Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 105 (2017) 3391 – 3396
Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Energy consumption and GHG emission for regional aluminum industry: A case study of Henan province, China

Sainan Liu, Shanshan Wang*, Ke Wang, Hui Yue, Lei Liu,Shuxian Yang,

Pengju Zhang, Ruiqin Zhang†

The College of Chemistry and Molecular Engineering,
Key Laboratory of Environmental Chemistry and Low Carbon Technologies of Henan Province, Zhengzhou University, Zhengzhou 450001, Henan, P. R. China

Abstract

Aluminum industry is a typical energy-intensive and emission-intensive industry. Henan's aluminum output occupies the first for many years until 2013 in the whole country. We analyzed 18 applicable to aluminum smelting process and 8 energy-efficiency technologies to alumina production process. The Conservation Supply Curve (CSC) is used in this paper. It is an analytical tool which selects the economically feasible technologies. Three scenarios are simulated. Under the BAU, S1 and S2 scenario, the energy consumption of the aluminum industry will decrease by 19%, 25%, and 29% compared to 2014 level respectively. The emission mitigation of GHG in S1 and S2 scenario are 3.2 Mt CO_2e and 5.4 Mt CO_2e, compared to BAU scenario in 2030. In addition, sensitivity analysis is conducted. Finally, some policy implications are proposed.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: Conservation Supply Curve; energy consumption; GHG emission potential; energy-efficiency

1. Introduction

Aluminium industry brings a huge environmental burden due to its high consumption and emission during its production process. Since 2000, Henan's aluminium industry has entered a period of rapid development. Meanwhile, Henan is the first largest aluminium producer. The share of Henan's aluminium production contributed to 6.4% of global total in 2014 [1]. So it is significant to evaluate the energy

* Corresponding author. Tel.: +86-0371-67781163; fax: +86-0371-67781163..
E-mail address: wangshanshan@zzu.edu.cn
* Corresponding author. Tel.: +86-0371-67781163; fax: +86-0371-67781163.
E-mail address: rqzhang@zzu.edu.cn

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.777

consumption and GHG emission for Henan's aluminium industry. Researches on aluminium industry mainly focus on the following perspectives: The first is the studies of energy consumption. Shao and Yang studied the situation of the non-ferrous metals industry in 2008 and they discovered that the energy saving potential of aluminium industry is great [2]. The second is the analysis of GHG emissions. Zhang et al. used a bottom-up calculation model and scenario analysis to project the future CO_2 emissions and abatement potentials for China's primary aluminium production [3]. Gao et al. utilized a cradle-to-gate life cycle assessment to calculate the GHG emissions and reduction potential [4].The third is energy efficiency by applying advanced technologies. Yao and Wan used DEA method to calculate the energy efficiency of China's electrolytic aluminium industry [5]. It is a pity that few people consider these factors at the same time.

The remnant of this paper is organized as follows; Section 2 illustrates the methodology of energy conservation supply curves (CSC).The results of energy consumption GHG emission are discussed in Section 3. Sensitivity analysis is presented in Section 4. Finally, the conclusion is given in Section 5.

2. Methodology

2.1. System boundary

System boundary of primary aluminium production contains five processes: bauxite mining, alumina refining, anode production, primary aluminium smelting and ingot casting.

2.2. Energy conservation supply curves

The concept of "Energy Conservation Supply Curve" is used to make a bottom-up model to evaluate the cost-effectiveness and the potentials of energy saving and GHG emission by applying energy efficiency technologies from both engineering and economic perspectives [6-9].

The fuel saving supply curves (FCSC) for alumina production process and electricity savings supply curves (ECSC) for aluminium smelting process are constructed by employing CSC model according to the next equations.

$$CCE = \frac{I \times AF + AOM}{AES} - CE \tag{1}$$

CCE is cost of conserved energy; I is investment; AF is annuity factor; AOM is change in annual operation and maintenance; AES is annual energy saving; CE is fuel cost (750 RMB/tce) or electricity price (0.55 RMB/kWh).

$$AF = \frac{d}{1 - (1 + d)^{-n}} \tag{2}$$

Where d is discount rate; n is lifetime of the energy efficiency measures.

In this study, the discount rate is 10%. Technologies and the parameters are from Dai et al [10].

2.3. Scenario settings

In this study, the time period covered is 2014-2030 with 2014 as the base year. Three scenarios are generated: the Baseline Scenario (BAU), the Energy Saving and Emission Reduction Scenario (S1) and the Strengthen Energy Saving and Emission Reduction Scenario (S2), as shown in Table 1. Energy intensity and GHG emission intensity of bauxite mining process, anode production process, and ingot casting process account for a small portion, so they will be assumed as a constant.

Table 1.Key features of different scenarios

Scenario	Scenario description
BAU	Annual unit energy consumption decrease rates of alumina production process and aluminium smelting process are 0.3%. The decrease rate of overall alternating current electric power consumption per ton of aluminium is 0.1%.
S1	Based on BAU scenario, the feasible economically technologies (the CCE of the energy efficiency technologies below 0) are applied
S2	Based on BAU scenario, ignoring the cost and all the energy efficiency measures are implemented fully. Moreover, the implementation rate is higher than the S1 scenario.

3. Results

3.1. Output of Henan's aluminum

Many studies have projected the aluminium output of China's aluminium and it shows an upward trend. However, Henan's aluminium output will be affected by infrequent bauxite resource, high electricity price and strict policy. Combined with elastic coefficient method, Pearl-Reed Growth Curve and expert opinion, Henan's aluminium output will be assumed as 3.2 million tons (Mt) in 2020, 3.0 Mt in 2025 and 2.8 Mt in 2030.

3.2. Future potential of energy saving for Henan's aluminum industry

Fig 1 shows energy consumption for Henan's aluminium industry from 2006 to 2030 for different scenarios. Due to financial crisis, aluminium production in 2009 declined and energy consumption also reduced. After 2009, energy consumption increased drastically until it peaks around 2012, and then shows a declining trend from 2013 to 2030, because of output reduction and energy efficiency improvement. The energy consumption declines by 19%, 25%, and 29% under BAU, S1, and S2 scenario in 2030, respectively. In 2030, the S2 scenario has higher potential of reducing energy consumption than S1 scenario.

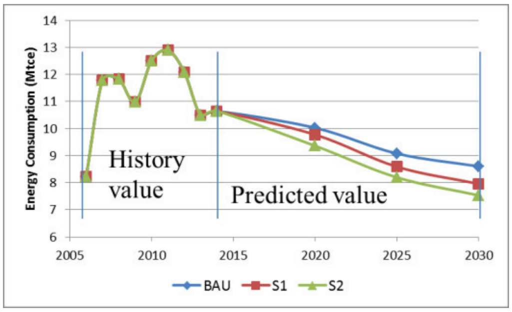

Fig. 1. Future energy consumption of Henan's aluminium industry in different scenarios

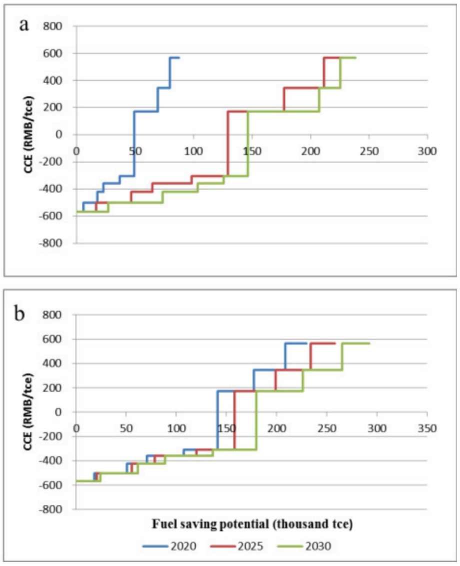

Fig. 2. Energy saving potential for alumina production process in S1 (a) and S2 (b) scenarios

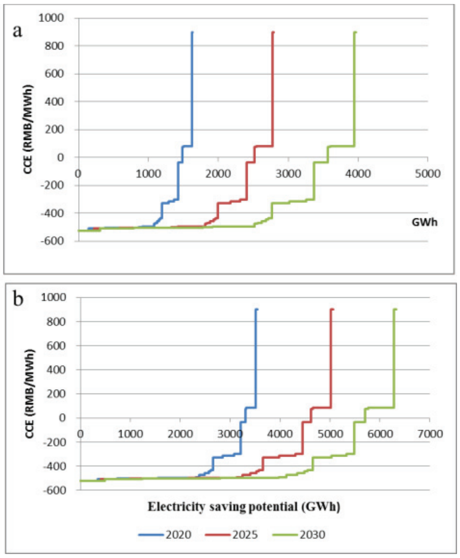

Fig. 3. Energy saving potential for aluminium smelting process in S1 (a) and S2 (b) scenarios

For the alumina production process, out of 8 energy-efficiency technologies, 5 technologies fall below the discounted average unit price (750 RMB/ton) of the coal. These 5 technologies are called cost-effective energy efficiency measures. Fig 2 shows the annual energy saving potential for alumina smelting processes between 2020 and 2030 under different scenario. Compared to BAU scenario, 49-146 thousand tce can be saved by applying cost-effective technologies in S1 scenario, 230-293 thousand tce can be avoided by employing all energy efficiency technologies in S2 scenario from 2020 to 2030. The energy saving potential of high efficiency and energy saving technology of flu solid roasting furnaces is the most, which accounts for 15%-28% of the total cost-effective fuel savings under the S1 scenario.

For the aluminium smelting process, out of 18 energy-efficiency technologies, 15 technologies fall below the discounted average unit price of the electricity (550RMB/MWh). As shown in Fig 3, Energy efficiency plays an important part in reducing electricity consumption. In S1 scenario, the cost-effective annual electricity saving potential is around 1490 GWh in 2020, 2510 GWh in 2025, 3560 GWh in 2030, separately. About 50% of the electricity saving can be attained by accelerating the use of aluminium flow state optimization technology, the new coke preheating start technology of aluminium reduction cell, and waste heat recovery technology in S1 and S2 scenario. These technologies not only are cost-effective technologies, but also have largest electricity-saving potential.

3.3. Emission mitigation for GHG in Henan's aluminum industry

The emission mitigation of GHG in S1 and S2 scenario is 3.2Mt CO_2e and 5.4Mt CO_2e, compared to BAU scenario in 2030. GHG emissions come mostly from aluminium and alumina smelting processes. For example, based on our assumption from 2014 to 2030 in S1 scenario, the GHG emission factor (GEF)of Henan's aluminium industry will decrease from 14.3 t CO_2e/Al ingot to 12.9 t CO_2e/Al ingot, which is10.5% lower than the 2014 level. There are two factors contribute to this reduction phenomenon. The first factor is the decrease of electricity consumption for aluminium smelting process, which was estimated to decrease from 13442 kW h/ Al ingot in 2014 to 11973 kW h/ Al ingot in 2030. This factor separately results in about 1060 kg CO_2/t Al ingot, which is 78% of the whole reduction. The second factor is the decline of GHG emissions for alumina smelting process, the GEF of this process will decline from 2100 kg CO_2/t Al ingot to 1800 kg CO_2/t Al ingot. It is noted that 300 kg CO_2/t Al ingot can be reduced In this study, the GHG emission factor of the electricity generation is assumed as a constant value.

4. Sensitivity analysis

4.1. Different discount rates

The sensitivity analysis is conducted as shown in Fig.4. In 2030 for S1 scenario, the electricity saving potentials for cost-effective technologies due to different discount rates (4%, 10%, and 30%) are about 3950 GWh, 3560 GWh, and 3000 GWh, respectively. Compared with the10% discount rate, the cumulative electricity saving potential will be 11% lower than the discount rate of 4% and16% higher than the discount rate of 30%. Aluminium electrolytic with energy saving devices of aluminium steel composite structure anode steel claw, as a typical technology that is impacted seriously by the discount rate, is cost-effective at the discount rate of 4%, but the CCE of this technology will be increased 11 times at discount rate of 30%. In 2030 for S1 scenario, fuel saving potentials for cost-effective technologies is about 210 thousand tce, 132 thousand tce, 59 thousand tce in different discount rates respectively.

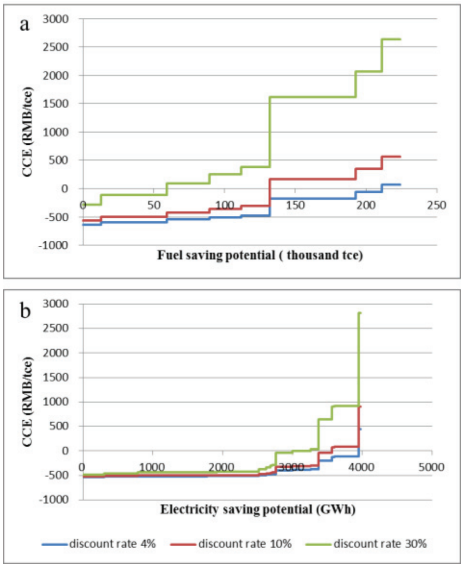

Fig. 4. Energy saving potential for alumina production (a) and aluminum smelting (b) processes at different discounts between 2014 and 2030 in S1 scenario

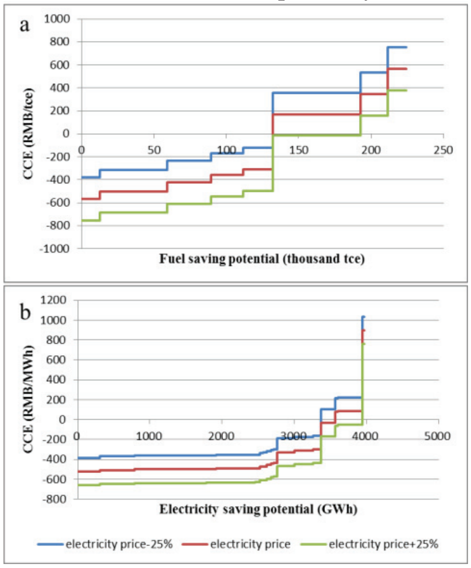

Fig. 5. Energy saving potential for alumina production (a) and aluminum smelting (b) processes at energy prices between 2014 and 2030 in S1 scenario

4.2. Energy price

The future energy price, in this study, was assumed to be 750 RMB/tce and 550 RMB/MWh, which might be an underestimate. Hence, to evaluate the sensitivity of the economic potentials, energy price increase or decrease by 25%. The results shows that the fuel saving potential and electricity saving potentials for cost-effective technologies are from110 to 190 thousand tce for the alumina production process and from 3370 GWh to 3950 GWhfor the aluminium smelting process with the increase of the energy price, as shown in Fig. 5, respectively. The associated GHG emission reduction of these processes is from 2.7 Mt to 3.4 Mt.

5. Conclusions

The reduction of aluminium output and advanced technologies can reduce the total energy consumption and GHG emissions effectively. Based on these research findings and the reality of Henan province, some policy implications (such as develop secondary aluminium production, take advantage of low grade bauxite and extend the aluminium industry industrial chain) are proposed.

Acknowledgements

This study is supported by China Sustainable Energy Project of U.S. Energy Foundation under Grant No. G-1410-22231.

References

[1] China Nonferrous Metals Industry Association, 2013. China Nonferrous Metals Industry Yearbook. China Statistics Press, Beijing.

[2] Shao Z, Yang Y. The potential of energy conservation in non-ferrous metals industry is great. *China Nonferrous Metal* 2010; **13**: 25–28.

[3] Zhang W, Li H, Chen B, Li Q, Hou X, Zhang H. CO_2 emission and mitigation potential estimations of China's primary aluminium industry. *Journal of Cleaner Production* 2015; **103**: 863-872.

[4] Gao F, Nie Z, Wang Z, Li M, Gong X, Zuo T. Greenhouse gas emissions and reduction potential of primary aluminium production in China. *Science in China Series E: Technological Sciences* 2009; **52**: 2161-2166.

[5] Yao P, Wang HY. Energy efficiency measures and the space difference analysis of China's electrolytic aluminium industry. *Journal of Industrial Technological Economics* 2012; **9**: 2–79.

[6] Zhang S, Worrell E, Crijns-Graus W. Evaluating co-benefits of energy efficiency and air pollution abatement in China's cement industry. *Applied Energy* 2015; **147**:192-213.

[7] Hasanbeigi A, Morrow W, Sathaye J, Masanet E, Xu T. A bottom-up model to estimate the energy efficiency improvement and CO_2 emission reduction potentials in the Chinese iron and steel industry. *Energy* 2013; **50**:315-325.

[8] Worrell E, Martin N, Price L. Potentials for energy efficiency improvement in the US cement industry. *Energy* 2000; **25** :1189-1214.

[9] Mao. X Zeng. A, Hu. T, Zhou J, Xing Y, Liu S. Co-control of local air pollutants and CO_2 in the Chinese iron and steel industry. *Environmental science & technology* 2013; **47**: 12002-12010.

[10] Dai YD, Xiong HW, Jiao J. Roadmap study on achieving technical energy conservation potential in China's industrial sector by 2020. China Science and Technology Press 2013, p. 140–146

Biography

Ruiqin Zhang is Professor and Dean of Key Laboratory of Environmental Chemistry and Low Carbon Technologies of Henan Province, Zhengzhou University. She is engaged in study of atmospheric environmental pollution and control, energy conservation and emissions reduction, and biomass energy research.