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Uncertainty analysis for multi-state weighted behaviours of rural area with carbon dioxide emission estimation

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ABSTRACT

This paper develops a spatial analysis approach, which incorporates three components and a carbon dioxide (CO_2) emission factor, has been developed to evaluate the multi-state weighted behaviours with CO_2 emission uncertainty of the rural areas at an administrative district level. A Mendel genetic algorithm (Mendel-GA) is applied to the spatial analysis problem, where the Mendel genetic operator implies the random assignment of alleles from parents to their offspring by using the Mendel's principles. A functional region affecting index Θ is developed as a fitness function for the Mendel-GA driven evaluation, in which a gross domestic product (GDP) data based method is utilised to estimate the CO_2 emission under uncertainty. A simulation for the city of Chongqing in China has been conducted and the results show that the proposed Θ modelling method can work valuably for the spatial analysis of the functional regions and can be taken as a technical tool for the policy makers at the rural area level.

1. Introduction

In the past decades, China's rapid economic growth has been promoting China to be one of the most important contributors to the global economy as well as the natural environment problem. Combined with China's large population, rapid urbanisation process, increasing household wealth demands and local economic reconfiguration, unbalanced pressure has been deployed on regional development and caused low efficient environmental recycle. The local impact of various air pollutants, such as carbon monoxide (CO), nitrogen oxides (NO_x) and sulphur dioxide (SO_2), on the regional economic development has been discussed [1–4].

Global warming is one of the most serious environmental problems that human currently is confronting. The mechanism of global warming has not yet been fully understood, however, it has been considered closely relating to the emission trends of the anthropogenic greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4). This has gained researchers' increasing interest and various countermeasures, such as technological development, abatement policies based on economic mechanisms and international negotiations have been discussed and partially applied into practices [5,6].

As been widely accepted, CO_2 emissions are connected with most of the human activities through mainly fossil fuels energy consumption, for example a fossil-fuel power station. To evaluate the dynamic behaviours of the regional areas coupled with energy consumption and CO_2 emissions, a few of interdisciplinary studies have been conducted. Berling-Wolff and Wu outlined the historical development of urban growth models, which showed the different disciplines and diverse theories could be brought together to hybrid the newly developed models including fuzzy logic theory and neural network theory [7]. Nejadkoorki et al. proposed a model for the road traffic CO_2 emissions estimation of an urban area with three modelling components (the determination of the road traffic characteristics, the road traffic CO_2 emission estimation and ArcGIS outputs illustrations) [8]. Weiss et al. introduced a bottom-up model for estimating the relationship between the non-energy consumption of fossil fuels and its CO_2 emissions [9]. Generally, the study of the regional dynamic systems needs to consider the integration of the interdisciplinary factors, especially the interaction between the economic activities and surrounding factors.

Genetic algorithms (GA) were firstly introduced in the 1960s inspired by Darwin's theory of natural evolution [10] and recognised as an ideal search tool for many engineering applications [11–29]. The Mendel-GA [24] is a GA method using Mendel's

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Table 1
Punnet-square for 1-bit chromosome in Mendel-GA [24].

		attrP$_1$		
attrO		*D*	*H*	*R*
	D	100 % *D*	50 % *D* 50 % *H*	100 % *H*
attrP$_2$	*H*	50 % *D* 50 % *H*	25 % *D* 50 % *H* 25 % *R*	50 % *R* 50 % *H*
	R	100 % *H*	50 % *R* 50 % *H*	100 % *R*

principles, in which Mendel's principles [30,31] of heredity are represented by a Mendel operator of a Punnet-square clarified by the Dominant (*D*), Recessive (*R*) and Hybrid (*H*) attributes. As defined by the attribute expressions, one of the three attributes *D*, *R* and *H*, which indicates the gene's genetic character $attrP_i$, is assigned to each chromosome bit by the specific genetic possibility. Table 1 [24] briefs these expressions which summarised the conclusions from the Mendel's pea plants experiments, and the specific values as percentages (25%, 50% and 100%) are also obtained from Mendel's researches on the genetic pea plants by tracing the inheritance patterns of certain traits in pea plants and described them mathematically.

In this paper the Mendel-GA, partially driven by the Punnet-square of Table 1 as an operator of the Mendel-GA (Mendel operator), is to be applied as an optimisation approach for a spatial analysis that incorporates three components and a CO_2 emission factor, and then the empirical analysis has been devised to evaluate the dynamic behaviours of the rural regions at an administrative district or a county level.

⟨1⟩ IF $attrP_1 = D$ AND
IF $attrP_2 = D$, THEN $attrO = 100\,\%\,D$;
IF $attrP_2 = H$, THEN $attrO = 50\,\%\,D$ or $50\,\%\,H$;
IF $attrP_2 = R$, THEN $attrO = 100\,\%\,H$;
⟨2⟩ IF $attrP_1 = H$ AND
IF $attrP_2 = D$, THEN $attrO = 50\,\%\,D$ or $50\,\%\,H$;
IF $attrP_2 = H$, THEN $attrO = 25\,\%\,D$ or $50\,\%\,H$ or $25\,\%\,R$;
IF $attrP_2 = R$, THEN $attrO = 50\,\%\,R$ or $50\,\%\,H$;
⟨3⟩ IF $attrP_1 = R$ AND
IF $attrP_2 = D$, THEN $attrO = 100\,\%\,H$;
IF $attrP_2 = H$, THEN $attrO = 50\,\%\,R$ or $50\,\%\,H$;
IF $attrP_2 = R$, THEN $attrO = 100\,\%\,R$;

The rest of this paper is structured as follows. Section 2 proposes a GDP-based representation of CO_2 footprint in China; Section 3 discusses the modelling process of a multi-state weighted behaviours with CO_2 emission uncertainty; Section 4 defines the fitness for the Mendel-GA optimisation; Section 5 discusses the simulation results and then Section 6 gives the conclusion and the future works.

2. CO_2 emission estimation of productive activities

There are some CO_2 inventories, such as the emissions database for global atmospheric research (EDGAR) inventory [32] and the regional emission inventory in Asia (REAS) [33–36]. The EDGAR inventory is a method of *global inventory*, which provides modelling on air pollution and climate via on 0.1 degree grid maps based on the methodology of the IPCC level 1. The REAS is a *regional inventory* to integrate historical, present, and future emissions in Asia on the basis of a consistent methodology. Our method is a *district* (county, town) level inventory, which is an alternative based on public data directly related to government policy-making, esp. for district level

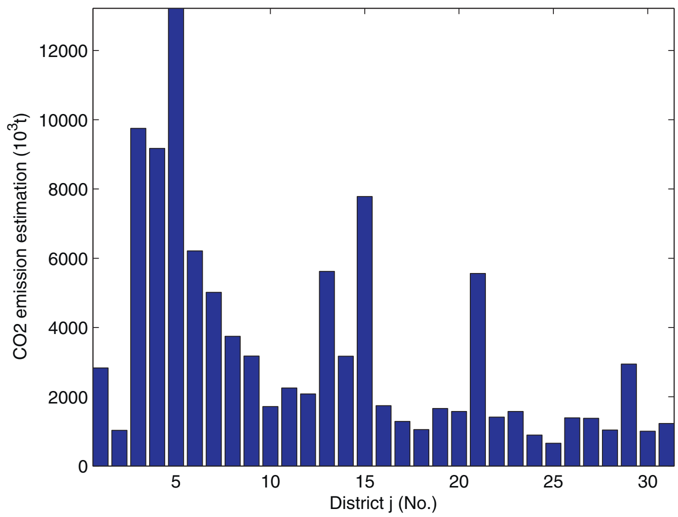

Fig. 1. CO_2 emission estimation of district *j* of CQ rural area.

of developing country which lacks of detailed data collection (but the GDP data are usually available).

Practically, the IPCC approach, however, can hardly be applied to estimating the CO_2 emission from local areas (county level) due to the following three reasons, (1) recent satellite data have shown that the decreasing use of coal is probably unrealistic, hence the coal consumption data should not be used [5,6], which indicates that the increasing complexity of the local energy consumption; (2) in the county level data of each sector, energy and non-energy consumption are not always available for technical and political reasons in China, which leads to the inevitable incompatibility of the IPCC method for this county level application; and (3) GDP is one of the most important national accounts that are primarily constructed to assist governments and others in a wide spectrum of decision making problems such analysis of markets and factors affecting market performance. Consequently, the policy-makers need an efficient way to interpret the energy consumption and CO_2 footprint in China.

To ensure the comparability of CQ rural area, an alternative of TCE/GDP based CO_2 emission estimation ($\hat{E}$) is proposed in this paper as given in Eq. (1), and the TCE/GDP energy statistics of CQ rural area are listed in Table 3. As shown in Fig. 1, κ_j is the CO_2 emission estimation of each district *j* accordingly, as can be calculated by Eq. (2), $j = 1, 2, \ldots, n_2$, $n_2 = 31$.

The energy consumption data constructed from the gross domestic product (GDP) g_j and the GDP related energy consumption e_j and electricity consumption f_j of district *j* of CQ rural area can be collected and are officially provided by the 'Chinese Energy Statistical Yearbook' and the 'Chongqing Statistical Yearbook'. $\hat{A}_j$ is the CO_2 estimation of the equivalent *energy* consumption of district *j*, $\hat{B}_j$ is the CO_2 estimation of the equivalent *electricity* consumption, as given in Eqs. (3) and (4), *t*.

$$\hat{E} = \sum_{j=1}^{n_2} \kappa_j \tag{1}$$

$$\kappa_j = \tau\gamma_0\alpha_0\beta_0(\hat{A}_j + \nu_0\hat{B}_j) \times 10^{-3} \tag{2}$$

$$\hat{A}_j = e_j g_j \tag{3}$$

$$\hat{B}_j = f_j g_j \tag{4}$$

where