

Doctoral Thesis (Abridged)

博士論文（要約）

**Quantification of regional carbon dioxide emissions from
production and consumption perspective**

（生産と消費の観点からの地域の二酸化炭素排出量の定量化）

LONG YIN

龍 吟

論文の要約

環境システム学専攻

平成 28 年度博士論文課程進学

氏名：龍 吟

指導教員：吉田 好邦

本博士論文は、2章と3章の部分は、雑誌掲載への投稿予定である。学位授与日から5年間インターネットでの公表をすることができません。

Quantification of regional carbon dioxide emissions from production and consumption perspective

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Background:

Burning fossil fuels such as coal, crude oil, and natural gas generates considerable CO₂, which accounts for the majority of greenhouse gas emissions. Anthropogenic activities release carbon emission in both production and consumption stages. The estimation method can then be divided into production and consumption-based, respectively. But the debates remain on who should be blamed for the emission since the emission accounting methods may generate totally different estimation results. To discuss the question, this research takes as Japan as a study area and evaluates the carbon footprint embodied in regional activities by both production and consumption accounting methods.

Summary:

In the first part, the production-based accounting is applied to quantify regional carbon emission. Then the decomposition method is used to analyze the influential factors that change before and after the year of the earthquake. The regional energy and emission structure are both analyzed and compared. However, the limitations of production-based accounting are also revealed based on this case study. The result comes to a demonstration of consumption-based accounting's advantage by revealing the emission embodied in the sectoral transaction. To further explore this advantage, this study uses Tokyo multi-regional input-output table to uncover the urban emission responsibility and its household emission features by month. However, although the consumption-based accounting excels in revealing emission embodied in consumption-behaviors, its application always limited by the data availability such as unavailable or undesirable input-output tables. Given by this, the result provides the alternative allocation priority to those areas that input-output data is not available while using consumption-based accounting. Finally, this research gives out an overall discussion of two accounting methods and its feasibility in the current accounting system.

To conclude, this research not only compares the different estimation generated by production and consumption-based accounting, both the advantage and limitations of each accounting method are demonstrated by four parts of empirical studies. The results are discussed in detail, and the policy implications of each section are given out.

Result:

This research aims at estimating carbon footprint, which embodied in regional activities. The estimation method can be divided into production and consumption-based, respectively. This research takes as Japan as a study area and tries to evaluate the sectoral emission by regions. Firstly, Section 2 introduces the current primary application of PBA and take ten areas of Japan as an example. The advantage of this method is to calculate the regional carbon emission as well as the driving force. To demonstrate this and give out emission variation drivers, the LMDI is applied to analyze the influential factors change before and after the earthquake. The change in the driving factor gives a clear picture of the earthquake's impact on different regions. The energy structure and emission structure also be analyzed. Up to here, the advantage of PBA is fully shown in Section 2. The PBA method used in Section 2 also has a disadvantage such as ignorance of embodied emission, which further conceals the carbon emission of consumption terminals. Responding to the disadvantage, this study firstly conducts a comparison with direct and indirect emission by nine major economics in Japan. The direct and indirect emission is estimated based on PBA and CBA, respectively. Moreover, a comparison analysis is conducted in Section 3.1. After revealing the sectoral embodied emission. This research applied the interregional I-O table to explain both sectoral and regional embodied emission by Section 3.2. In Section 3.3 and 3.4, the Tokyo multi-regional input-output model is modified and connected with household consumption inventory. The result gives us one of the most detailed households embodied emission inventory by month. This part of the results is vital for capturing household's emission characteristics with household features. The details of Section 2 and 3 are not included in this summary version due to the forthcoming publication based on listed sections. But, the complete version will be released on internet in 5 years.

Although previous sections thoroughly discuss the merit and advantage of the application of CBA, however, the I-O tables are not always available. In most areas, the single-regional I-O table is more common since multi-regional ones are comparatively time and labor-consuming. Given this, Section 3.5 then conducts a comparison analysis between using SRIO and MRIO at the same region to uncover the estimation difference. The result provides the alternative allocation priority to the areas that I-O is not available while using CBA.

Policy implications:

The discussion on accounting method will last for a long time based on the controversial topic of emission responsibility. The INDCs reduction target has been allocated to either sector or region. The total amount

of emission is essential to each region since it may have an impact on future emission allowance. Interregional transition is becoming more and more frequent according to the relocation of production and consumption. The megacities and areas are typical net consumers in current days. After the setting of INDCs by country level, the regional reduction target is expected in the near future. However, if only the production accounting method is considered, it will only conceal but not reduce the emissions. Therefore, a comprehensive considering of regional production and consumption is necessary for regional emission quantifications. And the policy implication generated by two accounting methods may benefit the regional decarbonization by different approaches.

Limitation and future perspective

Based on the economic input-output model, this research further extends the economic model into environment content. Due to the relocation of production and consumption, the complexity among regional transition hinders reaching the fair emission responsibility allocation in Japan. Limitations of this study can be summed up from two aspects. Firstly, the methodology limitation of the input-output model itself limits the overseas emission evaluation. Although the interregional input-output table is adopted in this study to bridge the gap generated by single ones, the equation still removed the export. However, consumption of overseas product also causes a large amount of emission due to the global trade. This limitation also points out one part of future study, which is expected to include the global-extended input-output table from Japan input-output table. The second limitation of this study is the policy implications for the different prefecture. Although this study aims at revealing the regional emission from the consumption perspective, the incomplete input-output data does not allow this target to realize. To the best of my knowledge at the current time, no official multi-regional input-output table is available in the year of 2011 of Japan. Although many tries have been made to incorporate trade record, the multi-regional input-output table compiling is still a crucial issue due to no complete trade data (open access) can be used. The lacked regional transition is estimated by the gravity model and three days of regional transition record. Each data is not accurate enough to reflect real interregional energy flow. Therefore, future work can be largely improved if the multi-regional input-output data is available in the future.

There are several interesting findings of this study, such as inefficient household energy consumption associated with social aging and household dilution, as well as the most significant carbon reduction potential in Japan is found to be heating demand in cold seasons. Therefore, future research is expected to locate how to cope with the future emission inefficiency brought by the older citizen as well as the environmental assessment of zero-emission household and electric vehicles.

Reference

- Ackerman, F., M. Ishikawa & M. Suga (2007) The carbon content of Japan–US trade. *Energy Policy*, 35, 4455–4462.
- Andrew, R., G. P. Peters & J. Lennox (2009) Approximation and Regional Aggregation in Multi-Regional Input–Output Analysis for National Carbon Footprint Accounting. *Economic Systems Research*, 21, 311–335.
- Ang, B. (2015) LMDI decomposition approach: a guide for implementation. *Energy Policy*, 86, 233–238.
- Ang, B. W. (2004) Decomposition analysis for policymaking in energy:: which is the preferred method? *Energy policy*, 32, 1131–1139.
- Büchs, M. & S. V. Schnepf (2013) Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO₂ emissions. *Ecological Economics*, 90, 114–123.
- Bhan, M., D. Sharma, A. Ashwin & S. Mehra (2017) Policy forum: Nationally-determined climate commitments of the BRICS: At the forefront of forestry-based climate change mitigation. *Forest Policy and Economics*, 85, 172–175.
- Boitier, B. 2012. CO₂ emissions production-based accounting vs consumption: Insights from the WIOD databases. In *WIOD Conference Paper, April*.
- Brizga, J., K. Feng & K. Hubacek (2017) Household carbon footprints in the Baltic States: A global multi-regional input–output analysis from 1995 to 2011. *Applied Energy*, 189, 780–788.
- Butnar, I. & M. Llop (2011) Structural decomposition analysis and input–output subsystems: Changes in CO₂ emissions of Spanish service sectors (2000–2005). *Ecological Economics*, 70, 2012–2019.
- Caro, D., S. Bastianoni, S. Borghesi & F. M. Pulselli (2014) On the feasibility of a consumer-based allocation method in national GHG inventories. *Ecological Indicators*, 36, 640–643.
- Cellura, M., S. Longo & M. Mistretta (2011) The energy and environmental impacts of Italian households consumptions: An input–output approach. *Renewable and Sustainable Energy Reviews*, 15, 3897–3908.
- Chen, G., M. Hadjikakou & T. Wiedmann (2017a) Urban carbon transformations: unravelling spatial and inter-sectoral linkages for key city industries based on multi-region input–output analysis. *Journal of Cleaner Production*, 163, 224–240.
- Chen, G., M. Hadjikakou, T. Wiedmann & L. Shi (2018) Global warming impact of suburbanization: The case of Sydney. *Journal of Cleaner Production*, 172, 287–301.
- Chen, G., T. Wiedmann, Y. Wang & M. Hadjikakou (2016) Transnational city carbon footprint networks–Exploring carbon links between Australian and Chinese cities. *Applied energy*, 184, 1082–1092.
- Chen, G. Q. & B. Zhang (2010) Greenhouse gas emissions in China 2007: Inventory and input–output analysis. *Energy Policy*, 38, 6180–6193.
- Chen, W., S. Wu, Y. Lei & S. Li (2017b) Interprovincial transfer of embodied energy between the Jing-Jin-Ji area and other provinces in China: A quantification using interprovincial input–output model. *Science of The Total Environment*, 584, 990–1003.
- Chris, R. 2015. *Systems Thinking for Geoengineering Policy: How to reduce the threat of dangerous climate change by embracing uncertainty and failure*. Routledge.
- Druckman, A. & T. Jackson (2009) The carbon footprint of UK households 1990–2004: A socio-economically disaggregated, quasi-multi-regional input–output model. *Ecological Economics*, 68, 2066–2077.
- ESO, J. (2015) Long-term Energy Supply and Demand Outlook. *Energy Strategy Office, General Policy Division, Agency for Natural Resources and Energy*.

- Fan, J.-L., Y.-B. Hou, Q. Wang, C. Wang & Y.-M. Wei (2016) Exploring the characteristics of production-based and consumption-based carbon emissions of major economies: A multiple-dimension comparison. *Applied Energy*, 184, 790-799.
- Fan, Y., Q. Liang, Y. Wei & N. Okada (2007) A model for China's energy requirements and CO₂ emissions analysis☆. *Environmental Modelling & Software*, 22, 378-393.
- Fang, K., L. Dong, J. Ren, Q. Zhang, L. Han & H. Fu (2017) Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China. *Ecological Modelling*, 365, 30-44.
- Freeman, R. & M. Yearworth (2017) Climate change and cities: Problem structuring methods and critical perspectives on low-carbon districts. *Energy research & social science*, 25, 48-64.
- Friedlingstein, P., R. Houghton, G. Marland, J. Hackler, T. A. Boden, T. Conway, J. Canadell, M. Raupach, P. Ciais & C. Le Quéré (2010) Update on CO₂ emissions. *Nature geoscience*, 3, 811.
- Fromelt, A., D. J. Dürrenmatt & S. Hellweg (2018) Using Data Mining To Assess Environmental Impacts of Household Consumption Behaviors. *Environmental science & technology*, 52, 8467-8478.
- Fry, J., M. Lenzen, Y. Jin, T. Wakiyama, T. Baynes, T. Wiedmann, A. Malik, G. Chen, Y. Wang, A. Geschke & H. Schandl (2018) Assessing carbon footprints of cities under limited information. *Journal of Cleaner Production*, 176, 1254-1270.
- Goldstone, J. A. (2002) Efflorescences and economic growth in world history: rethinking the "Rise of the West" and the Industrial Revolution. *Journal of world history*, 323-389.
- González, P. F., M. Landajo & M. J. Presno (2014) Tracking European Union CO₂ emissions through LMDI (logarithmic-mean Divisia index) decomposition. The activity revaluation approach. *Energy*, 73, 741-750.
- Guan, D. & T. Barker (2012) Low-carbon development in the least developed region: a case study of Guangyuan, Sichuan province, southwest China. *Natural Hazards*, 62, 243-254.
- Guan, D., J. Meng, D. M. Reiner, N. Zhang, Y. Shan, Z. Mi, S. Shao, Z. Liu, Q. Zhang & S. J. Davis (2018) Structural decline in China's CO₂ emissions through transitions in industry and energy systems. *Nature Geoscience*, 11, 551.
- Guo, B., Y. Geng, B. Franke, H. Hao, Y. Liu & A. Chiu (2014) Uncovering China's transport CO₂ emission patterns at the regional level. *Energy Policy*, 74, 134-146.
- Hu, Y., J. Lin, S. Cui & N. Z. Khanna (2016) Measuring Urban Carbon Footprint from Carbon Flows in the Global Supply Chain. *Environmental Science & Technology*, 50, 6154-6163.
- Hulten, C. R. (1973) Divisia index numbers. *Econometrica: Journal of the Econometric Society*, 1017-1025.
- IPCC (2014) Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2014: Synthesis Report*, 151 pp.
- Jeong, K. & S. Kim (2013) LMDI decomposition analysis of greenhouse gas emissions in the Korean manufacturing sector. *Energy Policy*, 62, 1245-1253.
- Jones, C. & D. M. Kammen (2014) Spatial distribution of U.S. household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density. *Environ Sci Technol*, 48, 895-902.
- Kanemoto, K., M. Lenzen, G. P. Peters, D. D. Moran & A. Geschke (2012) Frameworks for Comparing Emissions Associated with Production, Consumption, And International Trade. *Environmental Science & Technology*, 46, 172-179.
- Kaya, Y. (1990) Impact of carbon dioxide emission control on GNP growth: Interpretation of proposed scenarios. Paper presented to

- the IPCC Energy and Industry Subgroup, Response Strategies Working Group. Albrecht, J., Francois, D. and Schoors, K. (2002), *A Shapley decomposition of carbon emissions without residuals*, *Energy Policy*, 30, 727-736.
- Kerkhof, A. C., S. Nonhebel & H. C. Moll (2009) Relating the environmental impact of consumption to household expenditures: An input–output analysis. *Ecological Economics*, 68, 1160-1170.
- Kuramochi, T. (2015) Review of energy and climate policy developments in Japan before and after Fukushima. *Renewable and Sustainable Energy Reviews*, 43, 1320-1332.
- Lenzen, M. (1998) Primary energy and greenhouse gases embodied in Australian final consumption: an input–output analysis. *Energy policy*, 26, 495-506.
- Lenzen, M., S. A. Murray, B. Korte & C. J. Dey (2003) Environmental impact assessment including indirect effects—a case study using input–output analysis. *Environmental Impact Assessment Review*, 23, 263-282.
- Lenzen, M., L.-L. Pade & J. Munksgaard (2010) CO₂ Multipliers in Multi-region Input-Output Models. *Economic Systems Research*, 16, 391-412.
- Lenzen, M., M. Wier, C. Cohen, H. Hayami, S. Pachauri & R. Schaeffer (2006) A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan. *Energy*, 31, 181-207.
- Lenzen, M., R. Wood & T. Wiedmann (2010) Uncertainty analysis for multi-region input–output models—a case study of the UK's carbon footprint. *Economic Systems Research*, 22, 43-63.
- Leontief, W. (1970) Environmental Repercussions and the Economic Structure: An Input-Output Approach *The Review of Economics and Statistics* 52, pp. 262-271
- Li, N., D. Ma & W. Chen (2017) Quantifying the impacts of decarbonisation in China's cement sector: A perspective from an integrated assessment approach. *Applied Energy*, 185, 1840-1848.
- Li, Y., J. Meng, J. Liu, Y. Xu, D. Guan, W. Tao, Y. Huang & S. Tao (2016) Interprovincial Reliance for Improving Air Quality in China: A Case Study on Black Carbon Aerosol. *Environ Sci Technol*, 50, 4118-26.
- Liang, Q.-M., Y. Fan & Y.-M. Wei (2007) Multi-regional input–output model for regional energy requirements and CO₂ emissions in China. *Energy Policy*, 35, 1685-1700.
- Lin, B. & C. Sun (2010) Evaluating carbon dioxide emissions in international trade of China. *Energy Policy*, 38, 613-621.
- Lin, J., Y. Hu, X. Zhao, L. Shi & J. Kang (2017) Developing a city-centric global multiregional input-output model (CCG-MRIO) to evaluate urban carbon footprints. *Energy Policy*, 108, 460-466.
- Liu, H., W. Liu, X. Fan & W. Zou (2015) Carbon emissions embodied in demand–supply chains in China. *Energy Economics*, 50, 294-305.
- Liu, H., Y. Xi, J. e. Guo & X. Li (2010) Energy embodied in the international trade of China: An energy input–output analysis. *Energy Policy*, 38, 3957-3964.
- Liu, L.-C., Y. Fan, G. Wu & Y.-M. Wei (2007) Using LMDI method to analyze the change of China's industrial CO₂ emissions from final fuel use: An empirical analysis. *Energy Policy*, 35, 5892-5900.
- Liu, L.-C., G. Wu, J.-N. Wang & Y.-M. Wei (2011) China's carbon emissions from urban and rural households during 1992–2007. *Journal of Cleaner Production*, 19, 1754-1762.
- Long, Y. & Y. Yoshida (2018) Quantifying city-scale emission responsibility based on input-output analysis – Insight from Tokyo,

- Japan. *Applied Energy*, 218, 349-360.
- Long, Y., Y. Yoshida & L. Dong (2017) Exploring the indirect household carbon emissions by source: Analysis on 49 Japanese cities. *Journal of Cleaner Production*, 167, 571-581.
- Long, Y., Y. Yoshida, R. Zhang, L. Sun & Y. Dou (2018) Policy implications from revealing consumption-based carbon footprint of major economic sectors in Japan. *Energy Policy*, 119, 339-348.
- Mach, R., J. Weinzettel & M. Ščasný (2018) Environmental Impact of Consumption by Czech Households: Hybrid Input–Output Analysis Linked to Household Consumption Data. *Ecological Economics*, 149, 62-73.
- Machado, G., R. Schaeffer & E. Worrell (2001) Energy and carbon embodied in the international trade of Brazil: an input–output approach. *Ecological economics*, 39, 409-424.
- MacKenzie, D. (2009) Making things the same: Gases, emission rights and the politics of carbon markets. *Accounting, organizations and society*, 34, 440-455.
- Martinez, S., M. Marchamalo & S. Alvarez (2018) Organization environmental footprint applying a multi-regional input-output analysis: A case study of a wood parquet company in Spain. *Science of The Total Environment*, 618, 7-14.
- Matthews, H. S., C. T. Hendrickson & C. L. Weber (2008) The Importance of Carbon Footprint Estimation Boundaries. *Environmental Science & Technology*, 42, 5839-5842.
- McGregor, P. G., J. K. Swales & K. Turner (2008) The CO₂ ‘trade balance’ between Scotland and the rest of the UK: Performing a multi-region environmental input–output analysis with limited data. *Ecological Economics*, 66, 662-673.
- Mi, Z.-F., S.-Y. Pan, H. Yu & Y.-M. Wei (2015) Potential impacts of industrial structure on energy consumption and CO₂ emission: a case study of Beijing. *Journal of Cleaner Production*, 103, 455-462.
- Mi, Z., J. Meng, D. Guan, Y. Shan, M. Song, Y.-M. Wei, Z. Liu & K. Hubacek (2017) Chinese CO₂ emission flows have reversed since the global financial crisis. *Nature communications*, 8, 1712.
- Mi, Z., J. Zheng, J. Meng, H. Zheng, X. Li, D. M. Coffman, J. Woltjer, S. Wang & D. Guan (2019) Carbon emissions of cities from a consumption-based perspective. *Applied Energy*, 235, 509-518.
- MIC (2015) 2011 Input-output tables for Japan.
- MOE (2011) Japan's National Greenhouse Gas Emission in Fiscal Year 2011. *Ministry of the Environment Government of Japan*.
- MOE, J. (2018) Japan's National Greenhouse Gas Emissions in Fiscal Year 2017(Preliminary Figures). *Ministry of the Environment Government of Japan*.
- Mongelli, I., G. Tasselli & B. Notarnicola (2006) Global warming agreements, international trade and energy/carbon embodiments: an input–output approach to the Italian case. *Energy Policy*, 34, 88-100.
- Mousavi, B., N. S. A. Lopez, J. B. M. Biona, A. S. Chiu & M. Blesl (2017) Driving forces of Iran's CO₂ emissions from energy consumption: an LMDI decomposition approach. *Applied energy*, 206, 804-814.
- Munksgaard, J. & K. A. Pedersen (2001) CO₂ accounts for open economies: producer or consumer responsibility? *Energy policy*, 29, 327-334.
- Nansai, K., S. Kagawa, Y. Kondo, S. Suh, R. Inaba & K. Nakajima (2009) Improving the Completeness of Product Carbon Footprints Using a Global Link Input–Output Model: The Case of Japan. *Economic Systems Research*, 21, 267-290.
- Nansai, K., Y. Kondo, S. Kagawa, S. Suh, K. Nakajima, R. Inaba & S. Tohno (2012) Estimates of embodied global energy and air-

- emission intensities of Japanese products for building a Japanese input-output life cycle assessment database with a global system boundary. *Environ Sci Technol*, 46, 9146-54.
- Norman, J., A. D. Charpentier & H. L. MacLean. 2007. Economic Input– Output Life-Cycle Assessment of Trade Between Canada and the United States. ACS Publications.
- Ouyang, X. & B. Lin (2015) An analysis of the driving forces of energy-related carbon dioxide emissions in China's industrial sector. *Renewable and Sustainable Energy Reviews*, 45, 838-849.
- Perobelli, F. S., W. R. Faria & V. d. A. Vale (2015) The increase in Brazilian household income and its impact on CO₂ emissions: Evidence for 2003 and 2009 from input–output tables. *Energy Economics*, 52, 228-239.
- Reinders, A. H. M. E., K. Vringer & K. Blok (2003) The direct and indirect energy requirement of households in the European Union. *Energy Policy* 31, 139-153.
- Shahbaz, M., S. J. H. Shahzad & M. K. Mahalik (2018) Is globalization detrimental to CO₂ emissions in Japan? New threshold analysis. *Environmental Modeling & Assessment*, 23, 557-568.
- Shan, Y., Z. Liu & D. Guan (2016) CO₂ emissions from China's lime industry. *Applied Energy*, 166, 245-252.
- Shao, L., D. Guan, N. Zhang, Y. Shan & G. Chen (2016) Carbon emissions from fossil fuel consumption of Beijing in 2012. *Environmental Research Letters*, 11, 114028.
- Shigetomi, Y., K. Nansai, S. Kagawa & S. Tohno (2014) Changes in the carbon footprint of Japanese households in an aging society. *Environ Sci Technol*, 48, 6069-80.
- Sovacool, B. K. & M. A. Brown (2010) Twelve metropolitan carbon footprints: A preliminary comparative global assessment. *Energy Policy*, 38, 4856-4869.
- Su, B. & B. W. Ang (2012) Structural decomposition analysis applied to energy and emissions: some methodological developments. *Energy Economics*, 34, 177-188.
- Su, B. & B. W. Ang (2015) Multiplicative decomposition of aggregate carbon intensity change using input–output analysis. *Applied Energy*, 154, 13-20.
- Su, B., B. W. Ang & Y. Li (2017) Input-output and structural decomposition analysis of Singapore's carbon emissions. *Energy Policy*, 105, 484-492.
- Sun, X., J. Li, H. Qiao & B. Zhang (2017) Energy implications of China's regional development: New insights from multi-regional input-output analysis. *Applied Energy*, 196, 118-131.
- Tian, X., M. Chang, C. Lin & H. Tanikawa (2014) China's carbon footprint: A regional perspective on the effect of transitions in consumption and production patterns. *Applied Energy*, 123, 19-28.
- Timilsina, G. R. & A. Shrestha (2009) Factors affecting transport sector CO₂ emissions growth in Latin American and Caribbean countries: an LMDI decomposition analysis. *International Journal of Energy Research*, 33, 396-414.
- TMG (2016) 2011 Input-output tables for Tokyo. *Statistics Division, Bureau of General Affairs, Government of Tokyo, Japan*.
- TMG, B. o. E. o. (2012) The Tokyo Initiative on Smart Energy Saving
- Tukker, A., G. Huppes, J. Guinée, R. Heijungs, A. de Koning, L. van Oers, S. Suh, T. Geerken, M. Van Holderbeke & B. Jansen (2006) Environmental impact of products (EIPRO). *Analysis*, 22284, 1-13.
- Virtanen, Y., S. Kurppa, M. Saarinen, J.-M. Katajajuuri, K. Usva, I. Mäenpää, J. Mäkelä, J. Grönroos & A. Nissinen (2011) Carbon

- footprint of food – approaches from national input–output statistics and a LCA of a food portion. *Journal of Cleaner Production*, 19, 1849-1856.
- Wang, Z., W. Liu & J. Yin (2014) Driving forces of indirect carbon emissions from household consumption in China: an input–output decomposition analysis. *Natural Hazards*, 75, 257-272.
- Wang, Z., Y. Yang & B. Wang (2018) Carbon footprints and embodied CO₂ transfers among provinces in China. *Renewable and Sustainable Energy Reviews*, 82, 1068-1078.
- Wei, J., K. Huang, S. Yang, Y. Li, T. Hu & Y. Zhang (2017) Driving forces analysis of energy-related carbon dioxide (CO₂) emissions in Beijing: an input–output structural decomposition analysis. *Journal of Cleaner Production*, 163, 58-68.
- Weinzettel, J., K. Steen-Olsen, E. G. Hertwich, M. Borucke & A. Galli (2014) Ecological footprint of nations: Comparison of process analysis, and standard and hybrid multiregional input–output analysis. *Ecological Economics*, 101, 115-126.
- Wiedmann, T. (2009) A review of recent multi-region input–output models used for consumption-based emission and resource accounting. *Ecological Economics*, 69, 211-222.
- Wiedmann, T., J. Minx, J. Barrett & M. Wackernagel (2006) Allocating ecological footprints to final consumption categories with input–output analysis. *Ecological economics*, 56, 28-48.
- Wiedmann, T. O., G. Chen & J. Barrett (2016) The Concept of City Carbon Maps: A Case Study of Melbourne, Australia. *Journal of Industrial Ecology*, 20, 676-691.
- Wu, X. & G. Chen (2017) Energy use by Chinese economy: A systems cross-scale input-output analysis. *Energy Policy*, 108, 81-90.
- Xie, S.-C. (2014) The driving forces of China's energy use from 1992 to 2010: An empirical study of input–output and structural decomposition analysis. *Energy Policy*, 73, 401-415.
- Xu, S.-C., Z.-X. He & R.-Y. Long (2014) Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Applied Energy*, 127, 182-193.
- Yang, S., B. Chen, M. Wakeel, T. Hayat, A. Alsaedi & B. Ahmad (2017) PM_{2.5} footprint of household energy consumption. *Applied Energy*.
- Yang, Y., W. W. Ingwersen & D. E. Meyer (2018) Exploring the relevance of spatial scale to life cycle inventory results using environmentally-extended input-output models of the United States. *Environmental Modelling & Software*, 99, 52-57.
- Yu, S., Y.-M. Wei, J. Fan, X. Zhang & K. Wang (2012) Exploring the regional characteristics of inter-provincial CO₂ emissions in China: an improved fuzzy clustering analysis based on particle swarm optimization. *Applied energy*, 92, 552-562.
- Yuan, B., S. Ren & X. Chen (2015) The effects of urbanization, consumption ratio and consumption structure on residential indirect CO₂ emissions in China: a regional comparative analysis. *Applied energy*, 140, 94-106.
- Zhang, B., H. Qiao, Z. M. Chen & B. Chen (2016a) Growth in embodied energy transfers via China's domestic trade: Evidence from multi-regional input–output analysis. *Applied Energy*, 184, 1093-1105.
- Zhang, H., Y. Liang, Q. Liao, M. Wu & X. Yan (2017a) A hybrid computational approach for detailed scheduling of products in a pipeline with multiple pump stations. *Energy*, 119, 612-628.
- Zhang, H., Y. Liang, Q. Liao, X. Yan, Y. Shen & Y. Zhao (2017b) A three-stage stochastic programming method for LNG supply system infrastructure development and inventory routing in demanding countries. *Energy*, 133, 424-442.
- Zhang, H., X. Song, T. Xia, M. Yuan, Z. Fan, R. Shibasaki & Y. Liang (2018) Battery electric vehicles in Japan: Human mobile

- behavior based adoption potential analysis and policy target response. *Applied Energy*, 220, 527-535.
- Zhang, J., B. Yu, J. Cai & Y.-M. Wei (2017c) Impacts of household income change on CO₂ emissions: An empirical analysis of China. *Journal of Cleaner Production*, 157, 190-200.
- Zhang, M. & F. Guo (2013) Analysis of rural residential commercial energy consumption in China. *Energy*, 52, 222-229.
- Zhang, W., K. Li, D. Zhou, W. Zhang & H. Gao (2016b) Decomposition of intensity of energy-related CO₂ emission in Chinese provinces using the LMDI method. *Energy Policy*, 92, 369-381.
- Zhang, Y.-J., X.-J. Bian, W. Tan & J. Song (2015a) The indirect energy consumption and CO₂ emission caused by household consumption in China: an analysis based on the input–output method. *Journal of Cleaner Production*.
- Zhang, Y. & Z. Tang (2015) Driving factors of carbon embodied in China's provincial exports. *Energy Economics*, 51, 445-454.
- Zhang, Y., H. Zheng, Z. Yang, M. Su, G. Liu & Y. Li (2015b) Multi-regional input–output model and ecological network analysis for regional embodied energy accounting in China. *Energy Policy*, 86, 651-663.
- Zhao, M., L. Tan, W. Zhang, M. Ji, Y. Liu & L. Yu (2010) Decomposing the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. *Energy*, 35, 2505-2510.
- Zhu, Q., X. Peng & K. Wu (2012) Calculation and decomposition of indirect carbon emissions from residential consumption in China based on the input–output model. *Energy Policy*, 48, 618-626.