MINISTRY OF EDUCATION ANDTRAINING

MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT

THE VIET NAM INSTITUTE OF METEOROLOGY, HYDROLOGY AND CLIMATE CHANGE

Doan Thi Thanh Binh

RESEARCH ON DEVELOPING THE MITIGATION SCENARIO OF THE STEEL PRODUCTION SECTOR IN VIET NAM

Major: Climate change

Code: 9440221

SUMMARY OF DOCTOR THESIS ON CLIMATE CHANGE

Ha Noi, 2023

The thesis was completed at:

The Vietnam Institute of Meteorology, Hydrology and Climate Change

Supervisor: **Dr. Do Tien Anh**

Reviewer 1:

Reviewer 2:

Reviewer 3:

The thesis will be defended in front of the Institute-level thesis committee at: Institute of Meteorology, Hydrology and Climate Change

The Thesis can be found at the library:

1. Vietnam Institute of Meteorology, Hydrology and Climate Change
2. National Library of Vietnam

LIST OF THE AUTHOR'S PUBLISHED WORKS RELATED TO THE THESIS

1. Doan Thi Thanh Binh, Nguyen Thi Lieu, Vuong Xuan Hoa, Tran Duc Van (2023), "*Research to determine greenhouse gas emission factors in the iron and steel production sector in Vietnam".* Journal of Climate Change, Vol. 26, Jun/2023; page 19-29.
2. Doan Thi Thanh Binh, Nguyen Thi Lieu, Vuong Xuan Hoa (2023), *"An overview study and assessment of greenhouse gas emissions from Thai Nguyen iron and steel factory".* Journal of Regional Sustainable Development, Vol. 2, Jun/2023; page 139-148.
3. Doan Thi Thanh Binh, Do Tien Anh, Nguyen Thi Lieu, Vuong Xuan Hoa (2023), *"Research on developing mitigation scenarios for iron and steel production sector in Vietnam".* Journal of Regional Sustainable Development, Vol. 3, Sep/2023; page 95-103.

INTRODUCTION

1. The urgency of the thesis

The steel production sector in the world in general and in Vietnam in particular are considered one of the main sources of GHG emissions causing climate change. In Vietnam, there are three main technologies applied in the iron and steel production field: Blast furnace - oxygen blast furnace (BF - BOF, 08 units), Electric arc furnace (EAF, 34 units) and 38 Induction Furnaces (IF). In general, the application of technologies in the iron and steel production in Vietnam consumes a lot of energy as well as a large amount of fuels (gas, liquid fuels, coal of all kinds and electricity) of which GHG emissions are significant.

In order to monitor GHG emissions and evaluate potential emission reduction, the development of GHG mitigation scenarios in the iron and steel production sector has been carried out in the number of climate change studies and national reports. However, these studies apply IPCC’s default emission factors for different types of technology, with top-down approach data. Therefore, the uncertainty of the results remains high.

Therefore, the thesis "Research on developing the mitigation scenarios of the steel production sector in Vietnam" is essential for helping managers and organizations, businesses... in the iron and steel production field propose effective management solutions, achieving the goals of economic development, environmental protection and sustainable development for Vietnam's iron and steel industry.

2. Objectives of the thesis

- Determine the method to develop a typical GHG emission factor for the steel production activities in Vietnam ;
- Develop and assess the impacts of mitigation scenarios of the iron and steel production sector in Vietnam.

3. Subjects, scopes and research contents

Research subjects:

The thesis focuses on determining methods and calculations of emission factors for the BOF and EAF technologies. Based on that, the GHG emissions are estimated and the mitigation scenarios for the iron and steel production sector in Vietnam are developed.

Scope:

- Spatial scope: Thai Nguyen Iron and Steel Joint Stock Company is sellected for the pilot calculation of the emission factors. Then, the emission factors will be applied to Vietnam's steel production sector.

- Scope of time: In the thesis, GHG emissions inventory were conducted for the years from 2015 to 2019; the data series from 2020 to 2030 was applied to develop the BAU scenario and the GHG emission reduction scenario for the steel production sector.

Research contents:

Content 1: Overview of relevant studies on the world and in Vietnam

Content 2: Research on identification of the GHG emission factors of BOF and EAF technologies in Vietnam

Content 3: Development of the greenhouse gas emission scenarios for Vietnam's steel production sector

Content 4: Assessment of the impact of the GHG emission reduction scenario on the socio-economic development of Vietnam

4. Research question

1. Which method can Vietnam apply to determine GHG emission factors for BOF and EAF steel production technologies? Are those emission factors more accurate than the IPCC default values for steel production in Vietnam?

2. Are the GHG emission scenarios for the steel production sector in Vietnam developed by applying this GHG emission factor much different from the scenarios previously developed?

3. What are the impacts of the implementation of greenhouse gas emission reduction solutions in Vietnam's steel production on economic, social and environmental aspects?

5. Research hypothesis

- Argument 1: The method of moniotoring the GHG emission sources can determine the GHG emission factors by measuring the flow and concentration of GHG emissions in production stages in BOF and EAF steel production technology in Vietnam. These factors are similar and do not deviate much as the IPCC default parameters.

- Argument 2: The mitigation scenarios for the steel production activities based on the identified emission factors and pilot-study GHG reduction solutions have a scientific basis and higher reliability than using the default coefficients and generally emission reduction solutions on the world.

- Argument 3: GHG mitigation scenario of the steel production sector in Vietnam can bring economic, social and environmental benefits.

6. Contributions of the thesis

- Theoretical contribution: In the thesis, the PhD student has proposed a method to estimate emission factors for two types of steel production technology, particularly BOF and EAF in Vietnam, in order to provide a scientific basis for the calculation of Vietnam's GHG emissions inventory. Based on the identified emission factor, the PhD student has developed the mitigation scenarios for the steel production activities to evaluate the impacts of the mitigation scenarios on the socio-economic development in Vietnam

- Practical contribution: Firstly, the determination of specific emission factors of the steel production in Vietnam would beneficial to the GHG inventory activiteis, the evaluation of the potential emission reduction, and the development of effective GHG mitigation scenario which is more accurate and suitable with Vietnam’s conditions. Secondly, the development of GHG mitigation scenarios in the steel production sector will help managers within the steel production and climate change fields to identify roadmaps to both effectively reduce GHG emissions and ensure sustainable development.

7. Scientific and practical significance of the thesis

7.1. Scientific significance

Currently, the inventory and determination of GHG emissions in Vietnam in general and in the steel production in particular are required to use default emission factors of IPCC, international organizations or developed countries, and hence the inventory results still have an amount of uncertainty. Therefore, the thesis has identified specific GHG emission factors for the steel production which is suitable for domestic technology condition and assessed the potential to reduce GHG emissions in Vietnam’s iron and steel production field. Therefore, the results of the thesis have provided a scientific basis to the GHG inventory process and to the identification of the mitigation roadmap in the steel production sector of Vietnam.

7.2. Practical significance

- Apply specific GHG emission factors in Vietnam's conditions to improve the quality and reliability of information on the GHG emissions in each stage of the steel production process, and estimate the impact of the emissions of the steel production sector in Vietnam;
- Support for more accurate determination of the efficiency of mitigation measures, which can be applied in determining carbon credits when the Carbon market operates in Vietnam.

8. Structure of the thesis

In addition to the introduction, conclusions, and recommendations, the thesis includes the following main chapters:

Chapter 1: Overview of greenhouse gas emissions and GHG emissions scenarios of the steel production sector on the world and in Vietnam.

Chapter 2: Research method for emission reduction scenarios in the steel production sector in Vietnam.

Chapter 3: Results and discussions.

CHAPTER 1: OVERVIEW OF GREENHOUSE GAS EMISSIONS AND GHG EMISSIONS SCENARIOS OF THE STEEL PRODUCTION SECTOR ON THE WORLD AND IN VIETNAM

1.1. Overview of the status and methods of greenhouse gas inventories in the steel production sector

1.1.1. Current status of greenhouse gas emissions in the steel production sector

In the steel production process, the five main sources of CO_2 emissions include: furnaces, blast furnaces, blow furnaces, flat furnaces, and coking. In 2020, the steel production was directly responsible for ~2.6 Gt CO_2 emissions, representing ~7% of global emissions and 11% of global CO_2 emissions, in addition to ~1.0 Gt CO_2 from electricity used by the industry.

1.1.2. Guidelines and methods for conducting greenhouse gas inventories for the steel production sector

Guidelines and methods for national GHG inventories include: the Revised 1996 Guidelines (revised GL 1996), The Good Practice Guidance and uncertainty management in national GHG inventories (GPG 2000) and the 2006 IPCC Guidelines (GL 2006).

Guidelines at local and grassroots levels include: The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC); Guidance on implementing city-level GHG emissions inventory of JICA (2017); ISO 14067; ISO14404:2013-Method for calculating carbon dioxide emission intensity from iron and steel production. Part 1: Steel mill with blast furnace, Part 2: Steel mill with electric arc furnace (EAF).

1.1.3. Studies on GHG emissions in the iron and steel production sector in Vietnam

The implementation of the national GHG inventory complies with the IPCC guidelines on national GHG inventories. The results of the GHG inventory are shown in National Communication 1,2,3 and BUR1,2,3. In 2016, GHG emissions from the IPPU sector were 46,094.64 thousand tons of CO_2e, ranking second and accounting for 14.6% of Vietnam's GHG emissions. In the IPPU sector, emissions from the iron and steel production sector are 3,858.22 thousand tons of CO_2e (accounting for 8.4%, ranking second after emissions from the cement sector at 79.8%).

In addition, in Vietnam there are several other studies such as: Tran Xuan Truong (2020): Pham Chi Cuong (2012) and the assessment of the Vietnam Steel Association in 2020 and the PMR project for the steel sector (Ministry of Industry and Trade, 2020).

1.2. Overview of the mitigation measure in the steel production sector and impact assessment of GHG emission mitigation solutions

1.2.1. In the world

Studies have shown that CO_2 emissions from the global steel production will jeopardize the 1.5◦C climate target unless the steel production sector is rapidly decarbonized through production technologies with low emissions. The commonly used BF-BOF technology is almost impossible to decarbonize (Madeddu et al., 2020) because this technology requires very high temperatures up to 2000◦C (De Beer et al., 2000; Hasanbeigi et al., 2014). The only other more advanced process currently in use is natural gas-based direct reduction (NG-DRI) but is not widely deployed because natural gas in most countries is not as cost-competitive as coke (Moya and Pardo, 2013). Adding post-combustion carbon capture and storage to BF-BOF technology can reduce emissions by up to 60%.

The main strategy is electrification to significantly reduce GHG emissions. The technologies considered most promising are hydrogen-based direct reduction (H2-DRI) and iron ore electrolysis (Lechtenb ̈ohmer et al., 2016; Weigel et al., 2016 ; Philibert, 2017).

Many previous studies have individually investigated the emission reduction potential of different technologies, but only a few have considered new iron electrolysis technology (Fischedick et al., 2014; Lechtenb ̈ohmer et al., 2016; Weigel et al., 2016). In past studies, decarbonization pathways have mainly been assessed at national or sector level, while plant-specific characteristics and regional differences in socio-economic conditions have not been assessed.

1.2.2. In Vietnam

In Vietnam's updated NDC 2022, the steel industry's GHG emissions are calculated in the IPPU sector with the calculation method according to the 2006 IPCC Guidelines, Tier 1. Regarding deveping the mitigation scenarios, the BAU scenario for the IP sector was developed according to the revised GL 1996, GL 2006 and GPG 2000.

Assoc. Prof. Dr. Tran Xuan Truong in 2020 used the GHG emissions inventory method according to GL 2006 to calculate GHG emissions in Vietnam's metallurgical sector with detailed calculation methods and instructions for GHG emission factors and data sources.

Nghiem Gia and Vu Truong Xuan (2014) proposed a number of solutions to reduce GHG emissions in the metallurgical industry, including iron and steel production, such as: improving the quality of input technology or increasing the quality of ore to reduce the rate of coke used, choosing the environmentally friendly technology with low fuel consumption or using regenerative burners for billet furnaces combined with the system Heat storage/recovery chamber, and investment in coke production line using dry coke stamping method.

CHAPTER 2: RESEARCH METHOD FOR THE DEVELOPMENT OF THE MITIGATION SCENARIOS FOR THE STEEL PRODUCTION SECTOR IN VIETNAM

2.1. Research framework of the thesis

To carry out the thesis, the doctoral student proposes to apply a combination of bottom-up and top-down approaches. Accordingly, the GHG emissions of steel production technologies will be determined by measuring GHG concentrations and flow directly at the factory. GHG emission scenarios will be developed based on industry output data

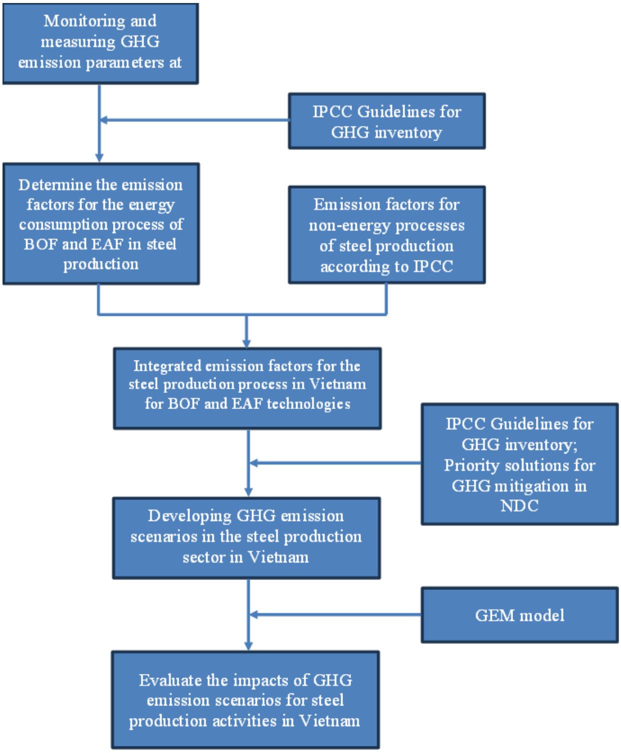

Figure 2.1. Research framework of the thesis

2.2. Methods of data collection and survey

The PhD student has collected accurate information about the location and current status of production activities; current emissions status data, fuel consumption used for production, and level of exhaust gas treatment at production facilities in the iron and steel factory area. The measurement and survey process were carried out continuously from March 1, 2023, to March 15, 2023.

2.3. Methods for monitoring emission sources

2.3.1. Measurement of the concentration of greenhouse gas components

Equipments:

The device used in the direct measurement is the Testo 350 exhaust gas meter, which is capable of quickly measuring many parameters and working in high-temperature environments, directly giving results about emission concentration .

How to measure:

The sensor bar measuring exhaust gas concentration is inserted into the sampling location at the chimney (behind the exhaust smoke treatment parts/equipment, behind the smoke fan) through pre-prepared probe holes. The sensor head is placed in the center of the chimney and kept fixed to ensure signal stability. Measurement values are recorded repeatedly, and the average value is taken to ensure the accuracy of measurement data.

2.3.2. Measurement of greenhouse gas flow at the emission source

Equipments:

To determine the exhaust smoke flow, the project uses a Testo 510 differential pressure measuring device and the measuring head is a Pitot tube.

How to measure:

Through on-site surveys, the only location for measuring exhaust smoke flow is on the smoke pipeline, at the exhaust fan intake, and behind the cloth bag dust filter of the steel furnace, which is suitable at the actual site. This location already has a visit door and is convenient for measurement work, ensuring measurements can take place.

2.3.3. The equation for GHG emission factors

After conducting monitoring and collecting necessary data and information from the factory, the emission factors is determined according to the following formula:

$$\mathrm{EF}x = \frac{\mathrm{C}x \text{ x } \mathrm{Q}}{\mathrm{B}} \text{ x } 10^{-9} \left(\frac{\text{ton GHG}}{\text{ton of products}}\right)$$

Where:

+ EFx: GHG emission factors (CO_2, CH_4, N_2O…)

+ Cx: GHG concentration x measured at the chimney (mg/m^3)

+ Q: GHG flow (m^3/h)

+ B: Production in one hour (ton/h)

2.4. Greenhouse Gas Eemission Inventory following the IPCC Guidelines

Three types of emissions from the iron and steel production process include: 1) emissions from fuel combustion 2) emissions during iron and steel production (physical and chemical conversion) (3) indirect emissions from electricity consumption. .

2.4.1. *Method for calculating emissions from production processes*

IPCC 2006 provides a formula for calculating GHG emissions:

$$\mathbf{E_{CO2} = BOF * EF_{BOF} + EAF * EF_{EAF}}$$

Where:

BOF = Steel output is produced using blast furnace technology (Basic Oxygen Furnace), ton

EAF = Steel output is produced using electric arc furnace technology (Electric Arc Furnace), ton

EF = emission factors of technologies, tCO_2/ton of products

2.4.2. Method for calculating emissions from fossil fuel consumption

The thesis determines the GHG emission factors for the fuel combustion process for coking and iron smelting, so the tier 2 method is used to estimate emissions:

$$\mathbf{Emissions_{GHG,\ En} = Production\ x\ EF_{GHG,\ En}}$$

Where:

$Emissions_{GHG,\ En}$ = GHG emissions from fuel combustion (tCO_2eq)

Production = Volume of coke and pig iron produced (tons)

$EF_{GHG,\ En}$ = Emission factors are measured and determined in the thesis of fuel combustion activities for coke and pig iron production.

2.4.3. Method for estimating emissions from electricity consumption

Indirect GHG emissions from electricity consumption are calculated by multiplying the amount of electricity consumed by the emission factor of the national power grid announced by the Ministry of Natural Resources and Environment. Accordingly, the EF of national power grid is 0.8154 tCO_2/MWh.

$$\textbf{Emissions}_{\textbf{GHG, Elec}} = \textbf{Electricity consumption x EF}_{\textbf{GHG, Grid}}$$

Where:

$Emissions_{GHG,\ Elec}$ = Indirect GHG emissions from electricity consumption

$EF_{GHG,\ Grid}$ = GHG emission factor of the national power grid

2.4.4. QA/QC work in environmental monitoring

Thai Nguyen Iron and Steel Joint Stock Company has used appropriate monitoring methods within current legal documents and regulations on environmental monitoring; suitable equipment for the identified monitoring method, ensuring the requirements of the technical and measurement method; and how to preserve samples with monitoring parameters according to current legal regulations on environmental monitoring.

2.5. Method for assessing the impact of mitigation

The GEM model which is a system "simulation" model capable of integrating different sectors and fields (e.g., economy, society, and environment including natural resources and integrating with climate change scenarios) is applied to evaluate the impact of the steel industry's GHG emission reduction scenario on Vietnam's socio-economic development.

CHAPTER 3: RESULTS AND DISCUSSION

3.1. Current status of steel production and steel production technology

3.1.1. Current status of steel production

According to the World Steel Association (2023), in 2022, world crude steel output of 64 countries is 1884.2 million tons, of which: 136.3 million tons (27 European countries), 45.8 million tons (other European countries), 111.3 million tons (North America), 43.4 million tons (South America), 21.1 million tons (Africa), 1383.8 million tons (Asia) and 50.4

million tons (Middle East). In Vietnam, steel production in 2022 reaches 29.339 million tons, decreasing by 11.9% over the same period in 2021.

3.1.2. Steel production process and technology

The complete steel production process includes six basic stages: (1) ore processing; (2) Creating molten flow; (3) Secondary steel manufacturing; (4) Continous casting; (5) Primary formation; (6) Production, fabrication and finishing. In the world, BOF technology is used to produce about 70% of steel output and EAF technoloy is used to produce about 30% of steel output. The two new technologies are: Smelting reduction - Oxygen conversion furnace – continous casting and direct reduction – electric ảe furnace – continous casting.

3.2. Current status of production, technology, production lines and greenhouse gas emissions sources at Thai Nguyen Iron and Steel Joint Stock Company

3.2.1. Research location

Due to limitations in measuring and surveying in the context of COVID - 19 and access to steel factories, the PhD student chose Thai Nguyen Iron and Steel Joint Stock Company to conduct research on calculation of emission factors by measuring GHG emission concentrations at the company's factories. The steel production line of Thai Nguyen Iron and Steel Joint Stock Company includes the fuel combustion process for coking and iron smelting and the steelmaking process using electric arc furnace (EAF). Therefore, by combining measurements of GHG emission factors from fuel combustion and calculating indirect GHG emissions from electricity consumption, the thesis will calculate the GHG emission factors for BOF technology and EAF technology. .

3.2.2. Identification of emission sources

With the above-mentioned production technology, Thai Nguyen Iron and Steel Joint Stock Company has the main point sources of greenhouse gas emissions at the coking plant, the iron smelting plant, the steel-making plant and the steel-rolling plant.

3.3. The current status of environmental treatment systems

Thai Nguyen Iron and Steel Joint Stock Company applies exhaust gas and wastewater treatment systems to collect and treat solid waste according to regulations. The factory has seriously and fully implemented the periodic environmental monitoring program.

3.4. Measurement results

3.4.1. Coking furnace

The results of monitoring measurements at the coking furnace chimney are as follows: Exhaust gas flow values ranging from 12,727 - 43,744 m^3/h, CO_2 concentration ranging from 892 - 1470 mg/Nm^3, CH_4 concentration ranging from 0.20 to 0.45 mg/Nm^3, and N_2O concentration ranging from 0.17 – 0.23 mg/Nm^3.

3.4.2. Iron furnace

The results of monitoring measurements at the iron furnace chimney are as follows: Exhaust gas flow values ranging from 46,882 - 67,208 m^3/h, CO_2 concentration ranging from 1520 - 2864 mg/Nm^3, CH_4 concentration ranging from 0.51 to 1.22 mg/Nm^3, and N_2O concentration ranging from 0.28 - 0.30 mg/Nm^3.

3.4.3. Steel furnace

The results of monitoring measurements at steel furnace chimney No. 1 are as follows: Exhaust gas flow values ranging from 71,568 - 172,975 m^3/h, CO_2 concentration ranging from 76 - 143 mg/Nm_3; CH_4 concentration ranging from 0.3 to 0.6 mg/Nm_3, N_2O concentration ranging from 0.1 - 0.2 mg/Nm^3.

The results of monitoring measurements at the smokestack of steelmaking furnace No. 2 are as follows: Exhaust gas flow values ranging from 3779 - 134692 m^3/h, CO_2 concentration ranging from 110 - 141 mg/Nm^3, CH_4 concentration ranging from 0.04 to 0.05 mg/Nm^3, and N_2O gas concentration ranging from 0.02 - 0.03 mg/Nm^3.

3.5. Determination of emission factors for iron and steel production activities

3.5.1. Calculattion of greenhouse gas emission factor for BOF technology

a. Greenhouse gas emissions from fuel combustion:

The results of the pilot calculation of GHG emissions factors at Thai Nguyen Iron and Steel Joint Stock Company show that the emissions from the coking process are about 0.62 tCO_2e per ton of steel; from the gang process is 0.29 tCO_2e per ton of steel. The GHG emission factor multiplied by the coke output and the cast iron output will estimate the GHG output from combustion. Accordingly, GHG emissions from coke refining fell from 84.1 thousand tonnes of CO_2 in 2015 to 83 thousand tons of CO_2. In 2019, GHG emissions from cane processing decreased from 55.2 thousand tCO_2e in 2015 to almost 50 thousand tCO_2e in 2019. This is due to the decline in the production of coke and cast iron. As a result, the total emissions from coke and cast iron processing fell from more than 139.3 thousand tonnes of CO_2 in 2015 to almost 133 thousand tCO_2e in 2019.

b. GHG emissions from non-energy processes using BOF technology

The GHG emissions from non-energy processes will be counted for the coke-making processes, forging, combustion, and steel production. the Non-energy GHG emissions of the company is calculated by multiplying the GHG emission factor for the non-energy process according to the IPCC with the output. The total non-energy emissions of these processes increased from more than 935.6 thousand tCO_2e in 2015 to 1472.5 thousand tCO_2e in 2019. Among them, emissions from the production of oxygen accounted for the largest proportion, with approximately 76 %. The second-largest emission from cast iron processing is approximately 15%. Emissions from coke preparation and combustion account for about 9%.

c. Summary of GHG emissions and the total GHG emission factors of steel plants applying BOF technology

Based on the results of GHG emissions from fuel combustion, non-energy process, and electricity consumption, the total GHG emissions of Thai Nguyen Iron and Steel Joint Stock Company are determined to increase from nearly 1.1 million tCO_2e in 2015 to more than 1.6 million tCO_2e in 2019. Combined with data on steel production, the GHG emission factor is estimated to decrease from 3.03 tCO_2/ton of steel in 2015 to 2.26 tCO_2/ton of steel in 2019 (average value average over 5 years is 2.63 tCO_2/ton of steel).

The average GHG emission factor of BOF technology was determined to be about 2.63 tCO_2e/ton of steel, which is quite similar to the calculation results of 2.51 tCO_2e/tons of steel in the PMR Project in the steel industry in 2020 and results about 3.46 tCO_2eq/ tons of steel of the State-level project on "Research and implementation of a GHG emissions inventory system and proposal of a roadmap to reduce GHG emissions for the metallurgical industry".

3.6.2. Calculation of greenhouse gas emission factor for EAF technology

a. Non-energy emissions by EAF technology

The results of calculating the experimental GHG emission factor at Thai Nguyen Iron and Steel Joint Stock Company indicate that process emissions from the steel-making process are 0.10 tCO_2eq/ton of product. The non-energy emissions by EAF technology was calculated by multiplying this emission factor with the steel output produced by the EAF steel production process . Accordingly, emissions using EAF technology increased from more than 52 thousand tCO_2eq in 2015 to nearly 62.5 thousand tCO_2eq in 2019.

c. Emissions from electricity consumption

Vietnam's national power grid emission factor in 2019 was announced by the Ministry of Natural Resources and Environment as 0.8154. The indirect emissions from electricity consumption was calculated by applying this emission factor with the electricity consumption data.

According to survey results, steel and cast iron production is the main source of electricity consumption. Therefore, the total emissions from these two sources are about 22.5 thousand tCO_2eq in 2015 and more than 20.8 thousand tCO_2eq in 2019. The decrease in emissions is mainly due to the decrease in pig iron output over the years.

d. Summary of greenhouse gas emissions and greenhouse gas emission factor of steel plants applying EAF technology

From the results of GHG emissions from fuel combustion, non-energy and electricity consumption, total GHG emissions are determined. Along with the total output, the total GHG emission factor of the steel factory applying EAF technology is also determined to be around 0,13-0,14 tCO_2eq/ton of steel.

3.7. GHG emission scenario for steel production sector

3.7.1. Baseline GHG emissions scenario

GHG inventories for the period 2015 - 2019 are conducted based on determined GHG emission factors and steel output according to BOF and EAF technologies collected from the Vietnam Steel Association.

Table 3.24. Total production of the steel industry

Unit: million ton

Year	2015	2016	2017	2018	2019	2020	2025	2030
BF – BOF	1,700	2,586	4,245	8,200	9,746	12,0	17,0	24,0
EAF	3,947	5,225	7,228	7,271	7,723	7,5	8,0	8,5
Total	**5,647**	**7,811**	**11,473**	**15,471**	**17,469**	**19,5**	**25,0**	**32,5**

Based on the the results of GHG inventory and forecast of iron and steel facilities in the period from 2015 to 2030, it can be seen that emissions increased significantly from 2015 from more than 7 million tons of CO_2eq to more than 64 million tCO_2eq in 2030. In which, emissions from BF - BOF (increasing from 4.72 million tons CO_2eq to 63 million tons CO_2eq); Emissions from EAF (increased from 0.5 million tons CO_2eq to more than 1 million tons CO_2eq).

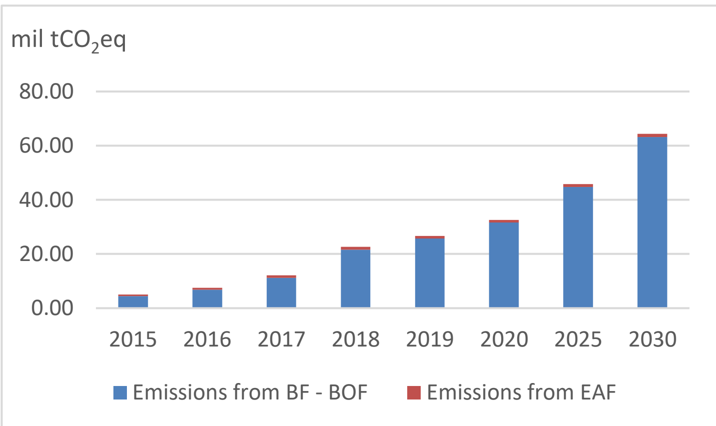

Figure 3.11. GHG emissions scenario of steel production to 2030

3.7.2. GHG emission reduction scenario

According to the results of pilot assessment of energy saving and GHG emission reduction potential of mitigation solutions at Thai Nguyen Iron and Steel Joint Stock Company, a summary of mitigation potential by technology is shown in Table 3.32.

Table 3.32. Potential for reducing greenhouse gas emissions through steel production technology

No	Technologies	Potential to reduce GHG emissions (tCO_2eq/ton of product)		
		Electricity	Heat	Total
1	EAF	0.65712	0.06	0.71712
	- Energy efficiency	0.09712		0.09712
	- Renewable energy	0.56		0.56
	- Bio-energy usage		0.06	0.06
2	BOF	0.09974	0.41571	0.51545
	- Coking process	0.00135	0.0000107	0.0013607
	- Syntering	0.00127	0.0000008	0.0012708
	- Iron production	0.09712	0.0057	0.10282
	- Bio-energy usage		0.41	0.41

From the emission reduction potential in Table 3.32 and the output by technology types, the amount of GHG emission reduction under the low carbon scenario is estimated in Table 3.33.

Table 3.33. The amount of greenhouse gas emission reduction under the low carbon scenario

Year	2020	2025	2030
BOF	6.19	8.76	12.37
EAF	5.38	5.74	6.10
Total	**11.56**	**14.50**	**18.47**

The total mitigation potential from energy - saving technologies and renewable energy for the steel industry in 2025 is about 14.5 million tCO_2eq and about more than 18.4 million tCO_2eq in 2030. Of which, the mitigation potential of BOF technology is from 1.5 to more than 2 times higher than that of the EAF technology. This is because the scale of BOF technology is much larger than that of EAF technology.

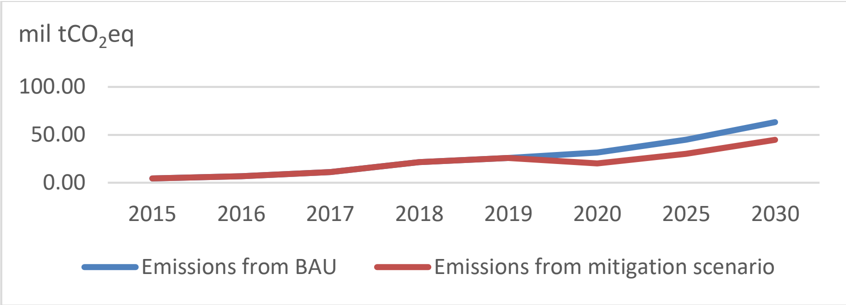

Figure 3.12. Greenhouse gas emissions according to the BAU scenario and the low carbon scenario of the steel production sector

The results of GHG emission reduction scenarios for the steel industry in Figure 3.12 show that the use of energy-saving and renewable energy solutions will have the potential to significantly reduce emissions by 2030. However, the trend of GHG emissions still increases compared to previous periods, partly because the steel output from BOF technology, which has a high GHG emission factor, increase while that from EAF technology which has a small emission factor increased insignificantly.

3.8. Assessment of the impact of the mitigation scenario of the steel production sector on socio-economic development in Vietnam

The mitigation measures expected in the GE scenario contribute to lower emissions and lower energy costs, generating higher economic growth and higher GDP compared to the corresponding BAU scenario. In the GE scenario, total real GDP grows 12% higher than BAU in 2030. From 2020 to 2030, real GDP growth in the GE scenario averages 7.2%, higher at 0.9% than the BAU scenario.

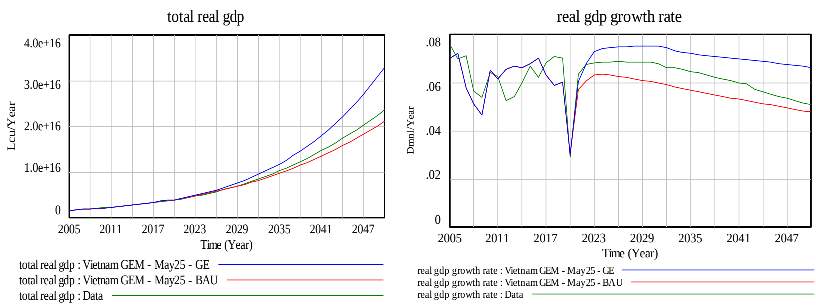

Figure 3.15. Total real GDP and real GDP growth rate

An additional increase in GDP leads to an increase in government income and the total investment. The total government revenue in the GE scenario is expected to be 12% higher in 2030 than in the BAU scenario. A similar trend is observed for nominal investments in the GE scenario, which is 13.5% higher in 2030 compared to the baseline scenario.

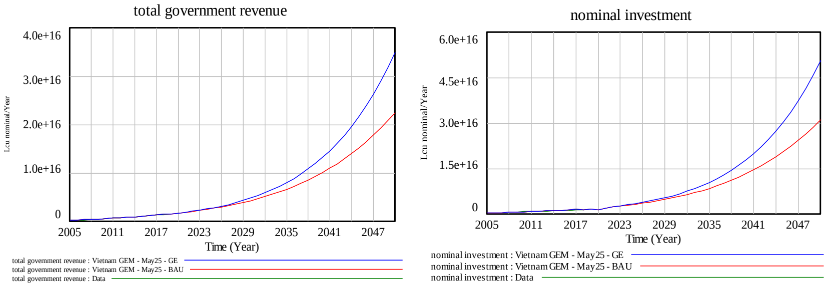

Figure 3.16. Overview of total government revenue and investments

Additional jobs created as a result of low carbon interventions contribute to reducing unemployment. While the unemployment rate in the baseline increases to 3.2% in 2030, the unemployment rate in the GE scenario decreases faster than the baseline, with an unemployment rate of 1.1% in 2030. 2030. Vietnam's total employment and unemployment rate in the BAU and GE scenarios are presented in Figure 3.17.

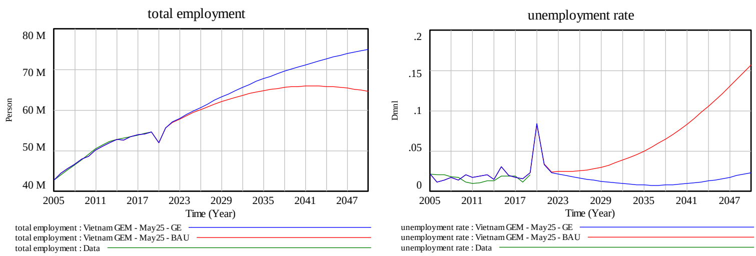

Figure 3.17. Total employment and unemployment rate

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

Through the research results, the goals set out in the Thesis were basically achieved as follows:

- Regarding the the first objective of Determining a method to develop a typical GHG emission factor for steel production activities in Vietnam, the PhD student has measured and monitored GHG emissions at production stages at Thai Nguyen Iron and Steel Factory. On the basis of measurement data, the PhD student has determined the emission factor for the fuel consumption process of steel production technology using the BOF and EAF technologies. The GHG emission factor for BOF technology is 2.63 tCO_2eq/ton of steel, and the GHG emission factor for EAF technology is 0.14 tCO_2eq/ton of steel. This result of the Thesis has proven Argument 1 and achieved goal 1 of the Thesis.

- In terms of the second objective of Develop and evaluate the impact of GHG emission scenarios for steel production activities in Vietnam, the thesis has developed a mitigation scenario for the steel production sector in Vietnam based on the forecast data on steel output according to the above-mentioned technologies in Vietnam. Specifically, the thesis has estimated greenhouse gas emissions according to the baseline scenario (BAU) - a scenario assuming there are no new solutions/interventions to save energy and reduce GHG emissions. Accordingly, GHG emissions from the baseline scenario will increase more than twice as quickly (from more than 26.7 million tCO_2eq in 2019 to more than 64 million tCO_2eq in 2030). In particular, GHG emissions from steel production technology using blast furnace - conversion furnace (BOF) are increasing and account for a major proportion of about 91.5% in 2030. GHG emissions from EAF steelmaking technology remain stable with a proportion of about 8.5% by 2030. It can be seen that to achieve the goal of GHG emissions reduction and green growth for the steel industry, it is necessary to focus on solutions/interventions for steel production activities using the BOF technology. In addition, the thesis has identified the mitigation of solutions/interventions for steel production technologies using the BOF and EAF technology. Solutions are divided into 3 main groups: (i) Energy saving; (ii) Use of renewable energy; and (iii) Use of biofuels. With the assumption of applying on a 100% scale to the steel industry, the mitigation potential by 2030 is about 18.5 million tCO_2eq. In particular, the mitigation potential of BOF technology is nearly twice that of EAF technology (12.4 million tCO_2eq compared to 6.1 million tCO_2eq). The results of the thesis have proven Argument 2 and partially achieved goal 2 of developing a scenario for reducing GHG emissions for the steel production sector based on the identified emission factor.

The thesis has also evaluated the impact of mitigation solutions on some main impacts on economic, social and environmental aspects as follows:

- Regarding macroeconomics, the results show the development of Vietnam's total real GDP and real GDP growth rate in the BAU and green economy (GE) scenarios compared to historical data. The mitigation measures expected in the GE scenario contribute to lower emissions and lower energy costs, generating higher economic growth and higher GDP compared to the corresponding BAU scenario. In the BAU scenario, the total real GDP is expected to increase from VND 3.91 trillion in 2020 to VND 7,293 trillion in 2030. The average real GDP growth rate in the baseline scenario is 6.1%. in the period 2020 to 2030. In the GE scenario, the total real GDP increases to VND 8,166 trillion in 2030 and VND 33,037 trillion in 2050, 12% higher in 2030 compared to BAU. From 2020 to 2030, the average real GDP growth rate in the GE scenario is 7.2%, 0.9% higher than in the BAU scenario.
- In terms of social aspects, the implementation of low-carbon development interventions leads to a decrease in both energy expenditure and emissions, which facilitate economic growth compared to the BAU scenario. Higher GDP growth leads to additional investment and higher job creation compared to the baseline. Higher job creation in the GE scenario contributes to lower long-term unemployment. In the BAU scenario, the employment figure increases from about 51.97 million jobs in 2020 to about 62.59 million jobs in 2030. The implementation of low-carbon interventions contributes to about a 2.2% increase in the employment figure in the GE scenario comapared with the BAU scenario.

Based on the above results, the thesis has completed all the set goals, proving that the thesis's arguments are well-founded and accurate, thereby confirming the novelty of the thesis. both scientific and practical. The results of the Thesis can be utilized for the implementation of GHG inventory, evaluation of the mitigation potential, and the development of the mitigation scenarios with higher accuracy and suitable with Vietnam's conditions, supporting decision-makers in the steel production sector and climate change in identifying roadmaps to both effective GHG emissions reduction and sustainable development targets. In addition, when the carbon market comes into operation, the identified emission factors for the steel manufacturing sector in Vietnam will bring benefits to the determination of carbon credits in a clearer and fairer manner.

RECOMMENDATIONS:

Within the framework of a Ph.D thesis, due to limited resources and time, the Ph.D. student can only carry out GHG monitoring and measurement at 01 steel factory and could not carried out the measurement at all steel factories in Vietnam with other technological conditions and types of production, such as factories using Induction Furnace (IF) technology. In addition, the calculation of emission factors for non-energy processes of the steel production sector still depend on the IPCC Guidelines, so the identified emission factor may not have the highest accuracy, so the development of mitigation scenario for the steel sector in Vietnam will have certain errors compared to the reality. To overcome the limitations of the Thesis and make orientation for the next research steps, the PhD student proposes the following recommendations:

- Continue the research direction of the thesis, carry out monitoring and measurements at all steel factories in Vietnam, especially factories using the IF technology.
- Currently, the IPCC default values are still used for the calculation of non-energy emission factors for the steel production sector and there is currently no research in Vietnam to determine this factor. Therefore, in the coming time, it is necessary to research and determine the emission factors for non-energy process of steel factories in Vietnam to replace the default values provided by the IPCC.

- Currently, a number of new types of steel production technology such as smelting reduction - oxygen conversion furnace - continuous casting and direct reduction - electric arc furnace - continuous casting are being developed on the world, so it is necessary to conduct research on those technologies if they are to be applied in Vietnam in the near future.