The figure 1 shows the two types of evolution curves in which:

i) the Fourier curve replicates the basic behavior for 16 years in addition, starting with 2003 (the Fourier regression needs to takie into consideration of a even number of data, therefore it has been choosed 16 years, covering a period before 1989 (the inventory data for CO_2 emissions were got from World Bank reports).

The equation of the evolution modeled by Fourier series:

$$f(x) = \frac{a_0}{2} + \sum_{k=1}^{\infty} a_k \cos\varphi_k + b_k \sin\varphi_k \quad (1)$$

where

$f(x) =$ the annual amount of the CO_2 emissions expressed in tones (t)

a_k and b_k - coefficients calculate by regression (table 1)

$\varphi_k = 2kx/L$, where L is the half of the interval considered (the interval is 16 years in this case).

Using this model, the CO_2 emissions forecast shows for the year 2007 an amount of 181 727 kt, for the year 2012 (the last year of the commitment period) an amount of 179 335 kt, and for 2019 an amount of 142 905 kt.

Table 1- a_k and b_k coefficients values

k	a_k	b_k
0	2355735.824000000	0.000000000
1	90484.447046770	- 417138.448078637
2	-103487.746084904	- 130912.878894239
3	67028.012337395	- 57868.366657304
4	74242.899199999	- 81208.896000000
5	26820.010715970	-30119.766568534
6	66915.896484904	-9177.944494239
7	68077.558699864	-30100.939189868
8	22222.159999999	0.000000000
9	68077.558699864	30100.939189867
10	66915.896484904	9177.944494239
11	26820.010715969	30119.766568534
12	74242.899200000	81208.896000000
13	67028.012337395	57868.366657304
14	-103487.746084904	130912.878894239
15	90484.447046771	417138.448078637

ii) the multi-linear curve describes a growing trend (with 5.9788 % / year as average) for this period. For the variables considered, we got a 5% / year growing for GDP and Energy production (these value results from NDP), and for the population we got a decreasing with 0.2 %/year.

The multi-linear regression equation:

$$EA_{CO2} = 1.7 \cdot GDP + 2.975341 \cdot toe + 41698 \cdot Cap - 985450.7 \quad (2)$$

where

EA_{CO2} – CO_2 emissions amount (kt)

GDP – Gross Domestic Product (mil.1995 USD)

toe – Commercial energy production (kt of oil equivalent)

Cap – Population (mil.)

For the equation 2, R^2 = 0.977, standard error = 7572.712, F value = 171.807

Using this model, the CO_2 emissions forecast shows for the year 2007 an amount of 180 270 kt, for the year 2012 (the last year of the commitment period) an amount of 241000 kt, and for 2019 an amount of 361 868 kt.

3. Iron and steel sector approach

Generally, there are two main types as methodologies wide spred for the elaboration of the assessment and forecast models for CO_2 emissions, at sectoral level or for an industrial unit:

- based on production evolution and national emission factors data, or recommended by International Panel on Climate Change (IPCC);
- carbon balance for a specific technological flow, considered in correlation with the forecasting of raw materials and materials containing carbon (input-output), as well as with the effects of technological upgradings.

The paper shows the results obtaining through the application of the methodology based on production evolution and CO_2 emission factors data.

Currently, in Romanian in and steel industry are used two types of technological flows are in place: the integrated flow, based on Basic Oxygen Furnace (BOF) and other one, based on Electric Arc Furnace (EAF). The CO_2 emissions released in iron and steel processes are calculating by the aggregation of the emissions from technological processes and from burning processes.

The data used for the elaboration of the forecast model have been achieved from the national GHG inventory, National Statistical Yearbook, and from the Romanian iron and steel companies.

The time series used for steel production includes even the Martin steel (having an important weight in the years 1989-1999, between 18 and 7% from the steel production structure will be composed only from BOF and EAF steel. Despite this, we considered as a necessity to rebuild the multiple-regression equation for the period 2000-2004. The equation obtained is:

$$EA_{CO2} = 3.1 \cdot CP + 252.486 \cdot 10^{-3} \cdot PIP - 16.109 \cdot \cdot 10^{-3} \cdot SP - 2.872 \quad (3)$$

where
EA_{CO2} – CO_2 emissions amount (kt)
CP – Coke production (kt)
PIP – Pig Iron Production (kt)
the total Romanian steel production) and in future,
SP – Steel Production (kt)

The regression coefficient is R^2= 0.9999, standard error = 0.672, F value = 1354339

The equation (3) was use for the forecasting of the CO_2 emissions released in iron and steel technological processes, for the period 2007-2012. For the both iron and steel flows, the table 2 shows the CO_2 emissions from burning processes, computed for the entire iron and steel sector.

Table 3 shows both the CO_2 emissions released in technological and in the burning processes adding the aggregate amounts of these.

Table 2 CO_2 emissions produced in the iron and steel burning processes

Year	Production, kt		Emissions factor, kt CO_2 / kt steel		CO_2 emissions, kt		
	EAF steel	BOF steel	EAF steel	BOF steel	EAF steel	BOF steel	Total
2001	1078.803	3677.197	0.75	1.192	809.102	4383.219	5192.321
2002	879.745	4507.255	0.75	1.401	659.809	6314.664	6974.473
2003	1086.769	4542.231	0.75	1.516	815.077	6886.022	7701.099
2004	1485.693	4676.307	0.75	1.581	1114.270	7393.241	8507.511

Table 3 CO_2 emissions (kt) produced in iron and steel sector

Year	From burning processes	From technological processes	Total
2001	5192.321	5041.23	10233.551
2002	6974.473	6761.17	13735.643
2003	7701.099	6014.65	13715.749
2004	8507.511	6275.29	14782.801

In order to have a image of the weight of the CO_2 emissions produced in iron and steel sector, in relation with the total CO_2 emissions amount issued by Romania, it has been calculated the percentage both to the net amounts and to the gross amounts. The net amount represents the CO_2 emissions amount remained in atmosphere after the substraction of the quantity sequestrated in forests from the gross value (without Land Use Change, Land Use Change and Forestry –LULUCF data from the national CO_2 inventory)

Table 4 CO_2 emissions weight produced in iron and steel sector from national emissions

Year	CO_2 emissions from iron&steel sector , kt	CO_2 emissions (kt) – national level		% iron & steel sector from national emissions	
		with LULUCF	without LULUCF	with LULUCF	without LULUCF
2001	10233.551	62711.37	100380.36	16.32	10.19
2002	13735.643	72486.05	107625.75	18.95	12.76
2003	13715.749	78247.21	113049.85	17.53	12.13
2004	14782.801	81692.64	116360.62	18.10	12.70

In the table 4 it can be observed that the weight of the CO_2 emissions released in the atmosphere by iron and steel sector is around 17-18% from gross emissions amount, that mean the iron and steel sector is one of the biggest sectors producing CO_2 emissions, with advantages and disadvantages came from here.

The forecasting of the CO_2 emissions from iron and steel sector for the period 2007-2012, based on the evolution of steel production, pig iron and coke, for a certain period and on national or IPCC emissions factors has been studied in three scenarios. Each of them uses different hypothesis (table 5 for the production structure, respective table 6 for emission factors).

Table 5 The hypothesis used for iron and steel production structure

Year	Scenario 1		Scenario 2 and 3	
	BOF steel weight (%)	EAF steel weight (%)	BOF steel weight (%)	EAF steel weight (%)
2007	75.00	25.00	77.00	23.00
2008	75.00	25.00	77.00	23.00
2009	75.00	25.00	78.00	22.00
2010	75.00	25.00	79.00	21.00
2011	75.00	25.00	80.00	20.00
2012	75.00	25.00	80.00	20.00

Table 6 The hypothesis used for emission factors

Year	Scenario 1 and 2		Scenario 3	
	kt CO_2/ kt EAF steel	kt CO_2/ kt BOF steel	kt CO_2/ kt EAF steel	kt CO_2/ kt BOF steel
2007	0.75	1.50	0.75	1.50
2008	0.75	1.50	0.74	1.45
2009	0.75	1.50	0.73	1.40
2010	0.75	1.50	0.72	1.35
2011	0.75	1.50	0.71	1.30
2012	0.75	1.50	0.70	1.25

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 around 20 Mt in 2012 (an amount less with around 2 Mt compared to second scenario, and around 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 figure 2 shows the comparative plotting of CO_2 emissions in the forecast period (2007-2012) for the all three scenarios.

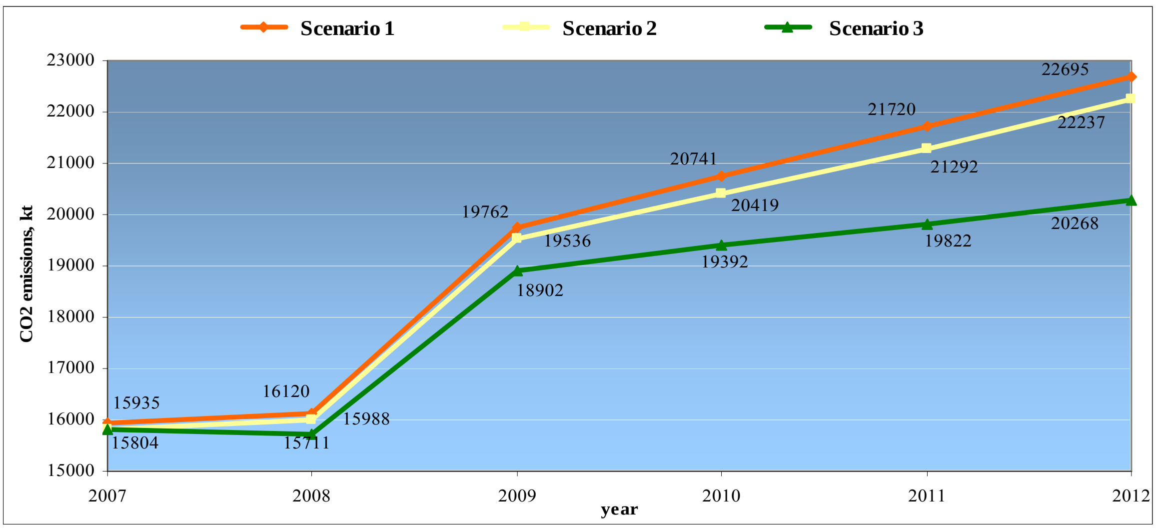

Fig. 2 The comparative plotting of CO_2 emissions in the forecast period (2007-2012)

The above analysis has been completed with an assessment of emissions weight to be release into atmosphere from iron and steel sector in the period 2007-2012 compared to the total gross national emission amount.

For the forecasting of CO_2 national gross emissions has been used the results reached by simulations after application of the general macro-economic model (multi-linear model). For the forecasting of CO_2 emissions from iron and steel sector, has been used the results reached by simulations, after the application of the specific iron and steel model, for all three scenarios.

4. Conclusions

Generally, for the national CO_2 gross emissions forecast it is recommending to use the results reached by simulations, after the application of general macro-economic forecast model. Both models used show that the Romanian CO_2 emissions amounts remain under the limit value (243914 kt CO_2) foreseen by Kyoto Protocol for the first commitment period (2008-2012), but after this period, a new analysis has to be done.

For the forecasting of CO_2 emissions released by iron and steel sector, the results reached by simulations, after application of the specific model based on the evolution in time of steel, pig iron and coke productions and on the amount of IPCC or national emissions factors, for the three scenarios, has been used.

In the third scenario, the amounts of iron and steel CO_2 emissions percentages, from the total CO_2 gross emissions at the national level, fluctuates between 8.22 minimum (in 2008) and 9.34 maximum (these amount will be reached in 2009). In addition, starting with 2009 until 2012, the trend decreases. This is caused by due to a more accelerate increase of the forecasted CO_2 emissions, to be released into atmosphere by other economic branches (without iron and steel), and that are taken into consideration when national CO_2 emissions inventory was set up.

Acknowledgements

National Program "Excellence in Research" (CEEX) supported this research under the project no. 638/2005 (GHGFORECAST Project). It is presenting only the results obtained after the second stage of the project.

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