Co-benefits and Trade-offs of Environmental Pressures: A Case Study of Zhejiang's Socio-economic Evolution

Abstract

Our societies are continuously grappling with how to achieve rapid economic growth while minimizing the challenges of environmental sustainability. In this avenue, numerous studies have contributed towards investigating socio-economic factors and developing policies targeting environmental pressures (EPs). While previous studies have tended to focus on the individual driving forces of EPs, the consideration of the co-benefits and trade-offs among different EPs and policies have been considerably overlooked. In China, previous studies have mostly engaged these issues at the national level and have overlooked the regional socio-economic characteristics – this presents a mismatch between regional policy applications and average national level research findings. Towards this end, this study examines the co-benefits and trade-offs of eight EPs in Zhejiang during the 2007-2015 period. Our findings revealed strict co-benefits in reductions of all eight EPs due to intensity changes as well as trade-offs due to changes in final demand structure and final demand composition. Sectoral results show that only the *Non-Ferrous Metal Ores* sector has strict co-benefits among all EPs from the production perspective, while eight sectors have strict co-benefits from the consumption perspective mainly including the *Mining and Washing of Coal*, *Ferrous Metal Ores*, *Electric Power and Heat Power* sectors. Our findings suggest important policy implications associated with utilizing co-benefits and avoiding trade-offs for EP mitigation: making full use of all driving forces, strengthening intersectoral coordination, and establishing a joint evaluation mechanism among different sectors.

Keywords: environmental pressure; input-output analysis; structural decomposition analysis; co-benefits; trade-offs

1. Introduction

Rapid economic growth has led to serious environmental sustainability challenges worldwide, especially in densely populated regions (Costanza, 1996). These challenges are categorized as Environmental Pressures (EPs), which are broadly defined as resource consumption and pollutant emissions (Eurostat., 2001). To advance relevant policies for tackling EPs, research in this area has investigated critical socio-economic factors and economic sectors which drive the reduction of EPs. The resolution of the analysis of these studies has focused at the global (Dietzenbacher et al., 2020), national (Wang et al., 2020), and regional (Yang et al., 2019) levels. While policies related to the reduction of EPs are often applied at the regional level (Liu et al., 2019), research focusing at this resolution is not enough especially on the region's economic sectors in the literature.

Existing studies have revealed that quite often by controlling one EP, other EPs may either decrease (through co-benefits) or increase (through trade-offs). For example, mitigating greenhouse gas (GHG) emissions by carbon capture and storage (CCS) may reduce SO_2 emissions while also increasing the adverse effects of eutrophication (Singh et al., 2012). As a result, focusing on single EPs (Yu et al., 2019) may increase the impacts on other overlooked EPs and induce problem-shifting (Yu et al., 2017). Thus, effective policy-making requires the consideration of a wide range of EPs, their co-benefits, and their trade-offs.

To fill the above knowledge gaps, eight typical EPs in China's Zhejiang province were used to investigate the following questions: 1) How do socio-economic drivers affect changes in typical EPs? What are the performances of the divers at the sectorial level? 2) Are there any co-benefits or trade-offs among different EPs? If so, where do these co-benefits and trade-offs exist? What are the sectorial level performances of these co-benefits and trade-offs? The eight typical EPs considered in this study include energy consumption, and emissions of CO_2, SO_2, soot, waste water, solid wastes, chemical oxygen demand, and ammonia nitrogen. Specifically, in this study, we investigate the co-benefits and trade-offs of EPs from the driving forces analysis and accounting analysis perspectives. Driving forces analysis uses structural decomposition analysis (SDA) based on the environmentally extended input-output (EEIO) model, while accounting analysis only uses the EEIO model.

As one of the world's largest emerging economies, China has achieved rapid economic development since the 'reform and opening-up' policies of 1978. During the past forty years, China has established different development modes in its sub-regions. There are three famous economic development modes in China (Bai and Jiang, 2017), including 1) the Wenzhou Mode in Zhejiang province (also called Zhejiang-Mode) (Shi and Ma, 2011) which is characterized by its private sectors; 2) the South Jiangsu Mode in Jiangsu province which is featured in its state-owned and collective sectors; and 3) the Zhujiang Mode in Guangdong province which is marked by its export-oriented economy. Despite the significant differences between the economic development modes, all the subregion faces the same problem on how to achieve rapid economic growth while minimizing the EPs. While the regional characteristics of economic development in China are critical in fine-tuning reduction efforts for EPs, most existing studies on EPs in China are at the national scale. These national-level studies only represent the average situation of China's development and do not take into consideration regional economic development characteristics, e.g., the economic development mode of Zhejiang province.

Compared with the development modes of China's other sub-regions, the economic development mode in Zhejiang province is a typically market-oriented development mode featured in the private sectors. Some researchers even argue that this development mode represents one of

China's future economic development modes (Zeng, 2011). As a result, it is important to analyze how Zhejiang province combats EPs during high-speed economic growth—especially how the co-benefits and trade-offs among different EPs are considered in this economic mode. Research in this avenue will provide a decision-making reference for the marketization of China and similar economies.

2. Method and data

2.1 Environmentally extended input-output model

This study uses the environmentally extended input-output (EEIO) model (Miller and Blair, 2009). Derived from the input-output model (Leontief and Wassily, 1986), the EEIO model is also a linear model, which assumes that one unit of output of in an economic system is produced from a fixed amount of input from various sectors. Due to its many advantages in quantifying both the direct and indirect EPs, this method has been widely used in environmental studies (Zhang et al., 2020). In this study, we use the EEIO model to evaluate EPs from the production- and consumption-based perspectives.

The production-based perspective ties EPs to resident institutions generating goods and services, while the consumption-based perspective ties EPs to final demands by considering life-cycle impacts (Li et al., 2020) throughout the socio-economic supply chains (Tian et al., 2019). The production-based EPs of each sector indicate the direct resources consumed and the pollutants emitted, expressed by Eq. (1); while the consumption-based EPs indicate the upstream resources consumed and the pollutant emissions caused by the final demand for products, expressed by Eq. (2).

$$ep_p = e\hat{x} \tag{1}$$

$$ep_c = eL\widehat{F_k} = e(I-A)^{-1}\widehat{F_k} \tag{2}$$

Assume that the economy is divided into n sectors, has k types of final demands (e.g., urban household consumption, fixed investment, etc.), and interacts with the natural environment through m categories of EPs. The $n \times 1$ column vectors ep_p and ep_c indicate the EPs of each sector from the production and consumption perspectives, respectively. The $m \times n$ matrix e indicates the EP intensity per unit of each sector's total output. The $n \times n$ matrix $L = (I-A)^{-1}$ is the *Leontief Inverse* matrix (Miller and Blair, 2009), where I is the $n \times n$ identity matrix and A is the $n \times n$ direct input coefficient matrix. The column vectors x and F_k indicate the total output and the *k-th* category of final demand. The hat ^ represents diagonalizing the vector.

2.2 Structural decomposition analysis

We perform structural decomposition analysis (SDA) of the quantity (*ep*) of EP, which is expressed as the product of several independent variables that represent the factors of decomposition. This is shown in Eq. (3):

$$ep = eLY_sY_cgp \tag{3}$$

The $m\times 1$ vector ep is the amount of EP represented by the material flow. The $n\times k$ matrix Y_s represents the share of each of the n sectors in each of the k categories of final demands. The $k\times 1$ vector Y_c stands for the percentage of the total final demand among the k categories of final demands. The scalars g and p are, respectively, the per capita final demand and the population.

The change in the EP indicator during [0, t] can be calculated by Eq. (4).

$$\Delta ep = ep(t) - ep(0) \tag{4}$$

When we consider the change of each variable over time, Eq. (3) can be expressed as:

$$\Delta ep = \Delta ep_e + \Delta ep_L + \Delta ep_{Y_s} + \Delta ep_{Y_c} + \Delta ep_g + \Delta ep_p \tag{5}$$

$$\Delta ep = \Delta eLY_sY_cgp + e\Delta LY_sY_cgp + eL\Delta Y_sY_cgp + eLY_s\Delta Y_cgp + eLY_sY_c\Delta gp + eLY_sY_cg\Delta p \quad (6)$$

The change of notation Δep indicates the change of the EP during a certain period of time. The right-hand sides of Eq. (5) and Eq. (6) represent the changes of the EP caused by the EP intensity change Δe (dEPI), production structure change ΔL (dL), final demand structure change ΔY_s (dys), final demand composition change ΔY_c (dyc), per capita final demand change Δg (dpg), and population change Δp (dpop).

To avoid the non-uniqueness problem of SDA, the changes of EP are decomposed by a complete decomposition technique proposed by De Boer (De Boer, 2008). As Δep_e, Δep_L, and Δep_{Ys} are related to economic sectors, we decompose these variables into economic sectors to explore the effect of these driving forces in economic sectors.

2.3 Data Sources

2.3.1 EP Inventories

In this paper, material flows are used to represent EPs (Eurostat., 2001). Given the policy relevance and data availability, we choose energy consumption, emissions to air (CO_2, SO_2, and soot), emissions to water (waste water, chemical oxygen demand (COD), and ammonia nitrogen (AN)), and solid wastes as EP indicators. These indicators have received particular attention from the national and local Zhejiang governments – notably, in the 13th National Five-Year Plan (State Council, 2016).

Energy consumption is a comprehensive indicator measured in tons of standard coal equivalent (tce). Energy consumption and CO_2 emissions data are from the China Emission Accounts and Datasets (CEADs). Data on the emissions of other pollutants (SO_2, soot dust, waste water, solid waste, chemical oxygen demand and ammonia nitrogen) from industrial sectors are derived from the Zhejiang Statistical Yearbooks (ZPBS, 2008-2016b) and the Zhejiang Nature Resource and Environmental Statistics Yearbooks (ZPBS, 2008-2016a).

Similar to most traditional SDA studies, we only consider energy consumption and pollutant emissions of the production sectors, not including those from residential consumption (Su and Ang, 2017). Due to data limitations, we consider the emissions of SO_2, soot, waste water, COD, AN and solid waste only from industrial sectors, while emissions from other sectors including the agriculture, construction, services and household sectors are not included in this study.

2.3.2 Monetary Input-Output Tables

The input-output tables (IOTs) for Zhejiang Province in 2007, 2010, 2012, and 2015 and the population data are from the Zhejiang Bureau of Statistics. Since the IOTs and EPs statistics are based on different sectoral classifications, all industries are aggregated into 26 integrated sectors to be consistent with the industrial classification of environmental data (**Supplementary Material (SM) Table S1**). In addition, to eliminate the impact of price changes on the results, according to the double deflation method (UNDESASD, 1999), the IOTs are converted into constant prices in 2007. The price indexes are derived from the Zhejiang Bureau of Statistics. Moreover, we reconstructed the IOT by removing the imports from the intermediate use and final demand (Liu et al., 2010).

3. Description of Zhejiang Province and the Zhejiang-Mode

Zhejiang Province is located on China's southeast coastline, maintains a population of 57.4 million, and covers a relatively small total area of 101,800 square kilometers, making it one of the smallest provinces in China. The area consists of mountainous and hilly areas (70.4%), plains and basins (23.2%), and lakes, rivers and reservoirs (6.4%). Moreover, Zhejiang is very poor in natural resource endowment, e.g., there are almost no fossil energy and ferrous metal reserves in Zhejiang Province. Despite these adverse economic conditions, Zhejiang’s economy experienced booming development after the economic reform in the year 1978. During the past 40 years, the province has established its own development model, dubbed the “Zhejiang-Mode”, which is based on prioritizing and encouraging entrepreneurship, with an emphasis on small market responsive businesses, and the production of low-cost goods in bulk for both domestic consumption and export. Currently, Zhejiang is one of the richest and most developed provinces in China. As of 2018, its gross domestic product (GDP) was USD 8.49×10^{11}, approximately 6.2% of the country's GDP. Its GDP per capita was USD 14,907 and ranked 5th in the country.

The Zhejiang-Mode is a typical market-oriented economy incorporating strong private sectors. Given the strong involvement of the public sector throughout most of China’s provinces, i.e., either through public investment, enterprises, regulation, and management, the Zhejiang-mode represents the most economically liberal or Laissez-faire mode of development in China. The private sector in Zhejiang Province has been playing an increasingly important role in boosting the regional economy since 1978. In the year 2018, there were approximately 6.07 million enterprises in the province, 90% of which were private enterprises. This indicates that on average, one in ten individuals owns an enterprise. The private sector generates 65% of the GDP, 74% of taxes, 77% of exports, and 87% of employment in Zhejiang (Yuan, 2018), all of which are considerably higher percentages than the national averages in China. These private enterprises usually cluster together and produce special products. For example, in 2009, approximately 10% of leather shoes in China were produced and exported by Wenzhou City in Zhejiang Province, contributing to 0.4 million jobs and more than USD 1 trillion in exports. Through the market-oriented development mode featured in the private sectors, Zhejiang Province has been transformed to an epicenter of capitalist development, market economics, and private enterprises.

4. Results

4.1 Trends of Zhejiang's GDP, population and EPs during 2007-2015

As seen from **Figure 1**, Zhejiang's GDP has increased by 128.68% from 2007 to 2015, with an annual growth rate of 10.89%. However, different EPs in Zhejiang Province show different trends during this period. The energy consumption and carbon emissions increased respectively by 32.23% and 13.39%, indicating a relative decoupling from the GDP. Owing to the energy structure optimization practiced by the local government, the growth rate of the total CO_2 emissions in Zhejiang Province slowed or even reversed during the "12th Five-Year Plan" period (State Council, 2011). During this period, other EPs, including the emissions of SO_2, soot, waste water, solid waste, COD, and AN declined respectively by, 32.39%, 17.07%, 26.77%, 65.60%, 68.83%, and 48.61%, indicating an absolute decoupling from the GDP.

As a result, in the market-oriented development mode featured in the private sectors, EPs in Zhejiang province are decoupled from the GDP during the period of 2007-2015, whereby energy consumption and CO_2 emissions are relatively decoupled, while emissions of SO_2, soot, waste water, solid waste, COD and AN are absolutely decoupled.

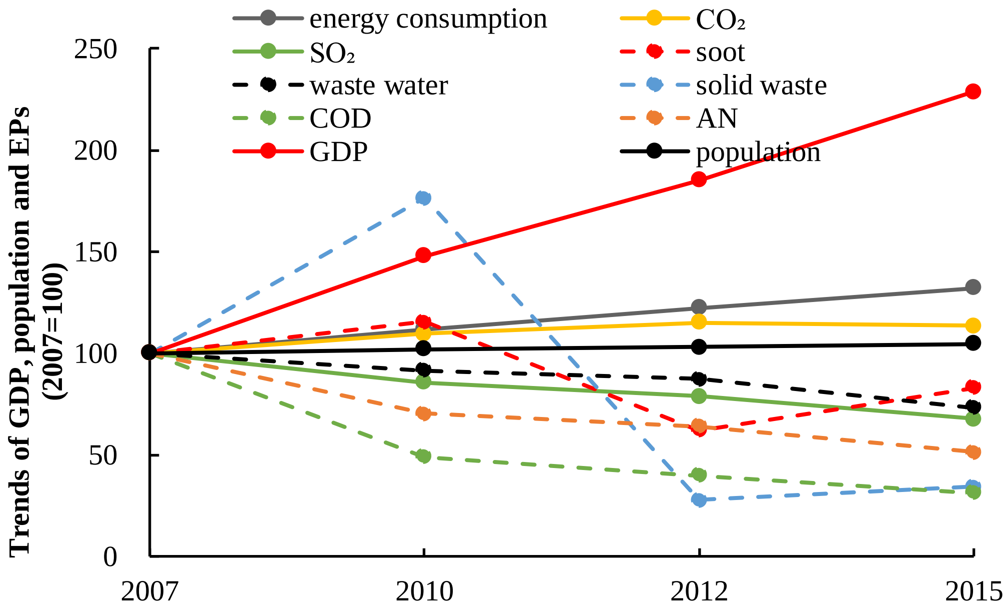

Figure 1. The trends of the GDP, population, and EP in Zhejiang Province during 2007-2015.

4.2 Co-benefits and trade-offs based on driving forces analysis

4.2.1 Overall effects

This study investigates six socio-economic drivers of eight representative changes of EPs in Zhejiang Province during 2007- 2015 (**Figure 2**). The evolution of these drivers during 2007- 2015 are shown in **SM Figure S1**. In general, intensity change is the main driving force behind the reduction of all EPs, contributing -127%, -372%, -263%, -395%, -300%, -178%, -147% and -153%, respectively, to the changes of energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN. The per capita demand change is the dominate driver increasing all EPs, contributing to 177%, 405%, 129%, 257%, 164%, 56%, 38%, and 60%, respectively, of the changes in energy consumption, the emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN. Changes of the population and production structure both increased all EPs by less than 36%. Changes of the final demand structure, however, had small effects, both positive and negative, on the reduction of all EPs, i.e., negative effects on CO_2 and AN emissions and positive effects on other EPs. Similar to changes in the final demand structure, final demand composition changes had a relatively small but mixed effect on the reduction of all EPs, i.e., a negative effect on soot emissions and AN emissions and a positive effect on other EPs.

During the 2007-2015 period, intensity changes reduced all EPs. As a result, there are co-benefits among the reduction of EPs in Zhejiang Province in terms of intensity changes. Meanwhile, there are trade-offs among the reduction of EPs in terms of two driving forces, changes of the final demand structure and changes of the final demand composition. The other three driving forces, including population changes, per capita demand changes, and production structure changes, mainly prevented the reduction of all EPs.

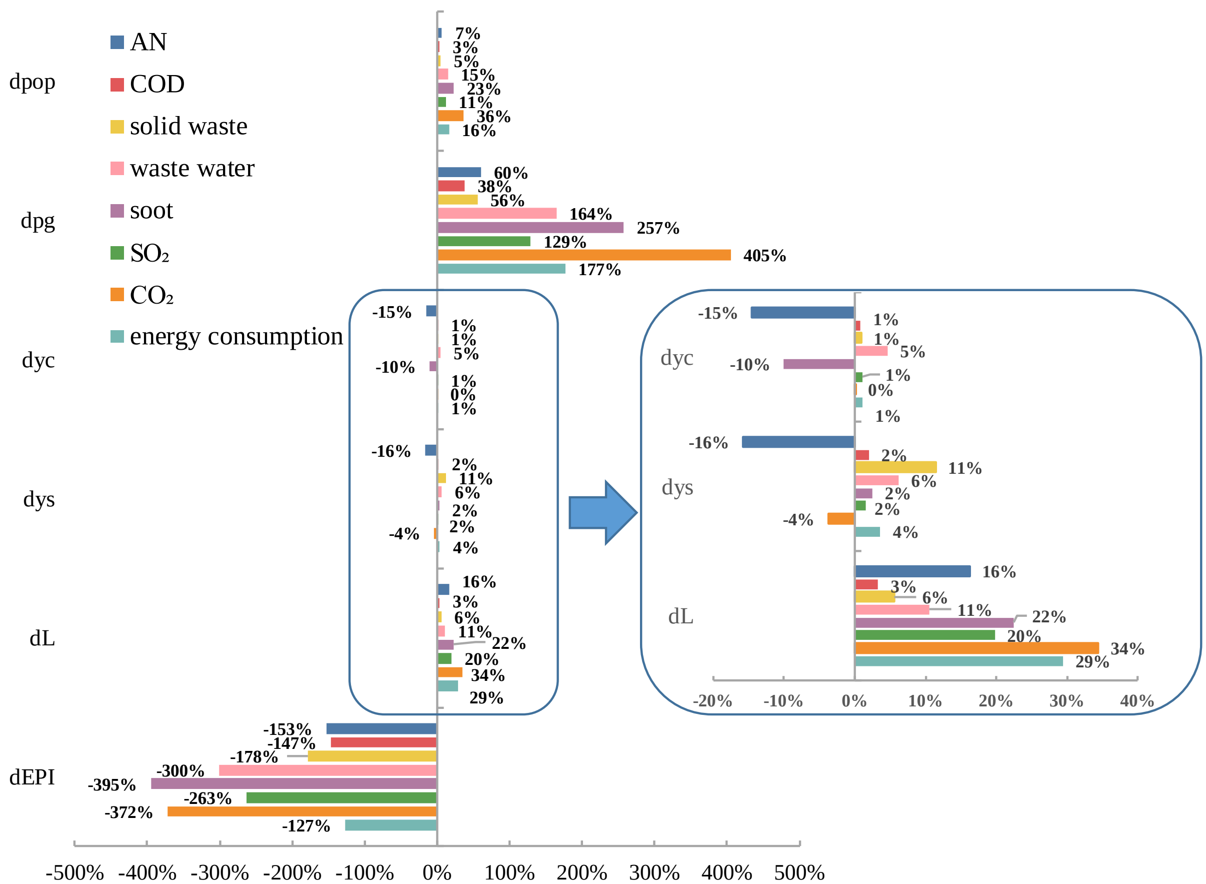

Figure 2. Driving forces behind EPs changes in Zhejiang Province during 2007-2015. Driving forces include the environmental pressure intensity (dEPI), production structure (dL), demand structure (dys), demand composition (dyc), per capita demand (dpg), and population (dpop).

4.2.2 Sectoral level effects

The results of the SDA analysis provide basic information about the co-benefits and trade-offs among different EPs in terms of the overall effects of each driving force. In this paper, we further explore the effects of each driving force on the changes of EPs at the economic sectoral level, and analyze the co-benefits and trade-offs among different EPs in terms of the effect of each driving force on the economic sectoral level. Conventionally, in a certain economic sector, co-benefits occur when two EPs decrease, while trade-offs occur when one EP increases and another decreases. In this paper, we consider 'strict co-benefits' at the sectoral level, i.e., co-benefits that occur when all eight (rather than at least two) EPs decrease in a sector. Furthermore, we define trade-offs at the sectoral level as at least one EP changing in the opposite direction to that of another EP. Here, we show the main effects of the three driving forces on the sectoral level, including intensity changes, production structural changes, and final demand structural changes. Detailed results and analyses can be seen in **SM Figures S2-S4.**

At the sectoral level, the effect of driving forces on changes in EPs varies greatly. The effect of intensity changes on EPs is mainly reflected in the Electric Power and Heat Power sector. The effects of production structural changes on EPs can be seen mainly in the Services; Services; Smelting and Rolling of Metals; and Papermaking sectors. The effects of final demand structural changes on EPs can be seen mainly in the Textile; and Chemical Industry sectors.

The effect of the driving force on changes in EPs in a specific sector may be opposite to its overall effect. The results also reveal that although the overall effects of intensity changes are positive for the reduction of EPs, there are still some economic sectors which prevented the reduction of some EPs. As shown in **Table 1**, among all 26 sectors, there are still five, five, six, ten, four, six, two and three sectors in which intensity changes increased respectively for energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste, COD, and AN.

Focusing on the effects of intensity changes on all EPs across all economic sectors, the results show that there are only five sectors in which intensity changes decreased all EPs (**Figure 3**). These included Foods and Tobacco; Textile; Textile Wearing Products; Papermaking; and Machinery. In all 21 other sectors, intensity changes decreased some EPs but increased other EPs. As a result, in terms of the intensity changes in the five sectors, the reduction of all EPs had strict co-benefit effects, while in the remaining 21 sectors, the reduction of EPs had trade-off effects with other EPs. This strict co-benefit effects and trade-off effects among EPs can also be found for production structure changes and final demand structure changes (**Figure 3**).

Table 1. The number of sectors in which EP increased (+) or decreased (-) in Zhejiang Province during 2007-2015

	Driving Forces Analysis						Accounting Analysis			
	intensity changes		production structure changes		final demand structure changes		production-based		consumption-based	
	+	-	+	-	+	-	+	-	+	-
energy consumption	5	21	12	14	14	12	23	3	17	9
CO_2	5	21	12	14	14	12	12	14	15	11
SO_2	6	20	12	14	13	13	14	12	4	22
Soot	10	16	10	16	15	11	19	7	12	14
waste water	4	22	14	12	15	11	10	16	5	21
solid waste	6	20	13	13	16	10	16	10	6	20
COD	2	24	14	12	14	12	6	20	1	25
AN	3	23	14	12	14	12	10	16	3	23

Figure 3. Strict co-benefits and trade-offs among eight EPs in Zhejiang's economic sectors during 2007-2015, along with the analysis of accounting and driving forces. Full data supporting this graph are listed in **SM Tables S2-S8**.

4.3 Co-benefits and trade-offs analysis based on accounting analysis

Using the EEIO model, we account EPs and their changes during the 2007-2015 period in economic sectors from both the production and consumption perspectives (**Figure 4**). Analysis on the economic sectors dominating EPs are shown in the **SM**. Based on these observations, we analyze how economic sectors contribute to the changes of EPs and the co-benefits and trade-offs among different EPs of economic sectors.

The results in **Figure 4** illustrate that the contribution of sectors to EPs changes varies greatly from different accounting perspectives. As depicted in **Table 1**, from the production perspective, there are 3, 14, 12, 7, 16, 10, 20 and 16 sectors among all 26 sectors in which EPs decreased, respectively, for energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste, COD, and AN. In comparison to results from the production perspective, EPs decreased in more sectors from the consumption perspective. Specifically, there are 9, 11, 22, 14, 21, 20, 25 and 23 sectors in which EPs decreased, respectively, for energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste, COD, and AN. For example, from the production perspective, energy consumption in all sectors increased except for in three sectors, i.e., the Mining and Washing of Coal; Non-Ferrous Metal Ores; and Electric Power and Heat Power sectors. In contrast, from the consumption-based perspective, energy consumption largely decreased in the Machinery; Manufacture of Artwork; and Electric Power and Heat Power sectors, accounting for respectively 96.33 Mtce, 101.81 Mtce, and 64.17 Mtce. The Electric Power and Heat Power sector increased CO_2 emissions by 13.03 Mt from the production-based perspective; however, this sector reduced CO_2 emissions by 4.76 Mt from the consumption-based perspective. The Construction sector contributed to the reduction of soot emissions (5.02 Mt) from the consumption-based perspective but slightly increased soot emissions from the production-based perspective.

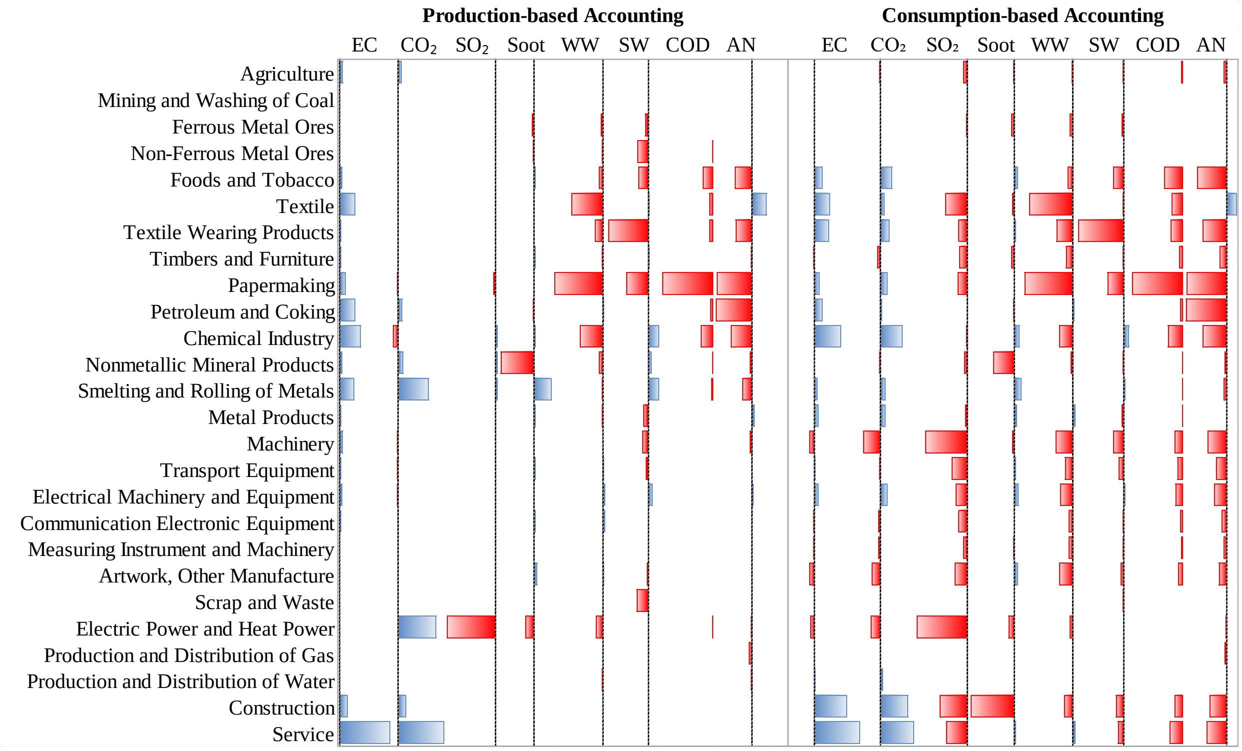

Figure 4. Production-based and consumption-based EP changes of sectors in Zhejiang Province during 2007-2015. EC, WW, and SW indicate energy consumption, waste water, and solid waste, respectively, in the figure. Red bars and blue bars indicate EP decrease and increase, respectively, in the figure. Full data supporting this graph are listed in **SM Tables S5-S8**.

In general, co-benefits mainly exist in the Mining sector, as the Mining sector contributed to the reduction of all EPs in Zhejiang Province during the 2007-2015 period. Given the resource endowment of Zhejiang Province, the small Mining sector grew at a very low rate during the 2007-2015 period and, consequently, caused a smaller effect on changes to all EPs. The trade-offs mainly exist in the Manufacturing; Electricity and Water; and Construction sectors. Taking the Textile sector as an example, energy consumption and the emissions of CO_2 increased, respectively, by 284 Mtce and 1.77 Mt; however, other EPs decreased during the 2007-2015 period. Most significantly, the discharge of waste water decreased by11,640 Mt from the consumption perspective. These observations indicate that there are co-benefits between energy consumption reduction and CO_2 emission mitigation in the manufacturing sector and trade-offs between energy consumption reduction and the reduction of other EPs.

When we use strict co-benefits (as defined above) to evaluate our results, we find that strict co-benefits and trade-offs vary greatly in economic sectors from different accounting perspectives. From the production perspective, there is only one sector (the Non-Ferrous Metal Ores sector) among the 26 sectors in which strict co-benefits occur among all EPs. From the consumption perspective, there are eight sectors with strict co-benefit effects for all EPs. These include the Mining and Washing of Coal; Ferrous Metal Ores; Timbers and Furniture; Nonmetallic Mineral Products; Machinery; Communication Electronic Equipment; Measuring Instrument and Machinery; and Electric Power and Heat Power sectors.

Based on the results for consumption-based EPs (**SM Figure S5 and Tables S9-S11**), we can further analyze effects of final demand changes on EP changes and identify the co-benefits and trade-offs among the EPs caused by each category of final demand. Results show that outflow change is the dominant driver behind changes in all EPs. This is mainly because Zhejiang Province's economic development relies on exports during this period. Results also show that there are no strict co-benefits among all eight EPs caused by the changes in the final demand.

5. Discussions

Under the market-oriented economic development mode featured in the private sector, Zhejiang Province has made remarkable achievements in economic development and EPs reductions during 2007-2015. Given the high speed of economic growth (with average annual GDP growth rates of 10.9%), all eight EPs still successfully decoupled from economic growth. Specifically, relative decoupling occurred for energy consumption and CO_2 emissions, while absolute decoupling occurred for emissions of SO_2, soot, waste water, solid wastes, COD and AN. As a result, it becomes a very important issue for both scholars and policy-makers to uncover the reasons behind this phenomenon and to reveal the co-benefits and trade-offs among these EPs. This research contributes in the following three aspects: 1) it reveals the drivers underlying reductions in EP within a fast-economic development mode; 2) it identifies the co-benefits or trade-offs among different EPs; and 3) it provides some generalized policy implications on reducing EPs.

5.1 The drivers of EP reductions

Our results show that intensity change is the main driving force behind the reduction of all EPs in Zhejiang Province during the 2007-2015 period. Intensity change contributes -127%, -372%, -263%, -395%, -300%, -178%, -147% and -153%, respectively, to the changes of energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN. This is primarily due to the refined policy on promoting cleaner production in Zhejiang province. Compared with the governments of other provinces in China, the government of Zhejiang is implementing more refined policies to eliminate backward production facilities for promoting cleaner production. To stimulate Zhejiang's cities and towns for promoting cleaner production, policymakers have linked the current reduction activities with the future development space, i.e., more reduction of EPs will permit for more future emission space (DEEZP, 2015). To promote the reduction of EPs within individual enterprises, the Zhejiang government evaluates the performance of enterprises, especially among heavy pollution industry clusters, to increase competition in reducing EPs by implementing cleaner production. These refined policies effectively increase the technological level of Zhejiang's industries and substantially reduce EPs. Zhejiang's policy experience in this avenue can be learned by other sub-regions within China.

The per capita demand change is the dominate driver which is increasing all EPs, contributing to 177%, 405%, 129%, 257%, 164%, 56%, 38%, and 60%, respectively, to changes in energy consumption, emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN. This is primarily due to the fast increase of affluence in Zhejiang province during the period 2007-2015. According to data from Zhejiang Provincial Bureau of Statistics (ZPBS, 2008-2016b), per-capita final demand has increased by 84%, from 48,000 CNY in the year 2007 to 88,000 CNY in the year 2015. The other four driving forces have relatively small effects on changes to EPs. Specifically, changes of population and production structure both increased all EPs by less than 36%. Changes to the final demand structure and final demand composition had both a relatively small but mixed effect on the reduction of all EPs.

In line with results from previous research, e.g., where (Liang et al., 2014) examine the driving forces of EPs at the Chinese national level, our research at the regional level, i.e., Zhejiang province, also reveals that intensity changes are the major driving forces for reducing EPs, while per-capita final demand is the major driving force for increasing EPs. However, our research advances previous studies by further exploring the performance of the driving forces at the sectorial level. The effect of the driving force on changes in EPs in a specific sector may be opposite to its overall effect. As a result, the advancement of these refined results can provide further targeted policy suggestions relevant to reducing EPs by making use of socio-economic drivers at the economic sectorial level.

Using intensity changes as an example, i.e., the major driver for reducing EPs, we demonstrate how to make targeted policy suggestions for reducing EPs. Our results reveal that during the period of 2007-2015, the intensity effect of reducing EPs, such as energy consumption and emissions of CO_2 and SO_2, is mainly reflected in the Electric Power and Heat Power sector. The decrease of intensity in this sector reduced energy consumption, CO_2 emissions, and SO_2 emissions respectively by 1057.49 Mtce (29.36%), 105.16 Mt (66.97%), and 48.89 Mt (74.13%). However, there are still some economic sectors that prevented the reduction of some EPs, e.g., the Agriculture and the Mining and Washing of Coal sectors. As a result, if policy-makers intend to reduce EPs by decreasing intensity, special attention should be paid to these sectors.

Similar to the intensity changes, analysis on the performance of other driving forces can also provide more targeted policy suggestions. Specifically, if we rely on controlling the production structure to reduce EPs, policies should focus on the Services; Smelting and Rolling of Metals; and Papermaking sectors. If the aim is to reduce EPs by adjusting the final demand structure, policies should focus on the Textile and Chemical Industry sectors.

In future development, population and per capital final demand may both increase with the rapid economic growth of Zhejiang Province, which will also inevitably increase all EPs. As a result, we should still rely on intensity changes to reduce EPs by promoting technological advancement. The potential effects of the final demand structure and final demand composition changes should also be viewed with great importance; whereby, EP mitigation will be more effective through the optimization of both the final demand structure and the final demand composition. Currently, production structure changes increased all EPs, and policy-makers should spend more effort on the action of “Industrial Structural Adjustment” launched by both the central and local governments to reverse the effect of production structure changes on EPs. Specifically, the action of “Industrial Structural Adjustment” should attach great importance in the Services; Smelting and Rolling of Metals; and Papermaking sectors.

5.2 Co-benefits and trade-offs among EPs

This study reveals that there are both co-benefits and trade-offs among the reduction of EPs in Zhejiang Province during the 2007-2015 period. In term of the driving forces, results in **Figure 2** also illustrate that the strict co-benefits mainly exist in intensity changes, while the trade-offs are observed from the final demand structure and composition. In terms of economic sectors, results on where the co-benefits and trade-offs exist are quite different based on different accounting perspectives. From the production perspective, there is only one sector (the Non-Ferrous Metal Ores sector) among the 26 sectors in which strict co-benefits occur among all eight EPs; while from the consumption perspective, there are eight sectors with strict co-benefit effects for all the EPs.

Previous research, e.g., (Yu et al., 2015), demonstrate that trade-offs in reducing EPs exist in the production structure change for Chongqing during 2000–2010. Our study advances previous research in the avenue through the following three aspects. First, our study reveals that trade-offs of reducing EPs exist in the final demand structure and final demand composition, for Zhejiang during 2007-2015. As a result, trade-offs may exist in both the production structure changes and demand structure changes. Second, our study further explored the sectorial level effects of co-benefits and trade-offs for reducing EPs. Understanding the co-benefits and trade-offs at the sectorial level may help policy-makers achieve the goal of reducing EPs more efficiently.

Using the intensity changes as an example, we demonstrate how to identify specific sectors and provide targeted policy suggestions on reducing EPs. At the sectorial level, results in **Figure 3** show that the reduction of all eight EPs had strict co-benefit effects between each other in five sectors and trade-off effects in the remaining 21 sectors. These five sectors include Foods and Tobacco; Textile; Textile Wearing Products; Papermaking; and Machinery. As a result, these five sectors can be identified as the targeted sectors where EPs can be decreased more efficiently by making use of the co-benefits of intensity changes.

Similar to the intensity changes, analysis about the performance of other driving forces can also provide more targeted policy suggestions. Specifically, in terms of production structure changes, the reduction of all eight EPs had strict co-benefit effects between each other in six sectors and trade-off effects in ten sectors. In terms of final demand structure changes, the reduction of all eight EPs had strict co-benefit effects between each other in nine sectors and trade-off effects in five sectors. These sectors should garner the full attention of policy-makers. If co-benefits can be pursued and trade-offs avoided, policy-makers may be able to lower the overall costs for mitigating all EPs.

5.3 Policy implications

The new findings of our research can also provide some generalized policy implications for the reduction of EP.

(1) Policy-makers should attach great importance to the sectorial level analysis of the driving forces as it may provide more chances for reducing EPs. The overall effect of driving forces behind changes of EPs is the sum of their effects in each economic sector. At the sectorial level, the effect of driving forces on changes in EPs varies greatly. Moreover, the effect of the driving force on changes in EPs in a specific sector may be opposite to its overall effect. Some evidence of this phenomenon can be found in the results of our study. Results from the analyses of the driving forces underlying changes to Zhejiang's EPs, revealed that although the intensity changes reduced all EPs overall, they also increased a few EPs in particular economic sectors. As a result, policy-makers should not only evaluate the overall performance of the driving forces behind changes to EPs but also their performance at the sectorial level. The more refined evaluation of the effects of the driving forces will help policy-makers identify undetected economic sectors in which the driving forces prevent or promote the reduction of EPs. Specifically, for driving forces that promote the overall reduction of EPs, policy-makers should be cautious about whether there are still some sectors in which the driving forces prevent reductions in EPs. For driving forces that

prevented the overall reduction of EPs, policy-makers should not be disappointed, as there may be some sectors in which the driving forces promote reductions in EPs.

(2) Policy-makers should make full use of the co-benefits and trade-offs of EPs at the sectorial level to reduce EPs more efficiently. From this study, we provide suggestions for dealing with the challenge and opportunities of the co-benefits and trade-offs among EPs. First, policy-makers should focus on a wide range of EPs rather than on a single EP, as there may be trade-offs among these EPs and the reduction of some EPs may induce the increase of other EPs. Second, policy-makers should analyze co-benefits and trade-offs among the EPs from each of the driving forces and pay full attention to all the driving forces, rather than rely on only a single driving force. If trade-offs among EPs caused by some driving forces are inevitable, one should make full use of other driving forces that induce co-benefits among EPs to reduce all EPs overall. Third, it is necessary for policy-makers to account for EPs from multiple perspectives when evaluating the co-benefit and trade-off effects of EPs at the economic sectorial level. By using multiple accounting methods, i.e., production- and consumption-based accounting methods, one will not only identify different sectors that are critical for changes to EPs but also identify the co-benefits and trade-offs among EPs at the sectorial level. Moreover, to seek more opportunities relevant to the mitigation of EPs at the sectorial level, policy-makers should strengthen inter-sectorial coordination and establish a joint evaluation mechanism among different sectors.

6. Conclusions

It is a challenge for an economic system to achieve rapid economic growth while reducing EPs. Previous studies mainly focus on the individual driving forces of EPs, the consideration of the co-benefits and trade-offs among different EPs and policies have been considerably overlooked. In

China, previous studies have mostly engaged these issues at the national level and have overlooked the regional socio-economic characteristics – this presents a mismatch between regional policy applications and average national level research findings. Towards this end, this study analyzes the driving forces for changes of eight typical EPs in Zhejiang province during the 2007-2015 period. More specifically, this study focuses on the co-benefits and trade-offs for the reductions of these EPs at the sectorial level. Our findings show that per-capita final demand is the major driving force for increasing EPs, which contributes 177%, 405%, 129%, 257%, 164%, 56%, 38%, and 60% to the changes of energy consumption and the emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN during 2007-2015. Results also revealed strict co-benefits in the reduction of all eight EPs due to intensity change, which contributes -127%, -372%, -263%, -395%, -300%, -178%, -147% and -153% to the changes of energy consumption and emissions of CO_2, SO_2, soot, waste water, solid waste COD, and AN. In general, EPs have more trade-offs than co-benefits at sectoral level. Compared with the production-based accounting, the consumption-based accounting observed more strict co-benefits of EPs at sectoral level. Our findings suggest important policy implications associated with utilizing co-benefits and avoiding trade-offs for EP mitigation: making full use of all driving forces, strengthening intersectoral coordination, and establishing a joint evaluation mechanism among different sectors. As the economic development mode in Zhejiang province represents one of China's future market-economy development modes, the experience from Zhejiang's development can be referenced by other Chinese regions and other developing economies around the world.

Due to data availability, this study considers only eight typical EPs and accounts for EPs from the production and consumption perspectives. Future studies may cover more EPs and examine them from more perspectives, e.g., the income and betweenness perspectives (Liang et al., 2016).

As this study employs EEIO and SDA approaches, the results could be influenced, to some extent, by sector aggregation (Su et al., 2010). Currently, due to the availability of data, there are 26 economic sectors in this study – the issue of sector aggregation can be examined as a future research avenue.

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