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Environmental footprint assessment of green campus from a food-water-energy nexus perspective

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Abstract

Universities not only can be considered as small communities due to their intensive population and their provision of complex services, but also play a vital role in the education system for global sustainable future. Thus, the environmental impacts and green operation of universities has great reference value for the design of sustainable development. In this study, we develop an environmental footprint framework based on life cycle analysis (LCA) to systematically and comprehensively understand how universities interact with the hydrologic cycle, energy resources and climate. Using Keele University in UK as an example, we further quantified the nexus and trade-offs between environmental elements including water, energy, food, waste and carbon emissions. We believe that this method will contribute to the development of footprint assessment and sustainable development, and the findings could serve as reference for policy-makers who are interested in developing green campuses.

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Keywords: environmental footprint; sustainable development; food-water-energy nexus; university

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1. Introduction

Universities play a vital role in the education system and its strategic advantage of universities in educating "future leaders", they can significantly contribute to the sustainable development objectives. Greening campus or sustainability campus both take into account the operational aspects based on environment impacts and educational aspect based on satiability education [1]. Nowadays, the work of green campus places more emphasis on spreading sustainable ideas and education due to their high societal impact [2, 3]. However, universities' own environmental impacts and resource efficiency cannot be ignored as there are over 13,000 universities worldwide and the number is still growing, especially in developing countries with more prominent environment problems. As a complex ecosystem, universities can be considered as 'small towns' due to their intensive population and their provision of complex services including education, commercial activities, medical services and outdoor activities which greatly consumes natural resources and causes significant impacts on the environment.

Due to its high complexity and massive interdependencies, a green campus which focuses on a single system often does not work well. However, most efforts for green campus are fragmented by focusing on a single area like waste management; such lack of integrated efforts may lead to inefficient implementation of its program objectives[4]. In addition, the food-water-energy nexus in universities still needs to be determined. Thus, it is important to establish a comprehensive evaluation system and green campus methology to fill the research gap. In this study, the environmental footprint framework analysis is proposed to systematically and comprehensively understand how universities interact with the hydrologic cycle, energy resources and climate. Trade-offs and the nexus between footprints are discussed to understand the food-water-energy and water-energy nexus. This study uses Keele University in UK as an example of green campus assessment. To our knowledge, this is the first example to assess the campus through environmental footprint framework analysis. We believe that this method will contribute to the development of footprint assessment and sustainable development, and the findings could serve as reference for policy-makers who are interested in developing green campuses.

2. Material and methods

2.1. Description of case study

Located in North Staffordshire, England, Keele University is a public research university established in 1949. Keele University occupies a 2500,000 m^2 rural campus and consists of extensive lawn, woods and lakes. With academic, domestic and commercial space including halls for student and staff residence, Keele University is a unique model to study as it is similar to a small-town ecosystem. In 2016, Keele University serves 9641 students and 1681 staff in total.

2.2. Environment footprint calculation

Humanity's "environmental footprints" are widely accepted as indicators reflecting the total anthropogenic pressures on the earth [5, 6]. Water footprint quantifies fresh water use and water pollution [7, 8]. Energy footprint maps the energy directly and indirectly required in human activities[9]. Carbon footprint measures CO_2 emissions [10]. In this research, the total water footprint of Keele University is composed of direct water footprint, water footprint of food and water footprint of energy. The total energy footprint of Keele University is composed of direct energy footprint, and the energy footprint of supply chain including water supply, waste disposal and wastewater treatment. The total carbon footprint of Keele University is composed of scope 1 carbon footprint (the direct emissions caused by fossil fuels consumption within the campus), scope 2 carbon footprint (the indirect emission caused by the electricity consumed by university) and scope 3 carbon footprint (including other indirect emission). Some literatures were referenced during the calculation process[11-15].

3. Results and discussion

3.1. Energy footprint assessment

With a campus of more than 250 buildings, 11328 students and staff, Keele University is a significant energy user. As shown in Table 1, the total direct energy footprint of Keele University was 42,811,409 kWh during the 2015/16 academic year, including 11,972,793 kWh of grid electricity energy consumption and 28,594,666 kWh of grid gas energy consumption. The grid electricity and gas consumption per capita in Keele University was 1057 kWh and 2524 kWh respectively. The grid electricity consumption per capita for the entire UK Higher Education (HE) sector during the 2015/16 academic year was 1516 kWh [20]. Keele University's smart energy system has important contributions to the significant low grid electricity consumption results compared to the national average. To reduce the grid electricity energy demand, 150 kWp of solar photovoltaic (PV) was implemented to produce 119,276 kWh of electricity in the 2015/16 academic year. In addition, a 60 kW biomass boiler was operated to produce 46726 kWh of electricity in the 2015/16 academic year. To improve energy production efficiency, Keele University uses a Combined Heat and Power (CHP) engine generating 140 kWp of electricity and 200 kWp heat from natural gas, which produced 1,309,300 kWh of heat energy and 774,391 kWh of electricity in the 2015/16 academic year. This demonstrates not only an improvement to the University's efficiency, but also its ability to control the heating systems better.

Table 1. Energy footprint of Keele University in 2015/16 academic year

	Sections	Kinds of energy	Energy footprint (kWh)
Direct energy footprint	Campus operation	Grid Electricity	11,972,793
		Grid Gas (minus CHP)	28,594,666
		Generated Electricity (Solar PV)	119,276
		Generated Electricity (CHP)	774,391
		Generated Heat (CHP)	1,309,300
		Biomass	46726
	Total	-	42,811,409
Indirect energy footprint	Water supply	Electricity	162627
	Wastewater treatment	Electricity	188048
	Wastes treatment	Electricity	-964870
	Total		-614195
Total energy footprint	-	-	42197214

Although water supply, sewage treatment and waste disposal are outside the scope of the campus management, these factors are closely dependent on energy. As shown in Table 1, it took 162627 kWh of energy to treat 290925 m^3 of water which was supplied to the campus and 188048 kWh of energy to treat 247879 m3 of wastewater in the 2016/2017 academic year. Waste management within the university plays a key role in meeting the university's sustainability objectives. In the 2015/16 academic year, 655.8 tonnes of waste mass (41.01% of the total energy produced) was used for energy recovery. Among them, 34.18 tonnes of food wastes were collected for anaerobic digestion and 12.25 MWh of energy was recovered. 621.65 tonnes of general wastes were collected for incineration, which produced 952.62 MWh of energy. Thus, the indirect energy footprint was -614195 kWh, resulting in a total energy footprint of 42197214 kWh. The total energy footprint per capita at Keele University in the 2015/16 academic year was 3725 kWh, which was only 17.75% of the UK's average total energy footprint per capita in 2016 (25257 kWh)[21], hence indicating the outstanding performance of the smart energy management at Keele.

3.2. Carbon footprint assessment

With the increasing attention to climate issues, Keele University predominantly monitors the carbon emission caused by nature gas (scope 1) and electricity consumption (scope 2) annually since 2009. As shown in the Figure 2, the carbon footprint of natural gas consumption in the 2015/16 academic year was 6654 tonnes of CO_2e. While the carbon footprint of gird and on-site generated electricity was 5229 and 401 tonnes respectively. The total scope 1 and 2 carbon footprint in the 2015/16 academic year was 11284 tonnes of CO_2e. As a response, some key projects were implemented to reduce the carbon footprint. 100% of the zero-carbon electricity produced by the Solar PV system is used on campus to avoid emissions exceedings 66 tonnes of CO_2e per year. Keele Library was upgraded with new efficient luminaires along with presence detection controls to ensure that lights were only on when needed. This project was started in July 2014 and the building electricity consumption has since decreased by 15%; equating to 180,000 kWh and 85 tonnes of CO_2e per annum.

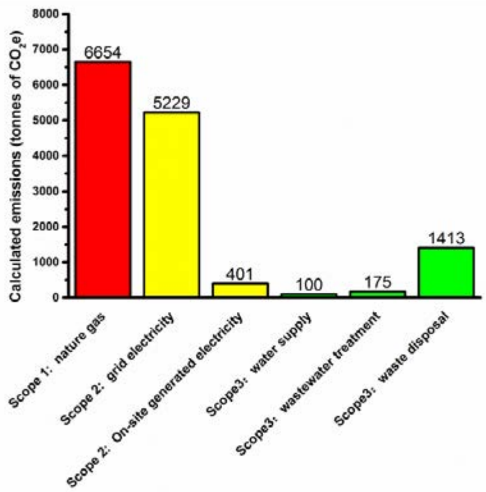

Figure 1. Carbon footprint of Keele University in 2015/16 academic year

The carbon footprint for scope 3 (including water supply, wastewater treatment and waste disposal) of Keele University was further studied. As shown in the Figure 1, the carbon footprint of water supply and wastewater treatment was 100 and 175 tonnes respectively. One key environmental improvement made by Keele University is that none of the University's waste was sent direct to landfill but was either reused, recycled or recovered by the waste contractor. As mentioned above, all the food wastes produced in the University's refectory (34.18 tonnes) was treated by anaerobic digestion for energy recovery. The carbon footprint during the production period of the food waste was 122.70 tonnes. While the carbon footprint during the anaerobic digestion period was -5.54 tonnes, which indicates that 5.54 tonnes of carbon footprint was saved due to the energy recovered by the anaerobic digestion process. Thus, the life cycle carbon footprint of food wastes at Keele University was 117.17 tonnes of CO_2e. In the 2015/16 academic year, 247.72 tonnes of green waste were collected for composting, which resulted in -10.40 tonnes of life cycle carbon footprint as there was no carbon emission during production. The carbon footprint of production and disposal for the 621.65 tonnes general waste during the 2015/16 academic year were 1276.25 and -230.01 tonnes respectively, hence resulting in a life cycle carbon footprint of 1046.25 tonnes. Simultaneously, 695.63 tonnes of waste paper, cardboard, plastics, cans and etc. were collected for recycling, which helped to save 1167.96 tonnes of carbon footprint during the recycling process and resulted in a life cycle carbon footprint of only 260.17 tonnes. Thus, the total life cycle carbon footprint of the waste section was 1413.17 tonnes. Such superior waste management system at Keele University resulted in more than 50% carbon footprint saving (1413.91 tonnes CO_2e). Therefore, the scope 3 carbon footprint and total carbon footprint of Keele University in the 2015/16 academic year were 1688 and 12972 tonnes CO_2e respectively.

3.3. Water footprint assessment.

Keele University is committed to managing water use efficiently, whilst also ensuring robust plans are in place to minimise the risk of pollution from water-related activities. Fresh water was supplied for halls of residence, and academic and central services buildings. The total water withdrawal of Keele University was 290925 m^3 during the 2015/16 academic year. In the early 2000's, Keele University introduced water efficiency measures which resulted in 92000 m^3 of water being saved. The water efficiency measures included an active leak detection and management plan, combined with careful monitoring of water use to reduce demand. However, water leak still constitutes approximately 30000 m^3 during the 2015/16 academic year due to the antiquated pipe system. All the wastewater produced (247879 m^3 in the 2015/16 academic year) at Keele was treated by a wastewater treatment plant operated by a third-party before discharge. Therefore, there was no grey water footprint and the direct water footprint of Keele University in 2015/16 academic year was 13046 m^3.

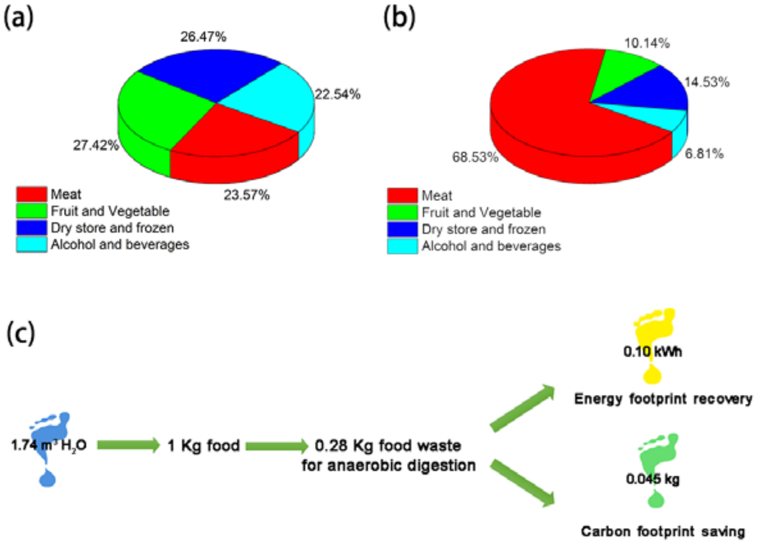

Figure 2. (a) composition ratio of food and drink consumption in Keele University in the 2015/16 academic year; (b) composition ratio of water footprint of food and drink consumption; (c) food-water-energy nexus at Keele Univeristy

The water footprint for food was further explored based on a life cycle perspective. In 2015/16, 158702 kg of food and drinks were purchased and supplied by University's refectory, bars and coffee shops. As shown in the Figure 2a, in the 2015/16 academic year, 37403 kg of meat (23.57% of the total food and drinks consumption) was provided by the University and this mainly includes beef, pork, lamb, chicken and turkey. The total water footprint of meat consumption was 157394 m^3, representing 68.53% of the total water footprint of food and drinks consumption. It is worth noting that turkey can partly replace chicken, as the water footprint intensity is only 1.77 m^3/kg, which is considerably lower than that of chicken which has a water footprint intensity of 3.86 m^3/kg. Although the consumption of fruits and vegetables was higher than meat, their water footprint was lower than meat consumption. In the 2015/16 academic year, the water footprint of fruit and vegetable consumption was only 23278 m^3 (10.14% of the total water footprint of food and drink consumption) with 43508 kg consumption (27.42% of total food and drink consumption). 42012 kg of dry store and frozen food, which mainly consisted of wraps, fries and bread, were consumed in 2015/16 and resulted in a water footprint of 33368 m^3 (14.45% of the total water footprint of food and drink consumption). The drinking culture of UK brought a great deal of alcohol consumption to Keele University. In 2015/16, 35779 kg of alcohol and beverages were consumed. The total water footprint of alcohol and beverages consumption was 15630 m3, representing 6.81% of the total water footprint of food and drink consumption. The calculated total water footprint of food and drink consumption was 229669 m^3. Figure 2c illustrates the water-food-energy nexus at Keele University. On average, 1.74 m^3 of water was consumed for production of 1 kg of food, hence resulting in 0.28 kg of food wastes which were collected for anaerobic digestion. Subsequently, 0.1 kWh energy was recovered and 0.045 kg of carbon footprint was saved.

Table 2 shows the consumptive water footprint of the various sources of energy consumption in the 2015/16 academic year. The water footprint of the direct energy consumption within campus, which includes grid electricity, gas, PV, CHP and biomass energy, was 296556 m^3 in total. The water footprint of the energy consumption during the water supply and wastewater treatment was 3805 and 4400 m^3 respectively. Thus, the total energy water footprint was 304761 m^3 and the total water footprint was 547476 m^3 in the 2015/16 academic year. The direct water footprint was only 2.38%. 55.67% of the total water footprint was consumed as energy input and 41.95% of the total water footprint was consumed as the food and drink consumption, which reinforces the importance of energy and diet management.

Table 2. The consumptive water footprint of energy consumption in 2015/16 academic year

Sections	Energy Types	Energy water footprint (m^3)
Energy consumption within campus	Grid Electricity	280163
	Self Supply Electricity (pv)	129
	Self Supply Electricity (CHP)	112
	Gas	4118
	Biomass	12034
Energy consumption of water supply	Electricity	3805
Energy consumption of wastewater treatment	Electricity	4400
Total		304761

3.4 Water-energy nexus analysis

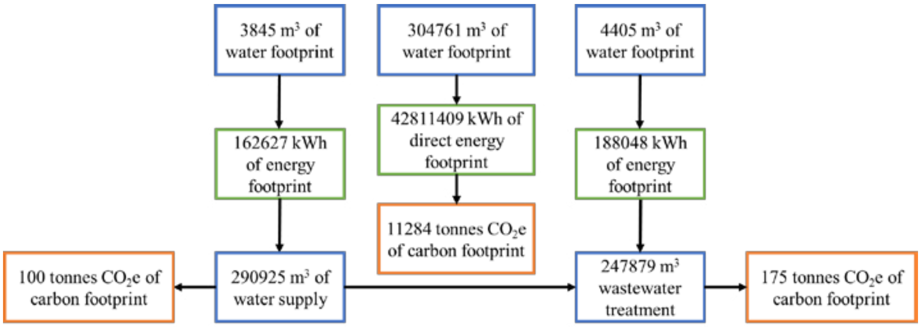

Figure 3. Energy-water nexus at Keele University in the 2015/16 academic year

Figure 3 illustrates the energy-water nexus at Keele University. In the 2015/16 academic year, 3845 m^3 of freshwater was required to produce the energy input of 162627 kWh which was needed for 290925 m^3 of water supply, and 100 tonnes of CO_2e was emitted during this process. 247879 m^3 of wastewater was discharged to the wastewater treatment plant for further treatment. During the treatment process, 4405 m^3 of freshwater was required to produce the energy input of 188048 kWh which was needed for wastewater treatment, and 175 of tonnes CO_2e was emitted. With respect to campus operation, 304761 m^3 of freshwater was required to produce an energy consumption of 41811409 kWh within the campus, and 11284 tonnes of CO_2e was emitted. This inextricably intertwined water-energy nexus reinforces the importance of energy and water integrated management. To reduce energy consumption and carbon emission, the university also sets itself a target to increase the proportion of energy consumption which is generated on site from low carbon footprint or low water footprint technologies including solar PV, wind, CHP and biomass amongst others.

4. Conclusion

In this study which examines the environmental footprint framework, energy footprint, carbon footprint and water footprint analysis are comprehensively performed to understand how universities interact with the hydrologic cycle, energy resources and climate. The total energy footprint, carbon footprint and water footprint of Keele University in the 2015/16 academic year was 42197214 kWh, 12972 tonnes CO_2e and 547476 m^3. Based on these figures, the food-water-energy and water-energy nexus were further investigated.

Green campus construction needs to consider its comprehensive environmental impacts. The environmental footprint framework proposed in this paper provides tools for understanding the direct and indirect consumption of water and energy resources in universities, through which more comprehensive information can be obtained. Thus, it can improve strategies for future green campus construction and assessment, whist taking into consideration the relevant energy–water implications.

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