AIM/End-use Model for Selecting of Low-Carbon Technology in Indonesia’s Iron and Steel Industry

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Abstract. As an intensive energy-consuming, iron and steel making industry has significantly contributed to the national GHG emissions as the energy consumption is supplied by fossil fuels with high carbon emissions. The industry also releases GHG emissions during production processes, in which the emissions are considered as IPPU (industrial process and product use) category. There are still rooms for improvements in this industry, particularly those related to the efficiency improvement of energy use as well as material use or processes that could lead to the GHG emission reductions. Therefore, the iron and steel industry important roles to achieve the target of Indonesia’s NDC commitment in reducing GHG emissions and also towards the direction of low-carbon development and future climate resilience. In this study, a quantitative evaluation was conducted to analyse the effectiveness of emissions mitigation on potential energy saving and carbon emission reduction using the bottom-up AIM/End-use energy model in 2010-2050. This tool was used to select an optimal technology in detail with minimum cost approach. Several energy models have been proposed previously to quantify carbon emissions. However, a separate analysis of emissions from energy usage and IPPU (Industrial Process and Product Use) has never been done. The energy model was built under the baseline scenario and the following relevant mitigation scenario options were investigated: (i) adjusted the production structure, by increasing material efficiency with the scrap use in steel production process BF-BOF (Blast furnace-Basic oxygen furnaces) route and scrap-EAF (Electric arc furnace) route (CM1 scenario), (ii) maximised energy efficiency, by promoting low-carbon technology and non-blast furnace technology (smelting reduction) that is unimplemented early in modelling years in Indonesia will be included in the energy model for future reference (CM2 scenario), (iii) carbon emissions reduction through substitution of fossil fuels to low emission fuels (CM3 scenario). The expected results from the AIM/End-use model of Indonesia's steel industry is to provide optimal mitigation options in terms of emission reductions and costs.

1. Introduction

Currently, climate change issue has become international obligations towards reducing greenhouse gas (GHG) emission. Indonesia has presented an Indonesia’s Nationally Determined Contribution (NDC), which set ambitious goals to reduce GHG emissions by 26% against the business as usual scenario by 2030. Further emissions reductions of 41% are expected with international supports [1]. Therefore, it is important to understand the impacts of various technologies and the effective carbon mitigation strategy in industry as one of the key sectors. In industry sector, manufacturing industry has become the main driver of Indonesia's economic growth and has contributed to 18.2% of the total gross domestic product (GDP) in 2016. Among these manufacturing industries, iron and steel is intensive energy-consuming and one of the major GHG emissions source (energy and IPPU sectors). According
to the profile of greenhouse gas emissions in the Indonesian industrial sector, the iron and steel industry accounts for 11.25 MtCO\textsubscript{2}e or 9.17% of the total industrial emissions [2]. Recent studies have evaluated the energy efficiency and carbon emissions reduction potential in the iron and steel industry. These studies concluded that production was the main contribution to changes of carbon emission while energy efficiency was the main factor reducing energy intensity. The quantitative evaluation was conducted to analyse the effectiveness of emissions mitigation in the iron and steel industry through different energy optimization models [3]-[6]. Common approaches apply bottom-up perspective and include detailed technological representations ECSC and FCSC (Energy and Fuel Conservation Supply Curve [7]), this model analysis energy and cost but does not include an analysis of environmental impact. MARKAL (Market Allocation Model), TIMES (The Integrated MARKAL-EFOM System) and MASSAGE (Model for Energy Supply Systems and Their General Environment) focusing on technologies to reduce emissions [8]-[10]. However, most of these studies over-simplified the iron and steel production process and lack detailed descriptions of the technology so that cannot comprehensively evaluate the impacts of mitigation strategy. LEAP (Long-range Energy Alternative Planning System) is an example of bottom up accounting model that was unable to analyse policies related to cost [11]. ISEEM (Industry Sector Efficiency Modelling) was developed specifically analysing the energy efficiency improvement and potential trading opportunities (commodity and carbon) in the iron and steel sector. The fact, this model is inappropriately applied in Indonesia that has not implemented a carbon trading system in the industrial sector [12]. NET-IS (National Energy Technology-Iron and Steel) provide an overview of the steel production process and technology in detail [13]. However, the scope of this model is limited to national scale. AIM/End-use model evaluated 21 low-carbon technologies in two routes of steel production processes (long process and short process) for evaluating alternative emission reduction through the selection of optimum technology in detail under cost minimisation objective [14]-[15]. However, the evaluation in this study was only conducted in short-term (2010-2020) and has not considered the non-blast furnace technology in the production process. Thus, the main objective of this paper is to analyse the effectiveness of emissions mitigation on potential energy saving and carbon emission reduction in Indonesia’s iron and steel industry by applying AIM/End-use model in the long-term (2010 to 2050).

2. Methodology
2.1. AIM/End-use Model
AIM/End-use model is a bottom-up energy technology selection model developed by the National Institute for Environmental Studies (NIES), Japan [16]. AIM/End-use was built on GAMS (General Algebraic Modelling System) optimisation modelling interface as a technologically detailed linear optimisation that selects the optimal technology at a minimum total system cost over a set of constraints [17]. This paper used the AIM/End-use model to evaluate the technology promotion process and forecast the potential for energy saving and CO\textsubscript{2} emission reduction for Indonesian iron and steel. For this study, the operational framework of this model involved four steps: development of the structure of Indonesia’s iron and steel industry, selection technology for energy saving and carbon emission reduction, scenario design, and development of AIM/End-use models.

2.2. Structure of AIM/End-use model in Iron and Steel Industry
AIM/End-use model can be used to simulate flows of energy and materials in an economy, from supply of primary energy and materials to conversion into secondary energy and materials, and finally to the delivery of various types of energy to satisfaction of End-use services through the detailed representation of technologies [18]. Figure 1 shows the structure of the AIM/End-use model for iron and steel industry, first evaluates future demand of steel according to socio-economic factors and then determined technologies based on the database of energy and technologies. Service technologies can be compared and considered exactly. Once the types of technology are selected, energy use and CO\textsubscript{2} emissions can be estimated. On this basis, further questions of what technology pathways are required to achieve environmental targets, as well as the potential for emission reduction and abatement costs under a combination of different technologies can be answered.
2.3. System boundary
The Indonesian iron and steel industry have a complex industrial structure. Steel is produced via two main routes namely, the blast furnace basic oxygen furnace (BF-BOF) route and the EAF route. The BF-BOF route requires coke and sinter as a source of energy and raw materials, where the process of making coke and sinter consumes energy and produces large amounts of CO$_2$ emissions. While another steel production process is the EAF route. Recycled scrap and direct reduction, iron/sponge iron are used as the main raw material. The processes of producing pig iron are omitted and the consumption of coal is reduced. The EAF route uses electricity as its main energy source, which is cleaner. Therefore, compared with the BF-BOF route, the EAF route provides more energy savings and CO$_2$ emission reduction. The system boundary of the Indonesian iron and steel production process is described in the AIM/End-use model as shown in Figure 2. The BF-BOF route comprises of the following processes: (i) raw material preparation (coke oven, sintering and palletising), (ii) blast furnace (BF), (iii) basic oxygen furnace (BOF), (iv) final product manufacturing (casting, rolling and finishing), and (v) energy conversion devices for on-site electricity production. Another steel production process, EAF route comprises of the following process: (i) palletising, (ii) direct reduction process, (iii) electric arc furnace and (iv) final product manufacturing (casting, rolling and finishing). In this study, the total CO$_2$ emissions generated in the process within the system boundary were calculated, while pellets purchased, electricity purchased or BOF slag which integrated into the cement industry were not counted because emissions were produced elsewhere.

![Figure 1. Structure of the AIM/End-use model.](image-url)
2.4. Objective functions.
The objective function minimises the total cost as shown in equation (1). The total cost comprises the total annualised initial investment cost (only for recruitments in that year), total operating cost, and total cost of energy and emission tax in that year.
\[ TC = \sum_i \left( \sum_l C_{l,i} \cdot n_{l,i} + \sum_k E_{k,i} \cdot \left( 1 - \xi_{l,i} \right) \cdot X_{l,i} + \sum_m \epsilon_m Q_m^i \right) \rightarrow \min \] (1)

2.5. Constraint conditions

2.5.1 Energy supply constraints. Total quantity of energy supply in the iron and steel industry cannot exceed its allowable maximum energy supply quantity or below its allowable minimum energy supply quantity, expressed by equation (2) and equation (3) respectively.
\[ \sum_{i \in Y_{ME}} Q^e_{k,i} = \sum_{i \in Y_{ME}} \left( \sum_{j \in w_{l,j}} \left( 1 - 5_{l,i} \right) \cdot E_{k,l,p,i} \cdot X_{l,i} \right) \leq E^\text{max}_{ME,k} \] (2)
\[ \sum_{i \in Y_{ME}} Q^e_{k,i} = \sum_{i \in Y_{ME}} \left( \sum_{j \in w_{l,j}} \left( 1 - 5_{l,i} \right) \cdot E_{k,l,p,i} \cdot X_{l,i} \right) \geq E^\text{min}_{ME,k} \] (3)
Where \( E^\text{max}_{ME,k} \) indicates the allowable maximum supply quantity of energy type \( k \) in the \( ME^\text{th} \) group of sectors and regions \( l \), and \( E^\text{min}_{ME,k} \) means the allowable minimum supply quantity of energy type \( k \) in the \( ME^\text{th} \) group of sectors and regions \( l \).

2.5.2 Total operating capacity constraints. Total operating quantity of combination a device must not exceed its operating quantity by the stock of a device, expressed by equation (4).
\[ X_{l,i} = (1 + A_{l,i}) \cdot S_{l,i} \] (4)
Where \( A_{l,i} \) means the operating allowance rate of a device \( l \) in a sector and region \( i \), and \( S_{l,i} \) means the stock of a device \( l \) in a sector and region \( i \).

2.5.3 Total steel demand and-supply balance constraints. Final service demand quantity in the iron and steel must be equal to the total service demand by multiplying the quantity of total service output supplied by all devices, expressed by equation (5).
\[ D_{j,i} = (1 + \Psi_{j,i}) \cdot \sum_{i \in w_{j,i}} A_{l,i} \cdot X_{l,i} \] (5)
\( A_{l,i} \) indicates supply output of service \( j \) per unit operation of a device \( l \) in a sector and region \( i \). \( \Psi_{j,i} \) means service efficiency improvement rate of service \( j \) in sector and region \( i \) and \( D_{j,i} \) means total service demand quantity of service \( j \) in a sector and region \( i \).

2.5.4 Internal energy and internal service balance constraints. The amount of input raw material per energy in the next stage must be equal to the intermediate products in the previous stage, expressed by equation (6).
\[ \sum_{i \in Y_{MR}} \sum_{j \in w_{INT}} D_{j,i} = \sum_{i \in Y_{MR}} \sum_{k \in w_{INT}} Q^e_{k,i} \] (6)
\( Q^e_{k,i} \) means the demand of internal energy \( k \) and \( D_{j,i} \) means the supply of internal service \( j \).

2.5.5 Device share ratio constraints on service output. Device share ratio of service output of its device \( l \) to the total service output of all devices regarding service \( j \) must not exceed the maximum limit or below the minimum limit, expressed by equation (7) and equation (8) respectively.
\[ \sum_{(l,p) \in w_{j,i}} A_{l,j,i} \cdot X_{l,p,i} \leq \sum_{(l,p) \in w_{j,i}} A_{l,j,i} \cdot X_{l,p,i} \] (7)
\[ \sum_{(l,p) \in w_{j,i}} A_{l,j,i} \cdot X_{l,p,i} \leq \sum_{(l,p) \in w_{j,i}} A_{l,j,i} \cdot X_{l,p,i} \] (8)
\( \theta_{l,j,i}^\text{max} \) indicates the maximum share rate of service \( j \) of a device \( l \) to the total service output of all devices in a sector and region \( i \) and \( \theta_{l,j,i}^\text{min} \) means the minimum share rate of service \( j \) of a device \( l \) to the total service output of all devices in a sector and region \( i \).
2.5.6 *Share ratio constraints on service output for group of devices*. Share ratio of service output of its group of devices to the total service output of all devices regarding service \( j \) must not exceed the maximum limit \( \omega_n^{\text{max}} \) or fall below the minimum limit \( \omega_n^{\text{min}} \), expressed by equation (9) and equation (10) respectively.

\[
\omega_n^{\text{max}} \cdot \sum_{(l,i,j)\in W_{ij}} \left(A_{l,i,j} \cdot X_{l,i,j}\right) \leq \sum_{(l,i)\in G_i} \sum_{t\in T} u_{n} A_{l,i} \cdot X_{l,i} \quad (9)
\]

\[
\omega_n^{\text{min}} \cdot \sum_{(l,i,j)\in W_{ij}} \left(A_{l,i,j} \cdot X_{l,i,j}\right) \leq \sum_{(l,i)\in G_i} \sum_{t\in T} u_{n} A_{l,i} \cdot X_{l,i} \quad (10)
\]

\( \omega_n^{\text{max}} \) means the maximum share rate of service \( j \) of a group of devices in the \( n \)th constraint to the total service output of all devices in a sector and region \( i \), and \( \omega_n^{\text{min}} \) means the minimum share rate of service \( j \) of a group of devices in the \( n \)th constraint to the total service output of all devices in a sector and region \( i \).

2.5.7 *Stock quantity balance*. Stock \( S_{l,i,t} \) of a device \( l \) in a sector and region \( i \) in the simulation year \( t \) is calculated by adding the remained stock that existed in the base year and recruitment quantity and deducting quantity of a device \( l \) retired regardless of its life time.

\[
S_{l,i,t} = S_{l,i,0} \cdot e^{-\frac{t_{l,i}}{T_{l,i}}} + r_{l,i} - w_{l,i} \quad (11)
\]

\( S_{l,i,t} \) means the stock of a device \( l \) in a sector and region \( i \) in the base year \( t_0 \).\( r_{l,i} \) is the recruitment quantity of a device \( l \) in a sector and region \( i \).\( w_{l,i} \) is the quantity of a device \( l \) retired regardless of its life time in a sector and region \( i \), and \( T_{l,i} \) is the life of device \( l \).

![Figure 2. Structure of Indonesia’s iron and steel industry in the AIM/End-use model.](image-url)
2.6. Low-carbon technologies for Indonesia’s iron and steel industry

In order to analyse the energy saving and emissions reduction in Indonesia’s iron and steel industry, in this study, 56 technologies were selected included in the main process in the iron and steel production (sintering, coking, palletising, iron making, steel making, casting rolling finishing, and energy conversion devices). Technology selection process was based on the least cost - optimum ability to reduce emissions and save energy at the minimum total system cost over a set of constraints. Among the low-carbon technologies selected, there were two types of technology namely technology retrofitting and substitution. Technology retrofitting means modifying the technology to improve energy efficiency of an existing technology. While technology substitution means the replacement of an existing technology by a new technology at the end of the service life of an existing technology or for meeting with the increase of energy service demands. The selected technologies related energy savings, lifetime and cost estimation are shown in Table 1.

3. Design Scenario

3.1. Scenario description

Scenario analysis is a common approach to predicting and simulating potential energy savings and emission reductions in the AIM/End-use model. Scenario setting in the AIM/End-use model is important to achieve that desired target. There are four scenarios generated in this study, these scenarios are defined as baseline scenario (BAU scenario) and mitigation scenarios (CM1, CM2, and CM3), which means that more ambitious energy conservation and emission reduction objectives are implemented in this scenario. The differences between these scenarios are listed in Table 2.

| Scenarios          | Scenario description                                                  |
|--------------------|-----------------------------------------------------------------------|
| BAU scenario       | No further energy savings and emissions reduction policy measures will be implemented during the scenario period. |
| CM1 scenario       | Adjusted the production structure, by increasing material efficiency with the scrap used in steel production process included basic oxygen furnace and electric arc furnace |
| (BAU+ adjusted the production structure) | Refers to maximized energy efficiency, by promoting low carbon technology and non-blast furnace technology (direct and smelting reduction) that is unimplemented early in modeling years in Indonesia |
| CM2 scenario       | Carbon emissions reduction through substitution of fossil fuels to low emission fuels |
| (CM1+ promoting low carbon technology) |                                                                       |
| CM3 scenario       | Carbon emissions reduction through substitution of fossil fuels to low emission fuels |
| (CM3+ substitution fuel) |                                                                        |

3.2. Parameter setting

This study sets 2010 as the base year consider the provisions on international agreements and reliable data of the iron and steel industry was available. The planning horizon is developed in 10-year time interval extending to 2050 as the target year. Other parameters used in AIM/End-use model include technical and emission parameters. The emission parameters consider emission factors for various energy sources and the electricity that use in iron and steel production process. Besides energy emission factors, some primary or secondary fuels may be used for non-fuel purposes and carbon that used from metallurgical cokes, pulverized coal, natural gas as reducing agent should be considered process-related IPPU emissions. Specific technical parameters including data of technology such as fixed investment cost, operations, and maintenance cost, lifetime, energy input-output per unit, and the amount of technology used in the base year [7]-[8],[11],[19]-[22].
| Process                        | Technology                                           | Code in AIM/End-use | Type | Fuel-saving (toe/t) | Electricity-saving (toe/t) | Capital Cost (US$ 2020/t) | Annual O M cost (US$ 2020/t) | Lifetime (year) |
|-------------------------------|-----------------------------------------------------|---------------------|------|--------------------|----------------------------|--------------------------|-------------------------------|-----------------|
| Coke making                   | Coal moisture control technology (CMC)              | IS_C_CM1            | R    | 0.00406            | 0                          | 78.68                    | 0.00                          | 20              |
|                              | Coke dry quenching (CDQ)                            | IS_C_CQ1            | R    | 0.03368            | 0                          | 94.02                    | 0.77                          | 20              |
| Pelletising                   | Grate klin                                          | IS_P_GKP            | S    | 0.00693            | 0                          | 53.22                    | 0.00                          | 20              |
| Sintering                     | Pellet waste heat recycling                         | IS_P_WH1            | R    | 0.00196            | 0                          | 1.95                      | 0.26                          | 20              |
|                              | Deep bed sintering technology                       | IS_S_DB1            | R    | 0.00191            | 0                          | 0.44                      | 0.00                          | 10              |
|                              | Reducing air leakage (10%)                          | IS_S_RA1            | R    | 0.00430            | 0                          | 0.15                      | 0.00                          | 10              |
|                              | Low temperatur sintering                            | IS_S_LT1            | R    | 0.00836            | 0                          | 0.22                      | 0.00                          | 10              |
|                              | Sintering waste heat recovery                       | IS_S_WH1            | R    | 0.01310            | -0.00239                   | 3.31                      | 0.00                          | 25              |
| Blast furnace-iron making     | Top gas recycling BF                                | IS_B_TGR            | S    | 0.02928            | 0                          | 79.82                    | 0.00                          | 30              |
|                              | Recovery of blast furnace gas (BFG)                 | IS_F_BG1            | R    | 0.00096            | 0                          | 0.44                      | 0.00                          | 15              |
|                              | Top Pressure Recovery Turbines (TRT)-wet            | IS_F_TR1            | R    | 0                  | 0.00263                    | 32.33                    | 0                            | 15              |
|                              | Top Pressure Recovery Turbines (TRT)-dry            | IS_F_TR2            | R    | 0                  | 0.00396                    | 29.46                    | 0.00                          | 15              |
|                              | Improved BF control system                          | IS_F_IC1            | R    | 0.00955            | 0                          | 0.40                      | 0.00                          | 15              |
|                              | Preheating of fuel and air for hot blast stove      | IS_F_PF1            | R    | 0.00597            | 0.00                       | 2.14                      | 0.00                          | 20              |
|                              | Recuperator on the hot blast furnace                | IS_F_RB1            | R    | 0.00717            | 0                          | 6.69                      | 0.00                          | 5               |
|                              | Injection natural gas in Blast Furnace              | IS_F_NS1            | R    | 0.00884            | 0                          | 6.51                      | -2.87                         | 20              |
|                              | Injection of Coke Oven Gas                          | IS_F_CG1            | R    | 0.00860            | 0.00159                    | 6.51                      | -2.87                         | 20              |
|                              | Pulverized Coal Injection (PCI) 130 kg/ t hM       | IS_F_PCI            | R    | 0.01552            | 0                          | 7.89                      | -2.15                         | 25              |
| Process                      | Technology                           | Code in AIM/End-use | Type | Fuel-saving (toe/t) | Electricity-saving (toe/t) | Capital Cost (US$ 2020/t) | Annual O M cost (US$ 2020/t) | Lifetime (year) |
|------------------------------|--------------------------------------|---------------------|------|---------------------|---------------------------|----------------------------|-------------------------------|-----------------|
| Basic Oxygen Furnace         | Flue gas waste heat recovery         | IS_I_FG1            | R    | 0.002150            | 0                         | 3.86                       | 0.10                          | 10              |
|                              | Recovery BOF gas and sensible heat   | IS_I_LD1            | R    | 0.002197            | 0                         | 24.28                      | 0                             | 15              |
|                              | Dry gas cleaning system (wet to dry) | IS_I_DG1            | R    | 0.003344            | 0                         | 4.68                       | 0.00                          | 15              |
|                              | LT-PR of converter gas               | IS_I_LT1            | R    | 0.016480            | 0                         | 0.27                       | 0.52                          | 15              |
|                              | Scrap preheating                     | IS_E_PRI1           | R    | 0                   | 0.00525                   | 8.39                       | -4.337                        | 30              |
|                              | Automated controls                   | IS_E_AC1            | S    | 0                   | 0.00263                   | 1.05                       | 0.00                          | 15              |
|                              | Post combustion                      | IS_E_PC1            | S    | 0                   | 0.00215                   | 1.10                       | 0.02                          | 15              |
|                              | UHP transformer                      | IS_E_UP1            | R    | 0                   | 0.00143                   | 9.16                       | 0.09                          | 15              |
|                              | Foamy slag practice                  | IS_E_FS1            | R    | 0                   | 0.00048                   | 11.03                      | -1.99                         | 15              |
|                              | Oxy fuel burners                     | IS_E_OF1            | R    | -0.005732           | 0.00430                   | 4.41                       | 0.4                           | 10              |
|                              | DC furnace                           | IS_E_FG1            | R    | 0                   | 0.00430                   | 4.304                      | -3                            | 25              |
|                              | Direct sheet plant                   | IS_R_DSP            | S    | -0.028300           | 0                         | 199.55                     | 0                             | 30              |
|                              | Thin slab casting (TSC)              | IS_R_TSC            | S    | 0.010987            | 0.00836                   | 220.70                     | -0.55                         | 25              |
|                              | Integrated casting and rolling (strip casting) | IS_R_ISC | S | 0.0067 | 0.00000 | 354.25 | -2.11 | 30 | |
| Hot rolling and casting      | Waste heat recovery from cooling water | IS_R_WH1            | R    | 0.000955            | 0                         | 26.07                      | 0.30                          | 15              |
|                              | Recuperative burners                 | IS_R_RB1            | R    | 0.001672            | 0                         | 2.76                       | 0                             | 10              |
|                              | Hot delivery and hot charging        | IS_R_DC1            | R    | 0.005493            | 0                         | 0.38                       | 0.29                          | 10              |
|                              | Process control in hot strip mill    | IS_R_PC1            | R    | 0.006688            | 0                         | 18.54                      | 0.00                          | 10              |
|                              | Low temperatur rolling               | IS_R_LT1            | R    | 0                   | 0.01565                   | 0.43                       | 0.00                          | 20              |
| Cold rolling and finishing   | Automated monitoring and targeting system | IS_O_AM1        | R    | 0                   | 0.00516                   | 1.99                       | 0                             | 10              |
|                              | Heat recovery on annealing line       | IS_O_HR1            | R    | 0.007165            | 0.00026                   | 4.41                       | 0                             | 10              |
### Table 2. Screened technologies, related energy saving potential and cost estimation (continued).

| Process                     | Technology | Code in AIM/End-use | Type | Fuel-saving (toe/t) | Electricity-saving (toe/t) | Capital Cost (US$ 2020/t) | Annual O M cost (US$ 2020/t) | Lifetime |
|-----------------------------|------------|---------------------|------|--------------------|---------------------------|--------------------------|-----------------------------|----------|
| Non blast furnace-iron making | COREX      | IS_N_COR            | S    | 0.54300            | 0.0756                    | 367.18                   | .0                           | 30       |
|                             | FINEX      | IS_N_FIN            | S    | 0.37440            | 0                         | 367.18                   | 0                            | 30       |
|                             | MIDREX     | IS_DR_MID           | S    | 0.25301            | 0                         | 399.10                   | 0                            | 30       |
|                             | Ulcored    | IS_DR_ULC           | S    | 0.18988            | 0                         | 399.10                   | 0                            | 30       |
|                             | SL/RN      | IS_DR_SLR           | S    | 0.47916            | 0                         | 344.39                   | 0                            | 30       |
|                             | Hisarna    | IS_DR_HIS           | S    | 0.41010            | 0                         | 159.64                   | 0                            | 30       |
Figure 3. Model structure of iron and steel industry in Indonesia.
4. Results and Discussion

The AIM/End-use model structure of iron and steel industry in Indonesia has been generalised as shown in fig.3. In this model, the production technology process based on the scenario that has been designed to reduce CO$_2$ emission and energy saving. The improvements in overall energy intensity and reduce CO$_2$ emission of steel production can be mostly attributed to the increased use of scrap, penetration of low-carbon technologies, and substitution of fossil fuels to low emission fuels.

Adjusting production structure through increased material efficiency with the scrap used considered to be one of the most promising mitigation options in the iron and steel industry. Production of steel using scrap was able to emit significantly lower CO$_2$ emissions than using iron ore because it eliminated the needs of previous processes (coking, sintering, blast furnace) to producing pig iron that consumes a large amount of coal. In this model, we considered the scrap used not only in the EAF route but also in BOF route. The importance of exploring the option for increasing the steel scrap use in the BOF route due its ability to reduce as many CO$_2$ emissions as would switch from the BF-BOF route to the EAF route and is applicable to existing BF-BOF plants in a reasonable timescale. Moreover, the increased scrap use in BOF might not require major changes in steel making practices, although there was a limit scrap caused by increased of impurities such as copper (Cu) that can decrease the quality of the steel produced. Therefore, it is important to determine the optimum amount of scrap used in the BOF.

In other CO$_2$ mitigation measures, several low-carbon technology options need to be developed and implemented in the iron and steel sector as shown in Figure 3. Low-carbon technology that was used in this model included existing technologies, efficient technologies, and advanced technologies. The existing technology represented the process technology that was currently used in Indonesia’s iron and steel industry. Efficient technologies represent modified technology to improve the energy efficiency of an existing technology. While advanced technologies were the updated version of current technologies such as a newly developed non-blast furnace that included both direct reduction and smelting reduction seem to offer the best prospects due to eliminating the necessary emissions from material preparation/coke making process to produce coke as a reducing agent in the iron making. It is assumed that these technologies, which have not been applied in the early years of model would be gradually included in the model for future reference to replace conventional blast furnace iron making process.

In the iron and steel industry energy system, the largest proportion of electricity sources were supplied by electricity purchased. On the other hand, domestic electricity production was still dominated by coal which produced large amounts of CO$_2$ emissions as the value of electricity emission factor increases year by year. Therefore, carbon reduction could be applied by increasing the use of natural gas and biomass to produced on-site electricity.

5. Conclusions

In targeting the iron and steel industry, this paper examined and developed the structure of AIM/End-use model in the Indonesian iron and steel industry based on relevant mitigation scenario options to select combinations of low-carbon technologies and mitigation options that would achieve the most optimal energy savings and CO$_2$ emissions reductions from energy and IPPU (Industrial Process and Product Use) sectors.

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