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Accounting framework of energy-water nexus technologies based on 3 scope hybrid life cycle analysis

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Abstract

A nexus technology(NT) simply refers to a technical configuration that draws together water, energy, land, and atmosphere, creating or reconfiguring interactions between them. To assess the environmental impact of energy-water NT, we build one assessment framework to demonstrate how the energy and water conflict, compete with each other in NTs to investigate the energy, water and carbon footprint of NTs based on 3 scope hybrid life cycle analysis. The idea and example of energy-water NTs are illustrated. The analysis workflow and accounting framework of NTs environmental impacts are presented. The unified environmental impact assessment framework for quantifying the trade-offs and synergies are built based on the defined evaluation index for the environmental impacts of NTs at 3 scopes categorizes. Combing the input-output (IO) analysis with life cycle analysis (LCA), the onsite and offsite material and energy use can be calculated to calculate water, carbon and energy footprint. To further investigate the energy and material input out of the IO limited system boundary, process based footprint analysis is incorporated into IO-LCA. By proposing accounting framework of the energy-water nexus NTs, we aim to investigate the synergies and trade-offs of NTs and explore the pathways for co-designing of economic system to provide foundations for integrated resource policy making.

Keywords: energy-water nexus; hybrid life cycle analysis; 3-Scope categories; consumption perspective

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1. Introduction

Energy and water are intertwined with each other during the production, trade and consumption processes [1-2]. The water extraction, distribution, and treatment consume large amount of energy, and the thermal power requires large amount of cooling water [3]. Besides the direct input interactions, there are indirect linkages between energy and water through industrial processes and products [4]. The direct and indirect linkage between energy and water are called energy-water nexus [5]. A comprehensive understanding of the energy-water nexus necessarily considers coupling at technologies through geographically and historically specific urban production and consumption infrastructures.

Coordinated management among different environmental aspects, like energy, water and carbon emissions, requires consideration of trade-offs or co-benefits among different elements [6]. The idea of energy-water nexus technology (NT) provides a promising approach to improve the resource utilization efficiency and mitigate the environmental impacts for the (re)configuration of political scale [7]. Although the NTs in political issues are often ignored and is rarely given special attention. Indeed, in terms of supply and distribution, the literature considers both the embedded energy in new or emerging NTs, and of existing systems [8]. The high energy intensity of alternative freshwater sources, the typical energy-water NT, like desalination of sea, are emerging as water sources deplete. Given that in practical terms ocean water is inexhaustible, seawater desalination provides a particularly pertinent example of nexus interdependencies for society with the technology and available energy supply to purify saltwater effectively has access to an unlimited supply of freshwater. Through the development of large-scale desalination technology, water scarcity issues are translated into issues of energy availability, and the associated with carbon emissions [2]. Another typical energy-water NT, water transfer project, like China South-to-North Water Diversion project, transported water from regions of abundance to areas of relative scarcity with a large amount of energy consumption and material input [10-11].

This study uses the 3-Scope categories to improve the hybrid life cycle model in carbon footprint analysis, 3-Scope hybrid life cycle model was proposed to identify the key stages, process, sectors and activities for achieving coordinated energy-water management.

2. Accounting framework

LCA is a widely accepted approach to quantify the environmental impacts of products or processes [12-14]. LCA includes two main methods: process based (P-LCA) and IO-LCA [15]. P-LCA approaches use the materials and energy data for each process involved in an activity, which can achieve level of detail desired. IO-LCA approach have advantage in capturing emissions from entire supply chain and eliminates error of process cut-off. However, IO-LCA approach have issues in uncertainties due to the level of aggregation of the sectors. Also, boundary of IO-LCA approach are limited to the sectors of IO categories. Hence, the combination of the P-LCA and IO-LCA, which is known as hybrid economic input-output based (EIO) approach have been mostly used for carbon footprint calculation [16].

In this research, the accounting framework is based on resource use in or emission from supply chain and on-site production activities. As shown in Figure 1, the application of the China IO-LCA model involved four sequential steps. First, system boundaries of nexus technologies are defined, mainly include material collection, production process, and transportation and end use. Then, hybrid LCA is established by combing P-LCA, IO-LCA and footprint analysis. In which, each material and fuel input was assigned to the most appropriate producing sector contained in the IO table according to Classification of National Economic Industries published by the Chinese government [17]. The average purchaser price of each input was established based on a comprehensive search of the literature [18]. Third, combing the 3 scope category, P-LCA and IO-LCA of the purchaser price for each input was converted into producer prices by subtracting out the value added margins for each sector from the China national IO table to derive a producer price to purchaser price ratio [19]. The producer prices were entered into the China IO-LCA model to estimate the economy-wide, indirect environmental burdens associated with the ‘cradle to gate’ supply chains for production and material inputs. Fourth, the key stages, process, sectors and activities are identified based on the footprint analysis for energy, water and carbon emissions.

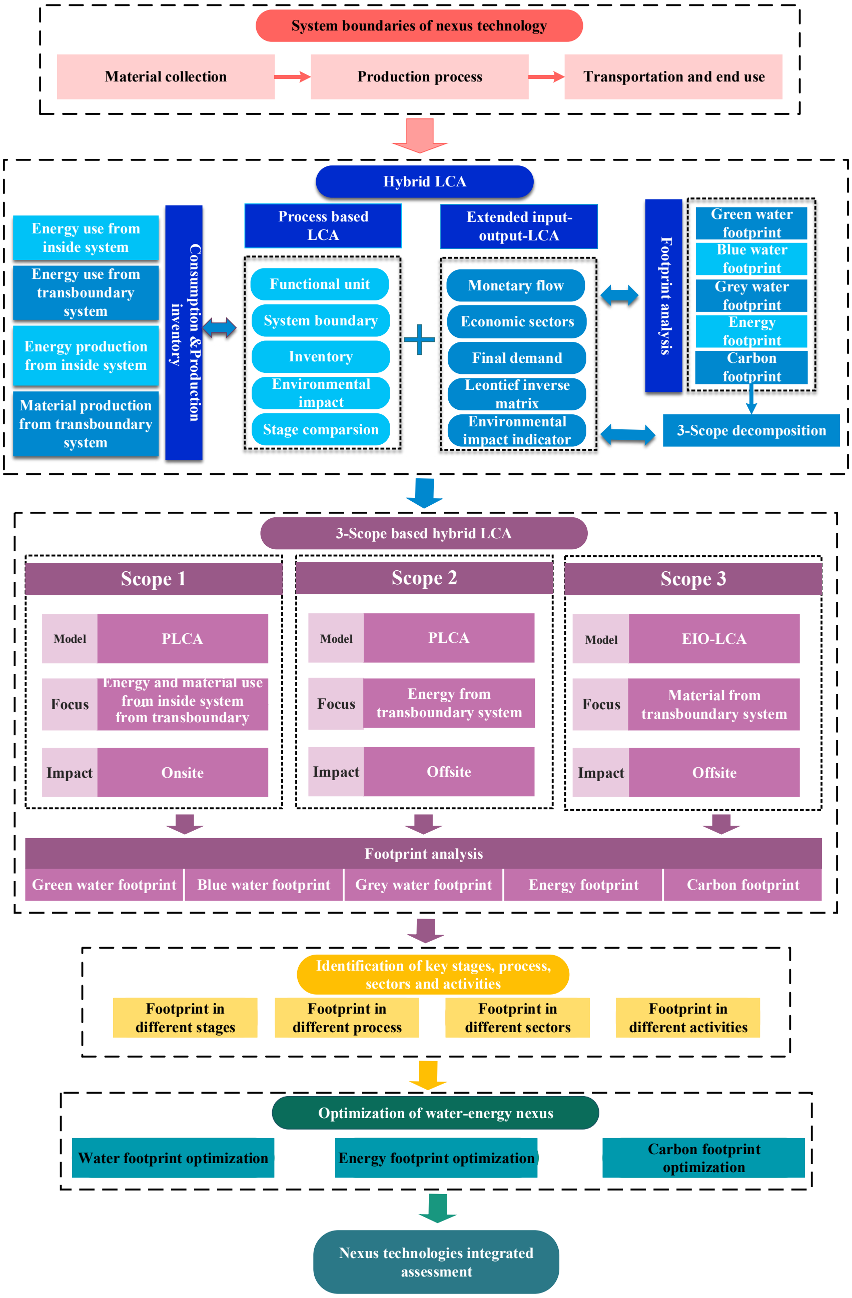

Figure 1. Framework and workflow of 3-S HLCA

3. Conclusions and Discussions

Others have compared the energy intensity of existing NTs to those new, arguing that increasing efficiency in the water sector will relieve pressure on energy resources. For example, Stillwell et al. proposed that the energy consumption of established wastewater treatment infrastructures is too high. The central argument of the energy-water NTs is the scarcity of water would threaten the supply of energy [10]. Some other energy-water NTs examples are shown in Table 1 [7].

Table 1. Examples of energy-water nexus technologies

Energy for water	**Water for energy**
Appliances, baths and showers	Appliances, baths and showers
Rainwater collection	Domestic heating and cooling
Sewerage treatment	District heating
Water recycling	Thermo-electricity (plant cooling)
Groundwater pumping	Biofuels
Desalination (sea and brackish)	Fossil fuels (extraction, processing)
Inter-basin transfer	Hydroelectric

Increasing interest in sustainability has resulted in several approaches for considering the broader environmental impact of industrial processes and products. Several methods include embodied energy analysis, carbon and water footprints, life cycle assessment(LCA) [20-21], and input-output (IO) [16], which are widely used for managing supply chains and designing products and processes. Footprint analysis is mainly based on LCA. The hybrid life cycle model integrates the traditional LCA and IO, which are usually called hybrid LCA, whose system boundary covers a wide range and the data accuracy is higher. However, the integration rules of traditional input-output based LCA (IO-LCA) are not clear and its results are not plausible for improvement measures [22-24]. Based on 3-S HLCA model in carbon footprint analysis, the 3-S HLCA water footprint and energy footprint was established. The accounting framework of energy-water NTs was proposed to identify the key stages, process, sectors and activities for achieving coordinated energy-water management.

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