Sustainable Business Models of Small-Scale Renewable Energy Systems: Two Resource-Scarce Approaches for Design and Manufacturing

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Abstract. We need to pay attention to both the design and manufacturing and business model approaches when analysing the sustainability of firms. Though there is increasing literature on the sustainable business model, little attention has been paid to solution design's implication for the sustainability of the business model. In this article, I compare the solution design and business model approaches of two similar small-scale bioenergy solutions (using the high-income context in a developed country and the low-income context in a developing country). The sustainability perspective is integrated into the business model framework, and the implications of technological solutions to business models are analysed. I demonstrate in this study that while a high-tech solution in the high-income context has been able to integrate technological and organisational sustainability into its business model, a low-tech solution in the low-income context has mainly focused on social sustainability, has not paid attention to ecological sustainability and is struggling with financial sustainability.

Keywords: Sustainability · Business model · Design and manufacturing · Bioenergy · Developing country · Developed country

1 Introduction

Seventy years ago in Finland, resources were scarce. Cars and buses used to run on wooden biomass fuels. Then, when the country started to become more prosperous, these solutions were forgotten, and fossil fuels gained popularity. Since oil prices started to peak 10 years ago, these century old technologies have been taken to use again – this time in the form of small-scale, off-grid energy production. At the same time, these technologies have been used in another context: to solve the energy poverty challenge; four billion people lack sustainable access to energy. These two contexts have many implications for sustainable design and manufacturing when we observe them from the lenses of sustainable business models.

The deployment of renewable energy technologies is critical for the ability of countries to move towards sustainable energy systems in the future. In this transition, small-scale renewable energy technologies that utilise biomass are one of

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the key sectors that can deliver mini-grid and off-grid solutions to urban and rural high-income, middle-income and low-income markets. Panwar et al. [1] argue that renewable energy technologies provide an excellent opportunity for the mitigation of greenhouse gas emissions so as to reduce global warming and respond to sustainable economic and social development. Becker and Fischer [2] argue that fossil fuels continue to dominate the energy markets, as they are believed to be cheaper than renewable energy sources. However, at the same time, renewable energy technologies are claimed to be more sustainable. These technologies can simultaneously contribute to social, economic and ecological development and climate change mitigation, bypassing fossil fuel-based development models [3].

The sustainable design and manufacture of renewable energy solutions can be related to the scarcity of resources. Recently, literature on frugal innovations has emerged to describe resource-scarce solutions in the contexts of developed and developing countries [4–6]; these innovations are often claimed to be sustainable [7–10]. However, there is little empirical evidence how sustainable frugal innovations are from the global perspective. Thus, the purpose of this study is to explore what implications design and manufacturing have on the sustainability of high-tech and low-tech solutions in the contexts of developed and developing countries. I first study the sustainability of one renewable energy solution in the low-income context, which is often claimed to be frugal and sustainable. I then compare it to a similar solution in the developed country context. To do this, I review the literature on sustainable design and manufacturing and apply the sustainability perspective as an analytical framework to the business model concept in order to explore the implications of sustainability in two different contexts of small-scale bioenergy solutions.

1.1 Literature Review

1.1.1 Sustainable Design and Manufacturing

Sustainability is a multidimensional phenomenon that can be integrated into firm activities in various forms. Wells [11] argues that integrating sustainability into business activities requires interplay between product design, manufacturing process and business model design. Companies can become more competitive (or greener) either by developing new products and services based on new technology and/or developing new business models [12, 13]. Therefore, we need to pay attention to both technological solutions and business models when analysing the sustainability of firms.

Sustainable design and manufacturing are connected to the triple bottom line perspective of interplay between the economy, society and environment. Beltramello et al. [14] argue that greener products and services enable the reduction of environmental pollution, optimise the use of natural resources and increase energy efficiency by providing new sources of economic growth. Levänen et al. [8] also emphasise the social and economic aspects of sustainability. Though there have been many attempts to conceptualise the aspects of sustainability, it can be argued that there is no comprehensive classification available. Thus, sustainability needs to be understood as a context-specific phenomenon.

Gassmann et al. [15] argue that different development, production and sales activities are needed for different customer segments in the developed and developing worlds. While concepts such as green products, Cleantech and industrial symbiosis have emerged to describe ecological sustainability in the developed market context, the concept of frugal innovation describes similar innovations in the emerging middle-income and lower-income markets [6]. The concept of frugal innovation highlights features such as simple technologies, lower cost and ease of use, in addition to ecological sustainability features, to make solutions affordable for the four billion people living in different levels of poverty globally [5, 16]. To understand how sustainable design and manufacturing make their way into the market and have ecological and social impacts, we need to turn to the business model concept that provides the analytical framework for this study.

1.1.2 Business Model as an Analytical Framework

A business model can be defined as a bounded analytical framework that describes how a firm does business [17]. The business model also describes how value is created for the customers and then captured for the focal firm [18]. It consists of a component structure to enable the modelling of key business activities of the focal firm [23, 24]. While Osterwalder's business model canvas has become the most popular component structure among practitioners, scholars do not seem to agree on an ideal component structure or exactly what defines a business model [19]. For example, in their recent review, Wirtz et al. [20] divided a business model into strategic, customer and market and value creation components and their subcomponents. Thus, there is no general consensus on an ideal component structure. Each scholar seems to define their own context-specific component structures.

Baden-Fuller and Morgan [21] argue that these structures can be driven from theoretical and/or practical worlds. Zott and Amit [22] argue that a business model considers elements that describe the architecture of an activity system. Thus, a business model is not a complete description of every activity a firm does but something more general that goes beyond a particular context [23]. Business model analysis includes defining the component structure to create boundaries, identifying the key activities to provide content and abstracting the activities to more general business model configurations.

In this study, the sustainable business model literature is applied to create boundaries and content for the component structure. Sustainable business models are closely related to material efficiency [24] and green [25] business models. A sustainable business model, as a concept, refers to environmentally benign business models. However, the same term could, and perhaps should, also comprehend the social and inclusive aspects of a business model [26, 27]. Based on the theoretical world of business models [17, 20, 27] and the practical world of renewable bioenergy solutions [28, 29], four business model elements are selected for this study: offer, customer interface, infrastructure and financial model. To integrate the sustainability dimension into these selected business model elements, I apply the framework of Bocken et al. [30], where they divide sustainable business model archetypes into technological, social and organisational groupings. Technological and ecological sustainability relates to the offer element, social sustainability relates to the customer interface element and organisational sustainability relates to the infrastructure and financial model elements (Table 1).

Table 1. Business model component structure and sustainability perspective

BM components	Traditional questions	Sustainability questions
Offer	What products and services are offered to the customer?	How does offering promote material and energy efficiency, create value from waste and substitute non-renewables?
Customer interface	Who are the customers, and how are relationships with customers organised?	How does the customer relationship promote the well-being of the customer?
Infrastructure	How are relationships with suppliers and human resources organised?	How do supply chain management and operations and maintenance promote ecological and social sustainability?
Financial model	How are costs and benefits managed to make a business profitable?	How does the integration of sustainability aspects into other elements promote financial performance?

2 Methods and Data

The comparative case study method is used to explore sustainable business models of small-scale bioenergy solutions in high-income and low-income contexts. The empirical part of this study uses an abductive approach to create a theory-driven iterative process between empirical and theoretical worlds, systematically combining the empirical world, framework, theory and case [31]. In this study, small-scale bioenergy solutions define the context of the empirical world, the business model concept provides the framework, the sustainability concept constructs the theoretical foundations and two small companies from Finland and India act as empirical cases.

In this study, I focus on analysing combined heat and power (CHP) biomass gasification technologies and their potential in the mini-grid and off-grid markets of developed and developing countries. Dong et al. [32] argue in their literature review that CHP gasification technologies can replace traditional energy production systems and increase energy savings, reducing greenhouse gas emissions and improving energy security. However, Kirkels and Verbong [33] argue in their review (of 30 years of biomass gasification) that there seems to be an overly optimistic advocacy of the potential for the development of small-scale gasification technology. Thus, two cases with similar small-scale biomass gasification solution providers were selected in this study, one from a developed market and one from a developing market. Energy production in the gasification process has three basic phases:

1. Pyrolysis, where solid biomass is charred and gasified in produced gas;
2. Gas purification, with filters and cooling; and
3. Electricity and heat from gas, using a combustion engine.

Volter was founded in 1998 when the prime minister of Finland (a former businessman) was looking for a self-sufficient electricity production solution for his remote cottage to replace the diesel engine. Volter offers a fully automated biomass gasification solution that utilises wood chips with energy production capacities of 30 kW electrical and 80 kW thermal output. Their first solution was piloted in 2009 in Kempele Ecovillage in Northern Finland, and by 2016, around 50 solutions were sold globally.

Husk Power System (hereafter, HPS) has been one of the most cited frugal energy innovations in recent years [8]. HPS was founded in 2007 when two wealthy Indians working in the U.S. decided to seek an affordable energy solution for their home village in the state of Bihar in Northern India. Bihar is one of the poorest state in India, and around 90% of Bihar's 100 million population are not connected to the reliable electricity grid. HPS offers a low-cost biomass gasification solution that utilises rice husk waste with an energy production capacity of 35 kW electrical output. In 2016, HPS had 68 operational plants in India and Africa, serving around 200 000 low-income customers. While Volter targets their solution to the wealthy, HPS targets the poorest of the poor in rural India, making the comparison between these two cases interesting.

The data was collected in two phases. In 2012–2013, I participated in a research project at the VTT Technical Research Centre of Finland with the case company Volter and conducted interviews and field visits during that period. The results of the research project, which are published in one report and seminar presentations, are used for this study [34, 35]. Emails related to the sustainability of Volter's solution were exchanged in October and November of 2016 with the CEO of Volter and a bioenergy expert from VTT. A field trip to India was made in February 2016, where key personnel of Husk Power System were interviewed in Patna, India, and two days were spent in one HPS gasification plant in the Mahjoria village. Notes were taken from personal discussions with HPS employees at the site, and photos were taken of the gasification plant. In addition, I have conducted systematic documentary material analysis on HPS, which includes 86 documents. The data was coded and analysed by identifying the key activities of the business model elements of both cases.

3 Results

In this section, the results of analysis of two case companies are presented, and comparison between two different approaches for sustainable design and manufacturing is made. The business model configurations of two case companies are described in Table 2, and after, a more detailed analysis of the business model activities is conducted.

Table 2. General business model configurations of the case companies

	Finland case (volter)		India case (HPS)	
	High-tech model	High-tech sustainability	Low-tech model	Low-tech sustainability
Offer	High investment cost, uncompromised quality, functionality and efficiency	Formal recycling of side streams and high pollution control	Low investment cost, compromised quality, functionality and efficiency	Informal reuse of side streams and medium pollution control
Customer interface	Reliable and seamless service	Green energy, self-sufficiency and security	Service pricing and door-to-door service	Raising awareness of renewable energy
Infrastructure	Automated and maintenance-free	Effortless operations and maintenance	Manual operations and maintenance intensive	Local employment and capacity building
Financial model	Revenues from green customers and costs from context-specific wood chip supply	Sustainability oriented customers and green image building	Donor dependency, high cost of operations and uncertain revenues	Poverty reduction and inclusive energy trends

3.1 High-Tech Resource-Scarce Business Model

In this section, Volter's solution design and manufacturing, business model and sustainability approach are analysed. The gasification process has many technical challenges created by the ash and tar content of the wooden biomass, meaning that there are high maintenance requirements. However, Volter has been able to develop a solution that functions autonomously without high maintenance requirements. This makes the solution viable in the high-income market context, where the labour force is expensive. Volter's solution model is visualised in Fig. 1, and the sustainability implications of its business model are analysed below.

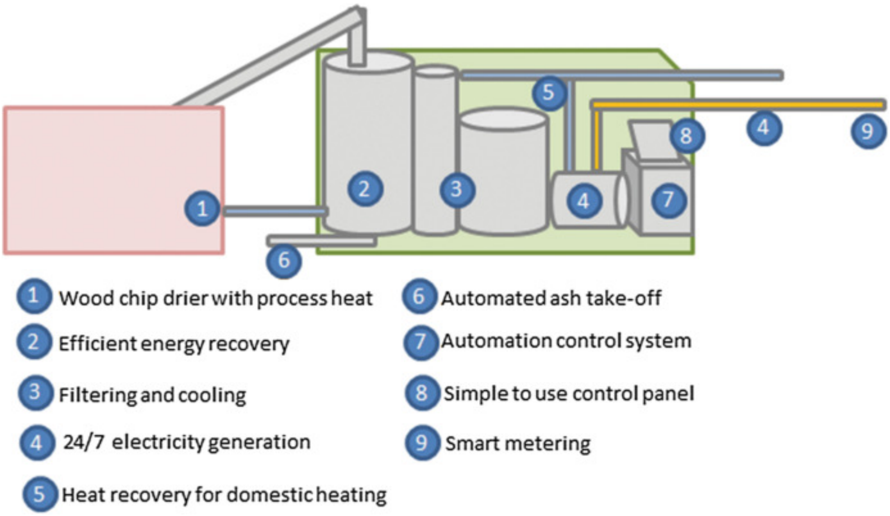

Fig. 1. Volter solution system model with key functionalities

Offer: 24/7, fully-automated green heat and electricity
Volter offers its customers a renewable combined heat and electricity solution that functions 24/7 regardless of weather conditions. This enables customers to become self-sufficient regarding local energy production and improves energy security when local raw materials are available. Volter has optimised their gasification, combustion and purification process to make gas clean, meaning that air pollution is minimised. Side stream ash is used as fertiliser or combusted in other processes. Volter has also been able to eliminate tar waste generation in the process; before, a couple of litres of condensate water were produced per day and delivered to a wastewater treatment plant.

Customer interface: Smart electricity and heating system
Volter's customers are high-income people living in remote areas, people willing to become self-sufficient regarding energy production and organisations that want a greener image. Volter manages its customer relationships by identifying environmentally aware customers and providing them energy with market prices and reliable customer service. Volter's solution improves customer well-being by reducing the air pollution and providing them with energy security.

Infrastructure: Local raw materials and maintenance-free
Volter utilises local wood chips, which have high moisture level requirements, to maintain an efficient gasification process. Volter has worked with research institutes and universities to improve the gasification and filtering processes and evaluate the ecological impacts. Volter has been able to automate its operations and maintenance, meaning that minimal involvement in terms of human labour is needed. Volter's plant requires basic 'housekeeping' weekly and monthly mechanical level maintenance. However, Volter employs highly qualified engineers for design and manufacturing and

installation services. A locally designed and manufactured solution provides employment, and a locally procured biomass provides income for forest industry actors.

Financial model: Subsidised green energy
Volter's financial sustainability is dependent of available subsidies, cost of alternative energy sources and cost of wood chips. For example, in Finland, Volter's solution is only financially sustainable in domestic off-grid production, as there is no feed-in tariff for under 100 kW and no need to pay the electricity tax or transfer fee. Costs are related to the availability of suitable raw materials, making its solution only sustainable in certain contexts. Thus, promoting sustainability through offering, customer relationships and business infrastructure activities is the basis for Volter's financial performance.

3.2 Low-Tech Resource-Scarce Business Model

In this section, HPS's solution design and manufacturing, business model and sustainability approach are analysed. The gasification process has many technical challenges created by the high ash and tar content of the rice husk waste biomass, meaning that there are high maintenance requirements. HPS has, however, been able to develop a solution that functions daily when manual operations and maintenance is done. This makes the solution viable in the low-income markets, where labour force is cheap. HPS's solution model is visualised in Fig. 2, and the sustainability implication of its business model is analysed below.

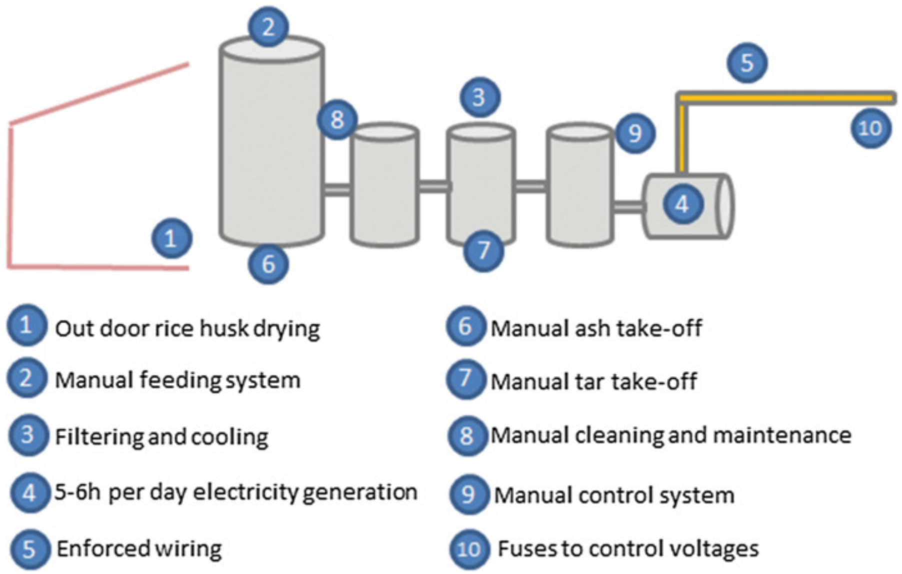

Fig. 2. HPS solution system model with key functionalities

Offer: Low investment cost and locally-produced night electricity
HPS offers locally-produced, affordable night energy to villages without access to electricity to replace their expensive kerosene-based lighting. In place of this inefficient lighting, HPS offers low-cost LED lights to its customers. Because of the high ash content of rice husk waste, HPS is only able to provide 5–6 h of electricity, as the system needs to be cleaned daily. It has also simplified the solution to reduce the initial investment cost. HPS is able to offer a solution with the same energy output as Volter but with almost one tenth of the up-front investment cost. HPS also reuses the ashes to produce incense sticks in its local factory, where they train and employ local women. For the most toxic side stream tar, HPS has not found a recycling or disposal solution yet. Also, HPS does not use the heat generated from the process, meaning that 70% of its total energy output is wasted.

Customer interface: Raising awareness with door-to-door service pricing
HPS's customers are living below the absolute poverty level (less than 2 USD per day), have low levels of education and lack awareness of the benefits of sustainable energy. Rural villages in India often lack access to electricity, and if there is main grid connection, it is normally only functional a couple of hours per day and never during the night when there is the highest demand for electricity. HPS has had to install fuses to control the misuse of electricity, enforce distribution lines to avoid the stealing of electricity and organise a door-to-door fee collection to improve revenue streams. Moreover, HPS had to build its own bamboo post distribution lines in order to gain informal electricity producer status. HPS intends to actively increase its rural population's awareness on the health harms of indoor air pollution (kerosene light) and to promote more sustainable solutions (LED light).

Infrastructure: Local raw materials and employment
HPS procures the local abundant rice husk waste for a fair price from local rice millers and utilises the waste as fuel. In the state of Bihar, there are no other uses for rice husk waste, as there are no process industries, such as cement industries, nearby. HPS employs four people in each plant from local villages to operate its plants and organises training for them in its own training centre. In addition, HPS employs and trains maintenance engineers in the training centre to serve various plants in the region. Finally, HPS employs local women in incense stick factories.

Financial model: Donor-based impact
HPS utilises a service-based pricing model. With less than 2 USD per month, villagers can use the lighting, charge their cell phones and use one fan for 6–8 h per day. By raising local awareness in the customer interface, employing locally and generating additional revenues using side streams in the incense stick factory, HPS is able to generate revenues so that some of its plants has become self-sustainable. Most importantly, by integrating the sustainability into offer, customer interface and infrastructure elements, HPS has been able to attract significant amounts of charity

investment to donate to plants in villages and finance their operations. However, operations and maintenance costs have been high, and uncertain revenue streams and investors' requirements for profitability have increased after the series-A round in 2013. Since then, HPS has shut down 30 unprofitable power plants.

4 Discussion and Conclusions

In this study, two approaches for the sustainable design and manufacture of small-scale bioenergy solutions were explored through lenses of the business model framework in developed and developing countries. The two cases demonstrate the need for radically different design and manufacturing approaches in order to promote sustainability in different parts of the world. Comparison of similar solutions in different contexts enabled viewing both cases from multiple perspectives.

Even though the HPS solution can be argued to be more sustainable than existing kerosene and diesel solutions in low-income rural contexts in Bihar, India [8], global comparison to Volter's solution provides a slightly different picture. The HPS business model can arguably be claimed as socially sustainable, but some challenges remain for ecological sustainability compared to Volter's solution: (1) While Volter captures and utilises heat in its process, heat output is not utilised in the HPS process, making the process inefficient, as around 70% of energy content of gasification process is wasted; (2) Even though part of the ash waste in the HPS process is utilised through incense stick production, there is no disposal for the remaining ashes and especially for toxic tar in condensate water. Instead, Volter has been able to eliminate tar waste by improving the gasification process and is recycling the ash waste. At the same time, HPS is having challenges with financial sustainability, as upfront investment is dependent on donations, operation and maintenance cost remains high and there is an uncertain revenue stream from low-income customers. Volter also faces financial challenges in Finland caused by institutional constraints, but they have found other markets that are more favourable for small-scale bioenergy production.

This study provides three main contributions to the discussion of sustainable design and manufacturing. First, the frugal innovation perspective is integrated into sustainable design and manufacturing so that frugal principles [5] promote sustainability, especially in the context of low-income markets. Second, the framework of comparative studies for traditional and sustainable business models is developed. Finally, we provide insight on the implication of two design and manufacturing approaches regarding sustainability and highlight the challenges in the low-income context.

The business model concept was applied in this study to provide an analytical framework to explore the sustainability of design and manufacturing approaches in two different contexts. In this study I separated the traditional and sustainable business model questions and these should be explored further. There is no ideal framework for the business model concept, and flexible use of this concept can act as a powerful tool in an analytical work when applied correctly and connected to a theoretical discussion.

To conclude, at the end of the Pikokaasu (small-scale gasification in Finnish) project in 2013, many experts in Finland argued that small-scale gasification solutions do not have significant commercial potential, which is why public support for these solutions was discontinued. However, Volter has proven this wrong, and in 2016, they announced that they have closed a deal in Japan for 25 bioenergy plants. At the same time, the donor community has advocated the sustainability of HPS, with many praising evaluation reports [36, 37]. It seems that, in industrial community in Finland, there has been over-scepticism, while the donor community has been overly optimistic, focusing on social sustainability. Thus, Volter has been able to make the small-scale gasification process greener while HPS has only been able to romanticise it.

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