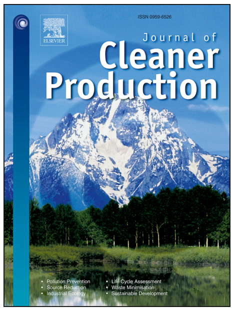

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Assessing the policy impacts on non-ferrous metals industry's CO_2 reduction: evidence from China

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Highlight:

- We model the policy impacts on non-ferrous metals industry (NMI) 's CO2 reduction based on decomposition method.
- Direct and indirect CO2 emission are considered in the study.
- CO2 emission of Chinese NMI is very likely to peak before 2030 under current policies.
- Chinese energy efficiency policies of NMI should be updated.

Abstract: The nonferrous metals industry (NMI) consumes a great amount of energy, and is a typical high CO_2 emission sector. The NMI is one of the eight most concerning industries in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. In this study, we summarized policies that impact Chinese NMI's development and grouped them into three types: energy structure policies, energy efficiency improving policies and production-scale policies. Based on those quantitative policy goals, a bottom-up model has been developed to study the CO_2 emissions of five NMI's major sub-sectors from 2010-2030. The results showed that if China's central government could stick to the CO_2 reduction policy strength of 13th Five-Year Plan (2016-2020), then the copper, lead and zinc industries can reach their emissions peak before 2030. Furthermore, if the Chinese government restricts the production of primary aluminum of 46.2 million tons in 2025, then the CO_2 emissions of China's non-ferrous industry could reach the peak

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in that year, when the CO_2 emissions peak is 297 million tons. Having benefited from the effective CO_2 reduction policies of NMI, China may reach its ambitious CO_2 peaking goals more easily.

Keywords: Non-ferrous industry, Carbon emissions, Policy evaluation, Peak

1. Introduction

The nonferrous metals industry (NMI) is a typical energy intensive, high greenhouse gas (GHG) emission industry (Wei et al., 2011). The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report lists the NMI as one of the eight most concerning industries (Fischedick et al., 2014). In 2016, the world's NMI produced 1.06 billion tons CO_2 and was responsible for 3% of global CO_2 emission(Janssens-Maenhout et al., 2017). China is world's largest producer and consumer of non-ferrous metals products, in particular, China's total production of aluminum, copper, lead, zinc and magnesium accounts for 49% of the world in 2016 (Wei et al., 2016). Due to the rapid growth in production, the CO_2 emissions of the Chinese NMI increased significantly. The annual growth rate of NMI's CO_2 emission was 9.4% during 2010-2015(CNMIA, 2009-2017). Under these conditions, the proportion of NMI's CO_2 emission of China's total CO_2 emission increased from 1.8% to 2.6% during 2010-2015(NBS, 2009-2016). China announced that its CO_2 emissions will peak by 2030, but the rapid growth of NMI's CO_2 emission brought huge challenges to China's ambitious goals. Hence, the Chinese central government introduced a series of policies and measures to control the growth in the 13th Five-Year Plan (FYP) period (2016-2020) (Mi et al., 2017c). It now becomes necessary to evaluate whether the current policies can meet the requirement of China's 2030 CO_2 peaking goal(Mi et al., 2017a). In this study, we group NMI-related CO_2 reduction policies into three categories and extract the quantitative policy goals from them. Based on historical data and policy goals, a bottom-up model is developed to calculate the annual CO_2 emission of the NMI from 2010-2030. By analyzing the results of our evaluation, we can identify which NMI-related CO_2 reduction policies are effective and can recommend how to improve the insufficient ones.

This evaluation is based on real policy goals and historical data. Policy makers could measure the strength of current polices and find quantitative solutions through this(Mi et al., 2017b). The earlier the deficiencies are found, the easier it will be for the government to improve these policies. The frame of this study is universal to all kind of industries and can be applied to various policy evaluations.

2. Literature review

Research on the CO_2 reduction of the NMI has been abundant. Generally, there are four highly emphasized subjects.

1) Calculations of the energy saving and CO_2 reduction potentials of the NMI. Lin and Zhang used a cointegration model to estimate electricity intensity of Chinese NMI, and to predict the future electricity saving potential in 2020 (Lin and Zhang, 2013). Wen and Li developed a technology system within a LEAP model to estimate energy conservation and CO_2 emissions reduction potentials for Chinese NMI in 2010–2020(Wen and Li, 2014). By using a Seemingly unrelated regression (SUR) model, Lin and Du simulated various energy conservation scenarios of Chinese iron steel and NMI in 2020 (Lin and Du, 2017). Based on provincial data of NMI in 2006-2011, Wang and Zhao predicted the energy conservation potential of Chinese NMI by using a Tobin regression model, where population density, GDP and energy price were considered in their calculation (Wang and Zhao, 2017). Yan and Fang used decomposition analysis to study the CO_2 reduction potential of Chinese manufacturing industry. Their results showed that the CO_2 reduction potential mainly come from the iron steel and non-ferrous industries (Yan and Fang, 2015).

2) Evaluations of the total factor productivity or energy-environment efficiency of Chinese NMI. Shao and Wang made a productivity index by using the Malmquiste-Luenberger method (Shao and Wang, 2016). Based on the annual data of Chinese 27 provinces during 2003-2009, two kinds of productivity indices were made for comparison. Their results showed that Chinese NMI's productivity was mainly effected through technological advances rather than endogenous factors. Shao et al. measured the total factor productivity of Chinese NMI's 30 sub-sub-sectors by using global data envelopment analysis (DEA) (Shao et al., 2016). Wang and Zhao used a non-radial DEA method to evaluate the energy-environment efficacy of Chinese 30 provincial NMIs from 2006 to 2011 (Wang and Zhao, 2017).

3) Identifications of the key factors and sectors for the CO_2 reduction and energy conservation of NMI. Based on the panel data of 29 provincial NMIs from 2000-2011, Shi and Zhao developed a Logarithmic Mean Divisia Index (LMDI) model to analyze the factors driving CO_2 emission's growth. They found that the expansion of the production scale is the main reason for the growth of Chinese NMI's CO_2 emission, but the energy efficiency of Chinese NMI has improved a lot

since 2000 (Shi and Zhao, 2014). Shao et al. investigated the CO_2 emissions of 12 NMIs from 2003 to 2010 based on their lifecycle performance. The authors used cluster analysis to identify the key affecting sectors (Shao et al., 2014).

4) Effects of decoupling of Chinese NMI's CO_2 emission. Ren and Hu adopted the refined Laspeyres index to analyze the decoupling effects and development stages of Chinese NMI's CO_2 emission. Their result showed that the industry scale and energy mix switching have contributed significantly to the increase of CO_2 emissions (Ren and Hu, 2012).

Former research did not evaluate the effectiveness of CO_2 reduction policies. Although several studies analyzed the CO_2 reduction potential of Chinese NMI in 2020, there is not enough research focused on NMI's contribution to China's 2030 CO_2 peaking goal. Furthermore, most former research is based on strong assumptions, thus a high degree of uncertainty should accompany these studies.

3. Methodology

Base on the research review above, it is clearly that studies of policy impact are insufficient. In order to assess the policy impacts on NMI's CO_2 reduction, we build the following framework to instruct this study.

3.1 Research framework

The analytical procedure in this study is described in Fig. 1, which can be summarized in five steps: identification of the NMI' major sectors and key factors, assessing CO_2 emission intensity improvement based on energy structure policies, assessing energy efficiency improvement based on NMI's national energy efficiency standards, predicting production scale based on 13th Five-Year Plan of NMI's development, and assessing the comprehensive CO_2 reduction effects by using the bottom-up decomposition method.

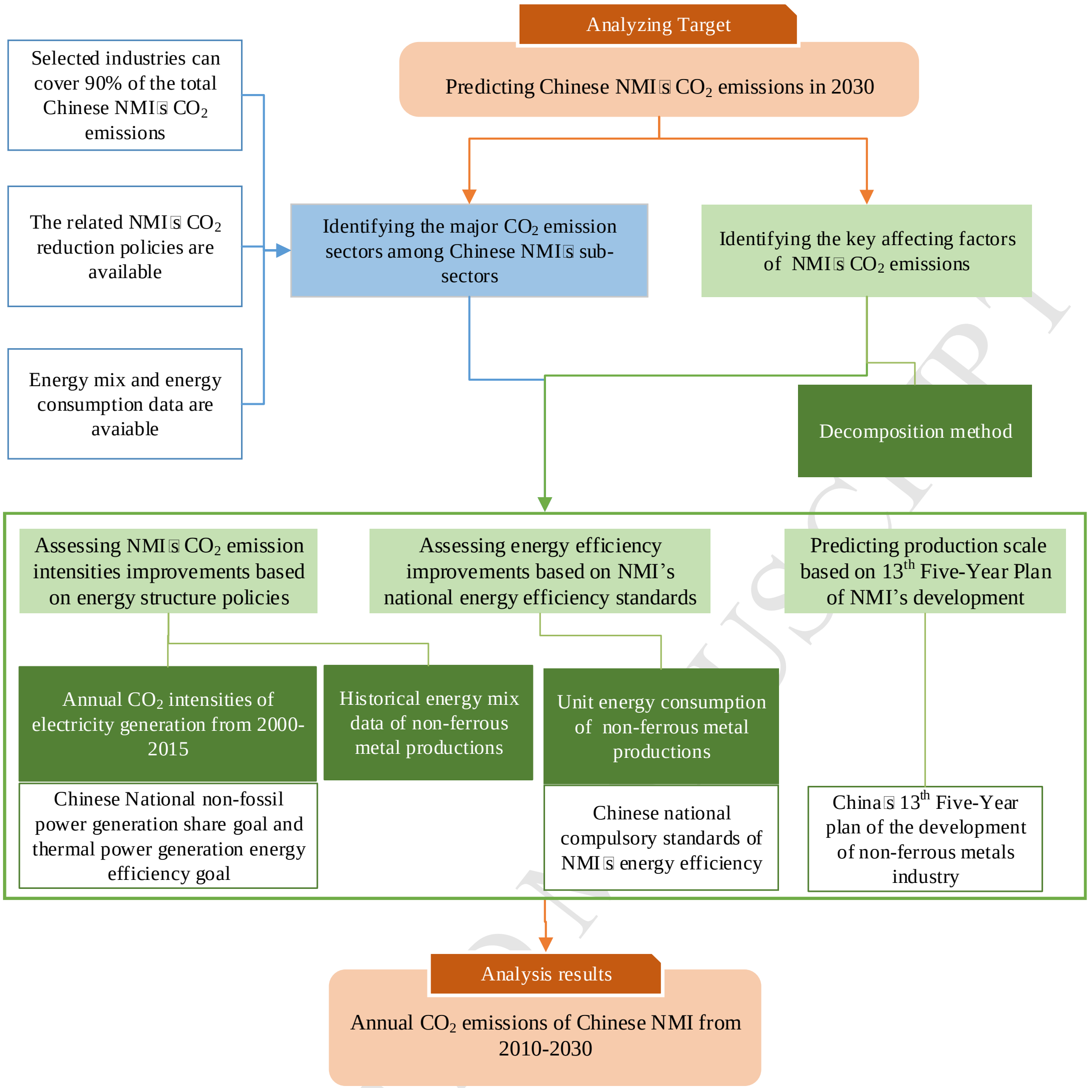


Fig. 1. Framework of this study

3.2 Identification of NMI's major sectors and key factors

Based on the Kaya Identity(Wang et al., 2017), we aggregate the total CO_2 emissions from *i* sector:

$$C=\sum_i C_i=\sum_i \frac{C_i}{E_i}\times\frac{E_i}{P_i}\times P_i=\sum_i F_iT_iP_i \qquad (1)$$

Where:

C: total CO_2 emissions of all non-ferrous metals industry (million tons CO_2),

C_i: CO_2 emissions of *i* NMI's sub-sector (million tons CO_2),

E_i: energy consumption of *i* NMI's sub-sector (million tons of coal equivalent, million tce),

P_i: production scale of i NMI's sub-sector (million tons),

F_i: CO_2 intensity of i NMI's sub-sector (ton CO_2 per tce),

T_i: energy efficiency of i NMI's sub-sector (tce per ton metal)

Based on the Eqs. (1), we get three major factors which affect NMI's CO_2 emission: CO_2 intensity, energy efficiency and production scale. The corresponding policies are: energy structure policies, energy efficiency improving policies and production scale policies. In this study, we focus on the NMI-related policies mentioned above and assess the CO_2 reduction effects brought by them.

There are 10 major sub-sectors in Chinese NMI system: copper, aluminum, lead, zinc, nickel, tin, antimony, mercury, magnesium and titanium. According to Fig. 1, the top five CO_2 emission sub-sectors are aluminum, copper, lead, zinc and magnesium. The average annual CO_2 emission of the five sub-sectors are 94% of the total from 2010-2015. In addition, Chinese central government introduced quantitative development policies only for the five major NMI's sub-sectors in the 13th FYP (MIIT, 2016). Therefore, aluminum, copper, lead, zinc and magnesium industries are identified as the major sub-sectors of Chinese NMI in this research.

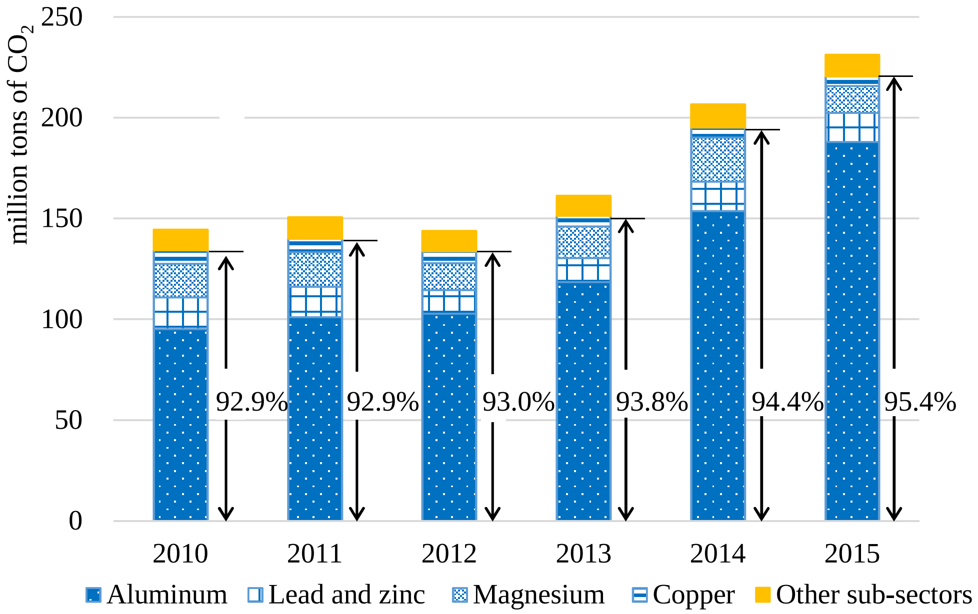


Fig. 2. CO_2 emissions of non-ferrous metals industry's sub sectors from 2010-2015, the numbers between bars show the 5 major sub-sectors' CO_2 percentages of total.

3.3 CO_2 intensity changes caused by energy structure policies

The CO_2 emission intensity means CO_2 emission from one-unit energy. The main energy sources of Chinese NMI are electricity and coal. Based on the electro-thermal equivalent method, the electricity and coal consumption of Chinese NMI are 35.5% and 59.1% of the total energy consumption respectively in 2015(CNMIA, 2009-2017). Ignorance of indirect CO_2 emissions will underestimate the total amount of Chinese NMI's CO_2 emission(Cong and Wei, 2010). In this study, we assume the electricity consumed by Chinese NMI is all from common power plants. The average CO_2 intensity of electricity can be calculated by Eqs. (2)(Cong and Wei, 2012):

$$F_{power} = F_{thermal}(1 - R_{non\text{-}thermal}) \tag{2}$$

Where:

F_{power}: average CO_2 intensity of electricity generation (g CO_2 per kWh),

$F_{thermal}$: average CO_2 intensity of thermal power generation (g CO_2 per kWh),

$R_{non\text{-}thermal}$: proportion of Non-fossil fuel power generation.

And we have Eqs. (3) to show the relation between CO_2 intensity of thermal power generation and standard coal consumption rate of power supply:

$$F_{thermal} = T_{thermal} \sum_{j} R_j F_j \tag{3}$$

Where:

$T_{thermal}$: standard coal consumption rate of power supply (g ce (coal equivalent) per kWh),

F_j: CO_2 emission factor of fuel j (t CO_2 per tce),

K_j: share of fuel j for thermal electricity generation.

The parameter F_j is constant, and the fuel share of China's thermal electricity generation is relatively stable. So we can estimate the $F_{thermal}$ in year h by using Eqs. (4):

$$F_{thermal,h} = \alpha T_{thermal,h} \tag{4}$$

For the CO$_2$ intensity of NMI's sub-sectors, we have:

$$F_{i,h} = \frac{F_{power,h} Q + \sum_k R_{k,i,h} F_k}{1 + \sum_k R_{k,i,h}} \tag{5}$$

Where:

$F_{i,h}$: CO$_2$ intensity of i NMI's sub-sector at year h (t CO$_2$ per tce),

Q: conversion factor of electro-thermal equivalent (kg coal equivalent per kWh),

$R_{k,i,h}$: share of k fossil fuel of i NMI's sub-sector at year h,

F_k: CO$_2$ emission factor of fuel k (t CO$_2$ per tce).

Chinese central government did not introduce policies directly related to the energy structure of NMI. Moreover, shares of fossil energies of Chinese NMI's sub-sectors were very stable in the past decade (coal was above 90% of the total fossil energy consumption). Therefore, in this study, we assume the shares of fossil energies consumed by Chinese NMI's sub-sectors will stay the same as the historical average, which means the energy structures of Chinese NMI's sub-sectors during 2015-2030 are set equal to the average from 2010 to 2015 in this model. Then we have Eqs. (6):

$$F_{i,h} = b_0 + b_1 F_{power,h} \tag{6}$$

$$b_0 = \frac{\sum_k R_{k,i,2010\text{-}2015} F_k}{1 + \sum_k R_{k,i,2010\text{-}2015}} \qquad b_1 = \frac{Q}{1 + \sum_k R_{k,i,2010\text{-}2015}}$$

Both b_0 and b_1 are constant in this model.

3.4 Energy efficiency improvements produced by national standards

There are three kinds of energy efficiency guiding numbers listed in the newest Chinese national NMI's standards issued by the Standardization Administration of China. They are energy efficiency standards for existing factories, new factories and the recommended advanced standard. In Table 1, both current and former version of standards are listed. We can find that Chinese NMI's national standards usually update about every five or seven years, the current energy efficiency standards for new factories have covered the recommended advanced standards of former version. This means that Chinese NMI's energy efficiency could reach the current recommended advanced standards in less than a decade. Based on these discoveries, we conservatively assume that Chinese NMI's energy efficiency would keep improving, and comprehensively reach the current new factories standards in 2020, then fully reach the recommended advanced standards in 2030.

Table 1 Chinese national energy efficacy standards of non-ferrous metals production (kg coal equivalent per ton metal)

	Code name	Effective year	Standards for existing factories	Standards for new factories	Recommended advanced standards
Refined copper	GB21248-2007	2008	950	700	550
Recovered copper	GB21248-2007	2008	510	470	400
Primary Aluminum	GB21346-2007	2008	1900	1850	1800
Refined lead	GB21250-2007	2008	650	540	470
Recovered lead		——	——	——	——
Primary zinc	GB21249-2007	2008	1850	1700	1200
Refined zinc	GB21249-2007	2008	2200	2100	1900
Magnesium	GB21347-2008	2008	6000	5000	4500
Current version:					
Refined copper	GB21248-2014	2014	300	280	280
Recovered copper	GB21248-2014	2014	430	360	350
Primary Aluminum	GB21346-2013	2014	1760	1680	1660
Refined lead	GB21250-2014	2015	540	370	355
Recovered lead	GB25323-2010	2012	185	130	120
Primary zinc	GB21249-	2015	920	900	900

	2014				
Refined zinc	GB21249-2014	2015	1800	2000	1850
Magnesium	GB21347-2012	2013	4000	3500	3000*

* This standard is cited from the 13th FYP of NMI’s development (MIIT, 2016).

3.5 Prediction of production scale based on national plan

Chinese central government issues the FYP development policies every five years. The latest quantitative production growth limitations for five major NMI’s sub-sectors can be found in the 13th FYP of NMI’s development. In addition, the government also gave the qualitative production policies for the period after 2020: the growth of copper and aluminum productions will slow down significantly after 2020, the production of lead will keep the current growth rate, the production of zinc will peak in the end of 13th FYP period, the production of magnesium will continue to grow fast after 2020 (MIIT, 2016).

Compared with the regulations of the 12th FYP period (2011-2015), the annual production growth of copper industry and aluminum industry decreased 63% and 64% respectively in the 13th FYP period (2016-2020). Since the policies of 13th FYP describe “the growth of copper and aluminum productions will slow down significantly after 2020”, we conservatively assume that the annual growth rates of copper and aluminum production in 14th FYP period (2021-2025) will be 30-50% lower than those in 13th FYP period, and the growth rates in 15th FYP period (2026-2030) will be 30-50% lower than in 14th FYP. The policies say lead production will grow at rate of 0.6% annually during 13th FYP period and stresses that this is a peak growth rate. Based on this description, we assume that the annual growth of lead and zinc production in 2021-2030 will stay at the rate of 0.6%. The last part, the annual growth rate of magnesium is set to be 7.1% during 2016-2020 and the 13th FYP of NMI’s development describes it is a high growth rate. Since the 13th FYP of NMI’s development predicts the growth rate of magnesium production will keep high after 2020, we assume that the annual growth rate of magnesium production will stay at 7.1% from 2021-2030. On the Table 2, we list the annual growth rate predictions of all five NMI’s sub-sectors.

Table 2 Predictions of annual growth rate for NMI’s sub-sectors

	Copper	Aluminum	Lead	Zinc	Magnesium

13th FYP 2016-2020	3.3%	5.3%	0.6%	1.7%	7.1%
14th FYP 2021-2025	1.65%-2.31%	2.65%-3.71%	0.6%	0.6%	7.1%
15th FYP 2026-2030	0.825%-1.617%	1.325%-2.597%	0.6%	0.6%	7.1%

The 13th FYP of NMI's development requires the shares of recovered copper and recovered lead should be more than 27% and 45% respectively in 2020. There are no other policies related to secondary metals production in this development plan. Based on this, we conservatively assume that the share of primary zinc in 2030 will stay the same level as 2020. Because of the lack of historical data and policy regulations, the secondary aluminum is not considered in this research (CNMIA, 2009-2017).

3.6 Data

Because the energy consumption data of NMI's sub-sectors before 2010 are unavailable, our historical CO_2 emission calculation of NMI's sub-sectors begins in 2010 and ends in 2015. The annual data of energy mix, energy consumption, energy efficiency and production scale are all collected from the Yearbook of Nonferrous Metals Industry of China (CNMIA, 2009-2017). The CO_2 emission factors are collected from China Energy Statistical Yearbook (NBS, 2009-2016) and Guidebook of Provincial Greenhouse Gas Emission Statistics (NDRC, 2011).

The prediction of average CO_2 intensity of thermal power generation is based on the data from year 2000 to 2015. All the data are collected from China low carbon development report 2017 (Zhang and Qi, 2017), National Energy Agency (NEA, 2011) and National Development and Reform Commission (NDRC, 2016a, b)

4. Results and discussions

Based on the methodologies mentioned above, we can estimate the CO_2 intensity of thermal power generation by using ordinary least squares methods. Next, CO_2 intensity, production scale and energy efficiency of NMI's sub-sectors can be calculated based on the quantitative policy goals we summarized. With the annual calculation results from 2016-2030, we can evaluate the comprehensive CO_2 reduction effects produced by current policies.

4.1 Assessment of CO_2 emission intensity changes

Based on Eqs. (4), we use OLS model to estimate the relation factor between $F_{thermal}$ and $T_{thermal}$. The calculation result shows a=2.4841 and is significant.

The NDRC introduced the 13th FYP of energy development in 2016. According to the plan, the standard coal consumption rate of thermal power supply should be decreased, the standards are 310 gce/kWh in 2020 and 300 gce/kWh in 2030 (NDRC, 2016a, b). We assume that the technology of power generation will develop smoothly, which means the energy efficiency of thermal power improves at same rate every year. With the national policy and estimation results of Eqs (4), we can get the annual average CO_2 intensity of thermal power generation from 2016 to 2030.

As we can find in Fig. 3, the annual average CO_2 intensity of thermal power generation decreased 19.6% during 2000-2015, and will decrease 5.6% during 2016-2030 under the influence of 13th FYP of energy development.

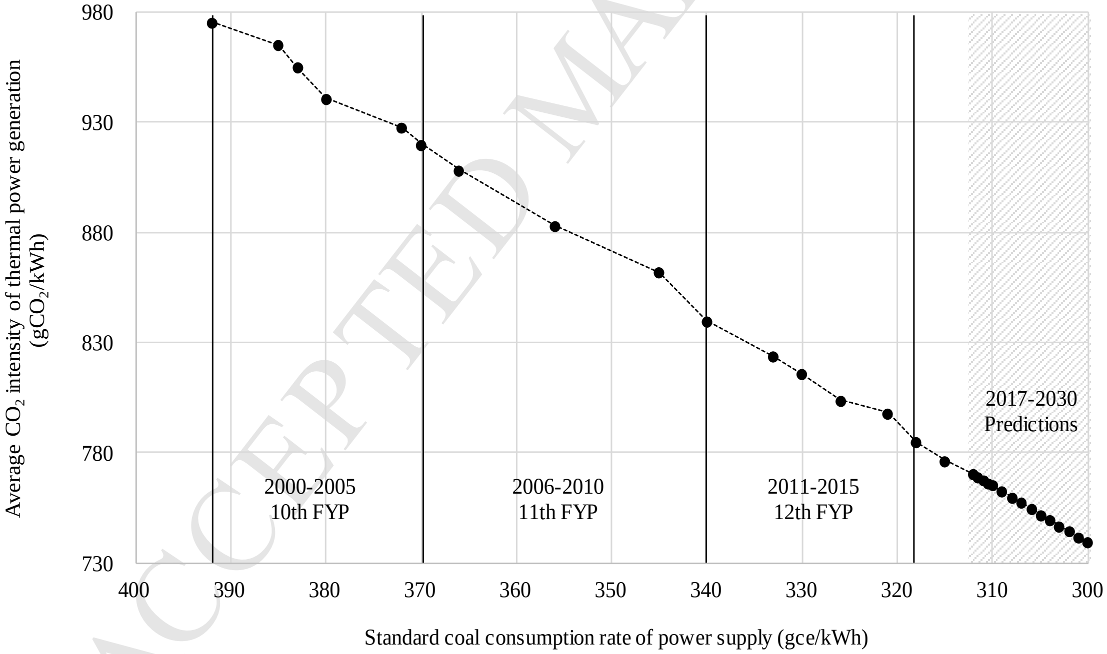


Fig. 3 Predictions of annual average CO_2 intensity of thermal power generation

Non-fossil fuel power generation contributed 27% to the entire national grid in 2015. According to the policies (NDRC, 2016a, b), the proportion of Non-fossil fuel power generation should increase to 31% in 2020 and 50% in 2030. We assume that this development goal could be reached smoothly, then we have the annual proportion of Non-fossil fuel power generation from 2016-2030 ($R_{non\text{-}thermal,\ h}$).

By bringing the estimation results of $F_{thermal}$, $R_{non\text{-}thermal}$ into Eqs. (2), we can get the annual average CO_2 intensity of electricity generation during 2016-2030 (F_{power}). The results show that China's average CO_2 intensity of electricity generation will fall down to 528 gCO_2/kWh of year 2020 and to 370 gCO_2/kWh of year 2030.

The average shares of each type fossil fuel consumption ($R_{k,i,2010\text{-}2015}$) can be calculated based on the historical data. With Eqs. (6) and results above, we could estimate the annual CO_2 intensities of five NMI's sub-sectors from 2016-2030. Details can be found in Table 3. We can simply verify the prediction results by comparing them with historical data. The CO_2 intensities of copper industry dropped about 5% during 2010-2015, similar decrease you can find during the period of 2016-2020, 2021-2025 and 2026-2030. The rest of 4 major industries share the same experience. This shows that our estimations are stable and reliable.

Table 3 CO_2 intensities of NMI's sub-sector and electricity generation *

	Unit	2010	2015	2020	2025	2030
Copper industry	gCO_2/gce	3.82	3.61 (-5.49%)	3.38 (-6.20%)	3.13 (-7.42%)	2.83 (-9.63%)
Aluminum industry	gCO_2/gce	3.82	3.62 (-5.21%)	3.41 (-5.87%)	3.17 (-7.00%)	2.88 (-9.04%)
Lead industry	gCO_2/gce	3.71	3.54 (-4.52%)	3.36 (-5.06%)	3.16 (-5.98%)	2.92 (-7.64%)
Zinc industry	gCO_2/gce	3.73	3.55 (-4.79%)	3.38 (-4.91%)	3.18 (-5.78%)	2.93 (-7.90%)
Magnesium industry	gCO_2/gce	2.98	2.95 (-0.88%)	2.92 (-0.95%)	2.89 (-1.08%)	2.85 (-1.31%)
Thermal power generation	gCO_2/kWh	824	776	765	752	739
National average power generation	gCO_2/kWh	652	592	528	456	370

* Numbers in brackets show decrease percentages between current year and last five years.

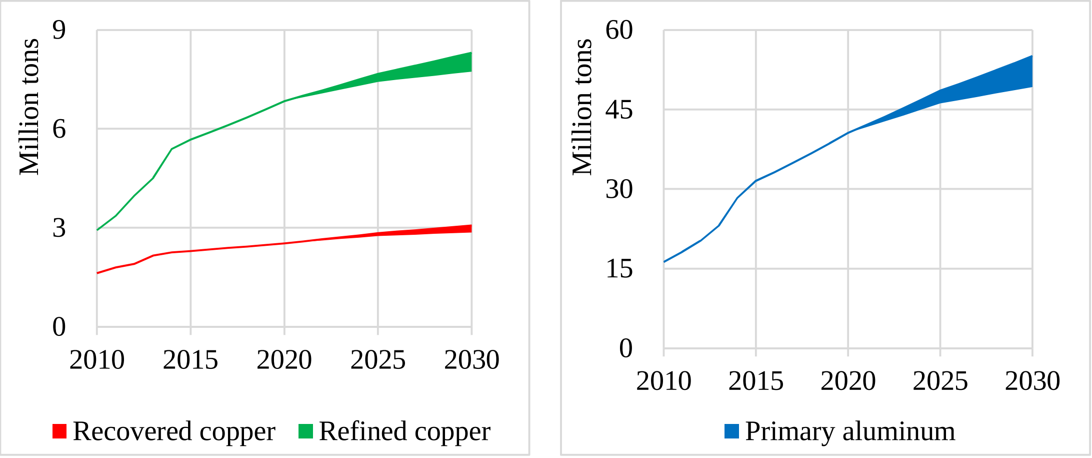
4.2 Production scales perdition and energy efficiency improvement

Based on the 13th FYP of NMI's development, production scales of five major sub-sectors can be calculated apparently. The Fig. 4 demonstrates the future production scales of five major sub-sectors following the current policies.

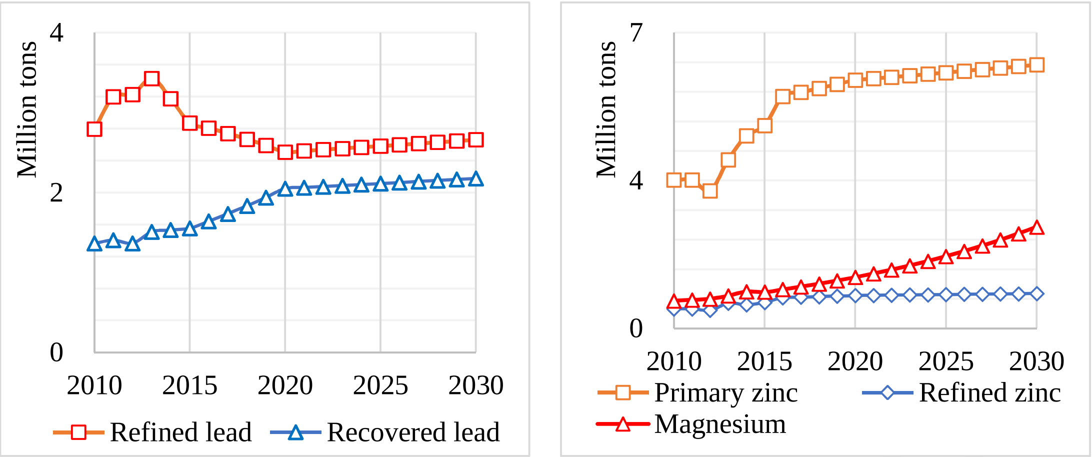
As mentioned above, we conservatively assume that the annual production growth of copper and aluminum industry will drop 30-50% during the 14th FYP and 15th FYP periods based on our description of national policy. In Fig. 4 (a) and (b), solid lines draw the historical data and certain development goals, and color blocks demonstrate the possible range of predictions. In detail, refined copper grows faster than recovered copper, the production scale of copper industry will be 9.4 million tons in 2020 and 10.6-11.3 million tons in 2030. The production of primary aluminum will hold the first position of all non-ferrous metal productions. China will produce 40.6 million tons of primary aluminum in 2020 based on current policy, and the production scale would continue to increase to 49.2 or even 55.1 million tons in 2030.

Because of the high secondary metals production requirement, recovered lead will replace the production of refined lead gradually before 2020. The production of refined lead decrease to 2.6 million tons in 2020 but recovered lead fills up this drop. The production scale of lead industry is 4.5 million tons in 2020 and 4.8 million tons in 2030. After soaring in the 12th FYP period, zinc industry is asked to control its growth rate in next policy cycles. Hence, the annual production of primary zinc and refined zinc will not change much during 2015-2030. The production scale of zinc industry is 6.7 million tons in 2020 and 7.1 million tons in 2030. Chinese central government believes the production of magnesium industry will keep increase rapidly. Based on this prediction, the production scale of magnesium industry will be 1.2 million tons in 2020 and 2.4 million tons in 2030.

From the results of the production predictions, we can know that the production structure of NMI is not changed greatly in the next decade, aluminum and copper are still the two largest production sectors. However, if we look inside of NMI's sub-sectors, we can find that high-energy-efficiency production is replacing the lower one. The annual production growth rates of secondary metals are higher than primaries. The work of CO_2 reduction would benefit from this situation.



(a) (b)



(c) (d)

Fig. 4. Production predictions of five NMI' major sub-sectors

The energy efficiency standards of NMI's sub-sectors listed in Table 1 are based on Chinese national standards and the 13th FYP of NMI's development. According to the analysis above, we conservatively assume that the sub-sectors could reach the new factories standards in 2020, and reach the recommended advanced standards in 2030. Energy efficiency predictions of five NMI' major sub-sectors can be found in Fig. 5.

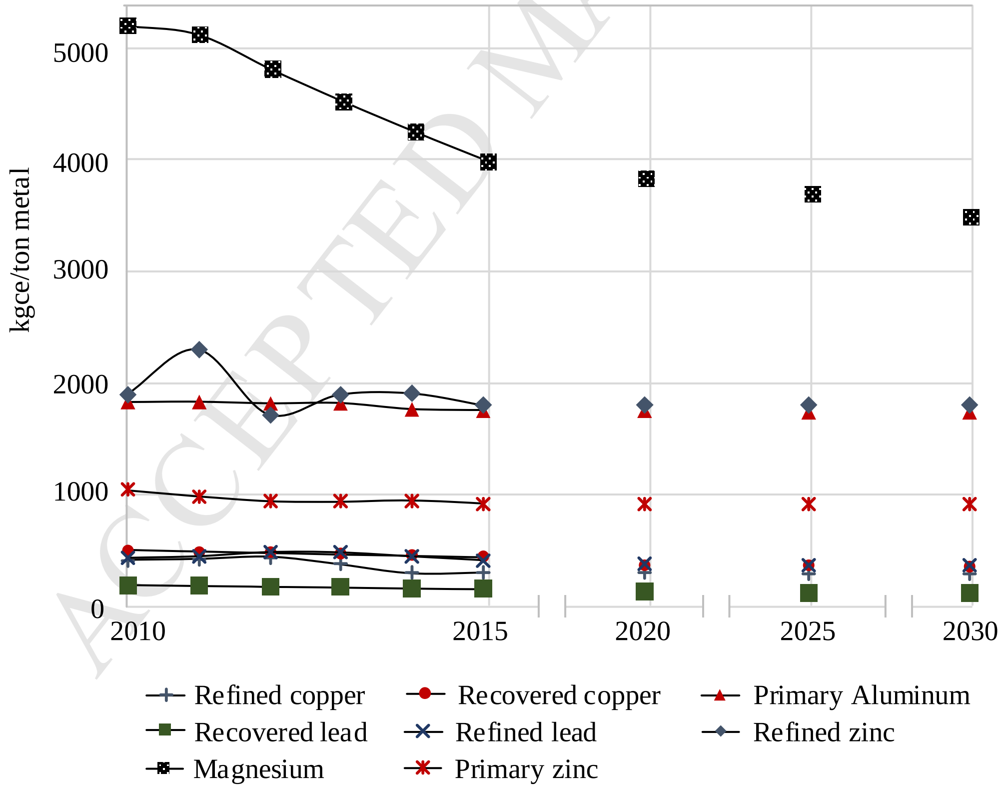


Fig. 5. Energy efficiency predictions of five NMI' major sub-sectors

As seen in Fig. 5, energy efficiency regulations for copper industry are relatively flexible in 2016-2030. During this period, the energy efficiency of refined copper and recovered copper improve 5.9% and 18.6% respectively. This improvement is clearly lower than the period of 2010-2015. For the lead industry, the government focused on the recovered lead production. The energy efficiency of refined lead and recovered lead improve 11.3% and 22.6% respectively in 2016-2030.

The unit energy consumption of magnesium production is much higher than others. However, national standards for magnesium energy efficiency are too moderate although there is huge potential in it. According to the historical data, the energy efficiency of magnesium has already performed better than national advanced standards in 2015. In the 13th FYP of NMI's development, the government set a new advanced benchmark for the energy efficiency of magnesium industry. Based on the new requirement, the energy efficiency of magnesium industry needs to improve 12.5% during 2016-2030.

The Chinese government has issued loose or possibly outdated energy efficiency policies for aluminum and zinc. The energy efficiency of primary aluminum in 2015 is only 0.9% lower than the advanced standard. Additionally, both the energy efficiency of primary and refined zinc have performed better than the advanced standards in 2015. So in this policy evaluation, we believe current policies will not produce positive effects in improving the energy efficiency of zinc industry during 2016-2030.

4.3 Assessment of policy impacts on CO_2 reduction

Based on the analyzing results of CO_2 emission intensity, production scale and energy efficiency, we can calculate the annual CO_2 emissions of non-ferrous metal productions from 2016-2030. Annual CO_2 emission growth rates of 8 non-ferrous metal productions are listed in Table 4. Annual CO_2 emissions of five NMI' major sub-sectors are plotted in Fig. 6. Chinese central government usually introduces new industry policy every five years. By this convention, we divide the evaluation period into three parts: the 13th FYP period (2016-2020), 14th FYP period (2021-2025) and 15th FYP period (2026-2030). CO_2 emission growth rates in each period can be found in table 4.

The total CO_2 emission of Chinese NMI increased at an annual rate of 9.7% during 2010-2015. Primary aluminum and refined copper should take leading responsibility for this rapid growth. The annual CO_2 emission growth rate of primary aluminum and refined copper is 11.9 and 6.5% during 2010-2015 respectively. At the same time, the CO_2 emissions of lead industry has already stopped growing. The annual CO_2 emission growth rates of the rest productions were all below 3%.

In the first evaluation period (2016-2020), the CO_2 emissions of Chinese NMI increases at an annual rate of 3.6%. Apparently, the 13th FYP of NMI's development produces positive impacts on stopping the rapid growth of CO_2 emission. The annual CO_2 emission growth rates of primary aluminum and refined copper is 3.9% and 2.1% respectively. Compared with the former plan period, the CO_2 emissions of recovered copper declines but the magnesium starts to soar at rate 6% per year. The rests of non-ferrous metals' CO_2 emission grow at the similar annual rate as in 2010-2015.

In the next two evaluation periods (2021-2025 and 2026-2030), we have two production scenarios for aluminum and copper industries. High production scenarios mean the annual production growth rates of aluminum and copper industries will decline 30% in each two periods respectively, and low production scenarios means it will decline 50%. These two scenarios are made based on the description of 13th FYP of NMI's development.

In the high production scenario, the production scale of copper and aluminum industry is 11.3 million tons and 55.1 million tons respectively in 2030. The total CO_2 emission of NMI will keep increase but the annual growth rate will drop down to 0.7% in the 15th FYP period. CO_2 emissions of all other NMI productions decline before 2030. The total CO_2 emission of Chinese NMI is 321 million tons in 2030, which increase 137% from 2015.

Table 4. Annual growth rates of NMI sub-sector's CO_2 emission

Industry	Production	2010-2015 Historical data	2016-2020 13th FYP	2021-2025 14th FYP	2026-2030 15th FYP
Copper	Refined copper	6.5%	2.1%	-0.3%*	-1.6%*
				0.3%**	-0.8%**
	Recovered copper	3.5%	-2.9%	-0.2%*	-1.5%*
				0.5%**	-0.7%**
Aluminum	Primary aluminum	12.0%	3.9%	1.1%*	-0.7%*
				2.1%**	0.6%**
Lead	Refined lead	-0.4%	-3.7%	-0.6%	-1.0%
	Recovered lead	-4.4%	-4.5%	-2.0%	-2.4%
Zinc	Primary zinc	2.8%	3.1%	-0.6%	-1.0%
	Refined zinc	3.6%	3.8%	-0.6%	-1.0%
Magnesium	Magnesium	0.4%	5.9%	5.9%	5.9%
Total NMI		9.7%	3.6%	1.1%*	-0.3%*
				2.0%**	0.7%**

* Low production scenario

** High production scenario

In the low production scenario, the CO_2 emissions of Chinese NMI peaks in 2025. The total CO_2 emission of Chinese NMI is 296 million tons in the peak year, despite of the 5.9% annual increase rate of magnesium industry's CO_2 emission. 82.1% of NMI's CO_2 emissions are originated from 46.2 million tons of primary aluminum production in peak year. The production scale of copper, lead, zinc and magnesium industry is 10.2, 4.7, 6.9 and 1.7 million tons respectively.

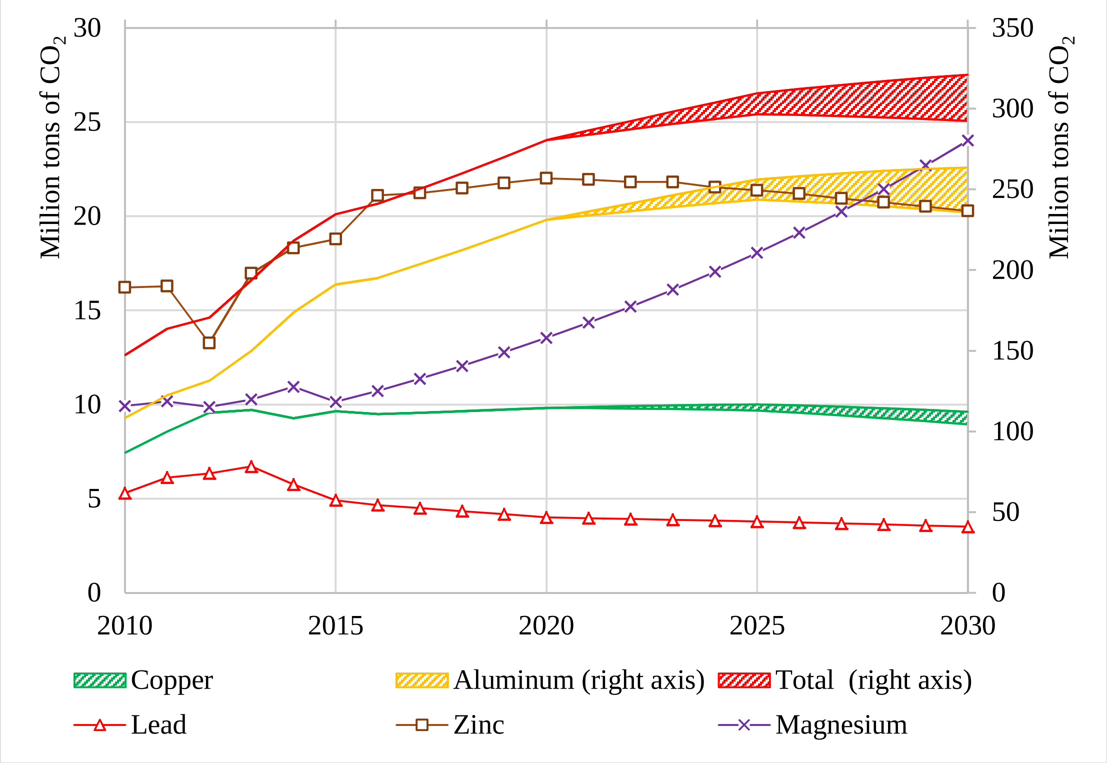


Fig. 6. CO_2 emission predictions of NMI and sub-sectors

Uncertainty exists in the assessment of production scale policies and energy efficiency policies. For the production scale part, the central government did not introduce quantitative development goals in the 14th and 15th FYP periods (2020-2030), so we evaluate the policy goals based on the qualitative description in the 13th FYP of NMI's development and the quantitative production performance during 12th FYP period. For the energy efficiency part, the national energy efficiency standards for existing factories and new factories enforceable, but the recommended advanced standards are not. Compared with the former versions, we find that Chinese NMI companies could reach the recommended advanced standards in an average of five years. In our study, we conservative estimate that Chinese NMI's companies will reach the goals in ten years. In the future, uncertainty can be avoided if the government give a specific policy explanation for the NMI's development plan.

5. Conclusions and policy implications

In this paper, using the idea of Kaya Identity, we summarize the national policies, standards, codes and measures related to NMI, and group the quantitative policies into three types: energy structure policies, energy efficiency improving policies and production scale policies. Based on the historical data and national policies, we estimate the CO_2 emissions of five NMI's major sub-sectors in 2010-2030.

Through the assessment of energy structure policy, we can find that NMI's CO_2 reduction benefits a lot from the cleaner electricity generation. According to the policies and our assessment, China's average CO_2 intensity of electricity generation will fall down to 528 gCO_2/kWh of year 2020 and to 370 gCO_2/kWh of year 2030. The CO_2 intensities of copper, aluminum, zinc and lead drop 6% annually during 2016-2030, and the CO_2 intensity of magnesium industry drops 1% annually during 2016-2030.

By assessing the production scale policies of Chinese NMI, we know that the all 8 kinds of major NMI productions will continue to grow before 2030. The magnesium industry has the top annual growth comparing to the five major industries. Secondary metals production of copper and lead will grow rapidly but will not dominate the market in 2030, so do the refined zinc. Based on the 13th FYP of NMI's development, we made two scenarios of the development of copper and aluminum industries. No matter in which scenario, the production structure of NMI stays stable. The aluminum holds the top 1 production scale and the copper industry follows. The production scale policy did not change the production structure of Chinese NMI greatly(Lin and Zhang, 2013).

The assessment results of energy efficiency policies show that the improvements of NMI's energy efficiency are moderate. Compared with the energy efficiency of current market, the Chinese newest national standards are incapable of leading the development of aluminum and zinc industries. Our assessment results show that the energy efficiency of aluminum and zinc industries improve no more than 1% by the national standards during 2016-2030. But the energy efficiency of copper, lead and magnesium industries will improve about 11% during 2016-2030.

The results of the comprehensive policies' assessment suggest that the CO_2 emissions of Chinese NMI is very likely to peak before 2030 under current policies. Yet even in our most pessimistic assumptions, in which China's production of primary aluminum increases to 55.1 million tons in 2030 (1.75 times larger than in 2015 and nearly equals to the global consumption in 2015), the annual growth rate of NMI's CO_2 emission will drop down to 0.7% during the 15th FYP period (2026-2030). Under current policies, the CO_2 emissions of copper industry, lead industry and zinc industry will peak before 2030. The peak CO_2 emissions of copper industry, lead industry and zinc industry is 9.8-10 million tons (peak in 2020 or 2025), 6.7 million tons (peak in 2013) and 22 million tons (peak in 2020) respectively. The CO_2 emissions of magnesium industry will keep increase at an annual growth rate of 5.9% during 2016-2030. Aluminum industry is the largest CO_2 emission source of Chinese NMI. Compared with the former FYP period, the annual growth of primary aluminum decreased 64% in the 13th FYP period. If Chinese government could stick to its current policy strength, which means to decrease the annual growth rate of primary aluminum 50% in the 14th FYP period, the CO_2 emissions of aluminum industry and the entire NMI could peak in the year of 2025. In this so-called low production scenario, the peak CO_2 emission of NMI is 297 million tons. The production scale of aluminum industry is 46.2 million tons in 2025 and will continue to grow before 2030. As mentioned above, if the Chinese government allows the production of primary aluminum to increase to incredible 55.1 million tons in 2030, the CO_2 emissions of NMI will not peak before 2030. However, the annual growth rate of NMI's CO_2 emission will be controlled down to 0.7%.

It is easy to come to the conclusion that China's current CO_2 reduction policies of NMI are effective, and NMI is very likely to be a contributor of the ambitious goal: China's CO_2 emission will peak by 2030. However, China's current CO_2 reduction policies of NMI are not perfect, some of them are even outdated. In 2015, there are 5 productions' energy efficiency performed better than China's newest national standards for new factories: refined copper, primary aluminum, primary zinc, refined zinc and magnesium. For primary zinc, refined zinc and magnesium, their energy efficiency even performed better than the newest advanced standards. These national standards are too conservative to guide the Chinese non-ferrous factories. We believe it is very necessary to update Chinese national energy efficiency standards for the energy conservation and emission reduction in future.

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