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Water footprint for energy production and supply in Thailand

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A B S T R A C T

Water and energy are both important resources that are inextricably and reciprocally linked. Indeed, energy production requires a lot of water (e.g., cooling water at power plants), and numerous studies have investigated the water footprint of energy production (WFEP). However, energy is typically supplied to domestic consumers by both domestic and foreign producers, so it is necessary to take both internal and external energy productions into account. The aim of this study is to evaluate the water footprints of energy production and supply in Thailand by applying standard water footprint analysis methods based on bottom-up approaches, which define separate footprints based on production and consumption perspectives. Our findings show that the WFEP for 2010 was nine times greater than that for 1986, while the water footprint of energy supply (WFES) was eight times greater because of the use of biomass energy. We discuss external dependency, the impacts on domestic water resources, and policy implications, and we suggest ways to promote a reliable energy supply by limiting the use of water resources for energy production in Thailand.

1. Introduction

Water and energy are both important resources for regional economies, and they are inextricably and reciprocally linked. Energy producers require a lot of water. Crude oil production, for example, consumes 1.1 m^3 water/GJ [1]. Numerous studies have investigated the water footprint of energy production (WFEP), which is the water directly and indirectly required for energy production. The WFEP of bioenergy is especially of interest because of the large amount of water consumed per unit of energy produced [1–3].

Energy is typically supplied to domestic consumers by both domestic and foreign producers, so it is important to consider both sources when analyzing the WFEP. Thus this study evaluates not only the WFEP but also the water footprint of energy supply (WFES). We selected the Kingdom of Thailand (hereinafter Thailand) as a study area, because the total bioenergy supply has been increasing (it is currently 18% of Thailand's total energy supply [4]) and the impact on water resources is of concern [5].

In this paper, we explain our methodology for analyzing the WFEP and WFES with a review of past studies. Next, we show the changes in the WFEP and WFES in the past 25 years. Finally, we discuss the policy implications of managing energy and water.

2. Methodology

2.1. Description of study area

Thailand is a country in Southeast Asia that borders on the Lao People's Democratic Republic (hereinafter Laos), the Kingdom of Cambodia, the Federation of Malaysia (hereinafter Malaysia), and the Union of Myanmar. There are 63.4 million people in the country, which has 75 provinces, a land area of 513,119 km^2, and the 2008 GDP was 4260 billion baht (US$128 billion) [6]. The climate is typically tropical, with dry and rainy seasons. The annual mean precipitation is about 1622 mm per year and renewable water resources are estimated at 438.6 km^3/year [7]. In 2010, the growth

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rate of primary energy consumption was 7.2%, and that of the economy was 7.8% [8]. Furthermore, Thailand positively promotes bioenergy production. The total bioenergy supply has been increasing, and in 2010, bioenergy supplied 22,002 ktoe, 18% of the total energy supply [4].

2.2. Water footprint of energy production

Numerous studies have investigated the WFEP [1–3,9–17], and the methods can be categorized into two groups. One is a bottom-up approach that defines the WFEP by multiplying the energy production by the water intensity parameters; this includes water required both directly and indirectly (e.g., crude petroleum production for power generation, feedstock for bioethanol production) [2,9–11,14,18,19]. The other is a hybrid approach coupled with a bottom-up approach and a life-cycle assessment (LCA) method based on an environmental input–output analysis model [20–23]; this includes water related to energy consumption (e.g., water required to produce vehicles that use biodiesel) as well as production processes [15,24].

A bottom-up approach is very versatile because it is simple, although there is a danger of double-counting. However, a hybrid approach is more suitable when the microscopic process flows (such as the energy consumption of a factory) are fixed, but care must be taken when allocating between multiple energy sectors or commodities (e.g., does water that is used to produce biodiesel-based vehicles belong to the factory sector or the automobile sector?). Thus we have adopted a bottom-up approach, since we include multiple energy commodities and it is difficult to identify their entire process of production and consumption. We then calculate the WFEP by multiplying the energy production (in GJ) by the water requirement content (WRC) of energy production (m^3/GJ). By using national energy statistics [8], we define the domestic production of crude oil, condensate, petroleum products, natural gas, lignite, and electric power generation, from 1986 to 2010. Electric power is further categorized into ten groups based on the generation process: fuel oil, coal/lignite, natural gas, diesel, hydro, geothermal, solar, solid biomass, biogas, and wind. We also included domestic biomass energy production from solid biomass (fuel wood, charcoal, paddy husk, bagasse, and agricultural waste), biogas, bioethanol, and biodiesel, from 2006 to 2010 [16].

2.3. Water footprint of energy supply

Several studies have defined a water footprint from a consumption perspective. Usually, the water requirement is calculated not only for production within the country (internal water footprint) but also for imported goods and services (external water footprint) [25]. The WF can be calculated from the bottom-up [26–35] or from the top-down [36–49]. The bottom-up approach uses detailed descriptions of individual production processes, such as the domestic production, export, and import of crops. The top-down approach uses a method of economic input–output analysis (EIOA) that is frequently used for environmental analysis [50].

These methods have primarily been used for analyzing the water footprint of agricultural goods, but they can be applied to energy commodities if domestic consumption and importation are known. The necessary data are available for applying the bottom-up approach to evaluate the WFES in Thailand. Since 1970, Thailand has published national input–output tables every five years, but they do not include bioenergy, which they are positively promoting, so the available data is not appropriate for a top-down approach.

It should be noted that the WFES is defined as the sum of both internal and external water footprints. The internal WFES is calculated by deducting from the WFEP the water footprint for exported energy, which is estimated from the exported energy goods (in GJ) and the WRC of energy production technology (m^3/GJ). The external WFES is computed by multiplying the WRC by each of the imported energy commodities. Data to determine the amount of energy imported or exported as crude oil, petroleum products, natural gas, coal, or electricity, is available from national statistics [8]. In addition, imported electricity can be further divided into hydro and other sources, based on the import data from Laos (hydro) and Malaysia (other sources) [51–60].

2.4. Water requirement content

The WRC (Table 1) was determined by reviewing previous studies of the use of water for energy production, since there is no data on water use for energy production in Thailand. The WRC can be defined based on water withdrawals [10,18] (e.g., cooling water taken into power plants) or water consumption [1,9,10,15,18,19] (e.g., evaporation from power plant cooling towers). We use water consumption, like most of the past studies. In addition, the WRCs for fossil fuel production (E1–E5), petroleum products (E6), and power generation (E7) include only water used directly, in order to avoid double-counting. On the other hand, the WRCs of bioethanol and biodiesel (E8b and E8c) also include water used indirectly, such as water for feedstock production. The WRCs of solid biomass (E8a) and biogas (E8d) do not include indirect uses due to data limitations. In Thailand, solid biomass consists of fuel wood, charcoal, paddy husks, bagasse, and agricultural waste, so water for forestry and by-products of agricultural production is considered to be an indirect use; this has been excluded since no suitable parameter values are available. In Thailand, biogas is mainly produced by residuum, and this transformation requires much less water than do the processes for fossil fuels or energy crops; this is why it can be considered negligible [10]. The details of creating the WRCs from the energy carriers of Table 1are presented below.

Table 1
Water requirement contents (WRC).

			WRC (m^3/GJ)	References
E1	Crude oil		1.01	[9]
E2	Condensate		1.01	Section 2.4.1
E3	Natural Gas		0.11	[9]
E4	Coal		0.17	[9]
E5	Lignite		0.17	Section 2.4.1
E6	Petroleum		0.36	[15]
E7	Electricity			
	E7a	Natural Gas	0.19	[10]
	E7b	Coal/Lignite	0.43	[10]
	E7c	Fuel oil	0.34	[10]
	E7d	Diesel	0.34	[10]
	E7e	Hydro	5.56	[10]
	E7f	Solid biomass	0.43	[10]
	E7g	Biogas	0.22	[10]
	E7h	Solar	0.01	[9,15]
	E7i	Wind	0.00	[9]
	E7j	Geothermal	3.22	[9]
	E7k	Other	0.31	Section 2.4.3
E8	Bioenergy			
	E8a	Solid biomass	2.01	[10]
	E8b	Bioethanol	75.51	Section 2.4.4
	E8c	Biodiesel	27.45	Section 2.4.4
	E8d	Biogas	0.00	[10]

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