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Models for the Measurement of Carbon Footprint from the Raw-Coal Production

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ABSTRACT

The paper defines the GHG emission source in the process of coal production and gives the measurement method of the carbon potential emission factors on the basis of the carbon footprint impact on the subsystem of raw-coal production. After that, it establishes the measurement models of carbon footprint in the subsystem of raw-coal production. The models are used to calculate the instance and verify the validity of the model based on prediction technique to the product capacity of the raw coal. The research has decision-making application and reference value for building the coal supply network of low carbon economy.

INTRODUCTION

At present, "Carbon Footprint" (CF) is usually used in the human organizations or activities as the term of carbon emissions to express (Saif Benjaafar et al. 2013, Xiaomin Wu et al. 2013, Yanju Wei & Shenghua Liu 2010, Yanjun Ding & Weijian Han 2013). CF, which is mainly composed of GHG (green house gases), is the main study object of the Ecological Footprint (EF). GHG emissions' statistics are often expressed by CO_2 emissions. In the subsystem of the raw-coal production, GHG emissions' statistics have different styles for the different methods of coal mining. On one hand, the GHG emissions come from the shafts mining; on the other hand, GHG emissions also come from open-pit mining (Zhenfang Zhang 2013). Because the shafts mining is the main form of coal production in China, this article mainly researches the measurement models of CF in the subsystem of the raw-coal production.

The subsystem of the raw-coal production exhausts CF, which mainly comes from the operation processing in the mining holes. The main emission sources of GHG include, emissions (CF_{m1}) from mining dissipation, ground handling and so on; the emissions (CF_{m2}) from the explosive blasting; respiratory CO_2(CF_{m3}) from underground workers; indirect emissions (CF_{m4}) from the power consumption (the processing of drivaging, fully mechanized, transportation, washing coal slime); the emissions (CF_{m5}) directly from gas power generation coal for energy (coal-fired power generation, boiler heating, etc.); and the emissions (CF_{m6}) directly from the fuel consumption. This paper studies the measurement models of CF by the CO_2 equivalent ($CO_{2\text{-}e}$) in the subsystem of the raw-coal production from CF_{m1} to CF_{m6}.

THE MEASUREMENT ANALYSIS OF CARBON FOOTPRINT IN RAW-COAL PRODUCTION

The measurement of the relative gas emission: First of all, the GHG emissions, which is the sum (as G_T, m^3/t), come from the escape gas of coal wall and falling coal releases gas quantity in the roadway of drivage. This measurement can be expressed as:

$$G_T=\sum_{t=1}\sum_{i=1}[149.76\times H_{(t,i)}\times V_t\times G_{0(t,i)}\times N_t\times Z\times(10^{-4}\times V^2_{r(t,i)}+0.04)\times(2\sqrt{Lt / Vt}-1)+1440\times H_{(t,i)}\times V_t\times B_t\times \rho_i\times G_{0(t,i)}]/P_c \quad ...(1)$$

Of which, $H_{(t,i)}$ represents the *i* kind of coal seam thickness of the *t* kind of drivage roadway, m; V_t represents the mechanical work rate in the *t* kind of the drivage roadway, m/min; $G_{0(t,i)}$ represents the gas content in the *i* kind of coal seam of the *t* kind of drivage roadway, m^3/t; N_t represents the amount of coal wall exposed in the *t* kind of roadway drivage; $V_{r(t,i)}$ represents the volatile matter of the *i* kind of coal in the roadway drivage, %; L_t represents the actual length of the *t* kind of the drivage roadway, m; B_t represents the actual width of the *t* kind of the drivage roadway, m; ρ_i represents the density of the *i* kind of coal, t/m^3; P_c represents the day volume of coal mining production, t/d; Z is the correlation coefficient. At the same time, this measurement method has already contained the residual gas content after the coal is promoted to the ground.

The second, the escape of gas from the coal surface of the mining process, near the surface layer of the mining coal, the relative gas escape amount of surrounding rock of coal mining work surface, which is combined as G_C, m^3/t; its measurement expression:

$$G_C = P_c\sum_{p=1}\sum_{i=1}[H_{c(i)}\times G_{0(p,i)}\times(K_t+L_{c(p,i)}/L_p)\times(\beta_p+1)+H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/(H_{c(p,i)}\times P_{c(p)})-P_c\sum_{p=1}\sum_{i=1}L_{g(p)}\times H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/\sum_{p=1}\sum_{i=1}[H^2_{c(p,i)}\times\varphi_p(1.2+\cos\theta)\times P_{c(p)}] \quad ...(2)$$

Of which, $H_{c(i)}$ represents the total thickness of the *i* kind of coal layer, m; $H_{c(p,i)}$ represents the thickness in the *p* kind of the working face of coal layer, m; $G_{0(p,i)}$ represents the gas content in the *p* kind of the coal mining face, m^3/t; $L_{c(p,i)}$ represents the coal seam width on the surface of the *i* kind of residue coal, m; L_p represents the actual length of the *p* kind of coal mining face, m; β_p represents the escape gas ratio of the *p* kind of the surrounding rock of the coal roof of the working face, the experience value, 0.10-0.25; $H_{g(p,i)}$ represents the adjacent coal thickness near the *p* kind of the mining face, m; $G_{1(p,i)}$ represents the gas content from the *i* kind of coal layer near the *p* kind of the mining face, m^3/t; $G_{2(p,i)}$ represents the residual gas content of coal seam with the *p* kind of mining face, m^3/t; $L_{g(p)}$ represents the distance of the adjacent layer near the *p* kind of the mining face, m; φ_p represents the disturbance degree of the mining roof of the *p* kind of the actual mining face (filling homework 45, caving roof operations 60); θ represents the dipping angle of the *p* kind of coal layer; $P_{c(p)}$ represents the rate of progress of the *p* kind of the actual mining face, t/d; K_t is the correlation coefficient.

Finally, the measurement method can be according to the relative average (G_A, m^3/t) of the escaping gas from the area of mining empty:

$$G_A = \sum_{a=1}\delta_a\times(G_T+G_C) \quad ...(3)$$

Of which, δ_a represents the gas ratio of the area of mining empty, experience value, 0.10 to 0.25. As a result, the first link GHG emissions (CF_{m1}), the sum of the relative of mine gas gushing amount, are mainly from the roadway, the mining face, the area of mining empty and the gas after remained in the coal lifted the ground, as G, m^3/t:

$$G = G_T + G_C + G_A = \sum_{a=1}(\delta_a+1)\times(G_T+G_C)$$

$$=\sum_{t=1}\sum_{i=1}\sum_{p=1}\sum_{a=1}(\delta_a+1)\times\{[149.76\times H_{(t,i)}\times V_t\times G_{0(t,i)}\times N_t\times Z\times(10^{-4}\times V^2_{r(t,i)}+0.04)\times(2\sqrt{Lt/Vt}-1)+1440\times H_{(t,i)}\times V_t\times B_t\times\rho_i\times G_{0(t,i)}]/P_c+P_c\times[H_{c(i)}\times G_{0(p,i)}\times(K_t+L_{c(p,i)}/L_p)\times(\beta_p+1)+H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/(H_{c(p,i)}\times P_{c(p)})-P_c\times L_{g(p)}\times H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/[H^2_{c(p,i)}\times\varphi_p(1.2+\cos\theta)\times P_{c(p)}]\} \quad ...(4)$$

This statistics part of GHG emissions (CF_{m1}) mainly come from the mining to the preliminary processing on the ground, which is the total gushing gas as *G*. It can be expressed as the CO_{2-e} for the *i* kind of coal during the mining, including running out of CH_4 and CO_2, which is measured as:

$$CF_{m1\text{-}CH4}=\sum_{i=1}Q_{T(i)}\times(G\times\gamma_{(i)CH4})\times(1-\eta_{m(i)})\times GWP_{CH4} \quad ...(5)$$

$$CF_{m1\text{-}CO2}=\sum_{i=1}Q_{T(i)}\times G\times\gamma_{(i)CO2} \quad ...(6)$$

Of which, $\gamma_{(i)CH4}$ represents the proportion of CH_4 in G; $\gamma_{(i)CO2}$ represents the proportion of CO_2 in G; $\eta_{m(i)}$ represents the recycling proportion of CH_4; GWP_{CH4} represents the global warming potential (multiple) of CH_4 (IPCC 2007). CF_{m1} econometric model can be expressed:

$$CF_{m1}=(CF_{m1\text{-}CH4}+CF_{m1\text{-}CO2})\times 1000$$

$$= G\times\sum_{i=1}Q_{T(i)}\times[\gamma_{(i)CH4}\times(1-\eta_{m(i)})\times GWP_{CH4}+\gamma_{(i)CO2}]\times 1000$$

$$=\sum_{t=1}\sum_{i=1}\sum_{p=1}\sum_{a=1}(\delta_a+1)\times\{[149.76\times H_{(t,i)}\times V_t\times G_{0(t,i)}\times N_t\times Z\times(10^{-4}\times V^2_{r(t,i)}+0.04)\times(2\sqrt{Lt/Vt}-1)+1440\times H_{(t,i)}\times V_t\times B_t\times\rho_i\times G_{0(t,i)}]/P_c+P_c\times[H_{c(i)}\times G_{0(p,i)}\times(K_t+L_{c(p,i)}/L_p)\times(\beta_p+1)+H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/(H_{c(p,i)}\times P_{c(p)})-P_c\times L_{g(p)}\times H_{g(p,i)}\times(G_{1(p,i)}-G_{2(p,i)})/[H^2_{c(p,i)}\times\varphi_p(1.2+\cos\theta)\times P_{c(p)}]\}\times\sum_{i=1}Q_{T(i)}\times[\gamma_{(i)CH4}\times(1-\eta_{m(i)})\times GWP_{CH4}+\gamma_{(i)CO2}]\times 1000 \quad ...(7)$$

In the above model, a small amount of emissions is in underground water or adsorption on the surface of the wet rock, that is the random emissions. This part number is not easy to measure and is less, so that this part of measurement can be neglected when conducting qualitative research on this part of CF.

Measuring carbon footprint from the explosives in coal production: Coal enterprises often use some industrial explosives in tunnelling or fully-mechanized coal mining process. The elements such as C, H, O, N are the main components of the industrial explosives used, whether oxygen balance or carbon balance. They can make chemical reactions with certain conditions, such as temperature and pressure. The main products include CO, NO_x and other harmful gases (Guoqun Wu 2014), CF_{m2}.

Accounting 1 kg mixed explosive largest exhaust volume, which is from the ratio of quality. Mixing explosives with different components is placed in the actual volume (V_{e1}) for explosion inside the certain cylinder. Under the condition of the approximate standard atmospheric pressure, the mixture explosives are detonated, the paper can measure the exhaust volume (V_m, m^3), the calculation expression as:

$$V_m=\sum_{m=1}[V_{e1}\times(P_1+P_2-P_3-P_4)]/(1.013\times10^5\times Tc\times M_m) \quad ...(8)$$

Of which, P_1 represents the change value of the U mercury, kpa; P_2 represents the atmospheric pressure value on real time, kpa; P_3 represents the vacuum pressure value in the explosion tube, kpa; P_4 represents the pressure value of the water vapour when the temperature rises to Tc (degrees Celsius, °C), kpa; 1.013×10^5 represents the conversion coefficient of one normal atmospheric pressure; M_m represents the quality of the *m* kind of components in the explosive mixture, kg.

After calculating the volume ratio values ($\eta_{v(g)}$, %) of the explosive tail gas, which is various mixed GHG, the paper can measure the volume mixed explosive tail gas, such as CO, NO_x, SO_2 according to the qualities of the various GHGs under the pressure of the gas volume (consulting relevant gas standard quality statistics). The calculation expression as:

$$\eta_{v(g)}=(M_{v(g)}\times6.4\times10^{-5}\times100)/V_{(g)} \quad ...(9)$$

Of which, $M_{v(g)}$ represents the volume of the unit quality of the *g* kind of GHG under the standard atmospheric pressure in mixed explosive tail gas, kg; 6.4×10^{-5} represents the conversion system for gas volume and quality, L/mg; $V_{(g)}$ represents the standard volume value of the g kind of GHG under standard atmospheric pressure, L.

After accounting V_m with 1 kg of mixed explosive tail gas, the carbon potential emission factors ($E_{f(g)}$, kg/kg) can be measured by the density of gas and V_m, $\eta_{v(g)}$, which is expressed as:

$$E_{f,p(g)}=V_m\times h_{v(g)}\times r_{h(g)}$$
$$=[V_{e1}\times(P_1+P_2-P_3-P_4)\times10^3]/(1.013\times10^5\times Tc\times M_m)$$
$$\times(M_{v(g)}\times6.4\times10^{-5}\times100)/V_{h(g)}\times r_{h(g)} \quad ...(10)$$

Of which, $\rho_{(g)}$ represents the density of the *g* kind of GHG in the mixed explosive tail gas under normal atmospheric pressure, kg/m^3.

Therefore, the explosive tail gas (GHG) from explosive in coal production can be measured by the model CF_{m2} set up base on the warming potential value GWP (g) of the *g* kind of gas, the average quality of the used explosives (M_e, kg/a) and the other correlation coefficients, CF_{m2} model as:

$$CF_{m2}=\sum_{g=1}M_e\times E_{f(g)}\times1000\times GWP_{(g)}$$
$$=\sum_{m=1}\sum_{g=1}M_e\times[V_{e1}\times(P_1+P_2-P_3$$
$$-P_4)]/(1.013\times10^5\times Tc\times M_m]$$
$$\times(M_{v(g)}\times6.4\times10^{-5}\times100)/V_{(g)}\times\rho_{(g)}\times$$
$$1000\times GWP_{(g)} \quad ...(11)$$

Measuring CO_2 emissions from workers breathing underground: Most core operations are in the process of coal mining underground, the working people have CO_2 emissions, underground emissions, which are also not ignored. From the angle of physiology, the paper can calculate the carbon potential emission factors (E_{fman}) with an average of 0.0642-0.0720kg/per person.h for an adult male working status underground. Therefore, measuring CO_2 emissions from workers breathing underground, the model CF_{m3} can be expressed as:

$$CF_{m3}=\sum_{h=1}H_r\times\sum_{w=1}W_u\times T\times E_{fman}\times1000 \quad ...(12)$$

Of which, H_r represents the number of working people underground, people/unit; W_u represents the number of times, unit/a; T represents the time unit each, h.

Indirect GHG emission measurement of power consumption: Power consumption is one of the important costs of coal production enterprises, and it is also the important account of CF. The electricity consumption of coal enterprises mainly includes: tunnelling, mining working face, electrical transport system, the matching centre, coal processing, pollution treatment process and all lighting systems. Therefore, coal enterprises have the indirect GHG emissions through purchasing power consumption from the regional power grid. The measurement of the indirect GHG emissions (CF_{m4}) from the electricity consumption of coal enterprises, the model is:

$$CF_{m4}=(\sum_{m=1}E_m+\sum_{L=1}E_L)\times E_{f\text{-}eCO2(q)}\times\eta_{E\text{-}p} \quad ...(13)$$

Of which, E_m represents the volume of the power consumption in the *m* piece of equipment or facilities, kwh/a;

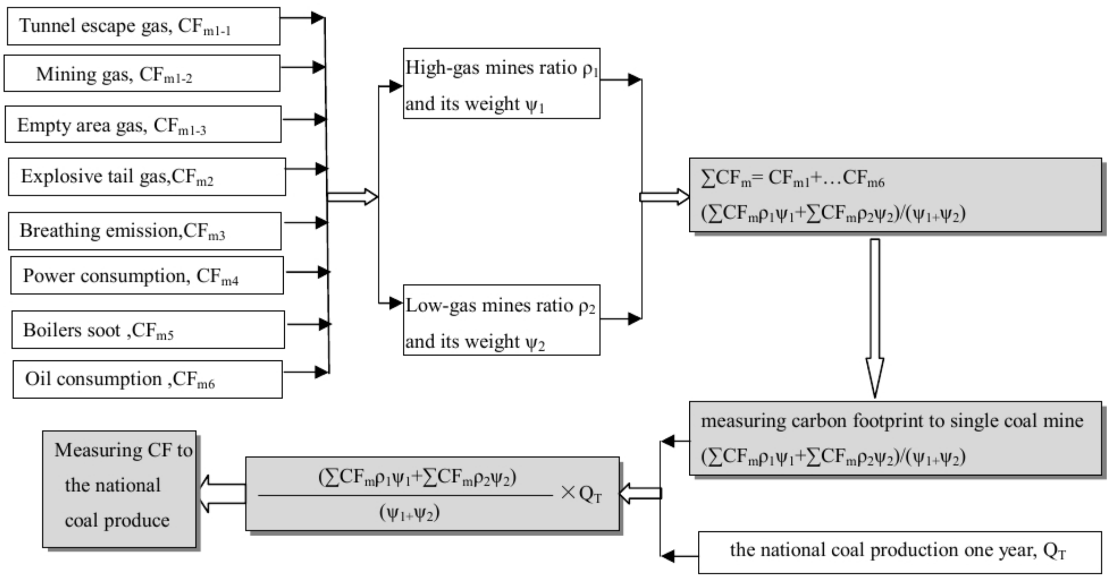

Fig. 1: The technology lines of measuring CF of the nation's raw-coal production one year.

E_L represents the power consumption in the *L* kind of the lighting equipment, kwh/a; $E_{f\text{-}eCO2(q)}$ represents the carbon potential emission factors in the *q* area, t $CO_{2\text{-}e}$/kwh; $\eta_{E\text{-}p}$ represents the proportion of the total power consumption for the purchased electricity accounts, %; CF_{m4} is the indirect GHG emissions of the outsourcing power, t $CO_{2\text{-}e}$/a.

Measuring soot emission from boilers: Coal enterprises are the direct consumers of the coal energy, too. These direct consumers of the coal energy can directly let out a large amount of CO_2, SO_2, NO_x and industrial boiler soot emissions from the coal-fired boiler heating. The measuring model of main emission can be expressed as:

$$CF_{m5CO2\text{-}e} = CF_{m5\text{-}CO2} + CF_{m5\text{-}NOx} \times GWP_{NOx}$$
$$= \sum_{s=1}\sum_{i=1} Q_{\text{用}(i)} \times E_{fCO2(i)} \times \eta_{C(s,i)} + \sum_{i=1} Q_{\text{用}(i)} \times E_{fNOx} \times GWP_{NOx}$$
$$= \sum_{i=1} Q_{\text{用}(i)} \times \eta_{C(s,i)} \times [E_{fCO2(i)} + 16.30 \times (\eta_{N(s,i)} \times \eta_{CN(s,i)} + 0.000938) \times GWP_{NOx}] \quad ...(14)$$

$$CF_{m5\text{-}SO2} = \sum_{i=1} Q_{(i)} \times \eta_{C(s,i)} \times \eta_{S(s,i)} \times \eta_{CS(s,i)} \times (1-\eta_{TS(s,i)}) \times 64/32 \quad ...(15)$$

Of which, $CF_{m5CO2\text{-}e}$ represents the GHG emissions volume from the coal-fired electricity, heating boilers, t $CO_{2\text{-}e}$/a; $Q_{(i)}$ represents the volume for enterprise use the *i* kind of coal consumption, t /a; $\eta_{C(s,i)}$ represents the conversion rate of the *i* kind of coal in the *s* kind of boiler, %; $E_{fCO2(i)}$, E_{fNOx} for emission factor (Ling Cao 2010, Lei Chen 2014).

Combining the mechanical properties of different types of boilers, the paper gives the scientific measuring model ($CF_{m5\text{-}s}$) of heating boilers soot for the coal enterprises, its expression as:

$$CF_{m5\text{-}s} = \sum_{i=1}\sum_{s=1} Q_{(i)} \times [A_{ar} + Q_{net,ar} \times \eta_{(s)} / (4.18 \times 8100)] \times \beta_{(s)}/100 \quad ...(16)$$

Of which, $CF_{m5\text{-}s}$ represents the GHG emissions volume from the coal-fired electricity or heating boilers soot, t/a; A_{ar} represents the containing ash content of the *i* kind of coal received basis, %; $Q_{net,\ ar}$ represents the low calorific value (Xin Dai & Yu Ma 2013, Haibin Liu & Bishan Wu 2014); $\eta_{(s)}$ represents the heat loss ratio for incomplete combustion in the *s* kind boilers, %; $\beta_{(s)}$ represents the fly ash amount in the *s* kind of boilers, %.

GHG emissions measurement of oil consumption: Coal enterprises are also the consumer of oil resources. In the process of coal production, the large mechanical equipments surface and underground require different types of oil as fuel, especially the whirr of mechanical and electrical transport system consume large amounts of gasoline and diesel. GHG emissions from oil consumption in the coal enterprises can be expressed as:

$$CF_{m6CO2\text{-}e} = CF_{m6\text{-}CO2} + CF_{m6\text{-}NOx} \times GWP_{NOx}$$
$$= \sum_{i=1} Q_{O(i)} \times E_{fCO2(i)} + \sum_{i=1} Q_{O(i)} \times E_{fNOx} \times GWP_{NOx} \quad ...(17)$$

$$CF_{m6\text{-}SO2} = \sum_{i=1} Q_{O(i)} \times E_{fSO2} \quad ...(18)$$

Of which, $CF_{m6CO2-e}$ represents the GHG emissions volume from the oil consumption in the coal production, t CO_{2-e}/a; $Q_{O(i)}$ represents the consumption volume of the *i* kind of oil according to the coal enterprise; t /a.

The technology lines of measuring carbon footprint of the nation's raw-coal production one year: On the basis of single raw-coal measuring, the paper combines different mine gas concentration difference, gives the technology lines of measuring carbon footprint of the national raw-coal production in one year, which is shown in Fig. 1.

CONCLUSION

This paper firstly defines carbon footprint (CF) and its dangers in the raw-coal production. CF is mainly composed of GHG (green house gases), and GHG emissions' statistics are often expressed by CO_2 emissions in the subsystem of the raw-coal production. After identifying the emissions sources of GHG in the process of coal production, the paper respectively sets up the measuring models for GHG emissions from the relative gas emission underground excavation, coal mining, land disposal to coal on ground, explosive blasting emissions, breathing CO_2 emissions of worker underground, indirect GHG emissions of electric energy consumption, direct GHG emissions of heating boilers and GHG emissions of fuel consumption based on combining with the methods of measuring the carbon potential emission factors. Finally, the paper gives the technology lines of measuring carbon footprint of the nation's raw-coal production in one year, which is practical to study the low economy.

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