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Rice husk based bioelectricity vs. Coal-fired electricity: Life cycle sustainability assessment case study in Vietnam

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Abstract

Bio-based electricity is known for its advantage on reducing negative environmental impact compared to conventional counterparts. However, the question is whether bio-based electricity is socially and economically sustainable. The paper assessed the sustainability of the rice husk based bioelectricity in Vietnam over its life cycle and compared it with that of coal-fired electricity. It is identified that rice husk based bioelectricity is better in some aspects, but worse in other aspect compared to coal-fired electricity. However, if the negative aspect is compensated by the positive ones, the rice husk based bioelectricity in this case study is more sustainable than coal-fired counterpart.

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1. Introduction

Since its first introduction, the notion of 'sustainable development' has become a common goal towards the decoupling of environmental and economic imperatives, while maintaining and enhancing social prosperity [1], [2]. There are several ways in which the energy sector can contribute to sustainability, such as the development and application of energy efficient technologies, utilization of renewable energy and development of rural and distributed energy systems. Energy efficiency measures and rural energy systems aim at using fossil fuels equitably, economically and efficiently are, by nature, short-term solutions for sustainability. In order to ensure robust, resilient and long-term sustainability, it is essential to rapidly transition from fossil fuel based energy systems to a renewable energy mix. The consumption of renewable energy leads to reduced environmental impacts associated with fossil fuel exploitation such as air pollution, carbon and greenhouse gas emissions and those related to the extraction of fossil resources such as land and water degradation [3].

In Vietnam, renewable energy is mostly deployed in the form of hydropower, comprising 37.6 percent of national electricity generation in 2011 [4]. Other forms of renewable energy contribute a comparatively small share, at 3.5 percent of the national electricity system [5]. However, it is planned that the shares of other types of renewable energy, including wind energy and biomass based energy, will gradually increase in the near future to 4.5 percent by 2020 and 6 percent by 2030 [5]. For bio-based electricity, it is expected that the installed capacity will increase to 500MW by 2020 and 2000MW by 2030, being equal to 1.1 percent of total electricity generation [5].

Vietnam is the second largest rice exporting country; therefore, the technical potential of biomass from rice is present. The national rice production yield has increased from 39.99 million tonnes in 2010 to 49.27 million tonnes in 2013 [6], [7]. With a Residue to Product Ratio of 0.2 for rice husk [8], the amount of rice husk, which can be used for electricity generation is about 0.8 million tonnes. This high proportion of available rice husk therefore makes it a technically feasible form of bio-based energy for small-scale electricity generation.

In addition, an on-site study showed that about 20 percent of rice residue is kept for fertilizing the subsequent crop, and the remaining is burnt on the field [8]. The open burning of

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rice residue causes incomplete combustion, which emits CO, N_20, CH4 and PAH [9]. As a result, the process is not only harmful for human health but also negatively impacts the environment. If the large amount of rice residue, which is traditionally openly burnt on the field, is used to generate electricity, it can partly sustain the national energy sector. Moreover, it may help to reduce the negative social and environmental impacts of open burning of rice residue, and offset the burning of fossil fuels to generate electricity.

The paper analyzes and evaluates sustainability of bioelectricity generated from rice husk over its life cycle with the hope of its apparent potential to facilitate the sustainable development of the energy sector in Vietnam. The sustainability of rice husk based electricity will be assessed on its relative contribution to the three pillars of sustainable development, environment, economy and society, in comparison with that of coal-fired electricity. Coal-fired electricity production is selected as the reference system because the Vietnamese electricity system is projected to become fossil fuel-intensive, with the share of coal-fired electricity increasing from 18.9 percent in 2011 to 46.8 percent by 2020 [4].

2. Methodology

Life cycle assessment is defined as the "compilation and evaluation of inputs and outputs and the potential impacts of a product system throughout its life cycle" [10]. In life cycle assessment, all input materials, emissions and wastes are accounted for in all stages from raw material extraction and processing, product and/or service manufacturing, use and disposal, and transportation. The comprehensive data requirements of the methodology make life cycle assessment a particularly effective mechanism for systematic assessment of environmental impacts of a product system [10].

The seminal definition of sustainable development was introduced as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' [1]. This definition requires the consideration of sustainable development under the lens of system thinking, or in other words, the system over time and space, with an appreciation of the needs of human beings and the limitations of natural resources.

Life cycle sustainability assessment (LCSA) extends the environmental boundaries of traditional life cycle assessment in an attempt to incorporate concepts of the sustainable development paradigm. It is defined as a method addressing environmental, economic and social sustainability of a product system over its life cycle, indicated through the measurement of either positive or negative impacts [11]. Life cycle sustainability analysis is implemented through an integration of environmental life cycle assessment (E-LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA) [11]. Detailed definitions of E-LCA, LCC and S-LCA can be found in Table 1.

Table 1. Three pillars of life cycle sustainability

E-LCA	(Potential) environmental impacts over a production system's life cycle [12].
LCC	All costs and benefits directly related to the product system over its life cycle with some consideration on the external relevant costs and benefits [13].
S-LCA	Social and socio-economic impacts of the product system throughout its life cycle, which causes directly/ indirectly and positively/ negatively affected stakeholders [11].

Although the research community accepts the life cycle sustainability concept, there is no current consensus on how to implement a life cycle sustainability assessment. There are a number methodologies that surround LCSA such as United Nations Environment Program Life Cycle Sustainability Analysis (UNEP LCSA), Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability (CALCAS), Advancing Integrated Systems Modeling Framework for Life Cycle Sustainability Assessment (AISMF LCSA), and the Prospective Sustainability assessment of Technologies (Prosuite). These methodologies share a common foundation, developed based on the three frameworks of E-LCA, LCC and S-LCA.

The most common methodology to assess the life cycle sustainability of a product system is following UNEP LCSA [11]. According to this methodology, the results of E-LCA, LCC and S-LCA are integrated with a set of weighting indicators to obtain a single common life cycle sustainability result [11]. The set of weighting indicators can be in the form of a Life Cycle Sustainability Dashboard with different scores and colors, or the Life Cycle Sustainability Triangle [14].

CALCAS is a framework proposed by the EU 6th Framework Co-ordination Action. This methodology is based on the ISO 14040- 14044 frameworks for E-LCA with integration of LCC and SLCA. It expands the concept of E-LCA to include physical, social, economic, cultural, institutional and political aspects, and broadens the boundary of a product system to assess the sustainability of a meso-system and an economy-wide system [15].

Halog and Manik developed AISMF LCSA through the combination of the E-LCA, LCC and S-LCA frameworks, incorporated with stakeholder analysis. The authors used multi-criteria decision analysis to obtain the indicators for life cycle sustainability assessment, which was then combined with agent-based and system dynamics modeling to ascertain the final results of sustainability decisions [16].

Most recently, another methodology with an emphasis on causal relationships, Prosuite, was introduced under the EC 7th framework program. On the foundation of the (ISO) E-LCA framework, sustainability is evaluated with five endpoint impacts of human health, social wellbeing (social aspects), prosperity (economic aspects), natural environment and exhaustible resources (environmental aspects). These endpoint indicators are then aggregated into one single score of sustainability by applying three approaches: graphical representation, weighted sum and outranking analysis [17].

As this methodology is developed under the E-LCA framework, it follows the common technique for implementing a LCA. The framework starts with defining the goal and scope, which requires setting up the goal, the technology, the product, their functional units, system boundary of the study, and other pertinent background and procedural information. This is then followed by data collection on raw materials and energy consumption,