

Cracow , 22th October 2020

Dr hab inż. Paweł Ocloń, prof. CUT
Cracow University of Technology
Faculty of Environmental and Energy Engineering
Department of Energy
Al. Jana Pawła II 37, 31-864 Cracow, Poland

The review of Doctoral Thesis
entitled: *CRITICAL TRANSMISSION SECTORS OF ENERGYWATER-GHG*
NEXUS
Authored by: Xuechao WANG

1. Thesis description

The PhD Thesis consists of six Chapters and 120 pages in total. In Chapter 1 the scope of the thesis is presented with the research gaps as well as research aims and objectives.

Chapter 1 presents aims and scope of the thesis: The overall aim of the research is to investigate and develop methods for exploring and identifying Water-Energy-GHG Nexus (WEGN) from the supply chain perspective by integrating the IO model, Geographic Information System and Supply Chain Network. The author found the following research gaps:

- a) Most present studies focused on the driving forces of water and energy consumption and carbon emissions; however, did not investigate in detail the consumption and emissions coefficients and sectoral environmental performance. The comprehensive studies on WEGN of multi-sectors are still very limited.
- b) The water used for energy, energy used for water, and energy-related GHG emissions has been primarily focused on in the present works, which cannot identify the relationships among different sectors and regions. Very limited studies focused on the sets of linked sectors and regions from the supply chain perspective. The WEGN and critical transmission sectors are also very less studied. Broader systems are necessary to be taken into consideration for a better understanding of the WEGN nexus.
- c) The embodied water, energy and GHG emissions of sets of linked sectors and regions still need in-depth exploration, especially for different countries of EU27 as well as different

regions in China. The associated benefits need more study to explore mutuality. The linkage between direct and indirect embodied water consumption, energy consumption and GHG emissions are especially crucial.

The author proposed three novel methodologies and applied them to three comprehensive case studies. The scope of the Thesis is divided into the following sections:

- a) Novel IO based assessment tool for identifying environmental efficiency in terms of WEGN.

This tool is used to extend the methodology of IO for assessing and understanding the regional environmental performance, where international trade are serving as an important basis for future considerations or planning for policymakers, and closely connects different regions. The relevant case study *Integrated Regional Environmental Efficiencies and Coefficients Identification* is performed.

- b) Sophisticated GIS and IO methodologies to reveal and map WEGN network

The approach is used to integrate GIS and IO methodologies for tracking the inter-regional and -sectoral WEGN flows, clarifying the regional, sectoral and worldwide patterns WEGN network, and identifying the associated benefits for different regions. The relevant case study *Disparities and Drivers of Carbon-Water-Energy Flows* is performed.

- c) Efficient IO and supply chain network-based assessment tool for quantifying WEGN coefficients

The tool is used to integrate the IO and Supply Chain Network methodologies for identifying the sectoral environmental performance from the supply chain perspective, where different sectors are closely connected, especially in a big economy. The relevant case study *Integrated Sectoral Environmental Performance Assessment* is performed.

Chapter 2 presents the key literature and achievements of the methodologies that are relevant to the objectives of this thesis. Section 2.2 describes the Water-Energy-GHG Nexus. The examples of water energy nexus are shown in Table 1 with categories, topic and references and main results. Section 2.3 and 2.4 present the Environmental Extended Input-Output and Geographic Information System (GIS) approaches, while section 2.5 presents the Supply Chain Network.

Chapter 3 analyzes the WEC nexus of EU27. The authors used EIO approach for calculating EWCC, EECC and ECEC. Both indirect and direct values of those indicators were calculated.

Also, the embodied consumptions of energy and water per capita and embodied CO₂ emission per capita are explored. The following conclusions are reached:

- a) The EU27 average EWCC (27 m³/k€,) is much lower than that of the world average value (75 m³/k€). Bulgaria (112.2 m³/k€), Estonia (77.2 m³/k€) and Greece (61.9 m³/k€) are embodied-water-intensive countries. On the other hand, Sweden, Denmark, Germany and Austria are with the highest water efficiency in the EU27. For the countries with high indirect EWCC, like Bulgaria, Luxembourg, Estonia and Ireland, they should strengthen and deepen the cooperation with upstream countries, focusing on improving the resource utilization efficiency, reducing environmental footprints from the supply chain perspective.
- b) The average EECC of EU27 (8.8 MJ/€) is much lower than the world average value (13.9 MJ/€), because of its better energy efficiency and relevant technologies. Bulgaria (23.3 MJ/€), Lithuania (16.4 MJ/€), Estonia (15.4 MJ/€) and Greece (14.1 MJ/€) are with the highest coefficient values, performing even worse than the world average level. Cyprus, Austria, Italy and Denmark have the highest energy efficiency in € unit. Bulgaria, Luxembourg, Czech Republic, Estonia and Slovakia are the top five countries in the EU27 in terms of indirect EECC, which means they import a massive amount of embodied energy from upstream countries during international trade.
- c) The EU27 average value of ECEC (286 t/M€) is much lower than the world average value (637 t/M€) in terms of embodied CO₂ emission. However, there are three countries, Bulgaria (914 t/M€), Estonia (825 t/M€) and Poland (647 t/M€), emit more CO₂ than the average world number. The smallest ECEC are in France (175 t/M€), Sweden (180 t/M€), Austria (212 t/M€), Italy (221 t/M€) and Spain (258 t/M€). Most of Luxembourg ECEC is indirect (89%), followed by Ireland (77%), Belgium (71%), Sweden (69%) and Malta (67%). They transfer a massive amount of embodied CO₂ emission to upstream countries during international trade.
- d) There are several countries, France, Sweden, Lithuania and Portugal, are with higher embodied energy consumption amount, however with lower CO₂ emission value, because these countries have higher renewable energy consumption share than that of other EU27 members. However, Poland, Slovenia, Estonia and Cyprus are on the opposite, with more CO₂ emissions because of their low renewable energy share in the national energy structures.

Chapter 4 presents a Sophisticated GIS-IO methodology to reveal and map WEGN network. The EU27 multiregional input-output model at a sector level is developed, to identify the inter-regional and -sectoral CWE flows, and clarify the regional, sectoral and worldwide patterns of EU27 CWE network. An environmental inequality across the EU27 is found. EU27 countries contributed 1.4 Gt less CO₂ emissions, 64.5 Gm³ less water utilization and 4.9x10⁴ PJ less energy consumption when compared to the rest of the world while generating the equivalent economic output in 2014. The author found that this has a dramatic effect on the global environment. Germany, France and Italy are the biggest beneficiaries in the CWE network in the EU27. It is recommend that the EU27 provide more technical support to upstream countries in the EU and elsewhere to improve the efficiency of resource utilisation.

Chapter 5 presents an efficient IO-SCN assessment tool for quantifying WEGN coefficients. It is found that the Water-Energy-Carbon Emissions nexus characteristics of light industry, heavy industry, and service industry were similar: water-intensive, energy-intensive, and carbon emission-intensive. The agriculture consumed nearly 65% of the national water supply, however, the water utilisation efficiency is only 32% and agriculture had much higher water consumption and direct water consumption coefficients. Light industry, service industry, and heavy industry were the top three sectors in terms of indirect water consumption coefficients. Heavy industry, light industry, and service industry were the top three sectors with the highest indirect energy consumption coefficients and carbon emission coefficients.

Chapter 6 presents the overall conclusions. The proposed novel methodologies have the following benefits:

- a) Consider embodied water utilisation, energy consumption and GHG emissions from the supply chain perspective;
- b) Make the WEGN network more visualized in case where the multi-regional or multi-sectorial linkages are intricate;
- c) Emphasize the critical embodied material transmissions among different regions or sectors, and insight the environmental performance;
- d) Provide a robust approach and a possibility for a broader system that is not solely limited to WEGN

2. Remarks and comments

The following remarks and comments to the author are provided:

1. Section 3.4.1 statements “where all parameters are introduced in section 3.2” should be replaced with “where all parameters are introduced in section 3.4”
2. Please explain in more detail how Figure 15 is obtained
3. It would be better to write EWCC instead of E^w , EECC instead of E^e and ECEC instead of E^c .
4. Please explain in more detail eq. (25) and how it is obtained
5. What means D in Eq. (25) and what is a value used?
6. Please explain how Figures 24, 26 and 28 are obtained?
7. What are the values of m and n in Eq. (30)
8. Please explain how Figure 33 is obtained?
9. Page 91, number in section “4.7.4.1” should be replaced with “5.7.4.1”.

3. Overall assessment

The major contribution of this PhD Thesis are:

- a) Novel IO based assessment tool for identifying regional environmental efficiency in terms of WEGN, especially for the regions that are closely connected by interregional trade.
- b) Sophisticated Integrating the GIS and IO methodologies (GIS-IO) to reveal and map WEGN network, tracking the critical inter-regional and -sectoral WEGN flows, clarifying the regional, sectoral and worldwide patterns of WEGN network, and identifying the associated benefits for different regions.
- c) Efficient IO and SCN based assessment approach (IO-SCN) for quantifying the sectoral WEGN coefficients.

The author provided a methodologies with the support of underlying equations, transformed the complicated WEGN network identification and analysis challenges into an easily understandable format. The author is an expert in field of environmental sustainability assessment, and fully achieved the objectives of his PhD Thesis.

He is an author of 15 ISI indexed papers, and 19 papers indexed in Scopus. He contributed in 15 invited lectures. He published papers in reputed journals such as: Journal of Cleaner Production, Renewable and Sustainable Energy Reviews, Applied Energy, Energy, Journal of Environmental Management, Energies, Sustainability, Ecological Indicators among others.

Based on the above contribution I am fully convinced that the evaluated Dissertation is a very good and novel contribution and I suggest awarding this PhD Thesis.