Modeling CF of Tobacco industry based on PLC across the supply chain

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Abstract In order to mitigate the effects of global warming, companies are being compelled by government, investors and even customers to control their greenhouse gas (GHG) emission in the supply chain. As a fundamental quantization parameter of carbon emissions measurement in the product life cycle (PLC) across the supply chain, the concept of carbon footprint (CF) captures the interest of government (policy makers), firms and consumers. However, calculating the carbon footprint is a prerequisite to confirm or refute best practices and policies for control CF. This article studies the method of calculating CF based on PLC across the supply chain of tobacco industry. Based on the conception of CF and the precondition of tobacco industry, this study analyzes four stages across the supply chain, including the raw material stage, manufacturing stage, distribution stage and the usage stage. It presents different models to measure CF at four stages respectively in the cigarette life cycle, for the different features different stages boast. Analytical and finite difference methods can be used to approximate CF as well as relevant soft such as a quasi-implicit variable time step solvers and Fluent, through which firms especially tobacco industry ones can find out what and where the carbon emits too much across supply chain. And then firms can implement corresponding measures to control or even reduce the carbon emission by attaching carbon label on a cigarette. Customers can consider the low-carbon product through carbon labels. For government or related organizations, it can opens a new way for setting comparisons among different practices and policies and then helps to promote efficient emission reduction policies, which can control the emission of GHG and mitigate global warming.

Keywords CF，Tobacco industry，PLC, supply chain

1 Introduction

Issues of global warming and GHG emissions are increasingly becoming one of the concerns among government organizations and firms. And this concern has intensified with the rapid growth in industry and the over GHG emissions since 2000[1,2], which has a great influenced on the sustainable development policy and even the life of human beings. As a result, companies are required to control their GHG emissions by government, investors and customers.

Traditionally, an increasingly number of firms invested in the supply chain net have focused on the efficiency of the logistic processing and on the value creation for downstream customers in the supply chain through reducing the costs of the production, raising the quality of deliver service and cutting most of delivery time[3]. Recently, with global warming slowly creeping into our daily life, customers have become attached the great value to less obvious dimensions, such as low-risks delivery, better visibility across the supply chain, low carbon emission across the supply chain (green supply chains)[4]. And the latter is the main idea in this article.

As more and more young or adult people inoculate themselves to developing the habit of smoking despite more nonsmokers fight for their rights to breathe fresh air, the smoking trend should continue to grow. In the world, it is said that more than 5.5 trillion cigarettes are produced and smoked per year. If we assume that 1000 cigarettes are equals to 3 pounds of pure carbon (it's not), this means 5.5 billion *1000 cigarettes, or 60.5 billion pounds of carbon dioxide (CO_2), assuming all of a cigarette is pure carbon. 60.5 billion pounds is 30.25 million standard tons, or 27.4 million metric tons. The annual estimate to the global CO_2 production is 27 billion metric tons, which would mean cigarettes account for 0.1% of the total carbon emission per year.[5] All stages of cigarette production and consumption contribute to global warming, from the growing and curing of tobacco to manufacturing and promotion and to the smoking and disposal of tobacco products.

Controlling the carbon emission and calculating CF based on PLC across the supply chain of tobacco industry is a great challenge for tobacco organizations today. However, it is a necessary to better understand the CF conception and to study CF calculating methods, quantify and analyze the impacts of

CF. Therefore, this article illustrates the mathematical models to calculating and controlling the CF based on PLC across the supply chain in tobacco industry. And it is also a need to attach carbon label on a cigarette then, which can give low-carbon conception to customers and bring advantages to the sever completion among companies.

2 Literature review

Along with the development of society and the rapid industrialization, vast quantities of GHG have been discharged into our atmosphere, namely CO_2, nitrogen dioxide (NO_2), methane and other non-CO_2 gases[6]. Rising concern about the effects of GHG emission on climate is pushing national governments and international environment communities to strengthen their efforts to formulate and implement means and polices to curb GHG emission across supply chain in the short, mid and long term. Among them, Britain was the first Western-power to pioneer the carbon label system, where Carbon Trust rolled out carbon label system in 2006 and the products of carbon label was available the next year, including potato chips, liquid shampoo and other similar products. Followed by Sweden announced the third environmental statement, the carbon label has been tried on food industry, planning from fruits and vegetables to dairy and fish. It is known to all, it is about China's rise as a global manufacturing power. In fact, China has already become top GHG emitter, largely caused by the manufacturing sector of its economy. And then Correspondingly, Taiwan made a counterpart police on carbon footprints label through “National commission on sustainable development” in 2008[7]. As for the standards and specifications on the CF, there exists several relevant state regulations, mainly related to GHG protocol in European Union (30% reduction as part of a global agreement), ISO 14067, ISO16759, PAS 2050:2008 in British, TSQ 0010 in Japan[8]. Theses polices and measures are used to add requires and certifications of CF on products in order to evaluate and disclose the activities of CF, creating green supply chain[9].

In definition, The Green Supply Chain covers every stage from the first to the last stage of production life cycle, such as the raw material souring and selection, manufacturing processing, distribution, usage and disposal (the final product delivering to customers and the end-of-life disposing of the product)[5]. CF is the very method to be used to quantity GHG emission and measurement of the efficiency of the Green Supply Chain Management

(GrSCM). CF is also a ideal approach to identify emission drives in a product, processes or service life cycle[10,11,12].

As a newly-emerging word "CF", the qualitative discussion and quantitative research is still under discussion so there is not many unified and acknowledged method to accurately measure CF across the supply chain. Calculating the CF poses several challenges and barriers, for practices occur at dislocated stages across the multi-stage supply chains. Currently, on one hand, there exists measurement models of CF: input-output (IO) method[13,14], life cycle assessment (LCA) model[15] and Intergovernmental Panel[16] on Climate Change (IPCC Guidelines) for national greenhouse gas inventories calculating approach[17].

Some initial calculating IO models toward CF as follows: Zhu, Sarkis, et al.,[18] illustrated an IO model on how to tap GrSCM, and as an outcome , GrSCM could help to reduce waste, minimize pollutions, even save energies, conserve natural resources and cut down carbon emission. And Zhu and Sarkis, et al.,[19,20]also showed the relationships between GrSCM operational practices and environmental and economic performance exist, and these are moderated by quality management and lean manufacturing practices and by institutional pressure in the relevant papers. Hervani, et al.,[21] presented conceptual framework of IO method and selected metrics to evaluate the environmental performance, which took carbon emission into evaluation performance.

The measurement models build on similar research in the recent past were focused on the CF of products or certain industrial level based on the method of Life cycle assessment (LCA). Bakhshi, et al.,[22] estimated the CF across the municipal water cycle through LCA method, and presented the good effects and then took almost every means to control the carbon emission in vision. In addition, Pattara, Raggi, et al.,[23] took the supply chain into consideration and modeled the assessment of the CF on wine based on LCA. And IPCC Guidelines that is on national level are usually suit to the applying of countries Alliance[24], making sure almost elements and segments of carbon emission would be involved in those countries or individuals [25].

On the other hand, some studies made the counterpart mathematical models or other non-math models to measure the CF and optimized supply chains based on green practices, catering to GrSCM. Derived from the definition and understanding of GrSCM, green practices should be considered into two dimensions, economic dimension and environmental dimension. Kainuma, Tawara, et al.,[26] had proposed and applied the multiple attribute utility theory method to evaluate the CF from both dimensions, assessing the economic and environmental dimension. And Ferretti et al., [27] assessed the economic dimension, such as scrap values, total costs and environmental dimension effects (pollution) of the transportation change from traditional supply of solid material to the liquid phase to receive the aluminum alloys. Sheu et al., [28] applied a linear multi-objective programming model into optimizing the operations of integrated logistics networks, based on the used-product return ratio or subsidies from governmental organizations for reverse logistics. Furthermore, they suggested numerical examples presented in the article can improve profits by 20% at least.

However, the previous researches mostly focused on estimating carbon emission of each sector and on corresponding measures. Moreover, fewer could exactly calculate the CF based on PLC or across the supply chain in recent years. The related literature is scarce with respect to modeling CF. Sundarakani, et al., [29] explored how to apply the general model to measure the CF across the supply chain. Cholette, et al., [30] calculated the CF and the energy of wine distribution associating with the transportation links and warehouse activities across the supply chain. Hussain M1, et al.,[31] quantified GHG emissions from the Pakistan Tobacco Company production using PLC approach, but he just calculated the whole carbon emission through questionnaire survey from tobacco growers and records from PTC manufacturing units, not through using specific models to obtain a relatively accurate measurement result. It could be seen that modeling the CF based on PLC across the supply chain has presented a major challenge for governments, firms, and even individuals today.

As one of the largest developing country in the world, China's carbon dioxide emission problem has become the focus of the academia and governments all over the world, and tobacco industry emerges and develops so quickly, which is of large land occupation, high energy consumption and serious climate change implications that contributes to global warming. Furthermore, carbon gases emitted from the tobacco industry occupy a large part of the whole GHG emission in China. Therefore, we find it absolutely essential to control carbon emissions in tobacco industry in China, which can arouse the public awareness of CF. And calculating the CF across the supply chain is a prerequisite for the implementation of low-carbon supply chain in Tobacco industry.

3 Mathematical models based on PLC

Product life cycle in the context of CF is defined as the consecutive interlinked stages of a product's development, from raw material extraction, manufacturing, distribution, and use up through final disposal.

Typically, there are two modes for a product life cycle: cradle-to-grave and cradle-to-gate (Fig. 1) [32]. In a cradle-to-grave mode, CF (one kind of GHG emissions) is captured in all stages of the product life cycle, from the extraction of raw materials for manufacturing until product disposal or recycling. While in a cradle-to-gate mode, CF

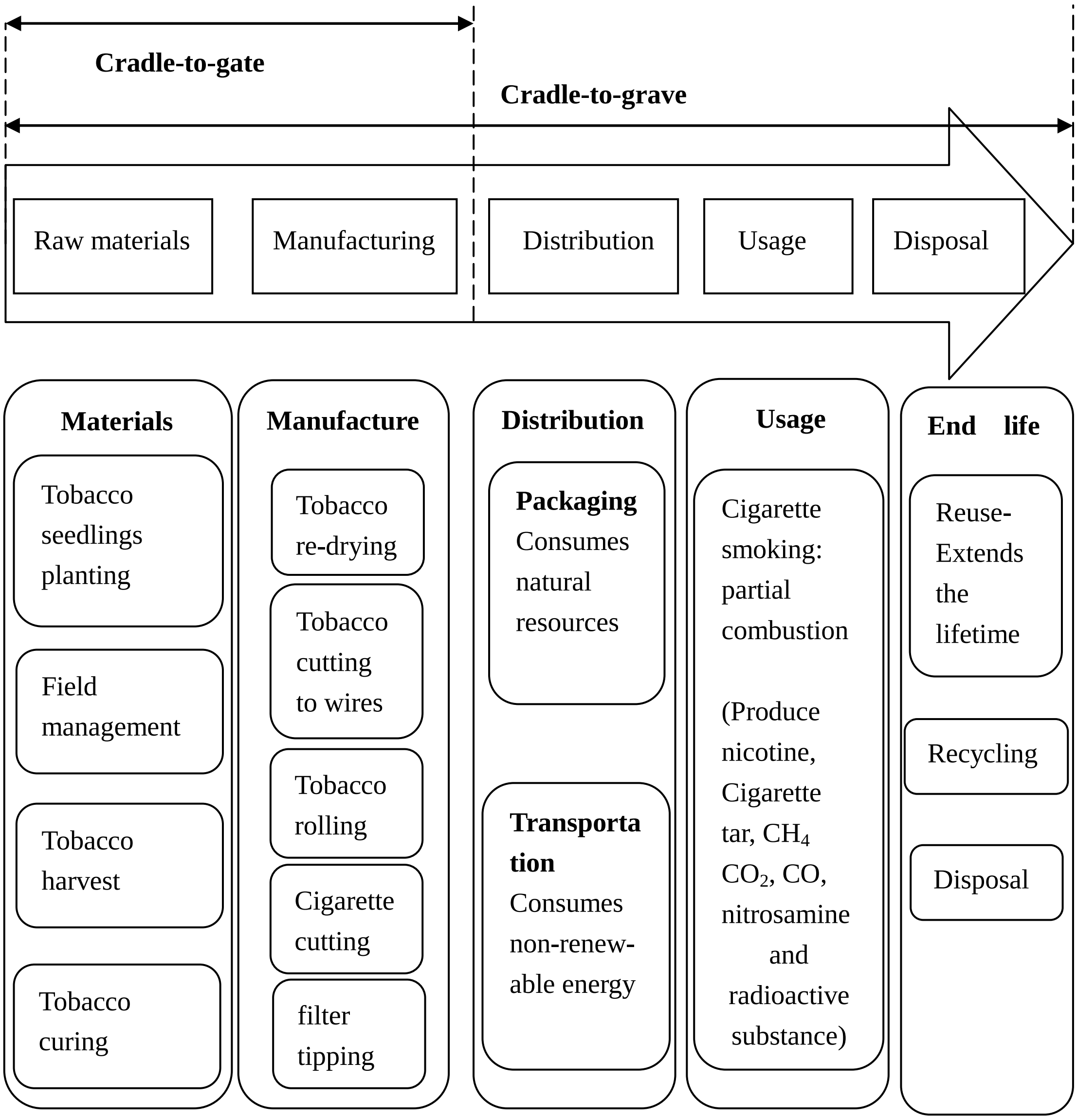

Fig.1. Cradle- to-gate and Cradle-to-grave product life cycle stages of Tobacco industry

is only considered from raw material extraction up to the point at which the finished products leave the organization.

Previous researches showed that organizations tend to choose the cradle-to-gate mode for CF analysis, for these stages involved can be controlled possibly. So they usually ignore the disadvantages of the cradle-to-gate mode, significantly underestimate the total CF in a product life cycle. Compared to the former, the cradle-to-grave mode would never neglect the CF resulting from direct and indirect energy consumed during the product stages across the supply chain.

It shows the cradle-to-gate and cradle-to-grave mode for Tobacco industry in Fig. 1. And the similar product life cycle stages could be also drawn for other products. The stages in the Tobacco production include the raw material, manufacturing, distribution, usage and disposal (end of life). At the raw material stage, there are a series of processes for raw materials and preparing semi-finished parts, including Tobacco seedlings planting, Field management, Tobacco drying and Tobacco Harvest. As for the stage of manufacturing, what happens in this stage: Tobacco re-drying, Filter Tipping, Tobacco Rolling and Cigarette Cutting. When it comes to the distribution stage, it exists two main processes, they are packaging and transportation, which are usually related to quantity, distance and consume some natural resources such as paper, plastic, aluminum, and etc. Obviously, these processes would result in waste. And GHG will be emitted, inclusding CO_2, N_2O, particular matter (PM), methane (CH_{24}), hydro fluorocarbons, per-fluorocarbons (PFC_S), sulfur hexafluoride (SF_6) and other greenhouse compounds. In the usage life of cigarette-smoking, it includes a complete and a partial combustion, producing nicotine, cigarette tar, methane (CH_4), CO_2, CO, nitrosamine, radioactive substance. The last stage is end-of-life, including recycling and disposal of rubbish. For Tobacco industry, the usage is usually completed and the last stage is rubbish disposal, to some extent. So in this article, we will focus on the former four stages except the end of life.

3.1 Model to calculate CF at the raw material stage

Considering all primary sources in the material stage of the supply chain, we assume they are under stable atmospheric conditions. And in order to reduce the complexity of our researches, only primary tier-1 supplier emission is considered in this article. In our case, CF is measured by applying Eulerian box model that takes a small and fixed control volume as characterized at this stage. In our research, the model approach is employed, because it has been widely used in air pollution, water quality, submarine outfalls, sediment erosion, oil dispersion and other similar types of pollution modeling.

Given different modeling objectives, model equations in different format have been built. Most common in this context are compartment and Eulerian box model in which the environment is divided into a number of volumes or boxes that is usually fixed in space and are treated as being homogeneous and well-mixed in chemical composition. The model is the simplest model to make our issues less complex and be solved. It is based on the mass conservation equation of the gaseous species in a fixed Eulerian box model. The diffusion equation is of the form as follows [33]:

$$\frac{d}{dt}\left(C_i\right)=\frac{q_i}{h}+R_i-\frac{v_{di}C_i}{h}+\frac{u}{\Delta x}\left(C_i^0-C_i\right) \qquad (1)$$

Where C_i is the carbon concentration of the specie "*i*" in kg; q_i is the mass emission rate of the specie "*i*" in kg/s; R_i is the rate of change of chemical transformation and emission in kg/s; x, y, z are the directions; h is the vertical depth over which dry deposition takes place in m; v_{di} describes the dry deposition velocity of species i; u $(C^0_i - C_i)$ is the entrainment of detrainment term, here u is the velocity that describes the exchange with air above the box, and the is C^0_i the concentration of specie i above the box. And v_{di} could be measured by the ratio of deposition velocity F and pollutant concentration Q. The solving equation is as follows:

$$v_{di}=\frac{F}{Q}=\frac{1}{R_a+R_q+R_s} \qquad (2)$$

Where R_a is the atmospheric resistance on turbulent surface layer; R_q is the quasi deposition resistance; R_s is the vegetation surface resistance.

When given the control volume in model, we take the form stated in Markiewicz (2004)[34]. The diffusion equation is of the form:

$$E_R=\iiint_v \frac{\partial C_i}{\partial t}dxdydz=\iiint_v \begin{pmatrix} \frac{\partial}{\partial x}\left(k_x\frac{\partial C_i}{\partial x}\right) \\ +\frac{\partial}{\partial y}\left(k_x\frac{\partial C_i}{\partial y}\right) \\ +\frac{\partial}{\partial z}\left(k_z\frac{\partial C_i}{\partial z}\right) \end{pmatrix} dxdydz$$

$$+\left(u\frac{\partial C_i}{\partial x}+v\frac{\partial C_i}{\partial y}+w\frac{\partial C_i}{\partial z}\right)dxdydz+\iiint_V\left(R_i\right)dxdydz$$

$$-\iiint_V\left(\frac{v_{di}C_i}{z}\right)dxdydz+\iiint_V\left(\frac{u}{\Delta x}\left(C_i^0-C_i\right)\right)dxdydz \qquad (3)$$

Where E_R is the mass CF at the stage of raw material; V is the control volume of the fixed box in m^3; u is the wind velocity at x direction in m/s; v is the wind velocity at y

direction in m/s; w is the wind velocity at z direction in m/s; k_x is the eddy diffusion coefficient across the Horizontal direction; k_y is the eddy diffusion coefficient across the wind direction; k_z is the eddy diffusion coefficient across the vertical direction.

According to the Divergence Theorem (Gauss Ostrogradzki), the high order partial different equations could be reduced. We choose the Gauss Ostrogradzki theory, because the volume integral of the higher order equation can be reduced to a two-order surface integral with the boundary of the volume. So the Eq.(3) is reduced to:

$$E_R = \iiint_v \frac{\partial C_i}{\partial t} dxdydz = \iint_S \begin{pmatrix} k_x \frac{\partial C_i}{\partial x} dydz \\ +k_y \frac{\partial C_i}{\partial y} dxdz \\ +k_z \frac{\partial C_i}{\partial z} dxdy \end{pmatrix} dxdy$$
$$-\iint_S \left(\left(uC_i dydz + vC_i dxdz + wC_i dxdy \right) \right) dxdydz$$
$$+\iiint_V \left(R_i \right) dxdydz - \iiint_V \left(\frac{v_{di} C_i}{z} \right) dxdydz \qquad (4)$$
$$+\iiint_V \left(\frac{u}{\Delta x} \left(C_i^0 - C_i \right) \right) dxdydz$$

And by introducing the initial and boundary value conditions, the analytically or numerical approximation methods could be used to solve this diffusion equation (Eq.(4)), as well as some certain assumptions. Therefore, the carbon emission E_R can be calculated through the model.

3.2 Model to calculate CF at the stage of manufacturing

Given that the manufacturing stage of the Tobacco is usually fixed and set up in the same place, the atmosphere condition would be assumed to be stable at the stage of manufacturing in our research. Considering this feature as the same as the material stage, Eulerian box model would be also chose to compute the CF. So we apply the equations (Eqs. (4)) as follows:

$$E_M = \iiint_v \frac{\partial C_i}{\partial t} dxdydz = \iint_S \begin{pmatrix} k_x \frac{\partial C_i}{\partial x} dydz \\ +k_y \frac{\partial C_i}{\partial y} dxdz \\ +k_z \frac{\partial C_i}{\partial z} dxdy \end{pmatrix} dxdy$$
$$-\iint_S \left(\begin{pmatrix} uC_i dydz \\ +vC_i dxdz \\ +wC_i dxdy \end{pmatrix} \right) dxdydz$$
$$+\iiint_V \left(R_i \right) dxdydz$$
$$-\iiint_V \left(\frac{v_{d\,i} C_i}{z} \right) dxdydz$$
$$+\iiint_V \left(\frac{u}{\Delta x} \left(C_i^0 - C_i \right) \right) dxdydz \qquad (5)$$

Where E_M is the mass CF at the stage of manufacturing stage.

And we will choose the methods as same as that calculating the E_M above.

3.3 Model to calculate CF at the stage of distribution

Here, the Lagrangian transport model would be applied to calculate the emission, due to the certain characters with source-receptor and logistics at the stage of distribution. In addition, the transport model has also been applied widely in water quality models, submarine outfalls and other pollution models.

The model is a multiple-layer receptor-oriented Lagrangian box model. The general Lagrangian model expressed by Lee et al. [35-37] is of the form as follows:

$$\frac{d}{d\mathrm{t}}(C_i) = E_{\mathrm{i}} + R_i(\mathrm{C_j}) - \frac{v_{di}C_i}{z} - \Lambda_i C_i \quad (6)$$

Where E_i is the emission rate of the species i; $R_i(C_j)$ is the rate of change of species i as a result of the chemical reactions of itself and other species j; Λ_i is the washout (wet deposition) coefficient of species i in s^{-1}.

As this model allows for sufficient explanation if emission growth in an open space, it is a great match with a CF growth variable in an open space domain. So we assume that the CF fits a 3D model. We take the modified form:

$$\frac{d}{d\mathrm{t}}(C_i) = Ex + Ey + Ez + R_i(\mathrm{C_j}) - \frac{v_{di}C_i}{z} - \Lambda_i C_i \quad (7)$$

Where E_i, E_i, E_i are the emission rate in the x, y, z directions respectively.

To calculating the diffusion, the diffusion equation from the TRACE model[38] is of the form:

$$\frac{\partial C_{\mathrm{i}}}{\partial t} = \frac{\partial}{dx}\left(k_x \frac{\partial C_i}{\partial x}\right) + \frac{\partial}{dy}\left(ky \frac{\partial C_i}{\partial y}\right) + \frac{\partial}{dz}\left(k_z \frac{\partial C_i}{\partial z}\right) + R_i(\mathrm{C_j}) - \frac{v_{di}C_i}{z} - \Lambda_i C_i \quad (8)$$

When considering different systems of different equations with varying boundary conditions, approximation methods such as the finite difference or finite element methods are needed. We follow the classical finite difference method of approximation since it has been well defined in many heat conduction problems. The finite difference method is based on the replacement of the derivatives by their approximate values expressed through the values of a function at a certain discrete equation.

Our research assumes that there is no chemical phase transportation, dry deposition and wet deposition at all the four stages. Furthermore, the model is assumed to two-dimensional box model. That is the wind speed is along the x direction.

Hence, we can reduce Eq. (8) as follows:

$$\frac{\partial C_{\mathrm{i}}}{\partial t} = \frac{\partial}{dy}\left(ky \frac{\partial C_i}{\partial y}\right) + \frac{\partial}{dz}\left(k_z \frac{\partial C_i}{\partial z}\right) \quad (9)$$

Eq.(9) can be solved either by using a quasi-implicit variable timestep solver or by using the finite difference method. Here, we chose the central differencing theory.

$$\frac{\partial C_{\mathrm{i}}}{\partial t} = \frac{\overset{n}{C_{ij}} - \overset{n-1}{C_{ij}}}{\Delta x} \quad (10)$$

$$\frac{C_{ij}^{n}-C_{ij}^{n-1}}{\Delta x}=\frac{k_{yi+o.5}\left(C_{ij}^{n-1}-C_{ij-1}^{n-1}\right)-k_{yi-o.5}\left(C_{ij-1}^{n-1}-C_{ij-2}^{n-1}\right)}{(\Delta y)^{2}}+\frac{k_{zi+o.5}\left(C_{ij}^{n-1}-C_{ij-1}^{n-1}\right)-k_{zi-o.5}\left(C_{ij-1}^{n-1}-C_{ij-2}^{n-1}\right)}{(\Delta z)^{2}}+\sigma \tag{11}$$

Where δ is the error term coefficient.

And with the initial and boundary value given, the Eq. (11) can make a system of two equations. We can get the explicit solution by solving the equations set.

So we could calculate the carbon emission at the distribution stage through the equation.

$$E_D=\int_T\left(\frac{k_{yi+o.5}\left(C_{ij}^{n-1}-C_{ij-1}^{n-1}\right)-k_{yi-o.5}\left(C_{ij-1}^{n-1}-C_{ij-2}^{n-1}\right)}{(\Delta y)^{2}}+\frac{k_{zi+o.5}\left(C_{ij}^{n-1}-C_{ij-1}^{n-1}\right)-k_{zi-o.5}\left(C_{ij-1}^{n-1}-C_{ij-2}^{n-1}\right)}{(\Delta z)^{2}}+\sigma\right)dt \tag{12}$$

Where T is the whole time of the distribution stage in s^{-1} and E_D is the mass CF at the distribution stage.

3.4 Model to calculate CF at the stage of usage

At the usage stage, it is known to all that the processes of cigars happen in the open air. Cigarettes often burn for longer periods of time, which leads to more secondhand smoke in the air. The smoke would diffuse into the atmosphere, which will result in air pollutions. Given researching the atmosphere carbon concentration in the open air, we use the Eulerian - Lagrangian Coupled model, comprising a Lagrangian particle dispersion model coupled to an Eulerian transport model.

The CF in the Lagrangian model at any receptor can be written as follows (Holzer et al., 2000; Lin et al., 2003) [38-39]:

$$E\left(x_n,t_n\right)=\int_{t_0}^{t_n}\int_V I\left(r_n,t_n\,|x,t\right)S\left(x,t\right)dvdt+\int_V I\left(x_n,t_n\,|x,t_0\right)E\left(x,t_0\right)dv \tag{13}$$

Where $E\,(x_{n},\ t_n)$ is the emission at receptor x_n at time t_n; $E\,(x_{n},\ t_0)$ is the initial emission at receptor x_n at time t_0; $I\ (x_{n},\ t_n \mid x,\ t\ )$ is the influence function linking sources and sinks $S(x,\ t)$ to the concentrations; dV is the volume element.

Here, the influence function would be assumed to correspond to the transition probability.

$p\ \ (x_{n},\ \ t_n \mid x,\ \ t\ )$ along the air mass trajectories $x_n\ (t)$, calculated by the Lagrangian model as follows:

$$p\left(x_n,\ t_n\,|\ x_0\right)=\frac{1}{N}\sum_{n=1}^{N}\delta\left(x_n(t)-x\right) \tag{14}$$

Where N is the number of air parcels emitted in the backward direction from the receptor point; $\delta(x_n\ (t)\text{-}x)$ is the data function representing the presence or absence of parcel i at location x.

Therefore, Eq. (14) can be written in discrete form as follows:

$$E\left(x_n,t_n\right)=\frac{1}{N}\frac{T}{L}\sum_{ijk}^{IJK}\left(\sum_{l=0}^{L}S_{ijk}^{l}\sum_{n=1}^{N}f_{ijk}^{n}\right)+\frac{1}{N}\sum_{ijk}^{IJK}\left(\sum_{l=0}^{L}E_{ijk}^{B}\sum_{n=1}^{N}f_{ijk}^{ln}\right) \quad (15)$$

S a Where *i*, *j*, *k* is the indices of a grid cell (air parcel); *l* is the time index in s; E_{ijk}^{B} is the initial background emission, which is calculated by the Eulerian model; f_{ijkn}^{n} is the index of "1"and "0": "1" means the parcel inside the *i*, *j*, *k* grid cell, "0" means the parcel outside the grid cell: $f_{ijk}^{n}=\begin{cases}1\\0\end{cases}$.

T is the duration of air trajectories in s; *L* is the steps when sources are sampled by trajectories.

Here, we assume that we consider the significance to a height *h* at 10m.

According to the previous articles (Holzer et al. (2000) and Lin et al. (2003)) [38-39], the sinks *S(x, t)* could be calculated with the sampling surfaces *F*(*x*, *y*, *t*) as follows:

$$S(x,t)=\begin{cases}\dfrac{F(x,y,t)M_{air}}{hd(x,y,t)M_c}, z\leq h\\ 0, z>h\end{cases} \quad (16)$$

Where M_{air} and M_c are the molar masses of air and carbon respectively; *d* is the average air density below *h*.

Finally, we put the Eq. (16) into the Eq. (15) and get the coupled model equation:

$$E_U=\frac{TM_{air}}{hNLdM_c}\sum_{ij}^{IJ}\left(\sum_{l=0}^{L}F_{ij}^{l}\sum_{n=1}^{N}f_{ij}^{n}\right)+\frac{1}{N}\sum_{ijk}^{IJK}\left(\sum_{l=0}^{L}E_{ijk}^{B}\sum_{n=1}^{N}f_{ijk}^{ln}\right) \quad (17)$$

Where, E_D is the mass CF at the usage stage.

And the first term in the Eq. (17) is associated with the emission from the Lagrangian model and the second term is the background carbon emission from the Eulerian transport model. From the Eq. (17), the whole carbon concentration at the usage stage could be computed.

3.5 The whole carbon emission in the life cycle of tobacco

The total CF across PLC is an aggregated sum of carbon emissions of the raw material stage, the manufacturing stage, the distribution stage and the usage stage. We can obtain the whole emission equation through the integration of four stage equations (Eqs. (4), (5), (12) and (13)) as:

$$E_W = E_R + E_M + E_D + E \quad (18)$$

Where E_W is the whole CF in the product life cycle of tobacco.

4 Case study

4.1 Initialization and setting of boundary conditions

Due to the great difficulty of achieving actual industry data, we apply the models given above into measuring the CF emission based on PLC across the supply chain with some previous data or second-hand data the previous literature or from public domain websites and some first-hand data in, to some extent.

To delineate the scope of our research and to facilitate for formulation of the models, some assumptions were made and summarized as following:

In this article, we only chose to present the numerical example of detailed calculation process of the last model (a cigarette at the usage stage) for it is most difficult model to solve. And as for other three stages, the calculating results are presented, considering the similar calculating process.

In Phrase IV, we assumed that cigarettes, with complete combustion, reacted completely to CO_2 (it doesn't). Smoke from cigarettes contains many other chemical compositions. Here, we consider the two main gases (CO_2, CO and CH_4), which influence the greenhouse heavily. Therefore, mixed gases diffusion is involved in our research.

Given the complexity of the Eq. (17) and the desire to achieve a high quality of the solution, we chose to make a numerical model through Fluent Software for simulation of the gas diffusion of the mixture and the calculation of the equation. It can conveniently make the problems on the analysis and calculation flexible. In addition it could help to reduce the experimental work of the blindness and workload effectively.

Specific assumptions for simulation and calculating part:

1) The calculating mixture gases are CO_2, CO and CH_4, and the space is the air under room temperature and ambient pressure.
2) The fluid is set as ideal gas; physical parameters for CO_2, CH_4, and air are determined by the parameters for material property built in Fluent.
3) We chose carbon dioxide equivalence (CO_{2e}) as the unit because there are several other greenhouse gas except CO_2 in our article. Some related conversion coefficient of other gases is summarized in the Table 1.
4) Turbulent mixing along the diffusion is considered constant and homogenous.

All other impinging variables remain a constant during the determination of the carbon footprint across the supply chain.

For one, simulation parameters are shown in Table 2. For another, calculation input parameters for the numerous model equations with both experimental data and actual Tobacco industry data are given in the Table 3.

Table 1 _Some related parameters on CO_{2e} from (IPCC, 2006)

Gas name	**Conversion coefficient**
CO_2	1
CH_4	25
NO	296

Table 2_ Calculation and Simulation parameters based on FLUENT

Name	parameter	Name	parameter
Number of Grids	1046029	Viscosity(CO_2),μs	8.369（$\mu pa.s$）
Grids Size: Max	0.837253	Density(C O_2), ρs	1.784（kg/m^3）
Grids Size: Min	1.30573e-10	Viscosity(CH_4),μs	17.071（$\mu pa.s$）
σ_k	1.0	Density(CH_4), ρs	0.648（kg/m^3）
$\sigma_{1\varepsilon}$	1.2	Volume Fraction	
$C_{1\varepsilon}$	1.44	(CO_2 : CH_4)	7:3
C_2	1.9	Diameter (diffusion source)	7.7mm

Table 3 _ Input parameters

Variable name	values	Unit	source
Receptor site	10		Assumed
Space volume	dv=10×10×10	m^3	
Fixed grid	28 ×16 ×12	m^3	Zhangboyin et al.（1999）
Diffusion height	H=500	m	Assumed
Duration time	900	s	Ganshin(2012)
Average air density below h	d= 1.225	kg/m^3	
Molar masses of air	M_{air} =29×10^-3	kg/mol	
Molar masses of carbon	$M_{c\ =}$12×10^-3	kg/mol	
Measurement height	h=10	m	Zannetri et al.(1999)
Resistance factor	$R_{a=0}$	s/m	Lee et al.(1999)
	$R_{q=5.0E+02}$		
	$R_{s=0}$		
Dry deposition	$v_{di\ =22}$	Ktonner/yr	Lee et al.(2000)
Wet deposition	$V_{wi\ =22}$	Ktonner/yr	Lee et al.(2000)
Deposition velocity	$\Lambda_{i\ =0.003}$	m/s	Sehmei (1980)
The steps	L=10		Assumed

4.2 The calculation results from usage stage and post-processing

The diffusion of cigarette smoke at the usage stage in tobacco area can be simulated numerically in the open space, during which diameter of a cigarette, speed of wind, gaseous medium should be taken into account. Results from our model simulation and calculation trough Fluent Software: Density and velocity of the mixture CO_2 and CH_4 are shown in Figure 2 and Figure 3 respectively during 900 seconds.

Can be seen from the Figure 2: during the 900 seconds period, the mixture can be approximately regarded as free diffusion flow, which could show you how the smoke diffused at different density at different time. Due to the high temperature with an estimated 800-900℃ in the center of a cigarette and 200-300℃ around the cigarette paper, a cloud of smoke diffused upwards. And the density is approximately between 1.3 and 1.55.

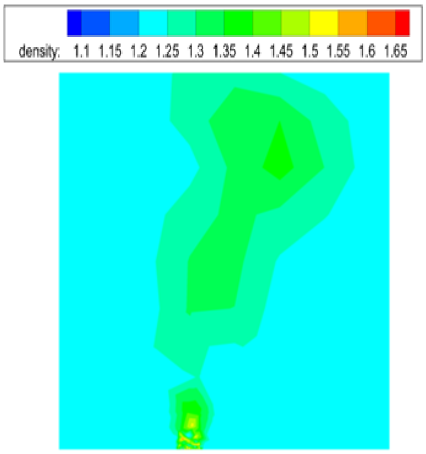

Figure 2. CO_2, CO and CH_4 diffusion density distribution nephogram

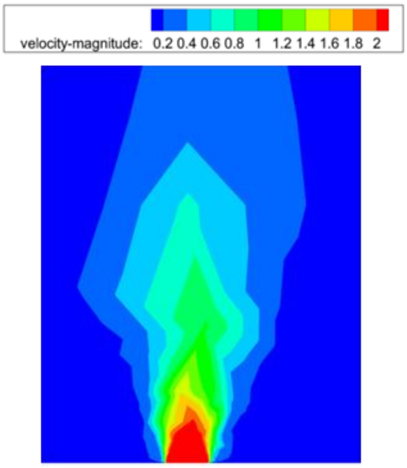

Figure 3. CO_2, CO and CH_4 diffusion velocity distribution nephogram

The Figure 3 visible: in a moment of lighting a cigarette, smoke diffused quite rapidly around the smoker and secondhand smokers in the open air, even peaking at 2m/s. And the smoke diffused much more slowly than before, with the speed of 0.2-1m/s. Because the concentration of CO_2 in space beyond a certain range will pose a threat to human life, the main purpose of numerical simulation is to determine the smoke diffusing amount that could show how the smoke emitted from a cigarette and help to control the greenhouse effect.

Through the model we set in Fluent Software, the parameters given in the tables (Table 1, 3) are fed into the Eq. (17) at the fourth stage, and the results have been calculated and summarized in the Table 4.

Table 4_The model results about CF of a cigarette at usage stage (unit: gCO_{2e}**)**

stage	T(s):	**CO_2**	**CH_4**	**CO**	**CO_{2e}**
Usage	900	2.94	0.18	0.55	3.67

During the certain 900 seconds period time (average duration time of smoking a cigarette), the amount of CO_{2e} emission is 3.67 gCO_{2e} in which the emission of CO_2 located the top with 2.94 gCO_{2e}, followed by CO. As firm, we could get the carbon emission information from calculating results that would play a huge role in implement CF labeling on cigarette product and in controlling the CF across the supply chain.

4.3 The calculation results based on PLC

Given that the calculation process of other three stages is similar to that in the usage stage, the calculating results are presented

Table 5_The model results about CF across Tobacco industry supply chain (unit: gCO_{2e}**)**

Supply chain Stage	CO_2	N_2O	CH_4	CO	CO_{2e}	Proportion
Raw material	0.45	0.12	0.03	0.00	0.60	10.52%
manufacturing	0.60	0.07	0.00	0.00	0.67	11.71%
Distribution	0.62	0.00	0.16	0.00	0.78	13.61%
Usage	2.94	0.00	0.18	0.55	3.67	64.16%
Total	4.61	0.19	0.37	0.55	5.72	
Proportion	80.66%	3.28%	6.43%	9.62%	1	100.00%

directly. Therefore CF across Tobacco industry supply chain are calculated and summarized in Table 5.

From Table 5, the total CF of a cigarette across the whole supply chain is an aggregated sum of carbon released from raw material stage (0.60gCO_{2e}), manufacturing stage (0.67gCO_{2e}), distribution stage (0.78gCO_{2e}) and usage stage (3.67gCO_{2e}). Therefore, the carbon emission from a cigarette based on PLC is 5.72 gCO_{2e}. Obviously, carbon emissions form usage stage is the highest (3.67gCO_{2e}) in the Tobacco industry supply chain because of the feature product boasts, occupying 64.16% of the total CF. Followed by distribution stage, it has occupied 13.61%. These two stages would be the highlight the firm should take corresponding measures to control CF.

From the results and analysis outlined thus far, it is obvious that CF stemming from these four stages based on PLC would warrant managerial attention. And the results from every stage could help the management find out what and where CF emits too much and take corresponding strategies to reduce or even control CF in the supply chain, mitigating the global warming.

5 Conclusion

This article discusses the method of calculating CF based on PLC across the supply chain in the tobacco industry. Considering of different features different stages boast, different models are built to calculate carbon emission at each stage correspondingly in product life cycle. More specifically, we applied the Eulerian box model into the raw material and manufacturing stage, the lagrangian transport model into the distribution stage and the Eulerian-Lagrangian Coupled model into the usage stage. Considering the similar calculating process of these models, this article only chooses to present the numerical example of detailed calculation process of the last model (Eulerian-Lagrangian Coupled model) to simulate cigarette smoke diffusion and calculate the amount of CO_2, CO and CH_4, for it is most difficult model to solve. And as for other three stages, the calculating results are presented directly.

With the approach presented in this article, firms especially tobacco industry ones could see what and where the areas of carbon emission emits too much through carbon labels informing carbon emission at different stages based on PLC across the supply chain. Further, based on carbon labels, firms can implement corresponding measures to control or even reduce the carbon emission in a product life cycle. On the other hand, customers would be informed the carbon emission information from carbon label added on a product, which is helpful to make them choose low-carbon life style. In addition, challenging advantages and market share are brought to these firms implementing carbon label. What is most important the low-carbon life style and low-carbon supply chain play an important role in mitigating greenhouse effects.

The article is an early attempt to calculate and control CF in the supply chain. Therefore, we hope to it can mitigate the effects of global warming. The challenging of obtaining the actual industry data has limited the preliminary results. We only consider the three main greenhouse gases include CO_2, CO and CH_4 in order to reduce the complex of calculation of the models. Actually, there are many other chemical compositions. What's more, our research range should be extended, such as considering a multi-echelon supply chain and the organization pressure involved in the model at each stage of the supply chain. And these models built in this article could be applied in other areas instead of only being applied in the tobacco industry. In its practical application, the initial framework, model development and analysis help firms to understand the total supply chain net.

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