Environmentally-extended input-output analysis and structural decomposition analysis for greenhouse gas emissions from the Construction sector in Australia

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This research assesses the greenhouse gas (GHG) emissions arising from the Australian Construction sector with changes in Australian economic system in the post-financial-crisis era. The Australian Environmental-Economic Accounts are combined with Australian input-output tables to construct the environmentally-extended input-output (EEIO) tables for GHG emissions. It illustrates the relationships between economic activities and GHG emission in the Construction sector. Although the total economic output of the Construction sector has increased by 34.78% from 313634 million $AUD in 2009–10 to 422706 million $AUD in 2014–15, both the direct and indirect effects of GHG emissions in the Construction sector have decreased by 24.62% and 31.44%. On the basis of EEIO, the structural decomposition analysis (SDA) method is applied to estimate the driving forces for the changes of GHG emissions from 2009–10 and 2014–15. The Australian Construction sector has been divided into four sub-sectors: Residential Building Construction, Non-Residential Building Construction, Heavy and Civil Engineering Construction, and Construction Services. The Construction Services sector had generated the largest amount of GHG emissions during the period, and the Residential Building Construction sector has the largest total effect for GHG emission. The growth of GHG emissions in these four sub-sectors between 2009–10 and 2014–15 was mainly affected by the Final demand's overall level of economic activity (the level effect). The level effect of Final demand results in the largest increase of GHG

emissions in the the Construction Services sector by about 1068 Giggrams. The novelty of the paper is that the SDA method has conducted enabled analysis for the drivers of the change of GHG emissions from these four sub-sectors disaggregated from the Australian Construction sector. Consequently, the detailed analysis for sub-sectors would lead to a better understanding of the causes of GHG emissions. It benefits the policy-makers to design pertinent strategies for the reduction of GHG emissions in the Australian Construction sector.

Topic

Classical IO applications (1) Economic Structural Change and Dynamics".

1. Introduction

Greenhouse gas (GHG) emissions mainly caused by human industrial activities have increased rapidly (Mass Audubon 2018). It has become the greatest ecological, economic, and social challenge of our time, which results in a worldwide, unnatural warming that's driving other changes in our environment.

Since the industrial revolution, the development of industry have cause the sharp growth greenhouse gases into the atmosphere. The levels of CO_2 are increasing mainly due to the burning of fossil fuels and deforestation from industrial activities. The global mean CO_2 level in 2013 was 395 parts per million (Climate Change In Australia 2017).

The Construction sector is Australia's third largest industry, behind only mining and finance, and produces around 8% of Australian Gross Domestic Product (GDP), in value added terms (Economics research 2015). The GDP of the Construction sector grew dramatically from about 24 billion AUD$ in 2009–10 to about 32 billion AUD$ in 2014–15 (ABS 2018c). Australia's construction sector is one of the largest growing sectors in the country, with commercial construction work expected to increase by 9.3% in 2018 (David Cartwright 2018).

As one of the highest emitting countries in terms of per-capita emission globally (Yu, Wiedmann et al. 2017), greenhouse gas emission accounted for 559 Mt CO_2-e in 2012–13 (Australian Government Department of the Environment and Energy 2017). The amount of greenhouse gas emissions from manufacturing industries and construction was 499 million metric tons (Trading Economics). The Construction sector directly generates the greenhouse gas emission, but also results in the indirect greenhouse gas emission. The Australian Bureau of Statistics (ABS) had found that the Construction sector directly generated 4.6 million metric tons GHG emissions and indirectly caused the 21.4 million metric tons GHG emissions in 1994–95 (Statistics 2001). The direct GHG emissions from the Construction sector increased from 4.6 million metric tons in 1994–95 to 9.2 million metric tons in 2013–14. The Australian government has a target representing a 50–52 per cent reduction in emissions per capita and a 64–65 per cent reduction in the emissions intensity of the economy between 2005 and 2030 (Australian Government Department of the Environment and Energy 2015). GHG emissions in the Construction sector always increased, which corresponds to the increase of the GDP of the Construction sector. We can analyse the relationships between the economic activities in the Construction sector and its GHG emission and quantify the drivers of the change of GHG emissions by applying environmentally-extended input-output (EEIO) model and the structure decomposition analysis (SDA) method

In contrast to other countries, the exclusive socio-demographic factors affects the growth of the GDP in the Australian Construction sector: 1) Australia's population is growing by 1.6% every year, which results in the increasing demand of new residential and commercial buildings; 2) Construction work in Australian urban areas has increasing because almost 50% the population is settled in Australian major cities; 3) Productivity in the Construction sector has been increasing by 2.8 annually, which benefits the growth of its GDP; and 4) the commercial building has been predicted to grow by 9.3% in 2018 (David Cartwright 2018). The change of GHG emissions due to the increase of the GDP in the Construction sector indicates that the need of knowledge about driving forces of GHG emissions has never been as significant as today. Therefore, the objective of this paper is analyzing the change of GHG emissions and quantifying the driver forces of the change in the Construction sector from 2009–10 to 2014–15. This work is the first one applying the SDA method to explore the drivers of GHG emission in the Australian Construction sector on the basis of the combination of the Australian Environmental-Economic Accounts with Australian input-output tables. Another novelty is to disaggregate the Construction sector into four sub-sectors to show the detailed analysis to illustrate a better understanding of the change of GHG emissions.

Previous studies related to the GHG emission in the Australian industrial sectors indicates the drivers for the change of GHG emissions all industrial sectors from 1976 to 2005 (Wood 2009) rather than the detailed analysis for the Construction sector. The carbon footprint of the Construction sector from 2009 to 2013 has been illustrated on the basis of IO analysis and data from the Industrial Ecology Virtual Laboratory (Yu, Wiedmann et al. 2017). These studies are significant because they showed indirect information about the GHG emissions in the Construction sector, which benefits the design of Australian environmental policies for GHG emissions. Our research focuses on the detailed analysis of GHG emission from the four sub-sectors (Residential Building Construction (RB), Non-Residential Building Construction (NRB), Heavy and Civil Engineering Construction (HCEC), and Construction Services (ConS).) in the Construction sector through the application of EEIO model and SDA method based on the Australian Environmental-Economic Accounts and Australian input-output tables published by the Australian Bureau of Statistics.

The paper is structured as follows. The basic methodology and sources of data for this study is given in Section 2. Results of EEIO analysis and the investigation of the driving forces for GHG emissions in

Australian Construction sector between 2009–10 and 2014–15 are illustrated in Section 3. Section 4 provides the discussion, and Section 5 draws conclusions.

2. Methodology

2.1 Environmentally-extended input-output analysis

In order to analyse the direct and indirect effects of the four sub-sectors in the Australian Construction sector on GHG emissions, the EEIO model accounting for the complex relationships between industrial sectors and environmental pollution in modern economies has been applied. Three types of the EEIO model have been illustrated by Miller and Blair (2009). The first type of the EEIO model is generalized EEIO models, which considers pollution generation and abatement activities as additional rows and/or columns for the basic structure of the IO model (Kitzes 2013, Su, Ang et al. 2013). The second one is the economic–ecologic models, which adds additional "ecosystem" sectors into the inter-industry framework to record the resource flows and environmental impacts between industrial and ecosystem sectors (Bailey, Allen et al. 2004, Wiedmann, Minx et al. 2006). The third one is the commodity-by-Industry models for environmental issues, which consider environmental factors as "commodities" in a commodity-by-industry input–output table through the application of supply-use matrix (Miller and Blair 2009) and offer detailed analysis for environmental factors because an industrial sector may produce more than one commodity (pollutants) (Lenzen and Reynolds 2014). This research applies the generalized IO models for the GHG emissions and adds it as an additional row for the IO framework.

An introduction of the basic form of EEIO analysis can be found. The basic structure of input-output model can be expressed as

$$\mathrm{x} = \mathrm{Ax} + \mathrm{f} = (I - A)^{-1}\mathrm{f} = \mathrm{Lf} \qquad (1)$$

where x is the $n \times 1$ vector of total output by industrial sectors, I is the $n \times n$ unit matrix. A is the input coefficient of IO model. f is the Final demand of the economy. $L = (I - A)^{-1}$ is known as the Leontief Inverse matrix.

The approach to construct the EEIO model for GHG emissions associated with industrial sectors is to add a vector $1 \times n$ of direct coefficients of GHG emissions, $e = [e_i]$ (Gigagram/million $AUD), each element of which is the amount of GHG emissions(ε) consumed from per dollar of total output in each industrial sector.

The basic structure of EEIO model for GHG emissions can be shown as

$$\begin{bmatrix} \mathrm{x} \\ \varepsilon + \mathrm{f}^* \end{bmatrix} = \begin{bmatrix} A \\ e \end{bmatrix} \begin{bmatrix} \mathrm{x} \\ \varepsilon + \mathrm{f}^* \end{bmatrix} + \begin{bmatrix} \mathrm{f} \\ \mathrm{f}^* \end{bmatrix} \quad (2)$$

$$\varepsilon' = \hat{e}\mathrm{x} = \hat{e}(I - A)^{-1}\mathrm{f} \quad (3)$$

where ε' is the transpose of the $1 \times n$ vector of GHG emissions, Gigagram (Gg), in each industrial sector. f^* represents $1 \times n$ vector of GHG emissions (Gg) by Final demand, which indicates direct effects of GHG emissions for Final demand. $\hat{e}$ with the "hat" over a vector e denotes a diagonal matrix with the elements of the vector along the main diagonal. For instance, if $e = [e_1 \quad e_2 \quad e_3]$ then $\hat{e} = \begin{bmatrix} e_1 & 0 & 0 \\ 0 & e_2 & 0 \\ 0 & 0 & e_3 \end{bmatrix}$. $\hat{e}L$ represents the total effects of GHG emissions for Australian industrial sectors.

Equation 3 can be expressed as follows:

$$\varepsilon' = \hat{e}L\mathrm{f} \quad (4)$$

2.2 Structural decomposition analysis

The aim of this section is to apply the SDA method to investigate the drivers of GHG emissions in Australian Construction sector. Previous researches have has revealed characteristics of the application of the SDA method on GHG emissions from four aspects: time periods (Rose and Chen 1991, Wachsmann, Wood et al. 2009), driving forces (Alcantara and Duarte 2004, Cellura, Longo et al. 2012), and mathematical approaches for the decomposition process (multiplicative and additive) (Hoekstra and Van den Bergh 2003, Zhu, Su et al. 2018).

This study analyses the driving forces of GHG emissions by applying additive structural decomposition analysis. The GHG emissions from the four sub-sectors in the Construction sector (ε) is decomposed into structurally significant drivers: the GHG emission intensity (changes in GHG emissions per unit of total economic output), technology effect (changes of GHG emissions caused by the change of industrial structure), the level effect of Final demand (the change of GHG emissions due to the change occurring in the overall level of Final demand), and the mix effect of Final demand (the changes of GHG emissions caused by the change of the proportions in different categories of Final demand) (Wei, Huang et al. 2017).

Based on Eq. (3), changes of GHG emissions between t_1 and t_0 ($t_0 < t_1$) can be formulated as

$$\Delta\varepsilon = \varepsilon^1 - \varepsilon^0 = \hat{e}^1 L^1 \mathrm{f}^1 - \hat{e}^0 L^0 \mathrm{f}^0 \qquad (4)$$

The research applies the process of decomposing the GHG emissions introduced by He, Reynolds et al. (2019).The process of decomposition by these effects can be summarised as:

$$\Delta\varepsilon = \left(\frac{1}{2}\right) \underline{(\Delta\hat{e})(L^0\mathrm{f}^0 + L^1\mathrm{f}^1)} + \left(\frac{1}{2}\right) \underline{[\hat{e}^0(L^1(\Delta A)L^0)\mathrm{f}^1 + \hat{e}^1(L^1(\Delta A)L^0)\mathrm{f}^0]} + (1/2)\underline{(\hat{e}^0 L^0 + \hat{e}^1 L^1)((1/2)\Delta f(B^0 + B^1) + (1/2)(f^0 + f^1)(\Delta B))} \qquad (5)$$

The matrix B is defined as the bridge coefficients matrix, which equals the final demand matrix elements divided by their corresponding column sums. The first term of the right-hand side means GHG emission intensity change. The second term of the right-hand represents technology change. The third term of that means the Final-demand change, in which the former represents the level effect of Final demand and the latter means the mix effect. f means the level of Final-demand expenditure over all sectors.

2.3 Data process

Australian Input-Output Tables for 2009–10 (ABS 2013) and 2014–15 (ABS 2017) were used in this study. For harminisation purposes, these IO tables were each aggregated to a harmonised seven industrial sectors from 114 industrial sectors. All the monetary values were deflated to constant 2009–10 prices based on the method introduced by Wood (2011). Australian Bureau of Statistics has published the Australian Environmental-Economic Accounts (ABS 2018a), which has illustrated the carbon emissions occurs in seven industrial sectors and Final demand from 2002–03 to 2014–15. In particular, the Construction sector is disaggregated into four industrial sectors: Residential Building Construction, Non-Residential Building Construction, Heavy and Civil Engineering Construction, and Construction Services. The amount of GHG emissions from each sub-sector are calculated through multiplying the total amount of GHG emissions in the Construction sector by the proportion of the total output in this sub-sector in the Construction sector. This method has been introduced to disaggregate food waste in industrial sector (Reutter, Lant et al. 2017).

4. Results

4.1 Environmentally-extended input-output analysis for GHG emissions in the Australian Construction sector and four sub-sectors

Based on the calculated economic activity and GHG emissions in the Construction sector in Australia from 2009–10 to 2014–15, the detailed results are shown in Fig. 1. The total GHG emission has only increased by 1.60% from 9307.1 Gg to 9456.1 Gg. Although the total economic output of the Construction sector has increased by 34.78% from 313634 million $AUD in 2009–10 to 422706 million $AUD in 2014–15, both the direct and indirect effects of GHG emissions in the Construction sector have decreased by 24.62% and 31.44%.

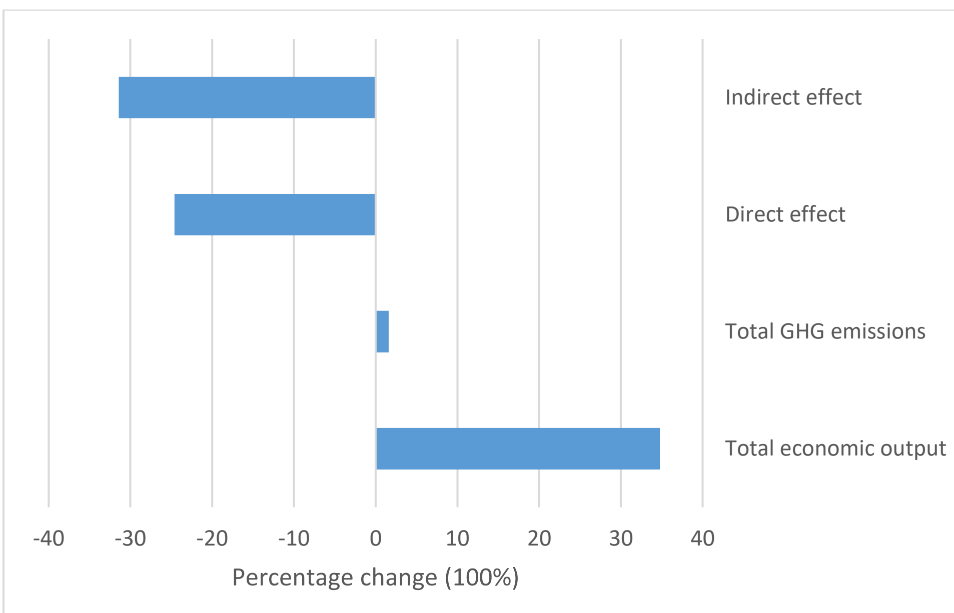

Fig. 4.1. Percentage change for the economic activity and GHG emissions in the Construction sector in Australia from 2009–10 to 2014–15.

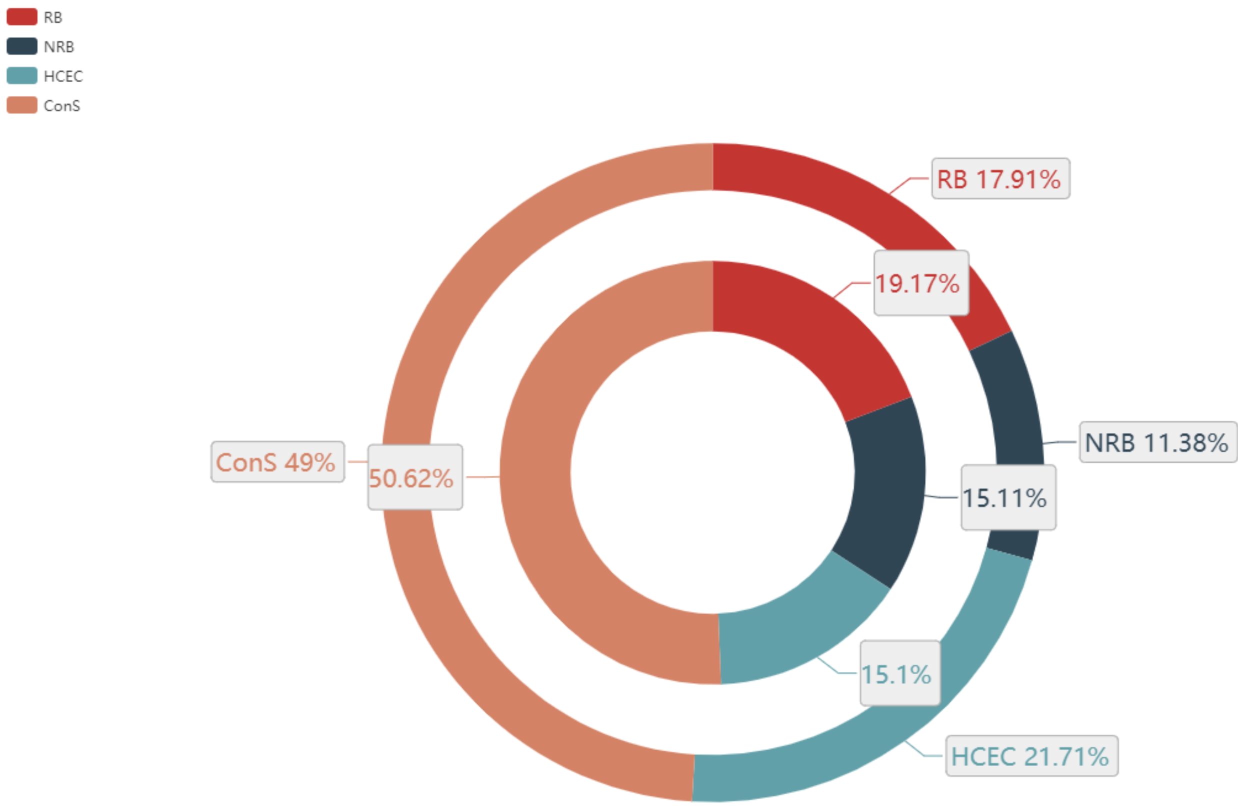

Fig. 4.2. Direct GHG emission from four sub-sectors of the Construction sector in 2009–10 and 2014–15, Gg. The circles represent the total amount of direct net consumption by four sub-sectors. The inner circle means the year of 2009–10 and the outer circle illustrates the year of 2014–15.

Australian GHG emissions generated from four sub-sectors (Residential Building Construction, Non-Residential Building Construction, Heavy and Civil Engineering Construction, and Construction Services) of the Construction sector has been shown in Fig. 4.2. The Construction Services sector accounted for almost half of the amount of GHG emissions in the Construction sector. The amount of direct GHG emission have been compared to analyse the GHG emissions in these four branches in 2009–10 and 2014–15. The amount of GHG emissions in the Construction sector increase slightly during the period. Although the percentages of GHG emission in Residential Building Construction, Non-Residential Building Construction, and Construction Services decreased from 2009–10 to 2014–15, that of GHG emission generated in the Heavy and Civil Engineering Construction had increased.

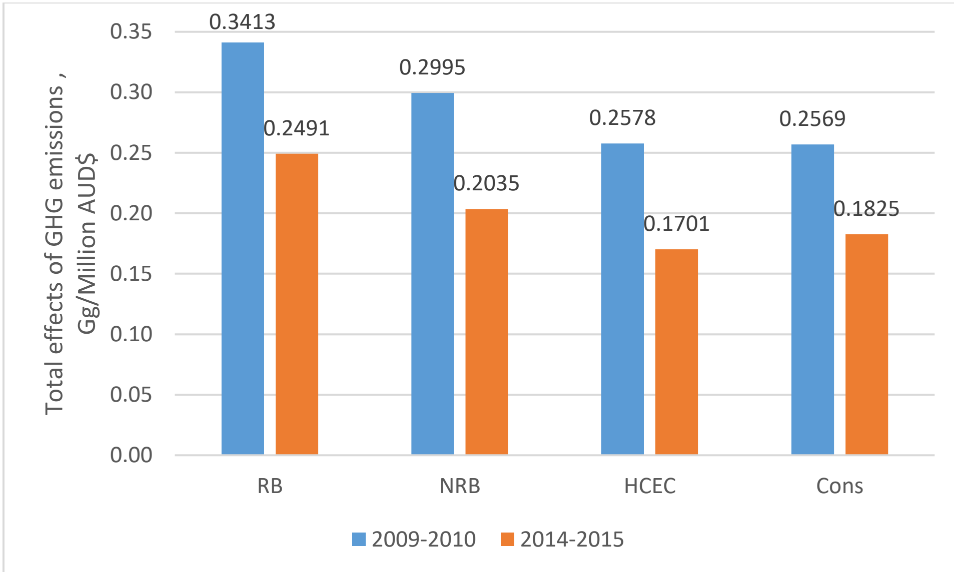

Fig. 4.3. Percentage change for the total effects of GHG emissions from the four sub-sectors in Australia from 2009–10 to 2014–15.

The total effects of these four sub-sectors have been illustrated in Fig. 4.3. It shows that the Residential Building Construction sector has the largest total effect for GHG emission, followed by the Non-Residential Building Construction sector, the Heavy and Civil Engineering Construction sector, and the Construction Services sector. There was a decrease trend for these four sub-sectors: the Residential Building Construction sector (about 27.01%), the Non-Residential Building Construction sector (about 32.05%), the Heavy and Civil Engineering Construction sector (about 34.02%), and the Construction Services sector (about 28.96%) from 2009–10 to 2014–15.

4.2 Structural decomposition analysis for GHG emissions from four sub-sectors in the Australian Construction sector

Structural decomposition analysis revealing the importance of driving forces to the changes of GHG emissions was conducted in four sub-sectors from 2009–10 to 2014–15. There are five major drivers to be investigated by using Eq. 5, including GHG efficiency, technology effect, level effect of Final demand, and mix effect of Final demand. Analysis in Fig. 4.4 shows that during the period for every sub-sector, the level effect of final demand was the major driving force for the increase of GHG emissions, which resulted in the largest increase about 1068 Gg in the Construction Services sector. The effect of the GHG efficiency results in the decrease of GHG emissions. The effect of the GHG efficiency causes the largest decrease of GHG emissions about 1316 Gg occurring in the Construction Services sector. The mix effect of Final demand contributed to the increase of GHG emissions in the Heavy and Civil Engineering Construction sector (about 481Gg) while it leaded to the decrease of GHG emissions in the Non-Residential Building Construction sector (about 225 Gg) and the Construction Services sector (about 186 Gg). Technology effect has only resulted in the increase of GHG emissions about 465 Gg and has minor effects on other three sub-sectors.

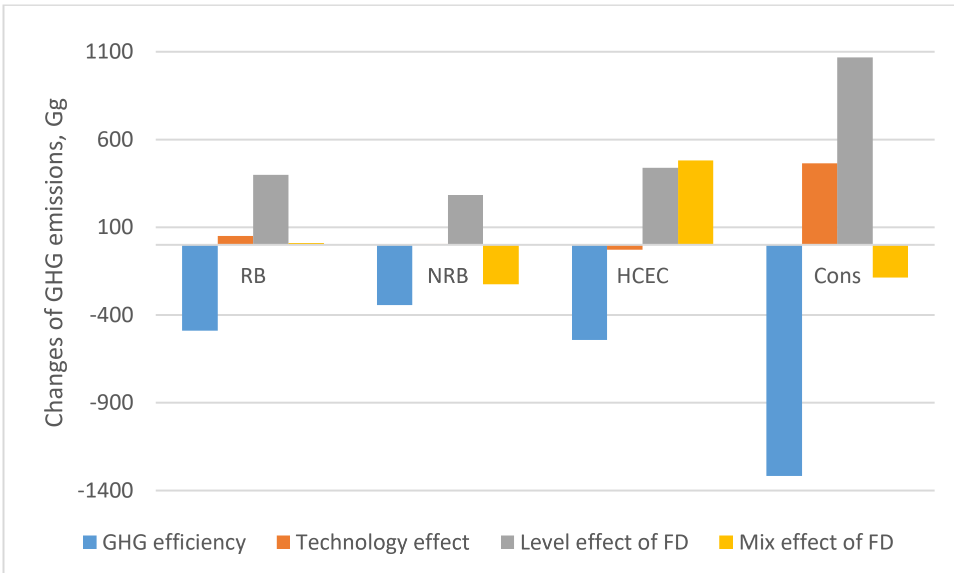

Fig. 4.4. Contribution of driving forces to changes of GHG emissions for four sub-sectors in the Construction sector

5. Discussions

The analysis on the basis of the two-year EEIO tables for GHG emissions in the Australian Construction sector and its four sub-sectors indicates the relationships between the development of Australian economy and the change of the amount of GHG emissions. The SDA method applied in this research shows the effects of the drivers on GHG emission from four sub-sectors in the Australian Construction sector. The percentage change of the total economic output in the Construction sector increases by 34.78% while that of total GHG emissions only increased by 1.60%. The slight increase of GHG emission corresponding to the sharp increase of the total economic output in the Construction sector indicates that the environmental policies designed by Australian government are effective. It is the first step to achieve the net zero goal by about 2050 in order to stay within the recommended carbon budget of 1% of global total, shown by Australian Climate Change Authority (Australian Sustainable Built Environment

Council 2016). The sharp drop of the direct effect of GHG emissions in the Construction sector between 2009–10 and 2014–15 shows that there are significant effects of the application of clean technologies and published environmental policies on the Construction on the reduction of GHG emissions. For example, with the support of the Energy Efficiency Opportunities Act 2014 (Australian Government Federal Register of Legislation 2014), the Construction sector has enhanced the energy efficiency, which lead to the direct decrease of GHG emission. The decrease of indirect effect of GHG emission in the Construction sector indicates that the productive process has a shorter supply chain because the amount of GHG emissions have reduced in the supply chain from the Mining sector over the Manufacturing sector to the Construction sector.

As a sub-sector in the Construction sector, the Construction Services sector accounted for almost half of the amount of GHG emissions in the Construction sector. It means the usage and maintenance of the commercial and residential buildings are the main reasons for generating GHG emissions. However, the amount of its emission have a slight growth. This can be explained by the application of environmental policies on the reduction of GHG emission, such as Commercial Building Disclosure (CBD) Program to reduce GHG emissions through the control of lighting, heating and cooling systems and managed effectively (Australian Government Department of Industry and Science 2015) and the design of baseline for GHG emissions in different commercial buildings (hotels, shopping centres, hospitals, and schools) (Australian Government Department of the Environment and Energy 2012).

The total effects of GHG emissions in these four sub-sectors experienced a decrease trend. The largest drop occurring in the Heavy and Civil Engineering Construction sector is 34.02%. The decrease of GHG emissions can partly been explained by the decline of the value of work done in the Construction activities in the period between 2009–10 and 2014–15 (ABS 2018b). In particular, the value of work done in the Roads, highways and subdivisions sector, which belongs to the Heavy and Civil Engineering Construction sector decreased from about 1105 million $AUD in 2009–10 to about 724 million $AUD in 2014–15 (ABS 2018b).

The decomposition from the SDA method performed on these four sub-sectors in the Australian Construction sector shows that while the level effect of Final demand resulted in the growth of GHG emission in these sectors, the GHG efficiency intensity limited that increase. It indicates that the way to lower the Australian GHG emission from the Construction sector is to enhance the effect of GHG intensity on the reduction of GHG emissions to offset the effect of the level effect of Final demand on increasing the GHG emissions. The function of technology effect should be paid more attention to reduce the amount of GHG emissions.

6. Conclusion

In this research, the application of EEIO has shown the relationships between economic activities and GHG emissions in the Australian Construction sector and its four sub-sectors. The SDA method showed that the extent to which structural economic change has influenced levels of GHG emissions has been investigated in two years.

A disaggregation of the Australian Construction sector into four branches was undertaken through the development of a model based on input–output and structural decomposition analysis. At a macro-level, changes in GHG intensity, Technology effect, level effect of Final demand, and mix effect of Final demand have influenced the generation of GHG emissions in these four branches.

The results of this research identify that the level effect of Final demand always plays an important role on the growth of GHG emissions at the four sub-sectors of the Australian Construction sector while the GHG intensity leads to the reduction of GHG emissions. The sector level analysis shows more details how to reduce the amount of GHG emissions in the Australian Construction sector. As for the major emitter of the Construction sector, new technologies and material should be applied to reduce GHG emission. For example, geopolymer concrete should have the potential to replace Portland cement concrete to lower the GHG emissions. A further important result was that there appeared to be a low level of technology effects on GHG emissions. This suggests that the real gains in improving technology on the Australian Construction sector would capture better outcomes on the reduction of GHG emissions.

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