Meeting the climate pledge via sustainable consumption wedge -development and application of dynamic hybrid multi-region LCI

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Abstract: This study proposes to apply a novel inventory method called Dynamic Hybrid Multi-Region Inventory (DHMRI) to overcome the limitation of existing "stabilization wedges" studies and consumption-based carbon footprint(CF) accounting. We apply this framework to prioritize the requirement of household behavior change to fulfill national reduction pledge in Taiwan. The estimation reveals that the carbon footprint per capita triggered by household consumption is 6.34 tons in 2006, shelter and service are the main contributors. Then the expansion of CF per capita in 2020 is estimated by category-specific GHG elasticity. As a result, 13 sustainable consumption wedges are identified, including enlarge the installation of renewable energy, reducing private car use, consumption only at hotel and supermarket with environmental certification, etc. This study indicates with this analytic framework, the "low-carbon lifestyle" can be transform from conceptual insipiration to practical strategies.

1. Introduction

Nowadays, with the emerging concern of global warming, a lot of effort had been spent to promote to mitigate greenhouse gas emission via altering life-style. For example, UNEP had initiated “kick the CO2 habit” campaign in 2008, which provide guidance for global citizens to help world transit into low-carbon through change of consumption pattern[1]. Without exception, Taiwan Environmental Protection Agency also attempt ask people to sign a “Declaration on Carbon Reduction Actions” , to commit themselves to low the meat intake, replace the private vehicle with bikes, switch to the energy-efficient goods etc.

However, there is only few studies focus on to prioritize the various options of behavior changes and quantify the real effect. The most well-know study is the behavior wedge developed by Stern and his colleagues [2]. The behavior wedge can be viewed as a supplementary to the stabilization wedges [3], which identified 15 alternatives to stabilize global GHG emissions at today level in 2050. Instead of focusing on enlarging the applications of certain existing technologies in the long-term, the behavior wedge attempts to reveal the mitigation potential of behaviorally oriented policies and interventions contribution in the short term. Although the above studies gain significant success regarding to the influence on policy recommendations, however, lack of “footprint” perspective during wedge identification contradicts to the essential features of global material economy and overlooks the main contributors of greenhouse gas emission.

As a result, this study aims to assess the carbon footprint (CF) of Taiwan and quantify the “Sustainable Consumption Wedges”(SCW) that could prioritize the main household behavior changes required in order to fulfill the national climate pledge.

2 Evaluating Carbon Footprint of Taiwan

2.1 Background

Carbon footprint refer to "*(the) measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product*."[4]The coverage of activity ranges from individuals, populations, governments, companies, organizations, processes, industry sectors, even nation. Although, the carbon footprint of goods and organization draw widely public attentions, and several labeling scheme and discourse program are established, but with consideration the policy effectiveness and global negotiations, the characterization of carbon footprint of single nation is necessary. Comparing to the traditional production-oriented national emission inventory guided by IPCC, consumption-oriented national carbon footprint covers the all direct and indirect emission trigger by the economic activities along the supply chains without limitation on terrestrial boundaries. Hence it provides more policy-relevant and scientific robustness information to allocate the responsibilities of global warming among different countries and consumption categories.

2.2 Method

The main analytical tool to quantify the carbon footprint is Environmental-extended input-output analysis. Environmental-extended input-output analysis(EEIO) has been recognized as a suitable tool to quantify the alteration of elementary flow trigger by whole economic activities[5]. But the assumption of technological indifference and low sectors resolution hinder the evaluation credibility and application of EEIO. As a result, multi-regional

input-output analysis(MRIO) has been developed to conquer cross-national tehnological indifference by deriving domestic technical coefficient matrice[6].

Several studies already apply this technique to quantify the carbon footprint of single country or for internal comparison. However, with the nature of top-down, the low resolution of sectors segmentation of EEIO set obstacles to quantify the environmental effect of specific behavior change. In the other aspect, hybrid life cycle assessment(Hybrid LCA) was proposed to integrate process modeling into EEIO framework to enhance the ability to address the variation of elementary flow of key processes and sectors[7]. Recently, Vringer and colleagues establish a novel inventory method call Hybrid Multi-Regional LCA(HMR) to increase the reliablity of evaluation with higher resolution of key processes [8].

For the reason to consider the technological progress and structural change induced by the future policy. This study aggregates the above concepts to develop dynamic hybrid multi-regional inventory (DHMRI). Based on the prinicple of integrated hybrid LCI and uni-directional trade assumption for the MRIO, the equation represent the computational structure of HMRI is formulated as below.

$$EM_{i,yr} = \begin{pmatrix} EF_{i,n} \times L'_{dom} \times Y'_{n} + LEFele_{i,j} \times Yele_{j,yr} \\ + EMU_{i,n,x} \times Yim_{n,x} \end{pmatrix} \quad \textbf{(1)}$$

EFi,n: Emission Factors of sectors n (excl.electricity) ;

L'_{dom}: modified Leontief Inverse ;

Y'_{n}: modified final demand;

EFele : life cycle emission factors of electricity;

Y elej,yr: The amount of electricity in target years.;

EMUi,n,x : environmental multiplier of sectors n from x regions ;

Yimn,x : importation of n sector from x regions.

This study utilizes process-based LCA approach to establish inventory model for electricity generation. For the remaining sectors, a multi-regional environmental extended input-output table is constructed to simulate the elementary flows altered by both *intermediate and final demand*. However, in order to avoid the double counting of hybrid inventory model, the Leontief inverse and final demand are modified to exclude the sectors and linkages covered by the process model. The data sources of inventory model are summarized by Table 3.

2.3 Evaluation Result

The evaluation result shows that the total carbon footprint of Taiwan in 2006 was about 454 million tons CO2-eq, which is 1.71 times of domestic GHGs emission. Among four final demand categories, export contributes around 55% of total carbon footprint, and half of it is attributed as embodied emission of fossil fuel import which triggered by exportation of energy-intensive goods. This trend implies that as open-economy without fossil-fuel resource; the attachment on energy-intensive goods set a difficult challenge to unlock the carbon dependency of Taiwan, since the carbon footprint of export is already as high as total domestic emission.

If the mitigation responsibilities are allocated from consumption perspective, the consumption-oriented carbon footprint is 204 million tons in 2006, which is share 0.7% of global GHGs emission. When only considering household consumption, the carbon footprint per person is only 6.34 tons. Moreover, the compositions of carbon footprint are disaggregated into eight categories: food, cloth, manufactured product, shelter, construction, mobility, and service. As the Figure shows shelter and service are the largest drivers of carbon footprint,

followed by food and mobility. The above four activities contribute 90% of carbon footprint jointly. With further analysis the above identification, the key consumption activities need to be corrected is exhibited. Therefore, the information indicates the choice and design of sustainable consumption wedges.

3. Identification of Sustainable Consumption Wedges

3.1 The procedure of Identification

From the above section, the characteristics of carbon footprint are revealed. In order to prepare an effective policies package to shrink CFs of Taiwan household consumption, the holistic review on the all possible options is important. This study identifies a term called “sustainable consumption wedges”, which represent those behaviors change that are able to reduces direct and indirect GHGs emissions to the atmosphere that starts at zero today and increases linearly until it accounts for a specific amount of CFs in 2020. Owing to that, the procedure to identify and quantify sustainable consumption wedges is discussed below.

The first step is to calculate the stabilization triangle, which explains the total amount of carbon footprint reduction required to achieve mitigation goal set by this study. Hence, the growth of CF should be projected to reveal without implementations of behavior changes, the expansion of CF would be. Owing to lack of precise data on future consumption pattern, the category-specific GHG elasticity estimated by Peters and Hertwich [9] are applied to forecast expansion of CF per capita. According to the latest projection, the average annual GDP growth rate will be 4.09% between 2006~2020, which already includes the economic recession in recently years. For population growth, under the medium growth rate, the total population will grows from 22.7 million to 23.4 million.

The projection demonstrates that under the business-as-usual, the CF of household consumption per capita will expand 50.9% to 9.56 tons. The contribution of each categories are also change, the share of food will be less than manufactured product and mobility. Combined with the population increase, the total CF of household consumption will expand 55.1% to 224 million tons in 2020.

However, Taiwan government had already commits to maintain the GHG emission at 2005 level in 2020. The above emission pledge is transferred to carbon footprint shrinking target as maintain the CF of household consumption at 2006 level in 2020. As a result, the stabilization triangle can be obtain, which equals to 558 million tons.

Since the stabilization triangle is known, the share of each sustainable consumption wedge is able to be allocated. The allocation principle are based on the contribution of project expansion of CFs, hence each categories owns common and differentiate responsibilities. Among the eight categories, the shelter and service holds the highest responsibilities, than followed by products and mobility. The construction only contribute less than 0.1 percent, hence it is omitted in the further discussion on substantial contents of sustainable consumption wedges.

The following paragraph will provide analysis and discussion on how to fulfill the sustainable consumption wedges for each category.

3.2 The Content of Sustainable Consumption Wedges

The continuing increase of household electricity consumption triggers CF expansion of shelter. There are two approaches to lower the CF: efficiency improvement and renewable electricity installation. Combined with adaptation of Top-Runner Program and promotion of decentralize renewable energy installation;

the CFs of shelf could be mitigated from 53.6 million tons to 30.2 million tons, which fulfill the requirement of sustainable consumption wedge for shelter.

Tab.1: Composition and forecast of carbon footprint in Taiwan

Categories	Carbon Footprint per Capita (tons)		CFs Elasticity [9]
	2006	2020 BAU	
Food	0.98	1.22	0.29
Cloth	0.19	0.32	0.79
Products	0.44	0.75	0.88
shelter	1.81	2.77	0.65
Construction	0.00	0.01	0.74
Mobility	1.02	1.72	0.83
Service	1.90	2.76	0.55
Total	6.34	9.55	---

For the consumption of the service, the electricity consumed by retailer, hotel, hospital and school are main drivers of CF in this category. Furthermore, the import goods used by retailer and hotel operation are also noticeable. Based on existing best practice of energy efficiency improvement of service sectors, this study assumes that thorough the pressure of green procurement, to cut the CF of service sector per capita to two-third level is possible. Therefore, another sustainable consumption wedge is reachable.

The mobility category shoulders third largest responsibility among different sustainable consumption wedges, it implies that to unlock the high dependency on private vehicle is urgent. If the fuel efficiency can be further improved to 33% in 2020, and applied to all vehicles, and the combination of better public transportation and ownership control could translate 25% of existing mileage from

private vehicle to public transportation. With those two strategies, the CFs of mobility could be maintained at existing level, hence another SCW is available.

The key contributors of manufacture products are consumer electronics, electric appliance, chemical product, plastic and papers. The approach to reduce the CF of consumer electronics and electric appliance are establishing standard to regulate the life cycle performance of energy related products. This study assumes the CF of unit energy related products could be cut by half comparing to existing technology. In the other aspect, most of chemical product and plastic are produced from petroleum, which has been viewed as an important problem for a long time. Meanwhile, Taiwan government has already proposed several regulations to lower the demand of plastic. The chemical product such as detergents, pesticide, and cosmetics, there are already lots of substitute made from bio-material available at the market. As a result, this study views the phase out of one-time plastic and increase the share the bio-material to 65% in 2020 are practicable. For the paper consumption, the paperless initiative could further reduce the 90% of paper consumption. With the successful implementation of above four mitigation alternatives, the SCW of manufacture product is obtained.

Reducing the CF of food consumption had been paid a lot of attention since 2007, several counties in Taiwan are already commit to participate the “no meat day” campaign, and Taiwan EPA plan to publish Guide to Low-Carbon Diet. According to this evaluation, the key contributor of this category is attributed to the demand of process food include meat, especially from imports. The average meat intake per capita is 216 g/d in 2006, which is more than two times of global average. According to McMichael and colleagues, if GHGs emissions from agriculture in 2050 should be limited to no more than their 2005 levels, the meat

intake per capita should be less than 90 g/d, and no more than 50 g of this should come from red meat.[10] If the above the target are implement in Taiwan in 2020, the CF of food consumption is able to cut down more than 53%. Hence, the SCW of food is accomplished.

The contribution of clothing is around 3% of household consumption. The directions to mitigate the CF of cloth are lower the cloth demand and replace the existing synthetic fiber with natural substitute. Based on the finding from EDIPTEX [11], the application of organic cotton could cut CF of textile by 10%. Hence the assumption to replace the half of synthetic fiber with natural substitute is made to evaluate the benefit. Moreover, if the life span of cloth could further extended for one-third, and supported by second hand market. The effect on GHG emission reduction of cloth reusing is 14%, according to the finding of Farrant and colleagues[12]. Those practices could reduce CF of clothes by more than three million tons per year in 2020, which meet requirement of SCW for cloth.

4. Conclusion

According to this study, although the real mitigation responsibility of Taiwan household consumption is far less than the industrial production, however, it still above the recommendation value to solve the climate problem. Owing to that, the 13 sustainable consumption wedges are proposed to shrink the total carbon footprint of household at 2005 level in 2020. Nevertheless, during implementation of those practices will face enormous challenges. the supplementary policies including the removal of energy subside, mandatory standard, reallocation of public spending are also needed. This circumstance recognizes that although the consumers have the abilities to contribute to significant mitigation of GHGs emission, the intervention of public sectors also

play importance role. For that purpose, the consumer should not limit their shelves in the role of private-sphere environmentalism, but also exhibits non-activist behaviors in the public sphere, to ask for a better public policy to support the implementation of sustainable consumption policies.

Tab.2: Mitigation responsibilities of sustainable consumption wedges

	Sustainable Consumption Wedges	Share of 2020	Mitigation Responsibilities (10^6tons CO_2-eq)
Shelter	Comprehensive penetration of Electric Appliance fulfill Top-Runner program	29.1%	23.91
	Enlarge the installation of renewable energy to 30%		
Service	Hotel with environmental certification	28.9%	21.28
	Supermarket with environmental certification		
Mobility	Reducing private car use	18.0%	17.26
	Improving fuel efficiency		
Products	consumer electronic products with carbon footprint labeling	7.9%	7.81
	paperless initiative		
	phase out of one-time plastic and increase the share the bio-material		
Food	Reducing Meat Intake	12.8%	5.81
Cloth	replace the half of synthetic fiber with natural substitute	3.3%	3.08
	life span of cloth could further extended for one-third		
	supported by second hand market		

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