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Review on Environmental sustainability of small-scale biomass power Technologies for agricultural communities in developing countries

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Abstract **Agricultural wastes are readily available in farming communities and can be utilised for off-grid electrification as an alternative to diesel generators. This work evaluates for the first time the life cycle environmental sustainability of these small-scale systems in the context of Southeast Asia. Rice and coconut residues are considered for direct combustion and gasification, and livestock manure for anaerobic digestion. Overall, anaerobic digestion is the best option for 14 out of 18 impacts estimated through life cycle assessment. The results also suggest that gasification has up to 12 times lower impacts per kWh than combustion, except for resource depletion. Combustion and gasification have 85% to two times lower impacts than diesel generators, except for eutrophication, ecotoxicity and human toxicity. Depending on the feedstock, global warming potential of anaerobic digestion ranges from being 170% lower to 41% higher than that of the diesel generator. Overall, providing power from residual biomass in small agricultural communities would reduce environmental impacts significantly while improving**

.*Keywords* **—Biomass electricity rural electrification Agricultural waste Gasification Anaerobic digestion Combustion Life cycle assessment**

I. INTRODUCTION

Identified as one of the Sustainable Development Goals (SDG) by the United Nations, access to affordable and clean energy can be translated to improved outcomes in education, health and peace [1,2]. An estimated 1.06 billion people around the world live in areas without electricity e the majority of whom are in rural communities in Africa and Asia-Pacific [3]. While an obvious solution is to extend the grid towards these areas, technical or economic constraints may prohibit this [4]. Hence, diesel generators are typically installed to provide power to these off-grid areas.

However, increasing concerns on energy security and environmental sustainability have shifted attention to alternative energy sources for rural electrification, including biomass [5]. There are multiple perspectives on biomass utilisation for rural development. Developing countries typically use biomass for cooking, although this trend declines as income increases [6]. Also, because biomass resources are considered renewable and widely distributed, various technologies are being developed for their conversion to other energy services, including electrical power, process heat and transportation fuels [7]. However, the limited availability of biomass resources has been highlighted as a constraint in energy development policies [8,9]. Thus, with the objective of meeting the SDG for energy access, this study limits its focus on the use of biomass for power without prejudice to other potential conversion pathways.

There are several methods to prepare nanosized materials. These materials may be used directly or in the form of supported nanoparticles on solids such as oxides, carbon or zeolites. Some usual methods for nanocatalysts preparation are impregnation, precipitation, chemical vapor deposition, and electrochemical deposition. Precipitation and impregnation methods are simple, cheap, and well-studied but it is difficult to control the size of particles. Chemical vapor deposition is widely used in the electronics industries but it is an expensive method.

Recent catalyst developments have led to the upgrade of biomass gasification processes to increase the syngas production and reduce the tar formation. In catalytic biomass liquefaction the main aims are to increase liquid yield and quality of products. Furthermore, nanocatalyst characteristics, such as high catalytic activities and high specific surface area have helped overcome some limitations on heterogeneous catalysts for their application in biodiesel production from biomass. In this paper the

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latest progress in nanocatalytic conversion of biomass has been reviewed. However, research studies have not been extended in all biomass conversion fields.

The use of biomass for power has been studied widely and many large-scale, grid-connected plants are already in operation. However, the sustainability of electricity from biomass is under scrutiny due to issues such as price, availability and land use [10]. For largescale operations, the supply of feedstock significantly affects transportation costs and operating times [10,11]. In rural farming communities, using locally available agricultural wastes as feedstock in small-scale power production could avoid these issues.

II. METHODS

A. Goal and scope

The main goal of the study is to evaluate the life cycle environmental sustainability of small-scale electricity systems for application in developing countries, using agricultural residues in direct combustion, gasification and anaerobic digestion. A further goal is to compare these biomass options with diesel generators to identify the most sustainable options. The functional unit is defined

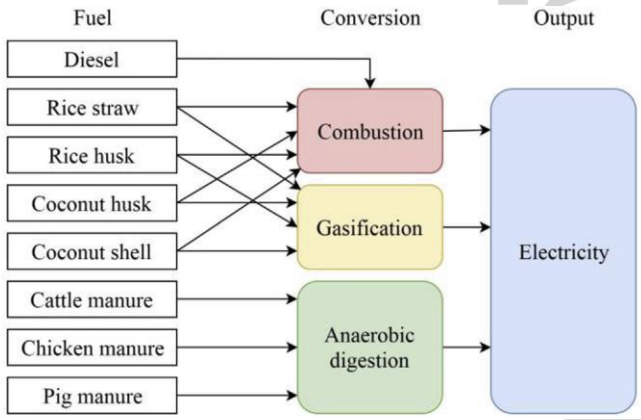

Fig. 1. Electricity production pathways evaluated in this study.

Southeast Asian context. While there is also a potential for heat cogeneration from waste biomass, this study limits the scope to electricity production since extensive use of heat is not expected in the selected tropical-climate region.

The scope of the study is from cradle to grave, taking into account the impacts of the systems across the whole life cycle. The system boundaries. The stages considered are: collection of feedstocks for biomass technologies and production of fuel for diesel generators; production of infrastructure components, their assembly, transportation and installation; operation and disassembly of the plants; and end-of-life waste management, including system credits for recycling of materials. Direct combustion of biomass is selected for consideration due to its prevalence in power and heat generation [21,27]. It is assumed that electricity is generated in a turbine typically used in mini combined heat and power (CHP) plants; heat recovery is not considered. Biomass gasification is also a relatively mature technology, suitable for rural electrification [14]. An air-fed downdraft gasifier has been assumed, as the most common type [28], with electricity generated by a micro gas turbine.

B. Life cycle inventory

The foreground inventory data have been sourced from the literature as detailed in the next sections. The background data arefrom the ecoinvent database .

C. Feedstock/fuel supply

Rice and coconut are the most produced crops in Southeast Asia and may be assumed as the representative crops for many rural locations. Similarly, manure from cattle, chickens and pigs is generated widely in rural communities e despite the industrialization of livestock farming, backyard farms in developing countries are expected to remain in business in the foreseeable future.

D. Infrastructure

Components are assumed to be manufactured in China and shipped by sea, except for construction and installation components, including reinforced steel and cement, which are sourced locally. The combustion system is assumed to use infrastructure similar to a 5kW mini-CHP system as inventoried in the ecoinvent database. The operational lifetime of the system is 100,000 h. For the gasifier, the inventory for a 13.2-tonne installation has been scaled down linearly to 626 kg, which is the weight of a representative small-scale (18 kW) air-fed downdraft gasifier.

III. CONVENTIONAL TECHNOLOGIES FOR BIOMASS TO BIOFUEL CONVERSION

The process of refining lignocellulosic feedstock to hydrocarbon biofuels can be divided into two general parts. Whole biomass is deconstructed to provide upgradeable gaseous or liquid platforms. This step is usually applied through thermochemical methods to produce synthesis gas (by gasification) or bio-oils (by pyrolysis or liquefaction), or through the hydrolysis route to provide sugar monomers that then deoxygenated to form upgraded intermediates. Thermochemical conversion process is a major method of biomass upgrading for biofuels production, offering a wide range of potential technologies (Hansen et al., 2010). In the following section gasification and direct liquefaction processes have been described as two main thermochemical conversion methods.

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A. Gasification

Gasification processes provide a competitive route for converting various, highly distributed and low-value lignocellulosic biomass to synthetic gas for generation of a broad sort of outputs: electricity, heat and power, liquid fuels, synthetic chemicals as well as hydrogen production (H2). The importance of gasification is that it is not constrained to a particular plant-based feedstock, and thus any lignocellulosic biomass can be considered appropriate (Luo and Zhou, 2012; Demirbas, 2008).Gasification of biomass is classified into two different ways, Low-temperature gasification (LTG) and high-temperature gasification (HTG).

B. Direct Liquefaction

Biomass can be converted to liquefied products through combined physical and chemical reactions, the technology being called direct liquefaction. In these processes the biomass macromolecules are decomposed to small molecules through heating and sometimes in the presence of a catalyst. Direct liquefaction may be divided into pyrolysis and liquefaction methods. Although both are thermochemical conversion methods, their operating conditions are different.

C. Liquefaction

Two main routes can be considered industrially for the liquefaction of biomass to bio-oils and these include, hydrothermal liquefaction, and catalytic liquefaction (Vertes et al., 2010).Hydrothermal liquefaction is based on the superior properties of water at higher temperatures and pressures. The reactivity of biomass is considerable in water especially under hydrothermal conditions. Biomass consists of components with polar bonds which are attacked by the polar molecules of water. At elevated temperatures and pressures these attacks are more sever. As a result, hemicellulose and cellulose are hydrolyzed very quickly at these conditions (Kruse and Dinjus, 2007). Hydrothermal liquefaction has another important advantage. Usually all biomass sources are wet and it is possible that their water content be at a range of up to 95wt. %. In most biomass upgrading methods it is necessary to dry feeds before processing. In hydrothermal liquefaction conversions of biomass perform with its high water content. The water content of the biomass not only is not a disadvantage but it is also useful by reducing the process' required fresh water. Using water as both reactant and solvent in the liquefaction has some other benefits as well. The degradable products of the process are completely soluble in water under elevated temperatures and pressures, which prevent any polymerization.

D. Pyrolysis

Thermal, anaerobic decomposition of biomass at temperatures of 377-527°C is called pyrolysis. A temperature of at least 400°C in pyrolysis process is needed to completely decompose the organic structure of the biomass into monomers and oligomers fragments. The noncondensable portion of pyrolysis products rise by increasing temperature to above 600°C. Pyrolysis operations are based on the size of biomass feeds and are divided into two main processes, slow pyrolysis and fast pyrolysis. The slow pyrolysis can disport to conventional charcoal production and intermediate pyrolysis (Vertes et al., 2010).In conventional charcoal production, large pieces of wood are slowly heated to 400°C for a long time (up to 18 hr). The sole product of such process is charcoal when wood was used as a raw material, in the conventional kilns. However, in large retorts with capacities of 100m3 and more, which is used in conventional industrial charcoal production, non-solid products are also achieved. Refining facilities are combined with pyrolysis units to collect and condense gas products.

IV. APPLICATION OF NANOCATALYSTS IN BIOFUEL PRODUCTION

A. . Nanocatalysts for biomass gasification

In biomass gasification, preventing tar and char formation is an important issue. Tar is a complex mixture of condensable hydrocarbons including aromatic compounds of single ring to 5-ring along with other oxygen containing hydrocarbons and complex polycyclic aromatic hydrocarbons (PAHs). The boiling temperature of tar is high and it condenses at temperatures below 350°C which creates major problems such as corrosion or failure of engines as well as blockage of pipes and filters. Tars may also act as poison for catalysts.

B. Nanocatalysts for biomass liquefaction

Alkaline salts, Na2CO3, KOH and so on, are commonly used as homogenous catalysts in liquefaction processes effects of some other catalysts on the liquefaction of biomass have also been investigated, such as NaHCO3) Ca (OH)2, Ba (OH)2,. The heterogeneous catalysts have been used in catalytic conversion of biomass. Different heterogeneous catalysts Pd/C, Pt/C, Ru/C, Ni/SiO2-Al2O3, CoMo/γ-Al2O3 (sulfided), zeolite, and Fe have been studied in conversion of the biomass. In catalytic hydro conversion of biomass, liquid catalysts have the advantage of being mono dispersed in reaction mixtures. In other words, solid catalysts have the superiority of higher catalytic activity in addition to being easily separated from the products.

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C. Nanocatalysts for biodiesel production

In the biodiesel production method, transesterification is the chemical reaction between triglycerides and alcohol within the presence of a catalyst for producing monoesters. The triglyceride molecules are transformed to monoesters and glycerol. They studied various forms of nano-CaO such as powder, pellets, and granules. They found that high yields of transesterification of soybeans oil are due to the higher surface area associated with small crystallite size and defects.

V. Conclusion

However, some of the key challenges in biomass conversion provide new research potential for improving quality of products and solving its related environmental problems. Introducing nanotechnology research to biomass conversion has witnessed rapid growth, which is mainly related to unique property of possessing high specific surface area. This study has evaluated for the first time the life cycle environmental sustainability of small-scale biomass systems for electricity generation in rural areas in developing countries. Direct combustion and gasification of rice and coconut residues have been considered alongside anaerobic digestion of animal manure. Without doubt, it is necessary to replace fossil energy resources with new safe sources. Among the existing choices, biomass seems to be the best option. The energy released from biomass is renewable and environmentally friendly, so it is strongly recommended to be applied. It is obvious that many methods are available for converting biomass to biofuel. The next best option is gasification, which also has the lowest global warming potential, particulate matter formation and photochemical oxidants potentials. Rice straw gasification is the best feedstock for these impacts due to the credits for avoided field burning.

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