Using an extended LMDI model to explore techno-economic drivers of energy-related industrial CO_2 emissions change: A case study for Shanghai (China)

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ABSTRACT

Although investment and R&D activities can exert significant effects on energy-related industrial CO_2 emissions (EICE), related factors are absent in existing index decomposition studies. This paper extends the previous logarithmic mean Divisia index (LMDI) decomposition model by introducing three novel factors (R&D intensity, investment intensity, and R&D efficiency). The extended model not only considers the conventional drivers of EICE, but also reflects the microeconomic effects of investment and R&D behaviors on EICE. Furthermore, taking Shanghai as an example, which is the economic center and leading CO_2 emitter of China, we use the extended model to decompose and explain EICE change. Also, we introduce renewable energy sources into the proposed model to carry out an alternative decomposition analysis at Shanghai's entire industrial level. The results show that among conventional (macroeconomic) factors, expanding

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output scale is mainly responsible for the increase in EICE, and industrial structure adjustment is the most significant factor in mitigating EICE. Regardless of renewable energy sources, the emission-reduction effect of energy intensity always focused on by the Chinese government is less than the expected due to the rebound effect, but the introduction of renewable energy sources intensifies its mitigating effect, partly resulting from the transmission from the abating effect of industrial structure adjustment. The effect of energy structure is the weakest. Although all the three novel factors exert significant effects on EICE, they are more sensitive to policy interventions than conventional macroeconomic factors. R&D intensity presents an obvious mitigating effect, while investment intensity and R&D efficiency display an overall promotion effect with some volatility. The introduction of renewable energy sources intensifies the promotion effect of R&D efficiency as a result of the "green paradox" effect. We argue that CO_2 mitigation efforts should be made by considering both macroeconomic and microeconomic factors to achieve a desirable emission-reduction effect.

Keywords**:** Industrial CO_2 emissions; Extended LMDI model; Investment and R&D activities; Macroeconomic factors; Microeconomic factors; Shanghai

1. Introduction

Many studies adopting the index decomposition approach (IDA) in energy and environmental impact factors analysis have been undertaken since 1980s [1-3]. Among various index decomposition methods, the logarithmic mean Divisia index (LMDI) approach in multiplicative and additive forms proposed by Ang and his colleagues [4, 5] has become the most popular method due to its incomparable advantages. Compared with other decomposition methods, the LMDI approach can absolutely eliminate residuals to realize complete decomposition and technically tackle the zero value issue. Ang [6] concluded that the LMDI approach is the most preferred decomposition method due to its outstanding properties in theoretical foundation, adaptability, the ease of use, and result interpretation. Consequently, it has gradually become the most prevailing decomposition method of driving forces of CO_2 emissions change [7-11].

However, the existing studies only considered several conventional factors on CO_2 emissions, including emission coefficient, energy mix, energy intensity, industrial structure, and output scale. These factors can address macroeconomic influences on CO_2 emissions, but cannot reveal the microeconomic root of CO_2 emissions change. Undoubtedly, enterprises' microeconomic behaviors, especially investment and R&D decision-making, play a crucial role in the performance of energy saving and emission reduction [12-17]. However, such microeconomic factors have not been investigated in the existing studies on the driving force decomposition of CO_2 emissions change. Therefore, it is necessary to combine those microeconomic factors with conventional factors to exactly explore the divers of CO_2 emissions change.

This paper fills such a gap by investigating Shanghai's energy-related industrial CO_2 emissions (EICE) for the period of 1994–2011. By using an extended LMDI model and considering 32 industrial sectors and 15 energy sources, we not only decompose EICE change into four conventional factors generally considered by the existing literature, but also introduce three novel factors specially adapted to explain the microeconomic root of EICE evolution. Therefore, the paper can be considered as an extension of the existing LMDI model and would be helpful to more comprehensively grasp the driving force of CO_2 emissions.

Since China's reform and opening-up in 1978, Shanghai has become the economic center and leading CO_2 emitter of China due to its highest levels of GDP per capita and CO_2 emissions per capita among 31 provincial-level regions of the mainland China [18]. Therefore, Shanghai is anticipated to play a leading role in responding climate change in China, which had become the world's largest CO_2 emitter in 2007 [19]. "Shanghai Energy Saving and Climate Change 12th Five-Year Plan" [20] has proposed a constraint indicator that the CO_2-equivalent emissions per GDP should decrease by 19% in 2015 compared with 2010 level and by more than 35% compared with 2005 level. This means the CO_2 emissions per GDP in Shanghai should drop from 0.84 tonnes/10^4 RMB in 2010 to 0.68 tonnes/10^4 RMB in 2015 at 2000 constant prices. [1] However, with rapid economic development, Shanghai is facing enormous challenges in promoting low-carbon development.

Shanghai Statistical Yearbooks [21] show that Shanghai's total energy consumption was 39.47 million tonnes of coal equivalent (tce) (i.e. 1156770972 GJ) in 1993, but increasing to 112.70 million tce (i.e. 3302966520 GJ) in 2011 with an average annual increase by over 10%. Such a rapid increase induced a sharp growth of CO_2 emissions, increasing from 59.68 million tonnes in 1994 to 139.65 million tonnes in 2011, with an average annual growth rate of over 5%. As depicted in Fig. 1, the share of EICE in the total energy-related CO_2 emissions of production and residential sectors in Shanghai remains above 55% over 1994-2011, indicating that industrial sector is the largest CO_2 emission sector in Shanghai. Therefore, in order to reduce the total CO_2 emissions, mitigation attention should focus on industrial sector.

Some scholars have explored the CO_2 emissions issue of Shanghai across the entire economy [22-26], but the specific investigation on the drivers of EICE change in Shanghai is absent. Since EICE change may be determined by various drivers [4], it is difficult to uncover real reasons from any single perspective. Hence, in order to provide more accurate decision-making information for

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[1] We calculate CO_2 emissions in Shanghai based on IPCC (2006), and the detailed is addressed in Section 2.

emission-reduction policy, it is critical to grasp various driving factors of EICE change and their characteristics at macroeconomic and microeconomic levels.

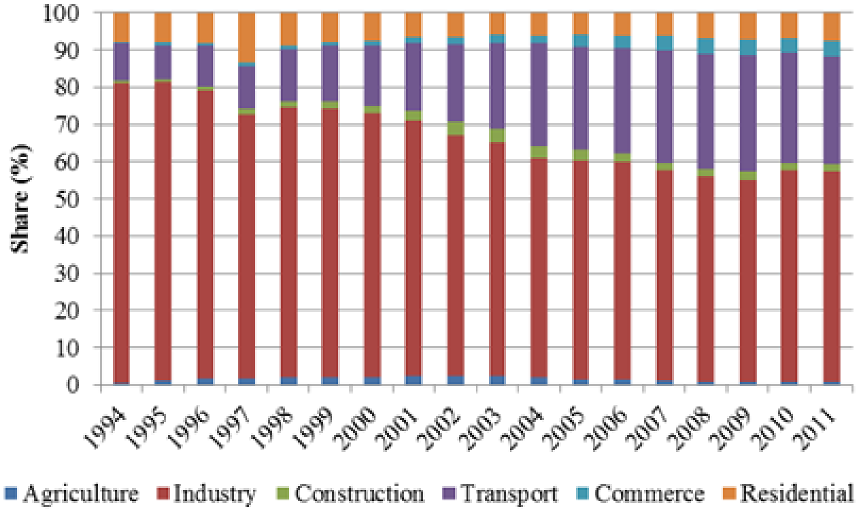

Fig. 1. Structures of energy-related CO_2 emissions of production and residential sectors in Shanghai.

The rest of the paper is organized as follows. In Sections 2, we first address some of the defects of the existing LMDI model and then present an extended LMDI decomposition model and the data description. Section 3 reports and discusses the decomposition results of EICE change in Shanghai. In Section 4, we provide some concluding remarks.

2. Methodology and data

2.1. Defects associated with existing LMDI models

It is noteworthy that the literature tends to decompose the drivers behind changing CO_2 emissions into several conventional factors, including emission coefficient, energy mix, energy intensity, industrial structure, output scale. However, besides the above factors, investment and R&D activities and their efficiency have significant impacts on industrial energy-saving and emission-reduction. If the equipment update and R&D efforts of industrial enterprises are targeting energy saving and emission reduction, then the related investment and R&D activities will facilitate the reduction in EICE. If they are targeting production scale expansion and productivity improvement, then based upon rebound effect theory, which holds that some parts of anticipative energy saving and emission reduction from the improvement of energy efficiency and productivity may be offset by the additional energy consumption and corresponding emissions resulting from the new round of economic growth induced by technological progress and efficiency improvement [27-29], the related investment and R&D activities may induce an additional increase in energy consumption and CO_2 emissions.

Such a phenomenon can be attributed to a so-called “output effect”, which is considered as one of essential function mechanisms of the rebound effect at the microeconomic level [28, 30, 31]. For instance, based on the decomposition of China’s CO_2 emissions from 1995 to 2007, Chen et al. [17] concluded that investment plays the most dominating role in increasing CO_2 emissions while the improvement of capital productivity exerts an important abating effect on CO_2 emissions. Also, based on an econometric analysis, Shao et al. [18] found that investment scale and R&D intensity have a remarkable mitigating effect and a significant promotion effect on EICE, respectively. Moreover, they concluded that technical improvement induced by the update of production equipment is the key determinant of EICE. Therefore, with regard to the investigation of driving factors on CO_2-equivalent emissions change, microeconomic factors, such as investment and R&D activities, should also be studied.

To better address the issues identified above, the analysis presented here does two things. First, based on data availability, the time span (1994–2011) of data samples in this paper is longer than those of existing studies on Shanghai’s CO_2 emissions, presenting more detailed information on historical trend of EICE change in Shanghai. Second, existing LMDI model is extended by introducing three novel factors (i.e., R&D intensity, investment intensity, and R&D efficiency).

Such an extended decomposition model not only considers the conventional driving factors of EICE change, such as energy structure, energy intensity, industrial structure, and output scale, but also includes the novel factors specially adapted to reflect microeconomic effects of investment and R&D behaviors on EICE change. It provides better understanding on the real root of EICE change so that the decision-makers can make more appropriate emission-reduction policies.

2.2. Extended decomposition model

Considering two dimensions (two-level decomposition) of 32 industrial sectors (*i*=1,2,⋯,32) and 15 energy sources (*j*=1,2,⋯,15) (see Table A.1), we adopt the LMDI approach to decompose the EICE change into the following eight factors:

$$\begin{aligned} CS &= \sum_{i=1}^{32}\sum_{j=1}^{15} CS_{ij} = \sum_{i=1}^{32}\sum_{j=1}^{15} \frac{CS_{ij}}{E_{ij}}\frac{E_{ij}}{E_i}\frac{E_i}{Y_i}\frac{Y_i}{R_i}\frac{R_i}{I_i}\frac{I_i}{Y_i}\frac{Y_i}{Y}Y \\ &= \sum_{i=1}^{32}\sum_{j=1}^{15} CC_{ij} \bullet ES_{ij} \bullet EI_i \bullet RE_i \bullet RI_i \bullet II_i \bullet IS_i \bullet Y \end{aligned} \quad (1)$$

Table 1
Definition of different variables in Eq. (1).

Variable	Definition	Variable	Definition
CS_{ij}	ICE by fuel *j* in sub-sector *i*	CC_{ij}	CO_2 emission coefficient: CO_2 emission per unit of fuel *j* in sub-sector *i*
E_{ij}	Consumption of fuel *j* in sub-sector *i*	ES_{ij}	Energy structure: share of consumption of fuel *j* in gross energy consumption in sub-sector *i*
E_i	Gross energy consumption of sub-sector *i*	EI_i	Energy intensity: gross energy consumption per unit of output in sub-sector *i*
Y_i	Output of sub-sector *i*	RE_i	R&D efficiency: output per unit of R&D expenditure in sub-sector *i*
R_i	R&D expenditure of sub-sector *i*	RI_i	R&D intensity: share of R&D expenditure in fixed asset investment of sub-sector *i*
I_i	Fixed asset investment of sub-sector *i*	II_i	Investment intensity: share of fixed asset investment in output of sub-sector *i*
Y	Gross industrial output	IS_i	Industrial structure: output share of sub-sector *i* in gross industrial output

Definitions of variables in Eq. (1) are summarized in Table 1. Among those factors, *CC*, *ES*, *EI*, *IS*, and *Y* are five familiar drivers in previous related studies, but *RE*, *RI*, and *II* never appear in existing index decomposition literature on CO_2 emissions. We define them as R&D efficiency, R&D intensity, and investment intensity, respectively. They all have significant economic meanings. R&D efficiency refers to the output per unit of R&D expenditure, reflecting the transformation capacity of R&D investment to output. All things being equal, the greater the value of *RE*, the more the output transformed from R&D expenditure. R&D intensity refers to the R&D expenditure per unit of fixed asset investment. Since R&D expenditure and fixed asset investment can be regarded as soft (innovation) and hard (physical) inputs of an industrial sub-sector, respectively, *RI* can largely reflect the innovation intensity and technological content of an industrial sub-sector. Hence, the greater the value of *RI*, the stronger the innovation sense. Investment intensity refers to the fixed asset investment per unit of output and is easy to be understood. It reflects the intensity of expanded reproduction of an industrial sub-sector. All things being equal, the greater the value of *II*, the stronger the capacity of expanded reproduction. Hence, the three novel factors can primely embody industrial investment and R&D activities at the microeconomic level. Their introduction not only keeps the integrality and consistency of existing LMDI model, but also makes up the shortcoming of existing LMDI model that it fails to examine the impacts of investment and R&D activities on CO_2 emissions change. Thus, the extended LMDI model allows us to investigate drivers of EICE change from techno-economic perspective at macroeconomic and microeconomic levels.

Taking the logarithmic differentiation of Eq. (1) with respect to time yields:

$$\frac{d\ln CS}{dt}=\sum_{i=1}^{32}\sum_{j=1}^{15}[w_{ij}(t)\bullet(\frac{d\ln CC_{ij}}{dt}+\frac{d\ln ES_{ij}}{dt}+\frac{d\ln EI_{i}}{dt}+\frac{d\ln RE_{i}}{dt}+\frac{d\ln RI_{i}}{dt}+\frac{d\ln II_{i}}{dt}+\frac{d\ln IS_{i}}{dt}+\frac{d\ln Y}{dt})] \qquad (2)$$

where $w_{ij}(t) = \frac{CC_{ij} \bullet ES_{ij} \bullet EI_i \bullet RE_i \bullet RI_i \bullet II_i \bullet IS_i \bullet Y}{CS} = \frac{CS_{ij}}{CS}$.

Integrating Eq. (2) over the time interval [0, *T*] yields:

$$\ln\frac{CS_T}{CS_0} = \sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\left(\frac{d\ln CC_{ij}}{dt} + \frac{d\ln ES_{ij}}{dt} + \frac{d\ln EI_i}{dt} + \frac{d\ln RE_i}{dt} + \frac{d\ln RI_i}{dt} + \frac{d\ln II_i}{dt} + \frac{d\ln IS_i}{dt} + \frac{d\ln Y}{dt}\right)dt \tag{3}$$

Exponentiating Eq. (3) yields:

$$\begin{aligned}\frac{CS_T}{CS_0} = {} & \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln CC_{ij}}{dt}dt\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln ES_{ij}}{dt}dt\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln EI_i}{dt}dt\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln RE_i}{dt}dt\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln RI_i}{dt}dt\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln II_i}{dt}dt\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln IS_i}{dt}dt\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15}\int_0^T w_{ij}(t)\frac{d\ln Y}{dt}dt\right)\end{aligned} \tag{4}$$

According to the Definite Integral Middle Value Theorem, Eq. (4) can be transformed as:

$$\begin{aligned}\frac{CS_T}{CS_0} \cong {} & \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{CC_{ij,T}}{CC_{ij,0}}\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{ES_{ij,T}}{ES_{ij,0}}\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{EI_{i,T}}{EI_{i,0}}\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{RE_{i,T}}{RE_{i,0}}\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{RI_{i,T}}{RI_{i,0}}\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{II_{i,T}}{II_{i,0}}\right) \\ & \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{IS_{i,T}}{IS_{i,0}}\right) \bullet \exp\left(\sum_{i=1}^{32}\sum_{j=1}^{15} w_{ij}(t^*)\ln\frac{Y_T}{Y_0}\right)\end{aligned} \tag{5}$$

where $w_{ij}(t^*)$ is a weight function given by $w_{ij}(t) = \frac{CS_{ij}}{CS}$ above at point $t^* \in [0,T]$.

Ang and Liu [32] proposed the use of the log-mean weight function introduced by Vartia [33] and Sato [34] and defined the weight function:

$$w_{ij}(t^*) = \frac{L(CS_{ij,T}, CS_{ij,0})}{L(CS_T, CS_0)} \tag{6}$$

where the logarithmic mean of two positive numbers is defined as:

$$L(x,y) = \begin{cases} (x-y)/(\ln x - \ln y), x \neq y > 0 \\ x, x = y > 0 \end{cases} \tag{7}$$

Then, Eq. (5) can be simplified as:

$$GS_{TOT} = CS_T / CS_0 = G_{CC} \bullet G_{ES} \bullet G_{EI} \bullet G_{RE} \bullet G_{RI} \bullet G_{II} \bullet G_{IS} \bullet G_Y \tag{8}$$

where $G_X = \exp\left(\sum_{i=1}^{32} \sum_{j=1}^{15} \frac{(CS_{ij,T} - CS_{ij,0})/(\ln CS_{ij,T} - \ln CS_{ij,0})}{(CS_T - CS_0)/(\ln CS_T - \ln CS_0)} \ln \frac{X_{ij,T}}{X_{ij,0}} \right)$, and *X* denotes *CC*, *ES*, *EI*, *RE*, *RI*, *II*, *IS*, and *Y*.

Eq, (8) is the multiplicative LMDI decomposition specification of EICE change, and by referring to Ang and Liu [32] and Ang [35], its corresponding additive LMDI decomposition specification can be written as:

$$\Delta CS_{TOT} = CS_T - CS_0 = \Delta CS_{CC} + \Delta CS_{ES} + \Delta CS_{EI} + \Delta CS_{RE} + \Delta CS_{RI} + \Delta CS_{II} + \Delta CS_{IS} + \Delta CS_Y \tag{9}$$

where $\Delta CS_X = \sum_{i=1}^{32} \sum_{j=1}^{15} \frac{CS_{ij,T} - CS_{ij,0}}{\ln CS_{ij,T} - \ln CS_{ij,0}} \ln \frac{X_{ij,T}}{X_{ij,0}}$.

By comparing Eq. (8) with Eq. (9), a mutual-transferable relationship between multiplicative and additive decomposition can be recognized, i.e., $\Delta CS_{TOT} / \ln GS_{TOT} = \Delta CS_X / \ln GS_X = \frac{CS_T - CS_0}{\ln CS_T - \ln CS_0}$, which makes separate decomposition using the multiplicative and additive schemes unnecessary [35].

Similar to some related studies [7, 17, 36-38], because the CO_2 emission coefficients of various energy sources are all assumed to be fixed when calculating CO_2 emissions, the G_{CC} and ΔCS_{CC} terms in Eq. (8) and Eq. (9) have no contribution to CO_2 emissions change and remain 1 and 0, respectively. Obviously, CO_2 emission coefficients are variable when taking into account the technical change of energy utilization. However, this is beyond our study scope as it involves the combustion efficiency change in engineering and technical fields. Hence, the final drivers of EICE change are decomposed into four effects and seven corresponding factors: scale effect (output scale G_Y and ΔCS_Y), structure effect (energy structure G_{ES} and ΔCS_{ES} and industrial structure G_{IS} and ΔCS_{IS}), intensity effect (energy intensity G_{EI} and ΔCS_{EI}, R&D intensity G_{RI} and ΔCS_{RI}, and investment intensity G_{II} and ΔCS_{II}), and efficiency effect (R&D efficiency G_{RE} and ΔCS_{RE}).

2.3. Data

China is now the largest carbon emission country in the world, accounting for one-quarter of global CO_2 emissions in 2011 and 80% of the world's rise in CO_2 emissions since 2008 [39, 40]. Shanghai is the economic center and the leading CO_2 emitter in China with higher GDP per capita and more CO_2 emissions per capita than other provincial-level regions. Such a special position results in that Shanghai should play a leading role in climate change mitigation. Therefore, the selection of Shanghai is of particular significance.

Based on data availability, we focus on a longer time span from 1994 to 2011 compared with all the existing studies on Shanghai. Since the scale and proportion of mining industry in Shanghai are very small and its fossil fuel consumption is close to 0 in most years, mining industry is excluded. Thus, 32 industrial sub-sectors are investigated in this study (see Table A.2).

Except EICE, all the data in Table 1 are derived from *Shanghai Statistical Yearbook on Industry, Energy and Transport* (1995–2009)*, Shanghai Statistical Yearbook on Industry and Transport* (2010–2012)*, and Shanghai Statistical Yearbook on Energy* (2010–2012). In order to eliminate the influence of price changes, we deflate the raw data at the current prices to constant 2000 prices through the corresponding price indices. Among them, the industrial output value is deflated by using the producer price indices for the products of various industrial sectors from *Shanghai Residents Life and Price Yearbook*, and the fixed asset investment and R&D expenditure are deflated by using the price indices for investment from *Shanghai Statistical Yearbook* and *Statistical Yearbook of the Chinese Investment in Fixed Assets*. In addition, the standard energy consumption used for decomposition is converted by corresponding standard coal coefficients in *China Energy Statistical Yearbook*.

We estimate the EICE of Shanghai over 1994-2011 by using the reference method proposed in the 2nd Volume (Energy Volume) of *2006 IPCC Guidelines for National Greenhouse Gas Inventories* [41] combined with China's released relevant parameters. The use of special parameters of every country is encouraged by IPCC (2006) [41] based on its methods. Therefore, we adopt the principle of priority to select the related parameters announced officially in China as well as and the second choice of the defaults provided by the IPCC (2006) [41] to assure the accuracy of the results. To obtain more accurate results, we consider all 15 fossil fuels reported in the statistical yearbooks, including raw coal, cleaned coal, coke, coke oven gas, other gases, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, refinery gas, natural gas, other petroleum products, and other coking products. The CO_2 emission coefficients of various fossil fuels and the estimated EICE of each sub-sector are reported in Tables A.1 and A.3, respectively. As we know, this paper takes into account the most energy sources among the related literature on Shanghai.

However, it's worth noting that renewable energy use is increasingly supported by the Chinese government and presents a rising trend. *China Electric Power Yearbook* [42] shows that the total power output of renewable energy sources, including solar power, wind power, and power from other renewable energy sources, [1] experienced a rapid increase from 0.09 million tce in 2004 to 8.0 million tce in 2012 in Shanghai. It has been a global consensus that the use and development of renewable energy sources will play a significant role in mitigating CO_2 emissions because the use and production processes of renewable energy sources almost can meet a zero-carbon target, regardless of the embodied CO_2 emissions of producing facilities. Hence, the absence of renewable energy sources may cause the biased decomposition results of energy intensity and energy structure. This problem is ignored by the existing index decomposition studies, which only consider fossil fuels. Although we plan to fill such a gap, unfortunate, the detailed data of renewable energy source use for industrial sub-sectors are not reported in any statistical documents. In China, the statistical data on renewable energy sources is very deficient, and only *China Electric Power Yearbook* [42] releases the power output from various renewable energy sources at the provincial level. Considering that the power generation from renewable energy sources in Shanghai is proposed for

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[1] Until now, hydropower and nuclear power are still blank in Shanghai.

the use of local production, [1] we assume that all the power generation from various renewable energy sources in Shanghai is used for industry sector and introduce it as a whole into our extended decomposition model. Such a treatment allows us to carry out an alternative factor decomposition investigation of EICE at Shanghai's entire industrial level in order to examine the effect of considering renewable energy sources on the decomposition results. The related decomposition analysis will be presented in Section 3.3.

Another important issue is whether to take into account electricity or not, which is a more complex problem. Although CO_2 is not directly emitted in the utilization of electricity, the indirect CO_2 emissions can be generated in the production process of thermal power. Such indirect CO_2 emissions caused by electricity consumption involve two aspects: local produced electricity and imported electricity. The former (i.e. local thermal power generation) has been considered in our study when estimating the EICE of industrial sub-sector of production and supply of electric power in Shanghai. As depicted in Fig. 2, the EICE from local thermal power generation remains a tiny value and share in the total EICE in most years, with a peak of 2.2% in 1999, and thereafter, its share keeps below 0.4%, indicating its minor role in the total EICE in Shanghai. With respect to the indirect CO_2 emissions from imported electricity, we are unable to calculate them because of the limitation of data availability. In China, there are hardly official statistical data to report the purchased electricity and its source of power generation across provinces. We only obtain the amounts of imported and locally generated electricity in Shanghai as a whole (see Table 2), but their source of power generation (thermal or renewable), place of origin, and used sector are not available. As shown in Table 2, although the industrial share in the total electricity consumption in

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[1] See *Shanghai Energy Development 11th Five-Year Plan*, http://www.shanghai.gov.cn/nw2/nw2314/nw2319/nw10800/nw11407/nw15790/u26aw8773.html

Shanghai presented a gradually downward trend from 77.74% in 1994 to 60.15% in 2011, industry keeps the largest consumer of electricity among various sectors in Shanghai. It is impossible to grasp the shares of imported and locally generated electricity in the total electricity consumption of both overall industry and its sub-sectors. Fortunately, a recent study [43, 44] indicates that unlike residential and commercial sectors, industrial electricity consumption in Shanghai is from local power plants. An energy flow analysis for Shanghai in 2010 from Energy Research Center of Fudan University [43] and Pan et al. [44] shows that the share of residential and commercial sectors in the total imported electricity is 110.2% in Shanghai, indicating that the imported electricity in Shanghai is mainly used by residential and commercial sectors rather than industrial sector. Therefore, following some related studies focusing on China and Shanghai [7, 17, 18, 22, 25, 26, 36, 37], we can ignore the effect of indirect EICE from imported electricity consumption on the decomposition results.

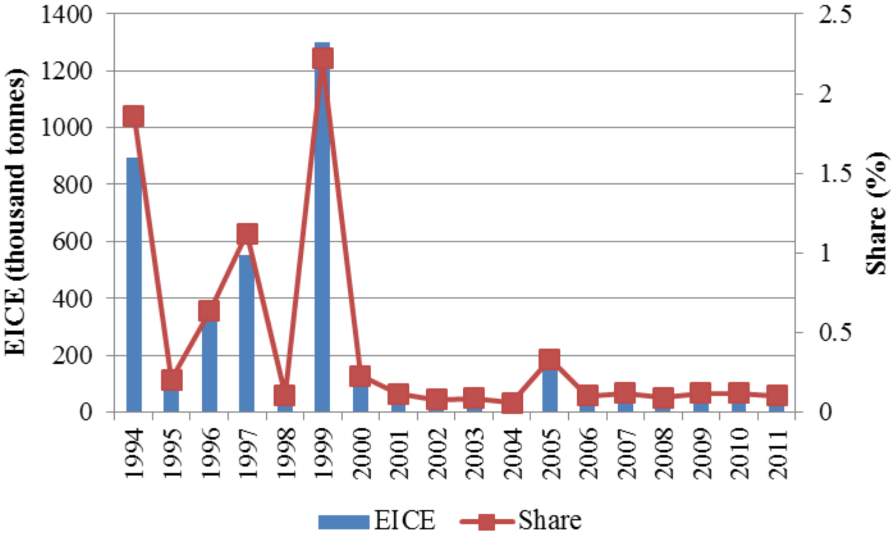

Fig. 2. Trends of EICE and its share of production and supply industry of electric power in Shanghai.

Table 2
Electricity balance and consumption in Shanghai (unit: 100 million kW•h).

Year	Local generation	Import	Export	Local consumption	
				Total	Industrial
1994	401.68	44.50 (11.79%)	68.88	377.30	293.31 (77.74%)
1995	406.82	46.36 (11.50%)	49.91	403.27	307.01 (76.13%)

1996	429.70	42.02 (9.76%)	41.32	430.40	318.18 (73.93%)
1997	459.18	45.40 (9.99%)	50.32	454.26	333.79 (73.48%)
1998	482.40	51.62 (10.69%)	51.08	482.94	343.60 (71.15%)
1999	499.85	52.73 (10.52%)	51.38	501.20	358.31 (71.49%)
2000	557.83	64.05 (11.45%)	62.46	559.42	393.13 (70.27%)
2001	576.35	73.59 (12.41%)	56.95	592.99	413.33 (69.70%)
2002	615.98	100.51 (15.57%)	70.78	645.71	447.46 (69.30%)
2003	693.93	126.12 (16.91%)	74.08	745.97	507.00 (67.97%)
2004	710.72	196.71 (23.83%)	81.99	825.44	555.08 (67.25%)
2005	740.94	201.43 (21.85%)	20.40	921.97	617.59 (66.99%)
2006	726.66	271.83 (27.45%)	8.34	990.15	657.16 (66.37%)
2007	740.97	346.76 (32.36%)	16.23	1071.50	706.33 (65.92%)
2008	794.16	383.43 (33.71%)	40.22	1137.37	725.64 (63.80%)
2009	781.79	389.81 (33.82%)	19.13	1152.47	697.48 (60.52%)
2010	943.89	399.20 (30.81%)	47.22	1295.87	786.61 (60.70%)
2011	1026.32	372.02 (27.77%)	58.72	1339.62	805.76 (60.15%)

Note: Local total consumption is equal to the sum of production and import deducted export; The percentages in parentheses are shares of import and industrial consumption in the total consumption, respectively; The data is derived from *Shanghai Statistical Yearbook* [21].

3. Results and discussion

3.1. Overall trends and contributions of various factors

We handle the zero values in the data set according to Ang et al. [5] and utilize Matlab7.6.0 to perform the decomposition process above. To reinforce the convenience and comprehensibility of analysis, we report the results of both multiplicative and additive decomposition considering that the former presents the comparative index of EICE change and the latter indicates its exact magnitude, which also facilitates the calculation of contributions of various factors to EICE change. Fig. 3 illustrates the trends of output value and EICE of entire industry in Shanghai in order to give assistance to discuss the decomposition results. The multiplicative and additive decomposition results of EICE change in entire period and three “Five-Year Plan” periods are listed in Figs. 3 and 4, respectively. Detailed results are listed in Tables A.4 and A.5.

Overall, there is an obvious EICE increase, with a value of 30.93 million tonnes from 1994 to 2011 (see Fig. 3 and Table A.5), and a growth rate of 64.3% (see Table A.4). EICE presents an accelerated increasing trend at three consecutive “Five-Year Plan” stages (see Fig. 5 and Table A.4).[1] During the 9th “Five-Year Plan” period (1995–2000), EICE’s increase and growth rate are 1.53 million tonnes and 3.0%, respectively, which are lower than those of other stages resulting from closing 84 thousands of small-scale emission-intensive enterprises during this period (See *White Paper on Environmental Protection in China 1996–2005*). During the 10th “Five-Year Plan” period (2000–2005), EICE had a great rise of 7.78 million tonnes by 14.6%, which can be attributed to the emergence of heavy industrialization in Shanghai reflected by a sharp rise of proportion of heavy industry output from 58.7% in 2000 to 74.5% in 2005. During the 11th “Five-Year Plan” period (2005–2010), although the Chinese government first proposed a quantitative constraint indicator of CO_2 emissions reduction and intensified the implementation of emission-reduction policy, Shanghai’s EICE had a faster rise than the last two periods, with an increase of 20.54 million tonnes by 33.7%, which is closely related to the notable rise of industrial production scale compared with the last two periods (see Fig. 3). The trend distinctly heightens the emission-reduction pressure in Shanghai. It is noteworthy that in the first year of 12th “Five-Year Plan” period (2010–2011), EICE had a decrease of 3.0% (see Fig. 3 and Table A.4), indicating the positive results of previous emission-reduction efforts.

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[1] This observation is based on a comparison of EICE changes presented in Fig. 5 ((a), (b), and (c)) and Table A.4 at three consecutive “Five-Year Plan” stages.

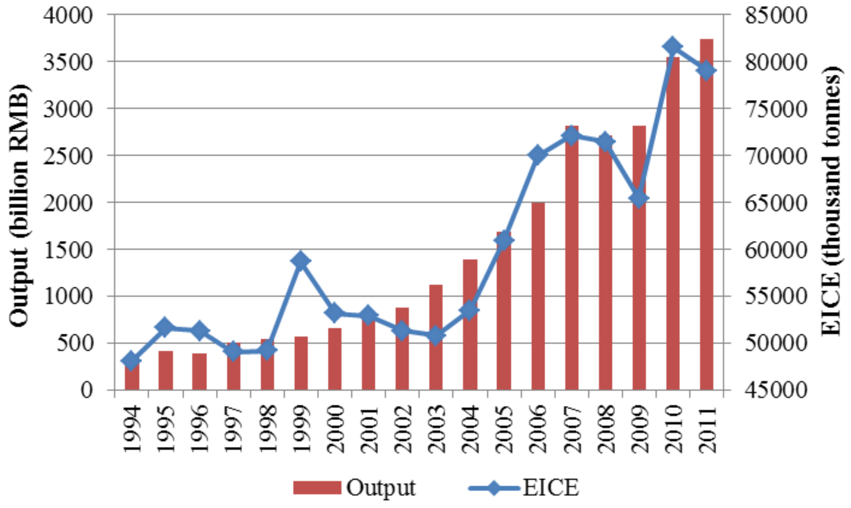
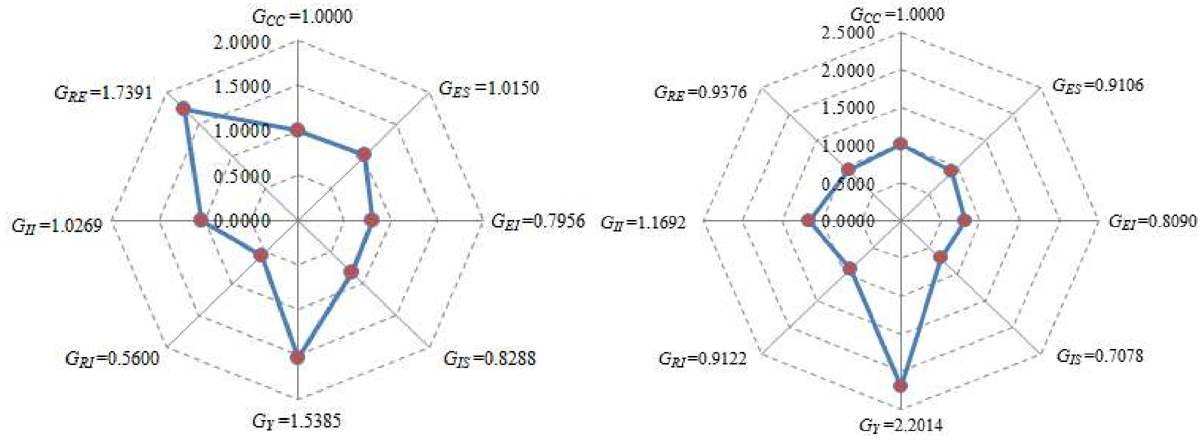
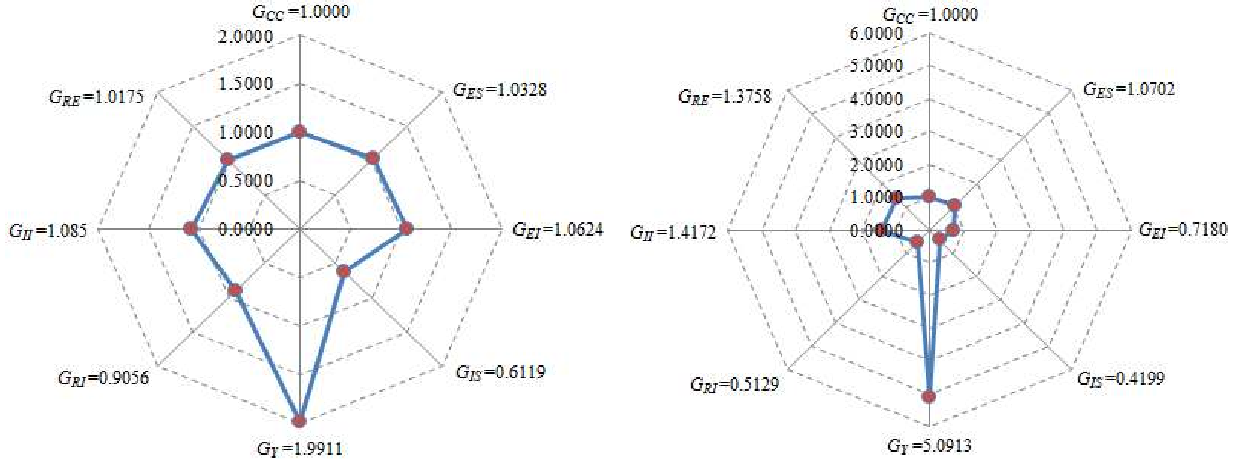


Fig. 3. Trends of output value and EICE of entire industry in Shanghai.

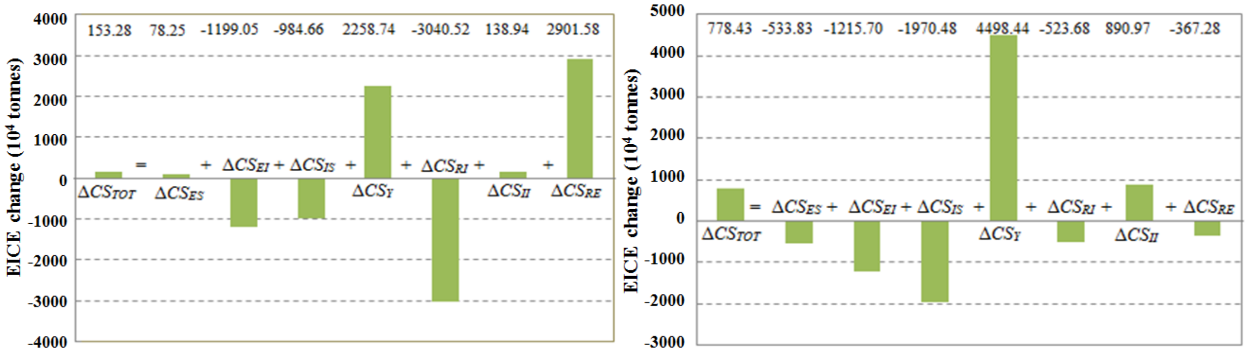


(a) 1995–2000 (b) 2000–2005

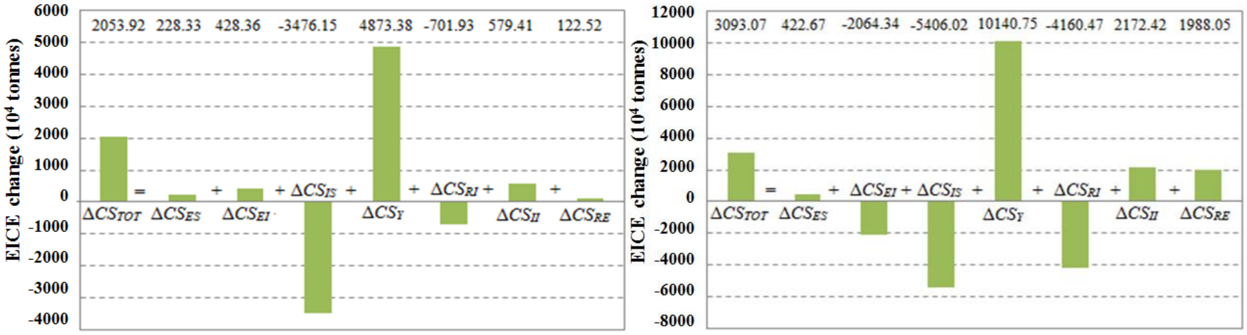


(c) 2005–2010 (d) 1994–2011

Fig. 4. Multiplicative decomposition results of EICE change in entire period and three “Five-Year Plan” periods (G_{CC}, G_{ES}, G_{EI}, G_{IS}, G_Y, G_{RI}, G_{II}, and G_{RE} denote the effects of emission coefficient, energy structure, energy intensity, industrial structure, output scale, R&D intensity, investment intensity, and R&D efficiency on EICE change, respectively).



(a) 1995–2000 (b) 2000–2005



(c) 2005–2010 (d) 1994–2011

Fig. 5. Additive decomposition results of EICE change in entire period and three “Five-Year Plan” periods ($\triangle CS_{ES}$, $\triangle CS_{EI}$, $\triangle CS_{IS}$, $\triangle CS_Y$, $\triangle CS_{RI}$, $\triangle CS_{II}$, and $\triangle CS_{RE}$ denote the effects of energy structure, energy intensity, industrial structure, output scale, R&D intensity, investment intensity, and R&D efficiency on EICE change, respectively).

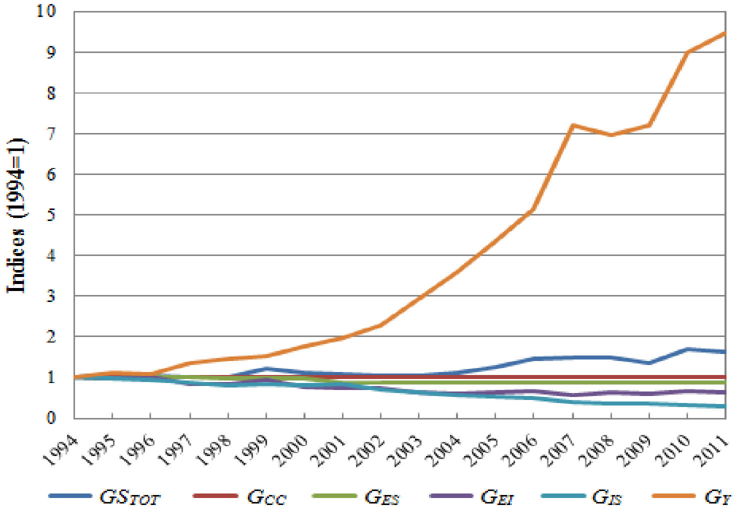
Next, we will discuss the contributions of various factors to EICE change, which refers to the proportion of EICE change caused by each factor at time *T* (i.e., the additive decomposition result of each factor) in the total EICE at time 0. Table 3 reports the contribution of each factor calculated through the additive results in Table A.5. With contributions from high to low during 1994–2011, the promotion factors of EICE are output scale (210.8%), investment intensity (45.2%), R&D efficiency (41.3%), and energy structure (8.8%), while the mitigating factors are industrial structure (-112.4%), R&D intensity (-86.5%), and energy intensity (-42.9%). Fig. 4 (d) and Fig. 5 (d) show that total promotion effects (306.0%) are much greater than total mitigating effects (-241.7%), causing a remarkable increase of 64.3% in EICE over 1994–2011. Particularly, the multiplicative and additive decomposition results of output scale are 5.09 and 101.41 million tonnes, respectively, resulting in that output scale becomes the first driver of EICE growth (see Fig. 6).

Table 3
Contributions of various factors to EICE change (unit: %).

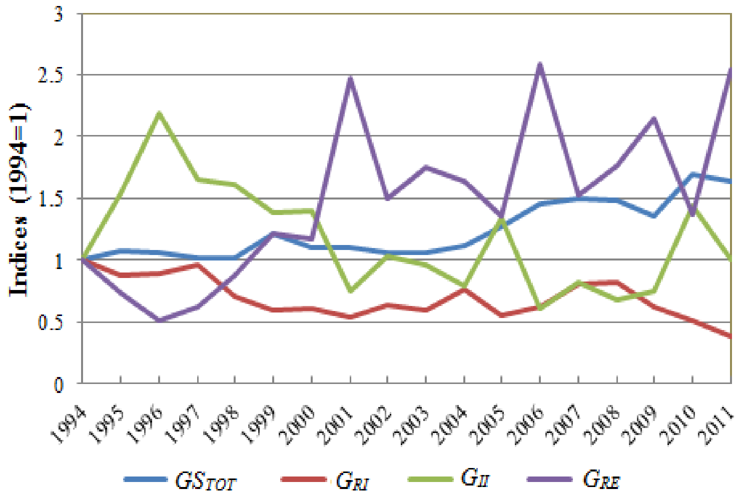
Stage	Growth of EICE	Energy structure	Energy intensity	Industrial structure	Output scale	R&D intensity	Investment intensity	R&D efficiency
1994-1995	7.39	-2.27	-1.17	-2.41	13.23	-14.00	44.77	-30.76
1995-1996	-0.71	2.90	2.64	-2.49	-3.77	2.25	34.99	-37.24
1996-1997	-4.28	0.26	-17.29	-9.70	22.45	6.74	-27.25	20.51
1997-1998	0.26	-2.23	0.84	-5.42	7.06	-30.73	-2.87	33.61
1998-1999	19.19	-2.00	12.46	3.67	5.06	-18.61	-16.43	35.04
1999-2000	-9.33	0.62	-18.97	-3.16	12.18	2.00	1.34	-3.34
2000-2001	-0.49	-9.05	-5.38	2.18	11.77	-11.97	-62.42	74.39
2001-2002	-3.11	-0.33	-2.13	-15.43	14.78	17.17	31.99	-49.17
2002-2003	-0.95	-0.78	-11.98	-12.48	24.29	-6.93	-8.12	15.05
2003-2004	5.37	-0.33	-4.24	-11.23	21.18	25.48	-19.07	-6.41
2004-2005	13.91	-0.60	1.20	-7.07	20.38	-36.04	56.43	-20.38
2005-2006	14.75	1.66	4.62	-8.97	17.44	14.99	-84.32	69.33
2006-2007	3.05	0.17	-11.31	-20.35	34.54	24.68	29.08	-53.76
2007-2008	-0.91	0.02	8.72	-6.18	-3.47	2.71	-17.61	14.90
2008-2009	-8.43	-1.06	-3.91	-6.73	3.27	-27.10	8.44	18.66
2009-2010	24.60	1.15	8.07	-9.51	24.89	-22.12	72.77	-50.65
2010-2011	-3.04	-0.39	-1.60	-6.11	5.06	-26.01	-34.99	61.00
1995-2000	2.97	1.51	-23.21	-19.06	43.71	-58.84	2.69	56.15
2000-2005	14.63	-10.03	-22.85	-37.04	84.55	-9.84	16.75	-6.90
2005-2010	33.68	3.74	7.02	-57.00	79.91	-11.51	9.50	2.01
1994-2011	64.28	8.78	-42.90	-112.35	210.75	-86.47	45.15	41.32

Note: Negative numbers denote the positive (favorable) contribution of reducing EICE.

Cumulative decomposition results converted from multiplicative decomposition results in Table A.4 are presented in Fig. 6 (see detailed results in Table A.6) to smooth the short-term fluctuant effects of various factors [37]. Due to the high volatility of G_{RI} , G_{II} and G_{RE} , we separately plot their results in Fig. 6 (b) for clear observation. Over 1994–2011, only output scale remains a positive effect on EICE and presents a sharp upward trend except 2008, revealing the dominant effect of output scale expansion on EICE growth, while other conventional factors remain the negative effects on EICE. Among them, industrial structure exerts the strongest mitigating effect. With respect to the three novel factors, only R&D intensity presents a persistent mitigating effect, while investment intensity and R&D efficiency show a very significant volatility, especially after 2000, with the circuitous downward and circuitous upward trends, respectively, indicating that after the 10th “Five-Year Plan”, industrial enterprises switched their investment and R&D directions owing to the impact of policy intervention. Overall, all the three novel factors exert the significant effects on EICE change, implying that it is necessary to take into account investment and R&D behaviors when examining the drivers of EICE (change).



(a) Trends of five conventional factors



(b) Trends of three novel factors

Fig. 6. Cumulative decomposition results of EICE change (1994=1) (G_{CC}, G_{ES}, G_{EI}, G_{IS}, G_Y, G_{RI}, G_{II}, and G_{RE} denote the effects of emission coefficient, energy structure, energy intensity, industrial structure, output scale, R&D intensity, investment intensity, and R&D efficiency on EICE change, respectively).

3.2. Explanation for influential direction changes of various factors at different stages

Since 1953, the Chinese government and its local governments would proposed a plan for national economic and social development every five years (there was an interval over 1963-1965), namely, "Five-Year Plan". It has been a consensus that China's development has an obvious five-year periodic property. Accordingly, to further explore the characteristics and reasons of EICE changes, we regard five years as one stage and compare the decomposition results at each stage with those at the end of the last corresponding stage. We display the trend of each factor in Table 4 and Fig. 7. For convenient comparison, we also report the contribution of each factor at the end of the 8th "Five-Year Plan" (1994–1995) and at the beginning of the 12th "Five-Year Plan" (2010–2011), when two major reform events of China just took place, respectively. The first was China's fiscal decentralization reform in 1994, when China's fiscal and taxation system was reconstructed. The impact of such a major reform on CO_2 emissions have been investigated by some researchers.

Zhang et al. [45] found that fiscal decentralization weakens the incentive of local governments to control CO_2 emissions and exerts a promotion effect on CO_2 emissions mainly in secondary industry. Fig. 3 illustrates that Shanghai’s EICE presented a rise during 1994-1995, which is just consistent with the conclusion of Zhang et al. [45]. Such an observation provides a reasonable support for considering the sub-period of 1994–1995. The second was the initial introduction of CO_2 emission reduction target as a constraint indicator into China’s “Five-Year Plan” at the end of 2010, when China’s 12th “Five-Year Plan” put forward that CO_2 emissions per GDP should decline by 17% compared with the 2010 level. This is the first time for China to propose a quantitative constraint indicator on carbon reduction in its “Five-Year Plan”. Whether the target could be effectively achieved has been a focus of the public and academia. As depicted in Fig. 3, Shanghai’s EICE just showed a decline during 2010-2011, indicating a preliminary result of China’s CO_2 emission reduction policy. Whereas, it is still necessary to comparably explore the driving force of such a decline. Therefore, we divide our observed period into five stages, including three “Five-Year Plan” stages and two rest stages. The influential direction change and its explanation on various factors on EICE change are addressed next.

Table 4

Types and trends of contribution of various factors at five development stages.

Type	Decomposition factor	Trend [a]	Average contribution rate (%)
Scale effect	Output scale	+ + + + +	45.29
Structure effect	Energy structure	－ + － + －	-1.49
	Industrial structure	－ － － － －	-24.32
Intensity effect	Energy intensity	－ － － + －	-8.36
	R&D intensity	－ － － － －	-24.04
	Investment intensity	+ + + + －	7.74
Efficiency effect	R&D efficiency	－ + － + +	16.30

[a] The sequence of trends is the end of the 8th “Five-Year Plan” (1994–1995), the 9th (1995–2000), the 10th (2000–2005), the 11th “Five-Year Plan” (2005–2010), and the beginning of the 12th “Five-Year Plan” (2010–2011); + and －stand for positive effect and negative effect on EICE change, respectively.

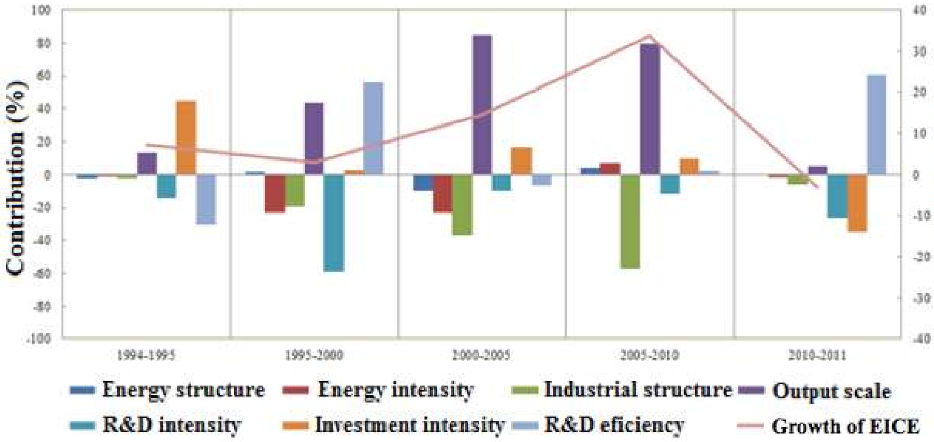


Fig. 7. Growth of EICE and contributions of its decomposition factors at five stages (i.e., the end of the 8th "Five-Year Plan" (1994–1995), the 9th "Five-Year Plan" (1995–2000), the 10th "Five-Year Plan" (2000–2005), the 11th "Five-Year Plan" (2005–2010), and the beginning of the 12th "Five-Year Plan" (2010–2011)).

(1) Scale effect: output scale. Industrial output growth is the most prominent factor for EICE growth at three full "Five-Year Plan" stages (see Fig. 7). This finding is consistent with the conclusions of most related studies [9, 36, 37]. Energy is considered as the most basic production factor. Economic development characterized by industrialization and urbanization induces substantial energy consumption and corresponding EICE [9]. Therefore, EICE's rise is a concomitant outcome of economic development and increasing industrial output in Shanghai. As shown in Fig. 3, except 1995–1996 and 2007–2008, industrial output scale in Shanghai experienced an obvious upward trend with an increase of above 10 times from 359.24 billion RMB in 1994 to 3743 billion RMB in 2011 by an average annual growth rate of over 15%. The average annual [1] increases in EICE resulting from output growth are 6.37, 4.52, 9.00, 9.75, and 4.13 million tonnes with the corresponding growth rates of 13.6%, 10.8%, 24.0%, 19.8%, and 5.3% at five stages (see Figs. 3 and 4 and Tables. A.4 and A.5), respectively, while the corresponding average annual growth rates of industrial output are 14.6%, 9.8%, 20.5%, 16.1%, and 5.3%, respectively,

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[1] For convenient comparison, we report the annual averages of actual results at three "Five-Year Plan" stages.

indicating that EICE and industrial output have the similar trends and thus EICE change largely depends on industrial growth.

(2) Structure effect: industrial structure and energy structure. Industrial structure adjustment provides a mitigating effect on EICE at all five stages and becomes the most influential factor in reducing EICE according to average contribution (see Fig. 7 and Table 4). This finding is different from the conclusions of some relevant studies [9, 36, 37] at the national level of China, indicating that industrial structure adjustment in Shanghai is more effective for mitigating CO_2 emissions than that of the whole nation. Industrial structure adjustment means that production resources are reallocated among industrial sectors with different technologies, efficiencies, and profits, inducing the changes of output share among different sectors. According to neoclassical growth theory, structural adjustment is an important source of sustainable growth and a radical approach to transform the development pattern [7]. Timmer and Szirmai [46] referred to the positive effect of structural adjustment on economic growth as the structural bonus hypothesis.

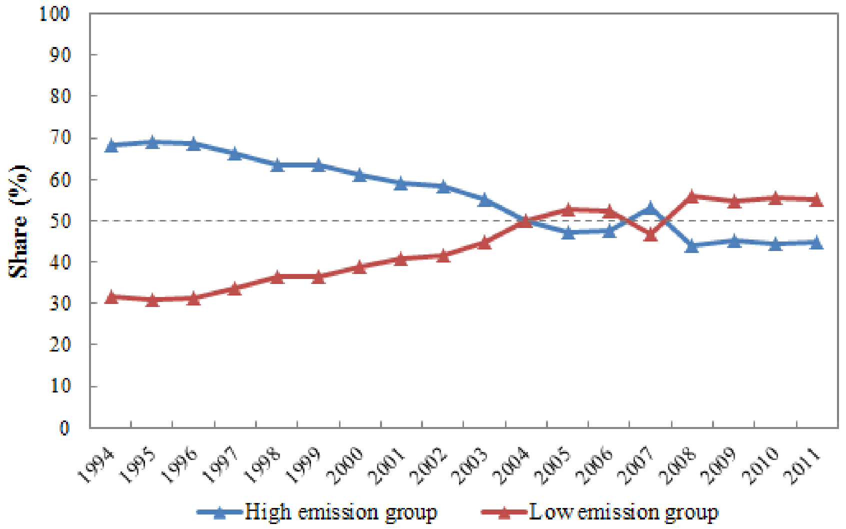


Fig. 8. Trends of output structure between high and low emission groups of industry in Shanghai (According to the ranking of annual average EICE over 1994-2011, high emission group corresponds to the top half of sub-sectors, and low emission group to the last half of sub-sectors).

Following Chen et al. [47], we consider industrial structural adjustment as the flow of production factors between industrial sectors with low energy consumption and CO_2 emissions and those with high energy consumption and CO_2 emissions. Since the development and opening of Pudong new district in Shanghai in 1990, Shanghai's industrial structure has gradually transformed from raw material processing and manufacturing with high energy use and pollutant emissions to a more balanced industrial development. High-tech industries with high added value and low energy use and CO_2 emissions, such as electronic and information technology industry, have rapidly developed in Shanghai. As depicted in Fig. 8, the output share of low emission group continuously increased while that of high group symmetrically decreased before 2005, and the share of the former first exceeded that of the latter in 2004. After that, although the share of the former decreased in some years such as 2006, 2007, and 2009, it remains dominant compared with the latter except 2007. Therefore, the contribution of industrial structure to EICE change is negative in most years. The average annual decreases in EICE resulting from industrial structural adjustment are 1.16, 1.97, 3.94, 6.95, and 4.98 million tonnes with corresponding decline rates of 2.3%, 3.4%, 5.8%, 7.8%, and 6.0% at five stages (see Figs. 3 and 4 and Tables. A.4 and A.5), respectively, indicating that factors' reallocation among different sectors drives the reduction in EICE and structural bonus exists in Shanghai.

Conversely, the effect of energy structure is the weakest and displays distinct instability, i.e. contributes alternatively to increased and decreased EICE over different periods of time. Most relevant studies also draw the similar conclusions and argue that it can be attributed to the coal-dominant energy endowment and consumption structures in China [9, 17, 37, 38, 48]. CO_2 emission coefficient of coal is higher than those of oil and gas. Hence, unlike other countries, the long-term coal-dependent energy structure determines that most energy-related CO_2 emissions in China come from burning coal. Although the share of EICE from coal-type fuel use decreased by about 20% from 1994 to 2011 (see Fig. 9), implying that industrial energy consumption structure in Shanghai has been improved to some extent, coal-type fuels are still EICE's main source, remaining the share of above 50% except 2006 and 2009. Average annual EICE changes resulting from energy structural adjustment are -1.09, 0.16, -1.07, 0.46, and -0.32 million tonnes at five stages (see Table A.5), indicating that the impact of energy structural adjustment on EICE is relatively marginal and its influential direction is sensitive. In the reality, it is difficult to mitigate EICE by altering the traditional coal-dominant energy structure in both China and Shanghai in the short term. The low-carbon pathway of energy structure adjustment requires longer time and more efforts [9].

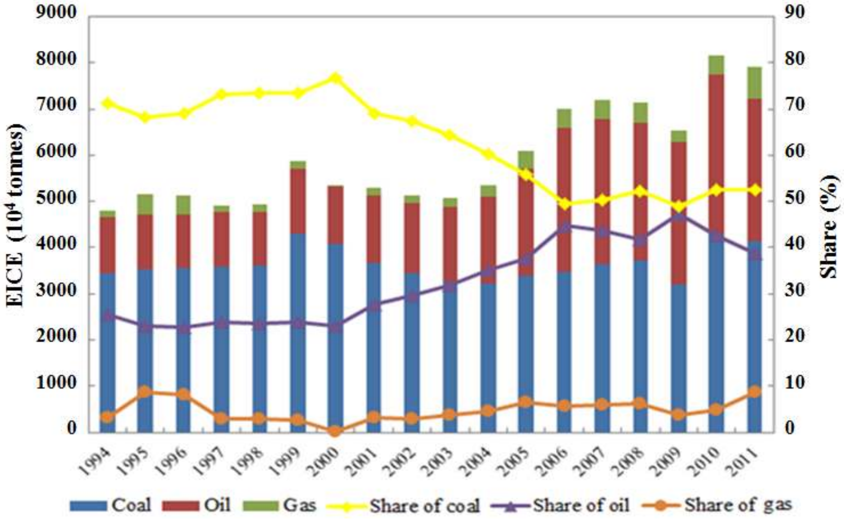


Fig. 9. Trend of EICE's energy source structure of entire industry in Shanghai.

(3) Intensity effect: energy intensity, R&D intensity, and investment intensity. Energy intensity and investment intensity are two factors with slight fluctuations in the influential direction, while R&D intensity remains mitigating effect on EICE at five stages.

Similar to most related studies, we find that the decline of energy intensity has a restriction effect on EICE except the 11th "Five-Year Plan" (see Fig. 7 and Table 4). The mitigation of CO_2 emissions largely depends on the decline of energy intensity, which implies the improvement of energy efficiency [7]. The energy intensity of entire industry in Shanghai experienced an obvious downward trend from 5.5 tce/10^5 RMB in 1994 to 0.95 tce/10^5 RMB in 2011, indicating continuous improvement of energy efficiency. Accordingly, as expected, energy intensity exerts a visible mitigating effect on EICE in most years. Conversely, once a sudden rise in energy intensity in some years occurred, e.g., 1996, 1999, and 2008, its contributions to EICE change became positive. Such results imply that the promotion of energy efficiency plays a crucial role in abating EICE.

However, some ambiguous years should not be neglected, e.g., 1998, 2005, 2006, and 2010, when a decline of energy intensity induced a promotion effect on EICE. The paradox can be clarified by the following two aspects. First, following related studies [7, 48], the impact of energy intensity on CO_2 emissions implicates an industrial structure effect, i.e., the energy intensity change of the largest CO_2 emissions sub-sector largely determines the influential direction of energy intensity of entire industry on the total CO_2 emissions. With respect to Shanghai, the average annual EICE of smelting and pressing of ferrous metals (SPFM) are 28.12 million tonnes and much larger than other sectors, with nearly 50% share in the total EICE. The trend of SPFM's energy intensity change is very close to that of multiplicative decomposition index of energy intensity factor (see Fig. 10), indicating that the influential direction of energy intensity on EICE change largely depends on SPFM's energy intensity change. This can explain the "paradox" in 1998 and 2010. Second, the rebound effect doctrine widely studied in recent years can be used to illuminate the "paradox" in 2005 and 2006, when both entire and SPFM's energy intensity declined with a positive contribution to EICE. As mentioned above, the rebound postulate holds that energy efficiency improvement reduces the unit cost and price of energy products, inducing an increase in the demand and consumption of productive services, which then incurs additional energy consumption. This lost part of energy conservation is called the rebound effect [27]. Some studies [29, 49, 50] testified that the rebound phenomenon exists in China and Shanghai. Therefore, the efforts of reducing energy intensity do not always decrease energy consumption and CO_2 emissions.

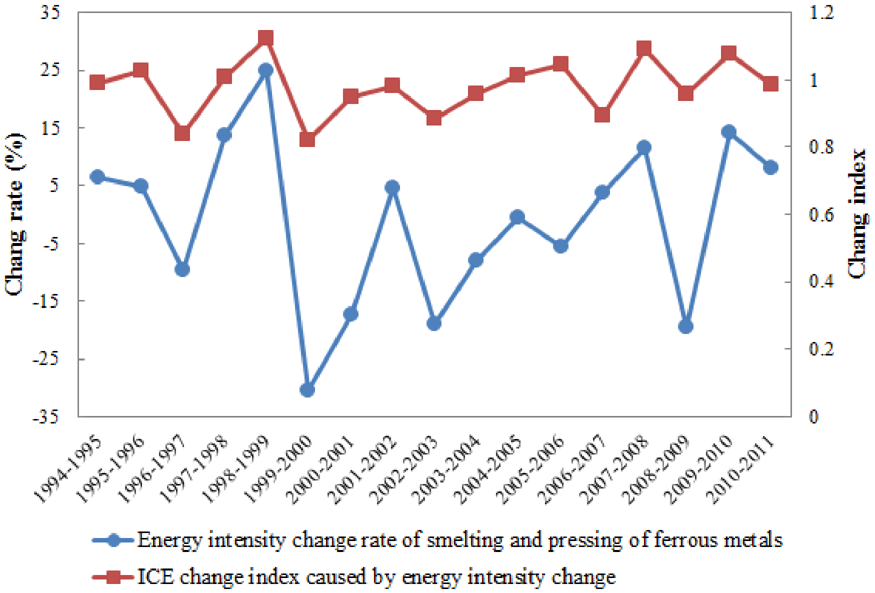


Fig. 10. Trends of energy intensity change rate of smelting and pressing of ferrous metals and multiplicative decomposition index of energy intensity factor.

Nevertheless, it is noteworthy that most related studies propose that improved energy intensity is the most prominent factor for mitigating CO_2 emissions in both China and Shanghai [7, 9, 17, 36, 37]. But our results indicate that it is not the most effective factor for mitigating EICE and its contribution is less than those of industrial structure and R&D intensity in the light of both average contribution at five stages and overall contribution over 1994–2011. The difference can be explained by one of three novel factors, namely, R&D intensity.

Many studies [7, 36, 51-53] found that technological progress is a crucial factor historically driving the promotion of energy efficiency in China. Considering that technology is an intangible asset and difficult to be directly measured, R&D expenditure is usually employed by many studies [15, 52-54] as a proxy of technology. Hence, the R&D intensity factor can reflect the impact of technological progress on EICE to some extent. In other words, R&D intensity and energy efficiency can reflect pure technological progress and its performance in energy conservation, respectively. However, existing studies on CO_2 emissions decomposition take no account of R&D intensity and thus employ energy intensity as a composition factor including technological progress and energy efficiency. Unlike them, our decomposition model embodies both energy intensity and R&D intensity, which allows us to distinguish pure technological progress factor (R&D intensity) from energy intensity. The total contributions of energy intensity and R&D intensity are -32.4% in Table 4 and -129.4% (for 1994–2011) in Table 3, respectively, more than those of the corresponding contributions (-24.3% and -112.4%) of industrial structure, implying that technological effect is still the most prominent factor for abating EICE in Shanghai. Therefore, from the perspective of aggregated technology effect, our result is consistent with that of most related studies.

As expected, R&D intensity presents a mitigating effect on EICE in most years, causing the average annual EICE reductions of -6.74, -6.08, -1.05, -1.40, and -21.21 million tonnes at five stages (see Fig. 5 and Table A.5), respectively. This finding is consistent with the conclusion of Fan et al. [55]. R&D intensity experienced a remarkable decrease trend from 12.9% in 1994 to 2.3% in 2011 with a peak value in 1997 (see Fig. 11), while the total R&D expenditure had a relatively unobvious fluctuation between 2 and 4 billion RMB apart from few particular yeas (see Fig. 12). Hence, the dramatic downward trend of R&D intensity can be explained by substantially increasing fixed asset investment, which raised from 29.87 billion RMB in 1994 to 113.40 billion RMB in 2010 with a growth of approximately 4 times (see Fig. 12), revealing a notable advanced efficiency of R&D activities in energy conservation and emission reduction and an evident neglect of technology investment.

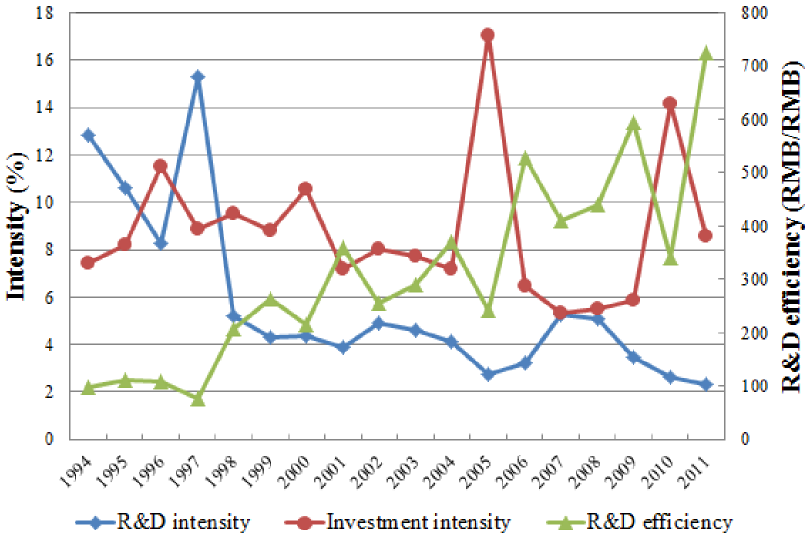


Fig. 11. Trends of R&D intensity, investment intensity, and R&D efficiency of entire industry in Shanghai.

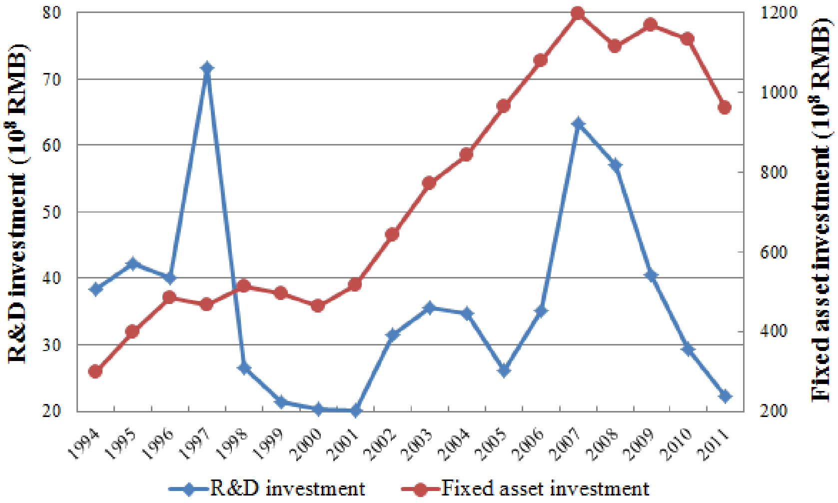


Fig. 12. Trends of R&D investment and fixed asset investment of entire industry in Shanghai.

It is noteworthy that the actual contribution of R&D intensity to reduce EICE largely depends on whether R&D activities is typically targeted at energy saving and emission reduction. As the result of R&D activities, the argument that technological progress is generally directed rather than neutral has been widely accepted [56]. Like a double-edged sword, R&D activities and its induced technological progress can exert either positive or negative effect on mitigating EICE. On one hand, if R&D efforts are mainly made to develop energy-saving and emission-reduction technologies or cleaner production technologies, then the induced technological progress will promote energy efficiency, carbon productivity, and the utilization of renewable energy sources to facilitate the abatement of CO_2 emissions. In this case, the technological progress is entitled as green technological progress, which is regarded as the permanent driving force of energy saving and emission reduction and sustainable development [57]. On the other hand, if R&D activities are mainly exerted to develop new products and improve the productivity of input factors, especially physical capital, then the induced technological progress will cause the expansion of production scale and the increases in input factors including energy use to go against the achievement of energy saving and emission reduction. The famous "Jevons' paradox" is a typical example of this case, which maintained that technological efficiency gains, specifically the more "economical" use of coal in engines doing mechanical work, actually increased the overall consumption of coal, iron, and other resources, rather than "saving" them [58, 59]. This is also an extreme case of the rebound effect mentioned above and entitled as backfire effect [59].

In short, R&D intensity should be considered as a crucial factor when decomposing EICE change as the influential direction of R&D intensity can be regarded as an indicator of "green" preference of R&D activities. Tables 3 and 4 show that R&D intensity exerts a positive effect on abating EICE in most years and at five sub-periods, indicating a "green" preference of industrial R&D activities in Shanghai.

So far, a satisfied explanation of the mitigating effect of R&D intensity on EICE have not been given, but the clue can be found from the comparison between the trend of R&D intensity change rate of SPFM and that of multiplicative decomposition index of R&D intensity (see Fig. 13). Similar to the industrial structure effect of energy intensity change mentioned above, as the largest EICE sub-sector, SPFM's R&D intensity change largely determines the influential direction of entire R&D intensity on EICE as a result of the close trends of the change rate and index in Fig. 13. Especially, after 2003, the emergence of heavy industrialization in Shanghai intensified the impact of SPFM as a representative of heavy industry on entire EICE change. Moreover, compared with energy intensity, the contribution of R&D intensity is relatively large in most years, indicating that microeconomic factors like R&D intensity are more easily adjusted in the short run and exert more flexible effects on EICE compared with macroeconomic factors like energy intensity.

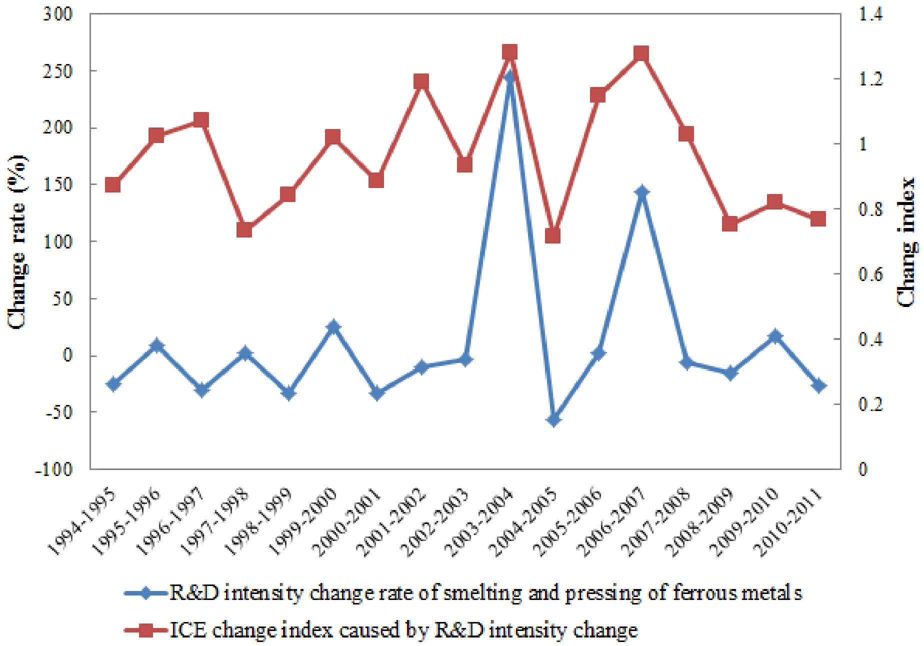


Fig. 13. Trends of R&D intensity change rate of smelting and pressing of ferrous metals and multiplicative decomposition index of R&D intensity effect on EICE in Shanghai.

Average annual EICE changes induced by investment intensity are 21.54, 0.28, 1.78, 1.16, and -28.52 million tonnes with the corresponding change rates of 54.0%, 0.5%, 3.4%, 1.7%, and -30.0% at five stages (see Figs. 3 and 4 and Tables A.4 and A.5), respectively, indicating a duality and an indirect improvement trend of its impact on EICE. China's economy has experienced a high-investment and high-growth period Since 1980s. Investment has become a primary driving force of economic growth. Hence, investment should be a principal influential factor on EICE. The increase in absolute investment scale means a new round of output growth, causing relevant increase in energy demand and EICE. However, investment intensity is a relative variable and thus shows a dual effect on EICE. On one hand, the increasing investment intensity can augment EICE through production scale expansion. On the other hand, it can improve energy utilization efficiency in the production process to partly abate EICE through upgrading production equipment. Some studies [14, 16, 19, 60, 61] argued that investment in information and communication technology (ICT) equipment plays a significant role in improving energy efficiency in both some developed countries and China.

Consequently, the fact that the influential direction of investment intensity turns negative at the beginning of the 12th "Five-Year Plan" indicates that under the guidance of energy-saving and emission-reduction policy, industrial enterprises have changed their investment direction towards production equipment with higher energy efficiency. Although the investment scale of entire industry experienced an overall upward trend (see Fig. 12), the evolution of investment intensity is irregular (see Fig. 11). Nevertheless, SPFM's investment intensity change can explain the direction change of investment intensity effect on EICE as depicted in Fig. 14, where the change rate and index have very consistent paces although the former has a more intensive fluctuation.

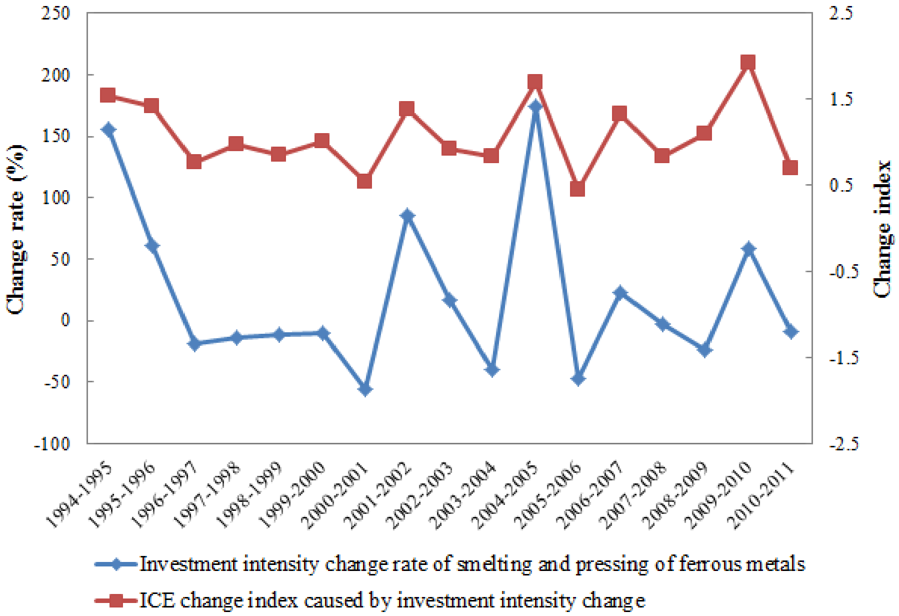


Fig. 14. Trends of investment intensity change rate of smelting and pressing of ferrous metals and multiplicative decomposition index of investment intensity effect on EICE in Shanghai.

(4) Efficiency effect: R&D efficiency. R&D efficiency presents an evident volatility, causing the average annual EICE changes of -14.80, 5.80, -0.73, 0.25, and 49.73 million tonnes with the corresponding change rates of -25.7%, 14.8%, -1.2%, 0.35%, and 85.8% at five stages (see Figs. 3 and 4 and Tables A.4 and A.5), respectively, implying an unstable effect of R&D efficiency on EICE with a circuitously upward trend (see Fig. 11). As discussed above, this is closely related to the focus of R&D effort of industrial enterprises, whose R&D activities are not always conducted for energy saving and emission reduction. When R&D investment is used for improving energy efficiency and reducing emissions, EICE can be mitigated. On the contrary, once R&D investment is used for enhancing productivity, it will boost enterprises to further expand investment and output scale and cause additional EICE. As shown in Tables A.4 and A.5, the influential direction of R&D efficiency frequently displays positive and negative alternation. Similar to investment intensity, the accordant evolution paths between R&D efficiency change rate of SPFM and multiplicative decomposition index of R&D efficiency can be observed in Fig. 15, revealing that the influential direction of certain factor on EICE largely depends on the change in this factor of SPFM, i.e., an implicit structure effect from the largest EICE sub-sector.

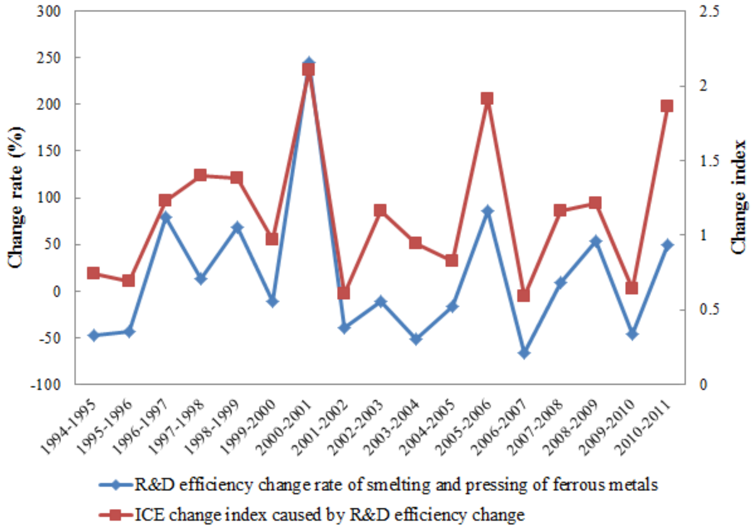


Fig. 15. Trends of R&D efficiency change rate of smelting and pressing of ferrous metals and multiplicative decomposition index of R&D efficiency effect on EICE in Shanghai.

3.3. Decomposition analysis of considering renewable energy sources

As mentioned above, the neglect of renewable energy sources in the existing index decomposition studies may lead to the biased decomposition results. Although the detailed data of used renewable energy sources of industrial sub-sectors are not available, we can treat the power generation from renewable energy sources in Shanghai as the used renewable energy sources of the whole industrial sector to carry out an alternative decomposition analysis at Shanghai's entire industrial level. Compared with previous decomposition results, we can inspect the effect of renewable energy source use on EICE change to some extent. Considering renewable energy sources, the extended decomposition model proposed above can be rewritten as:

$$CS=\sum_{j=1}^{16}CS_j=\sum_{j=1}^{16}\frac{CS_j}{E_j}\frac{E_j}{E}\frac{E}{Y}\frac{Y}{R}\frac{R}{I}\frac{I}{Y}Y=\sum_{j=1}^{16}CC_j\bullet ES_j\bullet EI\bullet RE\bullet RI\bullet II\bullet Y \qquad (10)$$

where *j* still denotes the variety of energy sources, and the 16th is the used power from renewable energy sources.

Because we have not the data of renewable energy source use of various sub-sectors and are unable to perform the decomposition analysis at the level of Shanghai's industrial sub-sectors, in Eq. (10), the subscript *i* in Eq. (1) is absent, and the industrial structure factor is excluded. Thus, the corresponding multiplicative and additive LMDI decomposition specifications are as follows, respectively:

$$GS_{TOT}=CS_T/CS_0=G_{CC}\bullet G_{ES}\bullet G_{EI}\bullet G_{RE}\bullet G_{RI}\bullet G_{II}\bullet G_Y \qquad (11)$$

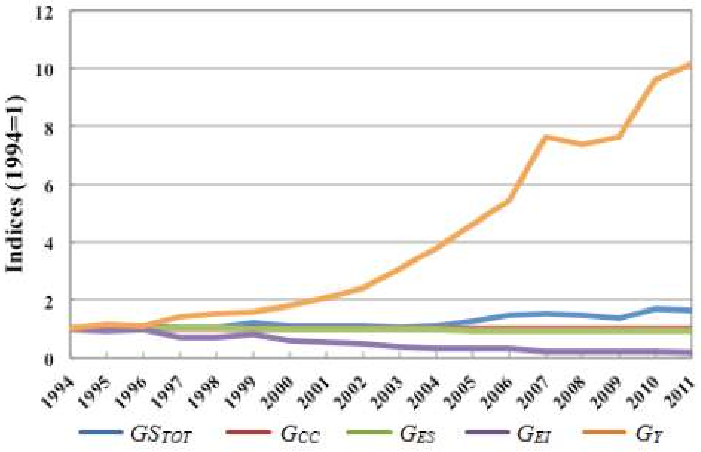
$$\Delta CS_{TOT} = CS_T - CS_0 = \Delta CS_{CC} + \Delta CS_{ES} + \Delta CS_{EI} + \Delta CS_{RE} + \Delta CS_{RI} + \Delta CS_{II} + \Delta CS_{Y} \qquad (12)$$

where $G_X = \exp\left(\sum_{j=1}^{16} \frac{(CS_{j,T} - CS_{j,0}) / (\ln CS_{j,T} - \ln CS_{j,0})}{(CS_T - CS_0) / (\ln CS_T - \ln CS_0)} \ln \frac{X_{j,T}}{X_{j,0}} \right)$, $\Delta CS_X = \sum_{j=1}^{16} \frac{CS_{j,T} - CS_{j,0}}{\ln CS_{j,T} - \ln CS_{j,0}} \ln \frac{X_{j,T}}{X_{j,0}}$,

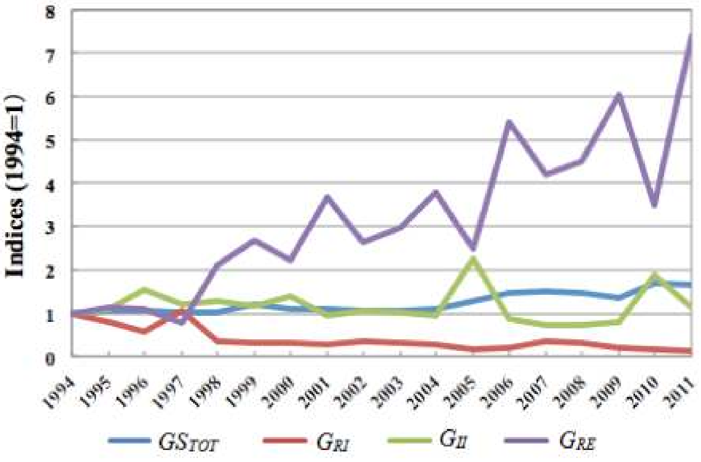
and X denotes CC, ES, EI, RE, RI, II, and Y.

Based on the alternative extended decomposition specifications above, we can obtain the decomposition results of considering renewable energy sources, which are reported in Tables A.7, A.8, and A.9. Furthermore, we calculate and illustrate the contributions of various factors to EICE change and their cumulative decomposition results year by year and at five stages in Table 5 and Figs. 15 and 16.

Considering that cumulative decomposition results can stabilize the short-term fluctuant effects of various factors to provide a more credible comparison, we first discuss the comparison of cumulative results depicted in Fig. 6 and Fig. 16. It is clearly seen that there is a highly similar trend for each factor between considering and not considering renewable energy sources, though their detailed values are different. During 1994–2011, the trends of output scale in Fig. 6 and Fig. 16 are identical and all remain an obvious promotion effect on EICE, indicating the dominant role of output scale in boosting EICE growth, while energy structure and energy intensity still remain the negative effects on EICE. Among the three conventional factors, the strongest mitigating role of industrial structure is replaced with energy intensity when considering renewable energy sources. With respect to the three novel factors, although their fluctuations in Fig. 16 look less than those in Fig. 6, they have highly coincident trends in two figures. When considering renewable energy sources, R&D intensity still exerts a durative mitigating effect except 1997, and investment intensity shows a circuitous downward trend around 1, while R&D efficiency has a circuitous upward trend and almost remains a promotion effect, again indicating that the significance of introducing the three novel factors. Hence, from the perspective of cumulative decomposition results, we do not find obvious difference between Figs. 6. and 16, indicating that the introduction of renewable energy sources does not exert a visible influence on the decomposition results.



(a) Trends of four conventional factors



(b) Trends of three novel factors

Fig. 16. Cumulative decomposition results of EICE change considering renewable energy sources (1994=1) (G_{CC}, G_{ES}, G_{EI}, G_{IS}, G_Y, G_{RI}, G_{II}, and G_{RE} denote the effects of emission coefficient, energy structure, energy intensity, industrial structure, output scale, R&D intensity, investment intensity, and R&D efficiency on EICE change, respectively).

Next, we turn to discuss the differences of contributions of various factors to EICE change between considering and not considering renewable energy sources. Unlike cumulative decomposition results, we find there have some differences between Tables 4 and 5 as well as Figs.

7 and 17. Except output scale and R&D intensity, the influential directions of other factors at some stages shown in Table 5 and Fig. 17 are reverse to those presented in Table 4 and Fig. 7.

Table 5
Types and trends of contribution of various factors at five development stages considering renewable energy sources.

Type	Decomposition factor	Trend [a]	Average contribution rate (%)
Scale effect	Output scale	+ + + + +	49.70
Structure effect	Energy structure	— — — — +	-1.68
Intensity effect	Energy intensity	— — — — —	-36.89
	R&D intensity	— — — — —	-43.87
	Investment intensity	+ + + — —	3.01
Efficiency effect	R&D efficiency	+ + + + +	40.86

[a] The sequence of trends is the end of the 8th "Five-Year Plan" (1994–1995), the 9th (1995–2000), the 10th (2000–2005), the 11th "Five-Year Plan" (2005–2010), and the beginning of the 12th "Five-Year Plan" (2010–2011); + and — stand for positive effect and negative effect on EICE change, respectively.

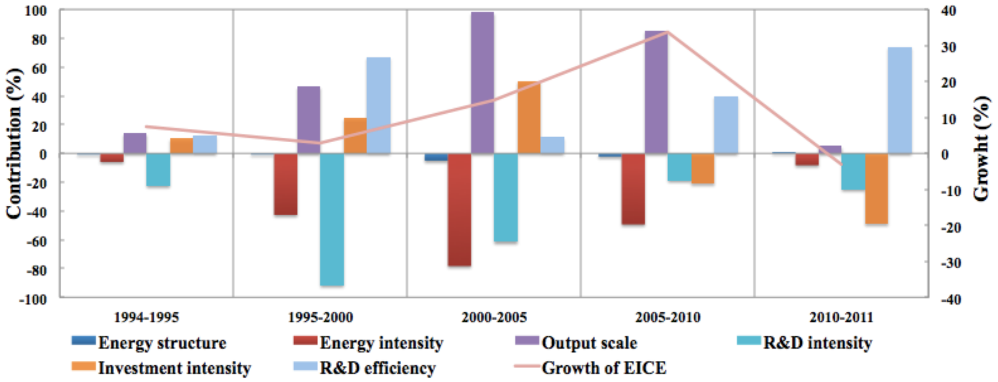


Fig. 17. Growth of EICE and contributions of its decomposition factors at five stages considering renewable energy sources (i.e., the end of the 8th "Five-Year Plan" (1994–1995), the 9th "Five-Year Plan" (1995–2000), the 10th "Five-Year Plan" (2000–2005), the 11th "Five-Year Plan" (2005–2010), and the beginning of the 12th "Five-Year Plan" (2010–2011)).

Firstly, the influential directions of energy structure reverse at three stages of the 9th "Five-Year Plan", the 11th "Five-Year Plan", and the beginning of the 12th "Five-Year Plan". When considering renewable energy sources, energy structure plays a positive role in abating EICE growth at first four stages and presents a slight promotion effect with a contribution rate of 0.08% during 2010–2011, implying that the introduction of renewable energy sources enhances the abating effect of energy structure adjustment on EICE growth to some extent. However, we notice that average contributions of energy structure in Tables 4 and 5 are very close. When considering renewable energy sources, energy structure is still the weakest factor with a contribution rate of 1.68%. This means that quantitatively, the introduction of renewable energy sources does not virtually change the influential degree of energy structure, though it exerts a phase impact. Actually, as depicted in Fig. 18, the used power from renewable energy sources was zero until 2004, and after then, the share of used power from renewable energy sources remained a very tiny proportion with an annual average of 0.19%, which is almost invisible in Fig. 18. Such a minor share is very difficult to generate a quantitatively notable impact on EICE, but the reverse influential directions at some stages imply that the increase in the use of renewable energy sources can exert a leverage effect on mitigating EICE. It is worthy to expect a significant role of renewable energy source in energy saving and emission reduction.

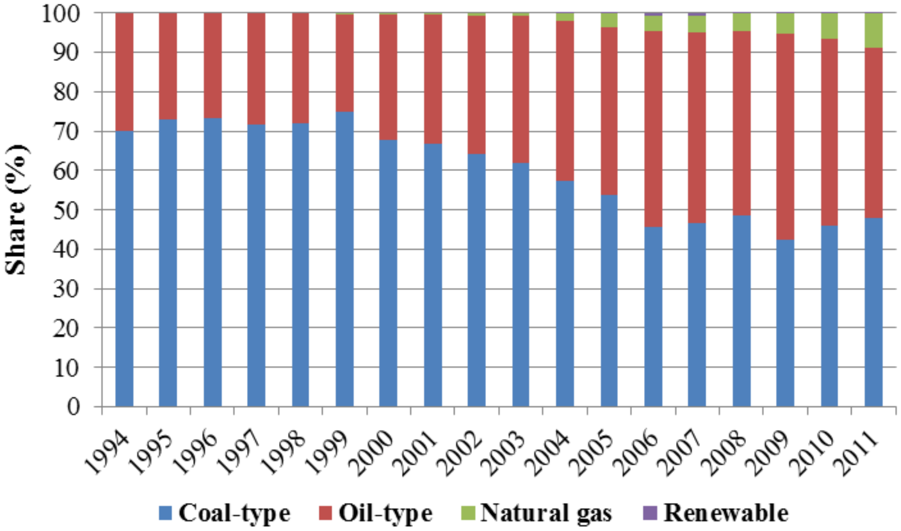


Fig. 18. Trend of energy source structure of entire industry in Shanghai.

Secondly, the contribution of energy intensity is obviously impacted by the introduction of renewable energy sources. After considering renewable energy sources, the influential direction of energy intensity turns minus at the 10th "Five-Year Plan" and thus remains minus at all the five stages, indicating a persistent mitigating effect on EICE growth. Moreover, quantitatively, the average influential degree of energy intensity in Table 5 is much greater than that in Table 6, increasing from -8.36% to -36.89%. Such observations provide an evidence for the argument that the introduction of renewable energy sources can intensify the mitigating effect of energy intensity on EICE growth. This can be attributed to two aspects. On one hand, the increase in used renewable energy sources is able to improve carbon productivity and carbon intensity, i.e. CO_2 emissions per output and CO_2 emissions per total energy consumption, respectively. This implies that CO_2 emissions at the same energy intensity level decrease since the share of low-carbon and even zero-carbon energy sources declines. On the other hand, as mentioned above, the influence of energy intensity on CO_2 emissions implicates an industrial structure effect [7, 48]. Since previous results have proved that industrial structure exerts an obvious restriction effect on EICE, such a restriction effect can partly transmit to the mitigating effect of energy intensity on EICE growth, though industrial structure is excluded when considering renewable energy sources. Anyway, we can draw a conclusion that the increase in the used renewable energy sources is in favor of the mitigating effect of energy intensity on EICE growth.

Thirdly, similar to energy intensity, after considering renewable energy sources, we find that the influential direction of investment intensity turns minus at the 10th “Five-Year Plan”, causing that its average contribution rate at five stages declines from 7.7% in Table 4 to 3.0% in Table 5. Again, such an observation indicates that as a relative variable, investment intensity presents a dual effect on EICE and an indirect improvement trend in mitigating EICE. As shown in Fig. 18, the use of power from renewable energy sources in Shanghai began in 2004. Coincidentally, after then, as shown in Table 5 at the last two stages, investment intensity remains a mitigating effect on EICE growth, while investment intensity remains a promotion effect at the first three stages. Such a shift implies that the introduction of renewable energy sources can indirectly induce the added investment of industrial enterprises to be more used to upgrade energy-saving and emission-reduction technology and improve energy use efficiency and carbon productivity. As pointed out by Ouyang et al. [49], to promote the substitution of renewable energy use for non-renewable energy use is a very effective way to mitigate the rebound effect caused by added investment and economic growth in China. Hence, the introduction of renewable energy sources can partly alleviate the adverse effect of investment expansion on abating EICE.

Lastly, with respect to R&D efficiency, after considering renewable energy sources, its influential direction turns positive at two stages of the end of the 8th "Five-Year Plan" and the 9th "Five-Year Plan", causing an increase in average contribution rate at five stages as shown in Table 5. Although such an observation is somewhat unexpected, it may be explained by the "green paradox" doctrine. Some recent studies [62-65] noticed a so-called "green paradox" phenomenon, meaning that some designs of climate policy intended to mitigate CO_2 emissions, but they might actually increase CO_2 emissions, at least in the short run, because producers increase the near-term extraction and use of fossil fuels in fear of higher future cost to lead to a rise of CO_2 emissions. In other words, an anticipated gradual introduction of green policies, or the anticipation that green policies will be implemented at some future dates, might thus result in a faster and undesired extraction and use of fossil fuels [65]. The possible police triggers of such a green paradox include an increasing carbon tax [62, 63] and an increasing subsidies or technological improvement for renewable energy sources [64, 65]. Its recent example is that OPEC does not cut its production of crude oil at all to counter the development of the U.S. shale gas even if the price of crude oil drops. Also, Zhang [66] has demonstrated that the green paradox phenomenon exists in China in some cases.

With respect to the related green policies in Shanghai, in 2006, Shanghai's local government put forward the anticipated targets of renewable energy development in *Shanghai Energy Development 11th Five-Year Plan* [67] for the first time. After then, a series of policies and measures were implemented to promote the development of renewable energy sources. In 2011, the local government further enacted *Shanghai New Energy Development 12th Five-Year Plan* [68] to propose some constraint indicators of the development of renewable energy sources. Since the green policies for the development of renewable energy sources in Shanghai experienced such a tightening course, it is not surprised to obtain the decomposition results of R&D efficiency above when considering renewable energy sources. In particular, a green paradox resulting from the subsidy policy to clean R&D activities has been discussed in some cases [64]. As argued by Acemoglu et al. [56], R&D can be directed at conventional "dirty" machines that lead to environmental degradation or to "clean" alternative machines that do not pollute. When enterprises encounter a tightening green policy, they would be worried about a higher future cost to carry out more current R&D activities targeting the productivity improvement of "dirty" machines, inducing an output scale expansion regardless of energy saving and emission reduction.

Again, such an observation indicates that microeconomic factors like the R&D activities of industrial enterprises are flexible and sensitive to green policies compared with macroeconomic factors. Once an inappropriate green policy is implemented, a counterproductive outcome would be incurred. Overall, as shown in Table 5 and Figs. 16 and 17, although the induction of renewable energy sources partly changes the influential degrees and directions of some factors at some stages, the relative orders of cumulative and average contributions of various factors are unchanged, indicating that the basic conclusions are tenable when not considering renewable energy sources. However, it can be expected that with the more development and use of renewable energy sources and the implementation of more emission-reduction policies, the influential structure (including degree and direction) of various factors on EICE in Shanghai will present a substaintial change.

4. Conclusions and policy implications

Using an extended LMDI model and considering 32 industrial sub-sectors and 15 energy sources, we not only decompose EICE change in Shanghai over 1994–2011 into four conventional factors mainly reflecting the macroeconomic cause of EICE change, but also introduce three novel factors specially examining the effects of investment and R&D behaviors on EICE change at the microeconomic level. Furthermore, in order to examine the effect of renewable energy source use on EICE change, we introduce renewable energy sources into the proposed model to carry out an alternative decomposition analysis at Shanghai's entire industrial level. Our results indicate that industrial structure is the most significant factor in inhibiting EICE and that R&D intensity also exerts an obvious mitigating effect on EICE when considering and not considering renewable energy sources. However, regardless of renewable energy sources, the effect of energy intensity that the Chinese government always attaches importance to is less than the expected as a result of rebound effect, but the introduction of renewable energy sources intensifies the mitigating effect of energy intensity on EICE growth, partly resulting from by the transmission from the restriction effect of industrial structure. The effect of energy structure on EICE is the weakest, even if the introduction of renewable energy sources enhances the abating effect of energy structure on EICE growth to some extent, indicating that the low carbonization adjustment of energy structure is still an arduous process in Shanghai.

Among the promotion factors of EICE, industrial output growth is the most prominent driving force due to rapid industrialization and urbanization in recent 20 years. Also, R&D efficiency augments EICE by improving productivity and stimulating investment and output, and the introduction of renewable energy sources intensifies its promotion effect to some extent as a result of the "green paradox" effect. Conversely, investment intensity is transforming towards a "good news" direction recently, especially after considering renewable energy sources. Therefore, under the premise of sustainable economic development, industrial structure and R&D intensity have become the key factors in abating EICE in Shanghai, while energy intensity and energy structure have a large improved potential as long as the rebound effect is effectively mitigated and green paradox effect is evaded through a reasonable design of green policies. In particular, although energy structure adjustment is more difficult than other factors due to current coal-dominant energy consumption structure and the tiny share of renewable energy sources in Shanghai, it can be expected to exert a significant effect from a long-term perspective.

Overall, all the three novel factors exert the significant effects on EICE change, indicating that in order to fully investigate the cause of EICE change, it is very necessary to take into account investment and R&D behaviors. Moreover, our observation that the novel microeconomic factors are more flexible than the conventional macroeconomic factors implies that the investment and R&D activities of industrial enterprises have volatile influences on EICE and are more sensitive to policy interventions. Hence, through policy guidance, they can exert more significant mitigating effects on EICE in the short run. Although the macroeconomic factors like energy structure are difficult to be adjusted for their greater stability and hysteresis, they can play a more persistent role in mitigating EICE. Therefore, the effort of abating EICE should be made by considering both macroeconomic and microeconomic factors in order to achieve a desirable emission-reduction effect.

Based on our findings above, we provide the following policy implications.

First, although industrial output growth is the most prominent driving force for EICE growth in Shanghai due to rapid industrialization and urbanization in recent 20 years, it is not feasible to abate EICE by decelerating industrial development. Obviously, a high and mandatory emission-reduction task will undermine China's economic growth and social stability. Hence, the Chinese government has to seek a trade-off between economic development and emission reduction. A gradual self-regulating process of emission reduction considering affordable reduction cost and social risk should be an advisable choice so as to achieve the "win-win" of economic development and emission reduction. During this process, emission-reduction policies should contribute to gradually counteract economic scale effect by activating composition and technique effect. In other words, China has to experience a structure and technology emission-reduction process. This goal can come true by transforming the pattern of China's economic growth. In particular, both circular economy and low-carbon development strategies should be addressed so that the total consumption on virgin materials and fossil fuels and the corresponding emissions can be minimized.

Second, the capital and R&D investment decisions of industrial enterprises play a crucial role in mitigating EICE. However, without policy interventions, enterprises' investment decisions tend to focus on improving productivity and expanding production scale, which deviates from optimal economic and environmental harmonious development path. Therefore, the government should enhance the promotion effect of fiscal policy on emission reduction and formulate relevant finance-taxation policies and incentive measures so that enterprises can pay more attentions on converting their investment direction towards energy saving and emission reduction. Moreover, some regulatory policy instruments, such as carbon-reduction liability, carbon emission audits, and carbon labels can be implemented to encourage industrial firms to improve their carbon emission performance through capital and R&D investments in green technological innovation and adoption.

Third, the low-carbon adjustment of industrial structure should be the focus of emission-reduction policy due to its outstanding mitigating effects on EICE. Industrial structure optimization is always regarded as a radical approach to transform economic development pattern and realize sustainable development [7]. Therefore, the government should make more efforts to adjust and optimize industrial structure by promoting technology- and knowledge-intensive manufacturing and the development of high-tech industries. The significant difference in the marginal environmental effect of output scale expansion among industrial sub-sectors suggests that the discriminating industrial reduction-emission policies should be implemented based on their different EICE efficiency. Hence, in order to promote industrial low-carbon development, the development of light and advanced manufacturing with low energy consumptions and high added value should be the focus. Meanwhile, those energy intensive industries with backward technologies and equipment should be gradually phased out.

Fourth, mainly attributed to the rebound effect, the emission-reduction effect of energy intensity is far less than efforts made by the government. The expectation and efforts of "producing more with less" at the microeconomics level may instead show the result of "producing more with more" at the macroeconomic level [29]. Due to poor energy resource endowment in Shanghai, which is a representative energy-importing-dependent metropolitan with a primary energy dependence degree of over 90%, it is particularly urgent and necessary to improve energy efficiency so as to mitigate CO_2 emissions. However, the potential rebound effect in the emission-reduction process suggests that policy-makers have to re-examine the emission-reduction policy solely relying on the improvement of energy efficiency and should never neglect the substantial influence of the rebound on expectant emission-reduction result. Since energy efficiency improvement may only partly solve CO_2 emission problem, the efforts of reducing energy intensity can exert desired emission-reduction effect only if the rebound effect is effectively restricted. Therefore, the more rational policy design should fully consider the potential rebound effect and restrict it through the market-oriented policy mix in China, especially the marketization reform of energy pricing [29, 50].

Last but not least, although our results show that the effect of energy structure adjustment on abating EICE is marginal in the short term, we must not abandon or despise the potential role of energy structure optimization in reducing EICE's absolute amount in the long run. Considering a coal-dominant energy structure and the scarce use of clean energy sources, many related studies [7, 9, 15, 17, 25, 37, 40, 49] suggested an enormous potential of energy structure adjustment in abating CO_2 emissions in China in the long term despite its current weak effect. As mentioned by Liu et al. [40], since coal-dominated energy structure has been a fundamental obstacle of low-carbon development, China must reduce its dependence on coal and support the application of clean and renewable energy sources. As shown in Fig. 18, a dominant proportion of coal-type fuels in the total energy consumption all the time in Shanghai and a tiny share of cleaner natural gas and power from renewable energy sources, just implicate the substantial room for the improvement of renewable energy sources. In addition, our observation that the introduction of renewable energy sources with a minor share in the total energy consumption reverses the phase influential directions of some factors on EICE, indicates that the increase in renewable energy source use might present a positive leverage effect on EICE change. Actually, both Chinese government and Shanghai's local government recently have treated energy structure adjustment by promoting the development of new and renewable energy sources as a strategic target. However, such an adjustment won't happen overnight and needs unceasing efforts. The government should devote to the construction of a diverse, safe, clean, and efficient energy supply and consumption system to promote the utilization of clean and renewable energy sources. In particular, some new energy technologies should be supported to further develop, such as high-efficiency and low-cost photovoltaic battery technology, solar thermal power generation technology, ground source heat pumps, etc.

Acknowledgements

We acknowledge the financial support from the National Natural Science Foundation of China (Nos. 71373153, 71003068, 71033004, 71250110083, and 71325006), the Program for New Century Excellent Talents in University (No. NCET-13-0890), the Ministry of Education Foundation of China, Shanghai Philosophy and Social Science Fund Project (Nos. 2014BJB001), "Shuguang Program" supported by Shanghai Education Development Foundation and Shanghai Municipal Education Commission (No. 14SG32), and the Key Project of Zhejiang Statistics Research Program (No. 201527).

Appendix A Classification of industrial sub-sectors and detailed results

Table A.1
Emission coefficients of 15 energy sources investigated in this study.

Fuel	Net calorific value	Carbon content	Carbon oxidation rate	Emission coefficient (unit: 10^4 tonnes $CO_2/10^4$ tonnes or 10^4 tonnes $CO_2/10^8$ m^3 (for gas))
Raw coal	20908	26.1	91.6	1.8300
Cleaned coal	26344	25.8	98.0	2..4423
Coke	28435	29.2	92.8	2.8252
Coke oven gas	16726	12.1	99.0	7.3466
Other gases	16726	12.1	99.0	7.3466
Crude oil	41816	20.0	97.9	3.0021
Gasoline	43070	18.9	98.0	2.9251
Kerosene	43070	19.6	98.6	3.0520
Diesel	42652	20.2	98.2	3.1022
Fuel oil	41816	21.1	98.5	3.1866
Liquefied petroleum gas	50179	17.2	98.9	3.1298
Refinery gas	46055	15.7	98.9	2.6221
Natural gas	38931	15.3	99.0	21.6219
Other petroleum products	40200	20.0	98.0	2.8890
Other coking products	33453	22.0	92.8	2.5042

Table A.2
Classification of industrial sub-sectors investigated in this study.

No.	Sector	No.	Sector
S1	Processing of food from agricultural products	S17	Manufacture of rubber

S2	Manufacture of foods	S18	Manufacture of plastics
S3	Manufacture of beverage	S19	Manufacture of non-metallic mineral products
S4	Manufacture of tobacco	S20	Smelting and pressing of ferrous metals
S5	Manufacture of textile	S21	Smelting and pressing of non-ferrous metals
S6	Manufacture of textile wearing apparel, footwear and caps	S22	Manufacture of metal products
S7	Manufacture of leather, fur, feather and related products	S23	Manufacture of general purpose machinery
S8	Processing of timber and manufacture of wood, bamboo, rattan, palm and straw products	S24	Manufacture of special purpose machinery
S9	Manufacture of furniture	S25	Manufacture of transport equipment
S10	Manufacture of paper and paper products	S26	Manufacture of electrical machinery and equipment
S11	Printing, reproduction of recording media	S27	Manufacture of communication equipment, computers and other electronic equipment
S12	Manufacture of articles for culture, education and sport activities	S28	Manufacture of measuring instruments and machinery for cultural activity and office work
S13	Processing of petroleum, coking, and processing of nuclear fuel	S29	Other manufacturing
S14	Manufacture of raw chemical materials and chemical products	S30	Production and supply of electric power and heat power
S15	Manufacture of medicines	S31	Production and supply of fuel gas
S16	Manufacture of chemical fibers	S32	Production and supply of water

Note: Other manufacturing includes the manufacture of artwork and the recycling and disposal of waste.

Table A.3

EICE of various industrial sub-sectors in Shanghai over 1994-2011 (unit: 104 tonnes).

Sector	1994	1995	1996	1997	1998	1999	2000	2001	2002
S1	7.41	26.64	15.72	13.13	30.93	28.73	22.81	26.60	27.52

S2	19.92	37.54	38.61	43.03	37.99	28.14	28.55	33.78	26.67
S3	12.34	17.74	10.73	12.16	10.30	8.96	12.35	14.22	11.56
S4	3.42	3.08	4.70	3.32	2.17	2.99	2.70	3.03	1.57
S5	139.52	160.48	127.78	107.35	112.02	97.06	129.35	131.37	119.27
S6	4.68	11.64	4.52	7.75	15.90	17.37	17.90	31.48	28.68
S7	5.30	4.78	2.53	2.00	3.51	4.50	4.55	3.87	3.89
S8	18.30	12.30	20.60	17.55	10.43	21.47	17.18	40.95	30.46
S9	3.33	1.92	3.33	3.42	4.47	4.60	2.75	2.34	2.00
S10	30.31	39.98	37.35	39.89	48.45	37.63	41.35	41.38	40.31
S11	2.98	2.86	7.65	5.96	4.75	3.88	4.62	5.10	5.10
S12	6.38	6.97	16.02	11.39	8.04	7.70	11.41	10.54	8.86
S13	63.86	119.56	153.26	158.18	213.84	233.01	253.64	980.72	1156.08
S14	400.19	421.62	480.24	392.05	317.95	279.72	381.67	474.15	385.31
S15	40.22	61.62	113.86	42.15	44.48	36.62	34.45	58.86	46.99
S16	648.78	565.64	575.15	575.48	587.12	666.63	811.28	25.34	22.32
S17	39.58	64.02	59.03	45.69	62.27	41.31	47.50	42.13	43.45
S18	46.34	15.74	15.44	17.64	22.22	25.25	22.44	32.64	33.12
S19	205.95	277.16	302.67	258.78	252.36	194.87	231.73	223.76	204.32
S20	2363.32	2824.16	2584.59	2536.98	2872.19	3733.10	2968.72	2833.84	2678.80
S21	26.06	28.45	31.65	29.59	22.32	21.91	27.65	23.65	24.48
S22	40.59	37.98	30.64	31.80	48.77	41.00	41.44	46.51	38.05
S23	210.43	58.38	46.90	76.53	55.36	48.64	47.30	47.72	52.25
S24	53.24	46.47	44.66	38.49	29.58	28.78	27.64	20.07	11.43
S25	56.44	54.76	48.30	51.22	38.04	42.75	46.84	49.04	45.56
S26	25.12	35.85	38.51	37.64	27.53	22.54	26.66	29.93	23.05
S27	17.36	18.45	26.48	24.39	20.45	22.06	30.18	31.14	45.51
S28	6.00	4.55	7.74	6.95	2.45	2.96	2.21	2.64	1.85
S29	188.45	194.56	172.83	179.43	10.80	11.01	9.11	6.94	6.36
S30	89.60	10.50	32.51	55.05	5.30	130.25	12.04	6.11	4.05
S31	35.38	1.54	71.62	85.15	0.93	21.89	2.01	14.27	0.75
S32	0.88	0.18	4.62	0.74	0.57	0.82	0.33	0.35	0.39
Total	4811.66	5167.10	5130.23	4910.91	4923.49	5868.14	5320.37	5294.49	5130.03

Table A.3 (continued)

EICE of various industrial sub-sectors in Shanghai over 1994-2011 (unit: 104 tonnes).

Sector	2003	2004	2005	2006	2007	2008	2009	2010	2011

S1	26.93	25.76	25.09	19.97	29.52	29.63	26.00	27.65	28.82
S2	27.73	35.90	39.05	33.64	34.20	34.72	35.36	37.20	35.66
S3	13.56	20.56	23.21	20.05	19.79	22.01	19.96	19.03	15.99
S4	1.42	1.50	2.36	0.95	0.92	1.02	0.84	0.98	1.47
S5	117.79	132.79	117.75	106.69	102.93	114.70	90.27	114.31	97.61
S6	28.19	36.98	37.75	30.24	34.99	34.79	17.12	32.52	45.44
S7	5.15	9.78	5.43	3.63	4.89	4.01	4.43	2.74	3.16
S8	40.18	19.36	13.25	13.16	9.86	10.17	7.50	10.09	13.03
S9	1.79	4.33	4.75	4.55	4.84	4.59	9.10	5.49	5.57
S10	40.43	37.13	69.29	75.87	76.53	79.40	46.20	123.86	122.70
S11	6.20	10.93	9.35	8.37	8.79	9.82	18.63	16.81	21.38
S12	11.71	10.57	12.47	10.69	9.99	11.41	6.90	8.59	9.22
S13	1221.89	1450.44	1834.79	1878.94	1794.32	1770.28	1667.77	1786.02	1704.93
S14	454.67	384.64	401.51	1162.87	1286.70	1245.27	1391.67	1817.29	1574.90
S15	46.23	44.86	37.07	49.37	42.92	32.54	93.16	27.84	27.16
S16	23.85	14.08	11.81	7.59	15.63	6.25	21.85	4.23	4.82
S17	54.48	60.57	74.60	61.09	56.21	54.68	13.00	48.20	44.28
S18	34.38	32.89	44.45	47.82	42.81	51.32	63.20	69.97	70.94
S19	220.81	246.55	270.21	265.15	242.76	247.60	149.72	421.91	361.88
S20	2418.15	2408.48	2692.45	2805.89	3019.18	3013.47	2398.64	3181.01	3289.35
S21	28.67	36.56	33.96	44.93	40.88	39.50	100.95	39.20	40.34
S22	39.39	57.90	54.76	60.47	57.80	59.71	63.28	85.15	87.10
S23	58.47	89.67	84.86	97.08	108.19	108.30	118.87	71.41	72.02
S24	14.80	27.74	14.91	13.76	14.34	21.73	23.85	46.85	60.08
S25	62.08	60.93	57.97	64.53	70.50	71.92	65.34	86.58	96.37
S26	28.72	34.64	46.39	46.85	33.73	31.81	31.39	27.07	26.61
S27	42.11	46.25	46.68	44.37	28.60	16.21	20.70	14.64	16.02
S28	2.01	2.43	2.04	2.03	2.28	2.18	2.13	2.10	1.82
S29	3.76	5.38	6.43	7.30	7.30	7.97	10.01	10.38	9.14
S30	4.45	3.16	20.29	7.27	8.43	6.37	7.81	9.48	8.01
S31	0.79	0.79	3.35	2.89	1.21	1.76	16.60	3.75	8.30
S32	0.36	0.45	0.53	0.26	0.39	0.48	1.02	0.38	0.59
Total	5081.13	5354.00	6098.80	6998.25	7211.43	7145.61	6543.27	8152.72	7904.72

Table A.4
Detailed multiplicative decomposition results of EICE change.

Stage	GS_{TOT}	G_{ES}	G_{EI}	G_{IS}	G_{Y}	G_{RI}	G_{II}	G_{RE}
1994-1995	1.0739	0.9784	0.9888	0.9770	1.1361	0.8736	1.5402	0.7432
1995-1996	0.9929	1.0296	1.0269	0.9754	0.9628	1.0228	1.4207	0.6882
1996-1997	0.9572	1.0026	0.8381	0.9056	1.2579	1.0713	0.7569	1.2332
1997-1998	1.0026	0.9780	1.0084	0.9473	1.0730	0.7357	0.9717	1.3988
1998-1999	1.1919	0.9818	1.1208	1.0341	1.0474	0.8435	0.8604	1.3779
1999-2000	0.9067	1.0065	0.8194	0.9674	1.1364	1.0212	1.0142	0.9655
2000-2001	0.9951	0.9133	0.9475	1.0221	1.1252	0.8869	0.5349	2.1079
2001-2002	0.9689	0.9967	0.9786	0.8550	1.1620	1.1906	1.3840	0.6069
2002-2003	0.9905	0.9922	0.8866	0.8822	1.2764	0.9328	0.9216	1.1633
2003-2004	1.0537	0.9968	0.9595	0.8964	1.2291	1.2817	0.8305	0.9395
2004-2005	1.1391	0.9944	1.0113	0.9360	1.2102	0.7136	1.6961	0.8263
2005-2006	1.1475	1.0156	1.0440	0.9197	1.1767	1.1501	0.4554	1.9092
2006-2007	1.0305	1.0017	0.8946	0.8184	1.4053	1.2752	1.3317	0.5888
2007-2008	0.9909	1.0002	1.0915	0.9398	0.9658	1.0276	0.8378	1.1615
2008-2009	0.9157	0.9890	0.9600	0.9321	1.0347	0.7534	1.0922	1.2153
2009-2010	1.2460	1.0103	1.0748	0.9185	1.2492	0.8206	1.9168	0.6358
2010-2011	0.9696	0.9960	0.9839	0.9398	1.0527	0.7679	0.7010	1.8579
1995-2000	1.0297	1.0150	0.7956	0.8288	1.5385	0.5600	1.0269	1.7391
2000-2005	1.1463	0.9106	0.8080	0.7078	2.2014	0.9122	1.1692	0.9376
2005-2010	1.3368	1.0328	1.0624	0.6119	1.9911	0.9056	1.0853	1.0175
1994-2011	1.6428	1.0702	0.7180	0.4199	5.0913	0.5129	1.4172	1.3758

Table A.5
Detailed additive decomposition results of EICE change (unit: 10^4 tonnes).

Stage	ΔCS_{TOT}	ΔCS_{ES}	ΔCS_{EI}	ΔCS_{IS}	ΔCS_{Y}	ΔCS_{RI}	ΔCS_{II}	ΔCS_{RE}
1994-1995	355.44	-109.04	-56.09	-115.96	636.53	-673.75	2154.05	-1480.30
1995-1996	-36.86	149.99	136.52	-128.40	-194.97	116.32	1807.78	-1924.10
1996-1997	-219.33	13.15	-886.76	-497.51	1151.80	345.77	-1398.11	1052.33
1997-1998	12.58	-109.31	41.29	-265.99	346.59	-1509.35	-141.09	1650.44
1998-1999	944.65	-98.68	613.62	180.58	249.13	-916.10	-809.17	1725.27
1999-2000	-547.77	36.29	-1113.34	-185.30	714.58	117.21	78.82	-196.03
2000-2001	-25.88	-481.35	-286.47	115.96	625.97	-636.81	-3320.99	3957.79
2001-2002	-164.46	-17.44	-112.75	-816.68	782.42	909.33	1693.80	-2603.13
2002-2003	-48.90	-40.02	-614.73	-639.99	1245.84	-355.35	-416.79	772.14
2003-2004	272.87	-16.74	-215.59	-570.74	1075.94	1294.63	-968.97	-325.65
2004-2005	744.80	-32.27	64.31	-378.42	1091.18	-1929.81	3021.06	-1091.25
2005-2006	899.45	101.47	281.51	-547.16	1063.63	914.25	-5142.29	4228.04
2006-2007	213.18	11.78	-791.60	-1424.01	2417.00	1727.30	2035.08	-3762.38
2007-2008	-65.82	1.64	628.56	-445.85	-250.16	195.47	-1270.27	1074.80
2008-2009	-602.34	-75.86	-279.16	-480.93	233.61	-1936.81	603.22	1333.59
2009-2010	1609.45	75.23	528.15	-622.46	1628.53	-1447.30	4761.70	-3314.40
2010-2011	-248.00	-31.83	-130.44	-498.40	412.67	-2120.52	-2852.34	4972.86
1995-2000	153.28	78.25	-1199.05	-984.66	2258.74	-3040.52	138.94	2901.58
2000-2005	778.43	-533.83	-1215.70	-1970.48	4498.44	-523.68	890.97	-367.28
2005-2010	2053.92	228.33	428.36	-3476.15	4873.38	-701.93	579.41	122.52
1994-2011	3093.07	422.67	-2064.34	-5406.02	10140.75	-4160.47	2172.42	1988.05

Table A.6
Cumulative decomposition results of EICE change (1994=1).

Year	GS_{TOT}	G_{ES}	G_{EI}	G_{IS}	G_{Y}	G_{RI}	G_{II}	G_{RE}
1995	1.0739	0.9784	0.9888	0.9770	1.1361	0.8736	1.5402	0.7432
1996	1.0662	1.0073	1.0154	0.9530	1.0939	0.8936	2.1881	0.5114
1997	1.0206	1.0099	0.8510	0.8630	1.3760	0.9573	1.6562	0.6307
1998	1.0232	0.9877	0.8581	0.8176	1.4765	0.7043	1.6093	0.8823
1999	1.2196	0.9698	0.9618	0.8455	1.5465	0.5941	1.3847	1.2157
2000	1.1057	0.9761	0.7881	0.8179	1.7574	0.6066	1.4043	1.1738
2001	1.1003	0.8915	0.7467	0.8360	1.9774	0.5380	0.7511	2.4743
2002	1.0662	0.8885	0.7307	0.7147	2.2977	0.6406	1.0396	1.5015
2003	1.0560	0.8816	0.6478	0.6305	2.9327	0.5975	0.9581	1.7467
2004	1.1127	0.8787	0.6216	0.5652	3.6045	0.7659	0.7957	1.6410
2005	1.2675	0.8738	0.6286	0.5290	4.3623	0.5465	1.3495	1.3559
2006	1.4544	0.8875	0.6563	0.4865	5.1329	0.6285	0.6146	2.5886
2007	1.4987	0.8889	0.5871	0.3982	7.2130	0.8015	0.8185	1.5243
2008	1.4851	0.8891	0.6408	0.3742	6.9660	0.8236	0.6858	1.7705
2009	1.3599	0.8793	0.6152	0.3488	7.2080	0.6205	0.7490	2.1517
2010	1.6944	0.8884	0.6612	0.3203	9.0044	0.5092	1.4356	1.3680
2011	1.6428	0.8849	0.6505	0.3011	9.4794	0.3910	1.0063	2.5416

Table A.7
Detailed multiplicative decomposition results of EICE change considering renewable energy sources.

Stage	GS_{TOT}	G_{ES}	G_{EI}	G_{Y}	G_{RI}	G_{II}	G_{RE}
1994-1995	1.0739	0.9940	0.9446	1.1437	0.8051	1.1045	1.1246
1995-1996	0.9929	1.0034	1.0294	0.9612	0.7297	1.4018	0.9776
1996-1997	0.9572	1.0106	0.7439	1.2733	1.8238	0.7732	0.7092
1997-1998	1.0026	0.9965	0.9349	1.0761	0.3437	1.0711	2.7167
1998-1999	1.1919	0.9735	1.1673	1.0488	0.8580	0.9253	1.2595
1999-2000	0.9067	1.0123	0.7834	1.1434	1.0136	1.1901	0.8290
2000-2001	0.9951	0.9958	0.8771	1.1393	0.8835	0.6823	1.6589
2001-2002	0.9689	0.9898	0.8412	1.1637	1.2512	1.1176	0.7151
2002-2003	0.9905	0.9852	0.7842	1.2819	0.9211	0.9623	1.1282
2003-2004	1.0537	0.9904	0.8642	1.2311	0.8363	0.9340	1.2803
2004-2005	1.1391	0.9889	0.9502	1.2122	0.6540	2.3496	0.6508
2005-2006	1.1475	0.9811	0.9891	1.1825	1.1958	0.3828	2.1845
2006-2007	1.0305	1.0045	0.7284	1.4084	1.5709	0.8179	0.7783
2007-2008	0.9909	1.0074	1.0186	0.9656	0.8951	1.0428	1.0714
2008-2009	0.9157	0.9812	0.9009	1.0359	0.7009	1.0601	1.3458
2009-2010	1.2460	1.0041	0.9832	1.2622	0.7217	2.4009	0.5771
2010-2011	0.9696	1.0008	0.9201	1.0529	0.7762	0.6073	2.1213
1995-2000	1.0297	0.9939	0.6561	1.5789	0.4056	1.2741	1.9353
2000-2005	1.1463	0.9541	0.4818	2.4938	0.5626	1.6011	1.1101
2005-2010	1.3368	0.9811	0.6536	2.0847	0.8510	0.8334	1.4100
1994-2011	1.6428	0.9533	0.1962	8.7821	0.1356	1.1440	6.4478

Table A.8
Detailed additive decomposition results of EICE change considering renewable energy sources (unit: 10^4 tonnes).

Stage	ΔCS_{TOT}	ΔCS_{ES}	ΔCS_{EI}	ΔCS_{Y}	ΔCS_{RI}	ΔCS_{II}	ΔCS_{RE}
1994-1995	355.44	-30.24	-284.13	669.80	-1081.21	495.52	585.69
1995-1996	-36.86	17.67	149.30	-203.83	-1622.55	1739.15	-116.60
1996-1997	-219.33	52.99	-1485.24	1212.92	3016.37	-1291.39	-1724.99
1997-1998	12.58	-17.11	-331.00	360.68	-5252.14	337.86	4914.27
1998-1999	944.65	-144.32	832.45	256.53	-824.03	-417.59	1241.62
1999-2000	-547.77	68.16	-1364.84	748.91	75.23	972.88	-1048.12
2000-2001	-25.88	-22.29	-695.77	692.17	-657.51	-2029.00	2686.51
2001-2002	-164.46	-53.68	-900.96	790.18	1168.17	579.37	-1747.53
2002-2003	-48.90	-76.03	-1240.86	1267.99	-419.54	-196.14	615.68
2003-2004	272.87	-50.12	-761.57	1084.56	-932.83	-356.20	1289.03
2004-2005	744.80	-63.79	-291.91	1100.50	-2428.41	4884.93	-2456.51
2005-2006	899.45	-125.06	-71.57	1096.08	1169.22	-6278.14	5108.92
2006-2007	213.18	31.91	-2251.86	2433.12	3208.70	-1427.96	-1780.74
2007-2008	-65.82	53.03	132.19	-251.04	-795.72	300.60	495.12
2008-2009	-602.34	-129.86	-713.47	240.99	-2430.55	398.96	2031.60
2009-2010	1609.45	29.64	-124.27	1704.09	-2387.13	6409.85	-4022.72
2010-2011	-248.00	6.22	-668.18	413.97	-2033.62	-4003.72	6037.34
1995-2000	153.28	-31.85	-2209.79	2394.91	-4731.96	1270.02	3461.94
2000-2005	778.43	-268.14	-4162.81	5209.38	-3278.59	2683.15	595.44
2005-2010	2053.92	-134.92	-3009.59	5198.43	-1141.59	-1289.61	2431.20
1994-2011	3093.07	-297.89	-10146.69	13537.65	-12450.77	838.29	11612.49

Table A.9
Cumulative decomposition results of EICE change considering renewable energy sources (1994=1).

Year	GS_{TOT}	G_{ES}	G_{EI}	G_{Y}	G_{RI}	G_{II}	G_{RE}
1995	1.0739	0.9940	0.9446	1.1437	0.8051	1.1045	1.1246
1996	1.0662	0.9974	0.9724	1.0993	0.5875	1.5483	1.0994
1997	1.0206	1.0080	0.7234	1.3998	1.0714	1.1971	0.7797
1998	1.0232	1.0045	0.6763	1.5064	0.3682	1.2822	2.1182
1999	1.2196	0.9779	0.7894	1.5799	0.3159	1.1865	2.6678
2000	1.1057	0.9899	0.6184	1.8064	0.3202	1.4121	2.2117
2001	1.1003	0.9857	0.5424	2.0580	0.2829	0.9634	3.6690
2002	1.0662	0.9756	0.4563	2.3950	0.3540	1.0767	2.6238
2003	1.0560	0.9612	0.3578	3.0701	0.3260	1.0361	2.9601
2004	1.1127	0.9520	0.3092	3.7797	0.2727	0.9678	3.7899
2005	1.2675	0.9415	0.2938	4.5818	0.1783	2.2739	2.4664
2006	1.4544	0.9236	0.2906	5.4180	0.2132	0.8705	5.3878
2007	1.4987	0.9278	0.2117	7.6310	0.3350	0.7120	4.1933
2008	1.4851	0.9347	0.2156	7.3687	0.2998	0.7424	4.4927
2009	1.3599	0.9171	0.1943	7.6329	0.2102	0.7870	6.0464
2010	1.6944	0.9208	0.1910	9.6342	0.1517	1.8895	3.4897
2011	1.6428	0.9215	0.1757	10.1440	0.1177	1.1475	7.4026

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