(Stop) burning for biogas. Enabling positive sustainability trade-offs with business models for biogas from rice straw

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Abstract

Rice is the main agricultural crop in the Philippines and central to the country's food security. One main challenge of rice farming is the management of the straw after harvest. With limited uses, the rice straw is currently burned or in some cases incorporated with significant environmental impacts. However, it can be an important feedstock for sustainable bioenergy and support energy access in the Philippines. The research was conducted around a 1,000 m^3 biogas pilot plant in Laguna province, Philippines. The aim of this research was to develop business models and assess their potential for improving energy access, agricultural practices, and empowering local rice-growing communities. Four business models were developed, reflecting energy supply and demand approaches. This was informed by interviews with stakeholders, including farmers, agricultural entrepreneurs, local authorities, and policymakers in the case study location. A multi-criteria assessment was conducted to evaluate synergies and trade-offs between different aspects of the business models. While all business models provided positive environmental, economic, and in particular social sustainability impacts, the farming community showed the most support for approaches that provide wider livelihood benefits beyond renewable energy access, such as diversification of agricultural activities and income generation. This demonstrated that bioenergy has the potential to create a virtuous circle of benefits for local communities in support of sustainable development. To achieve this, it is essential to take a holistic and multi-level approach to the different sustainability criteria to maximise benefits and mitigate negative impacts of bioenergy systems beyond energy technology.

1 Introduction

Rice is one of the main food crops globally with about 90% of it grown in Asia [1, 2]. Unlike many other food crops, rice is a single-use crop grown for human consumption only [1]. The farming methods range widely from manual small-scale to mechanised large-scale production [1]. In many regions in Southeast Asia rice is produced on a small-scale with rice farmers being among the poorest. Rice production not only provides the staple food but is also an important source of income and employment opportunities for rural communities [1]. The focus of this research is on the Philippines, which is one of the top-10 rice producers globally [2] with severely limited energy access beyond major urban settlements [3]. Rice is the main agricultural crop, being the basis for the livelihood of 2 million farm households [4, 5]. Rice production in the Philippines takes place on a small-scale with an average farm size of 1.4 hectares [4]. Some land preparation activities are mechanised, while plant management and harvesting activities have mainly been manual, but are also mechanising rapidly.

One main challenge of rice farming in the Philippines is post-harvest straw management. Every tonne of milled rice produces 0.7 t to 1.4 t of straw [6]. This results in a major waste disposal issue that could be turned in an abundant bioenergy resource. Currently most of the straw is burned after harvest [7]. The Philippines has legislations to prohibit the burning of straw [8, 9], but in the absence of alternatives, the burning continues as a quick and low-cost means of disposal [10].

In the Philippines, rice grows in crop cycles of 4-6 months and most of the straw is burned directly in the field after harvest, to clear the fields for the next rotation [11]. This has significant environmental and health impacts as various air pollutants (carbon dioxide, carbon monoxide, particulates, dioxins, furans) are released [10, 12]. Nutrient and soil organic matter loss may arise from straw burning or removal, but the impacts are limited in flooded rice fields if roots and stubbles are incorporated and site-specific fertiliser recommendations are followed [13-15]. Still, national and local authorities encourage the incorporation of rice straw, which also leads to greenhouse gas emissions as methane is released during the decaying process in the flooded fields. Most of the farmers spoken to during this research project have shifted from burning to incorporation to avoid penalties for burning and ensure support from the Agricultural Department for not burning. However, farmers see incorporation as challenging because it makes land preparation and transplanting more labour- and time-intensive.

At the same time, about 45% of the Philippines' energy supply is imported in the form of fossil fuels for transport and power generation [16], which creates a high market dependency and limits the access to affordable energy [3, 17, 18]. While about 90% of the population have access to the electricity grid [16, 19], the price for electricity is the second highest in Asia [20]. For domestic use, fuelwood, charcoal and LPG [21] are the most common cooking fuels. Especially in rural areas solid fuels are the most common household energy source causing significant damage to health [22].

Using rice straw for energy could be an attractive option due to its abundance in rural areas, particularly in low-income communities and because of high energy prices and the lack of alternatives to field burning. Previous work identified four barriers to using the straw: collection logistics, rice straw fuel characteristics, a lack of proven business models, and policy support [11]. Moreover, to use rice straw in an integrated and sustainable manner, the wider environmental, economic, and social impacts need to be considered. If rice straw is used for bioenergy, trade-offs need to be balanced enabling different stakeholders to achieve net benefits that encourage participation and long-term sustainability.

The objective of this research was to assess trade-offs and develop business models that unlock the potential of bioenergy to improve access to energy, agricultural practices, and empower local rice-farming communities. The participation and inclusion of rice farmers as partners and beneficiaries of a bioenergy system was a central aim. Based on this, the project focused on biogas production as a sustainable straw management option and alternative to burning or incorporation. A key to implementation is to understand is the requirements to change agricultural practices away from straw burning by improving the rice value chains, creating new income and employment opportunities, and improving access to clean energy and organic fertiliser (digestate). While there are usually commercial interests in developing business models, this research adopted a people-centric approach to evaluate the environmental, social, and economic trade-offs for local small-scale rice farmers and other relevant value chain actors and to understand the synergies between the different sustainability implications.

The work was part of the Innovate UK funded Energy Catalyst Round 4 project "Rice Straw to Biogas", with the aim to set up and test the anaerobic digestion of rice straw in a dry digester developed for this project [23]. All research activities were related to the biogas pilot facility established in the barangay San Francisco, municipality of Victoria, Laguna province in the Philippines. The results here presented are based on the fieldwork conducted during the project and focus on opportunities related to the pilot facility and corresponding value chains. The business models were developed through discussions and practical testing of supply chain activities and practices with the local rice-growing community. This allowed an evaluation of the feasibility of the activities and proposed business models, which was fed back and revised with the local stakeholders.

2 Methods

2.1 Case study region

In Laguna province about 30,000 hectares per year are planted with rice [4]. This is done in two cropping seasons, a dry and a wet season, with an area of about 14 to 16 thousand hectares respectively harvested each cropping season [4]. The average yield per cropping season in Laguna is about 4 tha^{-1}, with a total of 8 tha^{-1} from the two harvests each year [4, 24].

Rice farming in the study region, as in the rest of the Philippines, is done on a small scale. The typical rice farm size in Laguna is about 1.5 ha to 2 ha [25-27]. However, the rice fields are divided into smaller plots by dikes and small irrigation canals and farms typically have about 2 to 4 rice plots [26, 27]. Large-scale farming is not common in the Philippines, only 2% of all farm households count as large-scale with managing more than 7 hectares of land [5]. However, the main land use and management of large-scale farms is permanent meadows and pasture or wood and forest land [5].

Figure 1 Location of Laguna (map adapted from Google Maps) and image of R2B pilot facility in San Francisco, Laguna, Philippines. The picture shows the two 500m^3 digesters (Left: digester covered with grey canvas and digesting rice straw. Right: preparation of digester with rice straw bales).

The level of fully mechanised rice farming is very low in the Philippines and when machinery is used, mainly hand-driven semi-mechanised devices are deployed [28]. Tillage for land preparation is often carried out with hand-driven 2-wheel tractors. Transplanting is mainly manual or in some cases with small hand-driven transplanting machines. Weeding and application of fertilisers and pesticides is done by hand and manual harvesting is still practiced, although combine harvesters have been adopted increasingly in recent years. After manual harvesting, the rice is fed into a small petrol-driven thresher in-field. The threshed rice is collected in sacks and the straw accumulates in heaps in the field. The sacks of rice are carried by men or water buffalos off the field to the roadside for the collection by trucks of middlemen or traders.

The grain to straw ratio of rice is about 1 kg milled rice to between 0.7 kg to 1.4 kg of straw (green) [6], depending on variety, harvesting technique and moisture content. For the whole of Laguna province with a rice production area of 14-16,000 hectares [4] this amounts to roughly 56-64,000 tonnes of rice straw per season.

In Laguna over 95% of households are electrified [19]. The main fuels used for cooking are: fuelwood (>50%); liquefied petroleum gas (LPG ~ 40%) and charcoal (~ 35%) [21]. Households might use different fuels for different purposes. About 20% of the households also use electricity for cooking. LPG is particularly common in towns and semi-urban dwellings in Laguna province.

2.2 Data collection

To develop and assess the business models a multi-method approach was applied. The conceptual framework for the business model design has been adopted using the triple-layered business model canvas [29, 30] to identify and describe partners, activities, resources, main product or value proposition, distribution channels, customer relationships, and customers. The purpose of the project was to set up a pilot facility to test the technical feasibility of biogas production from rice straw. Another objective was to investigate possible business models that would integrate bioenergy as a solution to improve energy access and agricultural practices in the rice-growing community in a form that facilitated small-scale rice farmer participation. Hence, the focus was on stakeholder participation and opportunities for social inclusion. It required an understanding of stakeholder practices, preferences, relationships, and socio-cultural dynamics to increase the likelihood of a successful integration of bioenergy and technology uptake. While cost structure and revenue streams are key elements of business models, the economic profitability was not considered for this part of the work.

The data to inform the business models was collected through semi-structured interviews with stakeholders in the case study region in February and March 2018. Semi-structured interviews do not follow a strict list of questions and the open-ended questions allow the interviewees to steer the conversation and discuss topics relevant to them and possibly outside the awareness of the interviewer [31-33]. The majority of interviews were held with small-scale rice farmers. However, key experts in rice-farming communities, local and national authorities, and the local and national agricultural departments were also interviewed. Additionally, stakeholders relevant to the rice supply chain such as agricultural entrepreneurs, middlemen, traders, millers and commercial agriculturists at different scales were interviewed. The participants were selected based on their involvement in farming and community activities. The purpose of key expert interviews was to collect information on the region's agricultural system and institutional, regulatory and policy frameworks. They would also provide information on wider community structures and challenges to ensure other potentially relevant agricultural supply chains and energy supply aspects were captured and understood. Commercial stakeholders provided information about dynamics, drivers, technical and commercial feasibility, and challenges of rice and other agricultural supply chains. Farmers operating at different scales and near the location of the pilot plant were interviewed to obtain information about common agricultural practices, supply chain opportunities, and challenges. Additionally, consideration was given to livelihoods and resilience building, location-specific energy needs, dynamics and relationships within the farming communities and between different supply chain actors, and household and community decision-making. While most key experts were interviewed individually, most of the farmers were interviewed in groups of varying sizes with some farmers interviewed individually. In total 25 interviews were conducted with a total of 79 participants; 16 of these participants were key experts.

2.3 Data evaluation

The business model canvas structure [29, 30] was used to categorise and assess the collected data and to build four business models as possible bioenergy integration solutions for the case study area related to the technical capacity of the pilot facility.

Additionally, data from the interviews was used to identify and assess possible benefits and challenges for the rice farming communities and to evaluate trade-offs and synergies between different aspects of the business models. For this, a multi-criteria assessment (MCA) [34-36] was conducted for each business model. The MCA was used as an exploratory method rather than a decision-making tool [34, 36]. The criteria were identified through the interviews from topics brought up repeatedly, topics emphasised as important during the interviews, and the most relevant objectives of this project. To categorise these criteria and develop plausible relationships between them, sustainability was used as the overarching framework. Based on the information gathered in the interviews and discussions with academic and industrial experts during project meetings, the criteria were clustered according to the three sustainability pillars: environmental, economic, and social. Each criterion was ranked on a relative scale from 0 to 4 with 0 being the most negative impact, 2 no impact or benefit and 4 the highest benefit. Using qualitatively generated rankings made it impossible to weight the criteria precisely as these would have been biased depending on the perception and interest of the person ranking it (e.g., a local policymaker might weight employment opportunities higher than a trader, who might be more interested in a high revenue). MS Excel and SigmaPlot were used to assess the MCA data and produce the results as graphs. The aim of assessing the sustainability performance was to understand and indicate trends (e.g., positive or negative impacts) and synergies, rather than to provide an exact measurable outcome based on a very specific context. This also allowed a comparison of the sustainability performance between the different business models.

Once the business models had been designed and assessed based on the above methods, a second set of interviews was conducted in June 2019 in the case study region. During these interviews, the business models and the outcome of the trade-offs and synergies were discussed with the same groups of farmers interviewed during the first set of fieldwork. During these interviews the farmers also scored the business models choosing their first, second and third choice. Five group interviews were held with 33 farmers in total. Additionally, two policymakers and three agricultural entrepreneurs were interviewed individually. In the time between the two sets of interviews, the pilot plant was set up and started operating. This means during the first set of interviews the discussions were based on a theoretical technology intervention, while the second set of interviews was influenced by a practical technology intervention with which some farmers had interacted by providing straw, visiting, or even gaining employment.

While not being the focus of the research, the layout of the fieldwork allowed a high-level observation of possible shifts in perception due to engagement during the establishment of the facility. This informed the assessment and interpretation of the results because changes in perception affect local engagement and response to new developments.

3 Results

3.1 Business models

The development of the business models focused on the introduction of bioenergy as a solution to improve access to energy, agricultural practices, and empowering of local rice-farming communities. With a focus on wider socio-economic benefits, the farming community was given a central role in the business model development to ensure participation and inclusion, that rice farmers would be partners and beneficiaries of the business models.

Four business models were developed and are described and illustrated in Figures 2-5. BM1: Rice straw to biogas for farm households, BM2: Rice straw to biogas at a fuel station, BM3: Rice straw to biogas for electricity and heat in communities/businesses, BM4: Rice straw to biogas and mushrooms.

In all business models the partners are the rice farmers and the biogas facility operator, the main activities are rice-growing, harvest and straw collection, anaerobic digestion (AD), and the composting of the digestate. The composting of the digestate on the AD site was found to be the most viable treatment, producing a reduced volume, dryer and higher value product that is ready to use in agriculture and horticulture. The system's added value is in straw management, biogas, and compost production. BM4 includes the production of mushrooms, which is described in more detail in Figure 5.

Offering solutions for straw management is a central element of the business models. With the majority of farmers harvesting manually, collation and removal of the straw is not viable so it will remain as a pile in the field. There are few other uses for the straw [11] and burning seems to be the easiest and cheapest option. As it is prohibited to burn the straw [8, 9], farmers are encouraged by the agricultural authorities to incorporate it back into the soil [37]. However, interviewed farmers indicated that straw spreading and incorporation are challenging and costly as they need to pay for labour to spread the straw, it increases time and effort for land preparation, and the straw will not decay quickly enough for the next planting. Offering a straw removal service at no extra cost is therefore important for the farmers. Two different options have been discussed with them: manual in-field collection after manual harvest; and offering a mechanised harvesting service with straw collection using a combined harvester and baler. The two straw management options are flexible for each business model and would not affect the other downstream processes of the AD operations.

The main difference in the business models are the distribution channels and the final consumers. Hence, it was possible to test different options with the farming community to understand their needs and preferences for access to the different products and services. This helped to test to what extent farmers and other stakeholders would expect a direct benefit from the bioenergy system integration in terms of access to energy and compost from the biogas plant and related services.

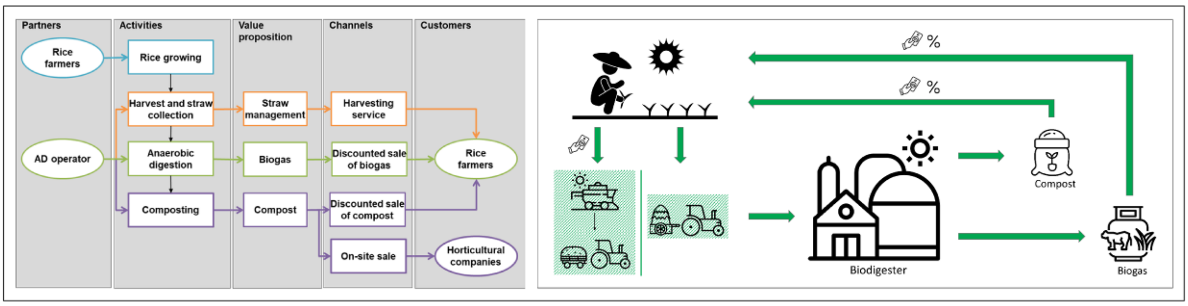

Figure 2 BM1: Rice straw to biogas for farm households. The left side of the figure presents the schematic of business model canvas; the right side presents the iconified business model discussed with stakeholders.

In BM 1, rice farmers who provide straw can buy bottled biogas and compost at a discounted price in relation to the straw they provided. The biogas can be used for cooking and the compost is used in vegetable or seedling beds. The farmers are partners and consumers with direct access to and benefits from the biogas system. Surplus biogas and compost is sold at the open market with no discounts to other end users.

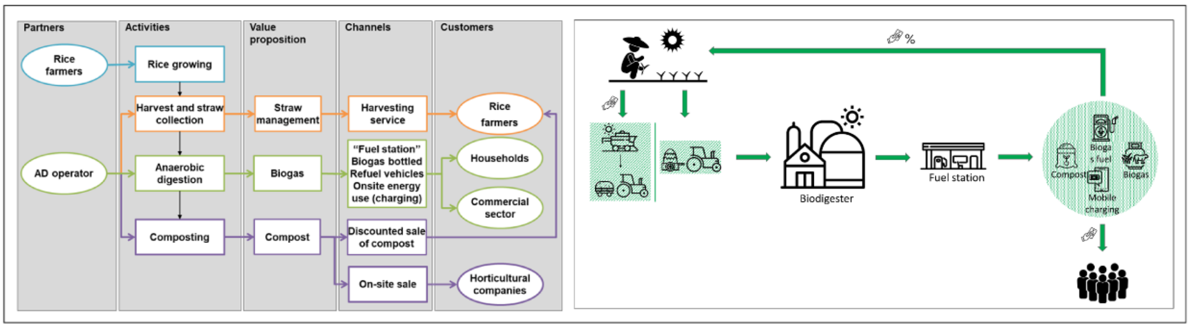

Figure 3 BM2: Rice straw to biogas at a fuel station. The left side of the figure presents the schematic of business model canvas; the right side presents the iconified business model discussed with stakeholders.

In BM2, biogas and compost are sold onsite of the AD facility similar to a fuel station. Anyone can purchase biogas and compost for home and farm use or directly fuel vehicles that can run on biogas. As the facility has a combined heat and power (CHP) unit, customers could also directly charge devices like mobile phones and electric scooters. Farmers providing straw would receive a discounted price on products and services.

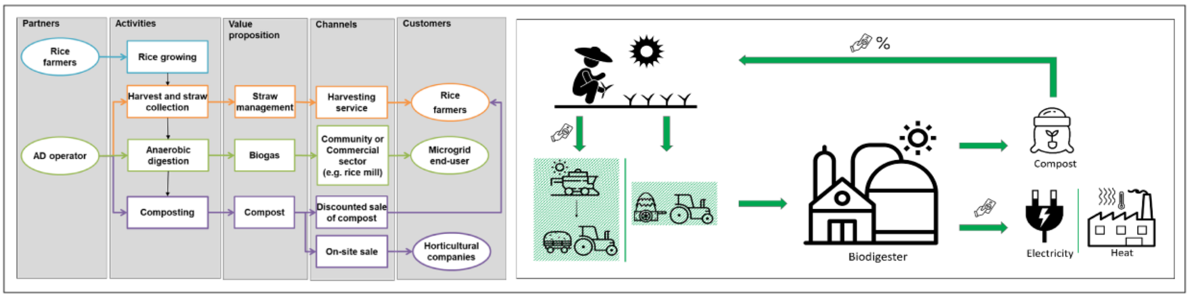

Figure 4 BM3: Rice straw to biogas for electricity and heat in communities/businesses. The left side of the figure presents the schematic of business model canvas; the right side presents the iconified business model discussed with stakeholders.–

BM3 is a microgrid providing energy directly to either a commercial facility or small community. Given the structures and connectivity of dwellings in the case study area, an integration with a commercial unit such as a rice mill is most likely. All energy would be used within the microgrid, while compost is sold with a discounted price to the farmers providing straw or sold at full price to other end users.

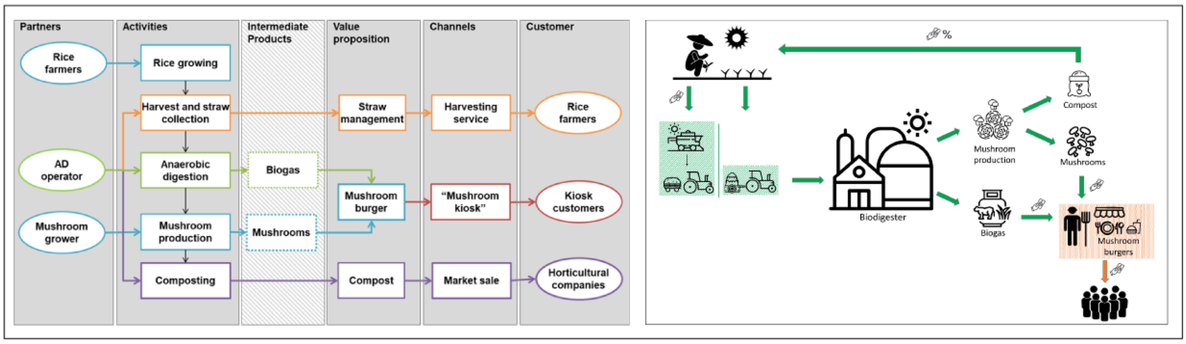

Figure 5 BM4: Rice straw to biogas and mushrooms.The left side of the figure presents the schematic of business model canvas; the right side presents the iconified business model discussed with stakeholders.

BM4 includes the production of straw mushrooms (*Volvariella volvacea*) after the AD process. Many farmers see straw mushroom production as an additional income opportunity. However, straw would need to be pasteurised beforehand to suppress the development of undesirable fungi. Tests at the pilot facility showed that growing mushrooms on the digestate does not require any further pre-treatment of the straw and additionally, mushroom growing supports the composting process of the digestate. In this business model farmers would grow mushrooms on the digestate and the biogas would be used to process the mushroom into a higher value products such as mushroom burgers, which then could be sold in small roadside kiosks. The mushroom strand of the business model could be a franchise.

3.2 Stakeholders' feedback on the business models

3.2.1 Straw management

Farmers in Laguna practice mainly manual harvest, with and an increasing uptake of mechanised harvesting. This is based on several economic, technical, and socio-economic reasons.

Most farmers do not harvest themselves but pay for an harvesting services. This can be small companies with organised workers providing harvesting, a community activity with farmers helping each other or in some cases, a farmer employing farmworkers. According to the farmers, manual harvest takes about one day per hectare, the farmer pays 10% of the harvest to the harvesters, 10% to the threshers, and about 2 to 3% for carrying the sacks of rice to the roadside, which depends on the distance of the field to the road. For mechanised harvest the farmer pays 12% of the crop for harvesting and threshing as this is done in one process. With a combine harvester, one hectare is harvested within one hour. Regarding the cost and time, many farmers prefer mechanised harvesting and an increased shift to mechanised harvesting could be observed over the lifetime of the project. However, there are some limiting factors. The size and layout of many fields limits the use of larger machinery as it would be difficult to manoeuvre on small plots and to move across the dikes and canals without damaging them. This is particularly relevant for plots further away from the roadside and in remote locations with limited infrastructure. During the wet season in some locations, the mud can be too deep to use heavy machinery.

In most cases different farmers do not plant and therefore harvest at the same time. There can be time differences between the farms and plots of a few days or even a few weeks. In the case of small-scale farmers, plots not necessarily have direct roadside access and border to plots of others. This can make it impossible to reach more remote fields ready to harvest without damaging crops of others. This is mainly a problem when farmers operate individually and not in co-operatives where timings could be managed and agreed with others. In addition, co-operative members do not necessarily have fields next to other co-operative members.

There are also cases where farmers could harvest mechanically, but prefer manual harvest, especially when the harvesting is seen as a community activity, providing income for farmworkers and other community farmers. Even though, mechanised harvesting with a combine harvester is quicker and cheaper for the farmer, many farmers raised this issue of providing community members and farmworkers with an important guaranteed income. Nonetheless, these farmers were also open to mechanised farming if income for these workers could be provided through new activities related to the bioenergy intervention, e.g., straw collection and transport or working on the AD site.

From a commercial point of view, mechanised harvest and straw collection are more efficient. All rice farmers saw offering free straw management solutions as a great benefit. Most farmers were positive about providing their straw if it would not create any additional cost for them and would not interfere with the timing of their agricultural activities. Before the setup of the pilot plant some farmers raised the issue of only giving the straw if they would be paid for it. However, once the pilot plant was operational and farmers experienced the first few harvests with having the straw quickly removed from their fields at no cost, even farmers who suggested payment before, volunteered to provide straw free of charge.

3.2.2 Energy access and co-products and co-benefits from the bioenergy system

Improving energy access was one of the central objectives of the project and goes beyond simply providing energy. Consideration is given to the community's energy needs and end uses, as well as supporting the participation, inclusion, and possibly co-ownership. The stakeholder' engagement process showed that energy insecurity in terms of energy provision and cost is not a major concern for most rice farmers in Laguna. Most of the farm households are connected to the electricity grid, use LPG, and to some extent fuelwood and charcoal for cooking. While some farmers pointed out the high cost for energy, there were no reports of lacking energy access. This does not mean that there is no energy insecurity or lacking energy access for some households, but it was not a challenge for farmers engaged with during the project. Despite this, the business models were designed to provide energy benefits to the farmers and possibly improve energy access by providing new opportunities for using energy.

As described in the methodology section, the farmers were asked to discuss the business models considering the products and services as well as possible benefits and participation provided through the different business models. Following the discussion, they were asked to score the business models according to their first, second and third choice. The results from this exercise are illustrated in Figure 6.

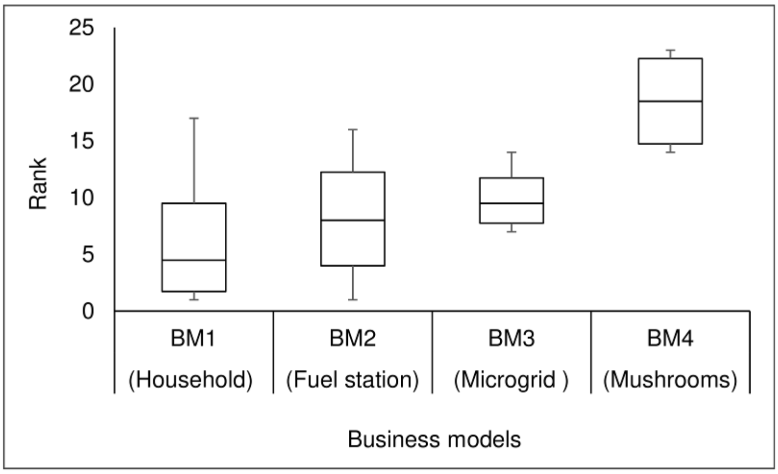

Figure 6 Scoring of the business models. The centre line of the graphs presents the median of the scores with the box showing the lower and upper quantile and the whiskers the lower and upper extremes.

BM1 provides energy in the form of biogas for household use directly to the farmers providing rice straw. For most farmers this was the least preferred option. This option seemed only interesting for farmers if biogas would cost less than current fuels, such as LPG. As most farm households in the case study area use and have easy access to LPG, several farmers suggested that this could be more relevant for more remote villages where most people still use fuelwood and charcoal.

BM2 offers energy in different forms (for household use, transport fuel, electricity) to a wider group of people. Most farmers preferred this business model over BM1 as this offered more flexibility and choice in terms of energy use. Farmers were very favourably disposed towards a discount scheme for those providing straw, however, there was also strong support that this business model offers energy to people who do not provide straw.

BM3 received similar support to BM2, but farmers showed a more consistent level of agreement for BM3 over BM2. Farmers were favourable towards the opportunity of electricity access and potential heat. Electricity prices in the Philippines are one of the highest in S.E. Asia and an opportunity for independent off-grid electricity supply was seen as a big benefit. This applied to domestic and commercial applications. For example, a reliable energy supply for rice mills and dryers would also improve the quality of milled rice for the farmers. Most of the local mills where farmers process the rice for their household consumption do not have dryers with sufficient capacity and quality. Farmers normally dry their rice before milling on the roads or in their yards, which affects the quality of the rice significantly. Many farmers saw the potential for better-equipped mills due to the energy provided from the AD facility as a big benefit.

BM4 was the business model that received the most support from the farmers. The discussions for this business model shifted away from energy as farmers saw the opportunity of diversifying their agricultural activities and having an additional income from either mushroom growing or running a franchise. Mushroom growing is seen by many farmers as what they called a “livelihood project” that offers additional and new opportunities to rice farming. Currently, many farmers struggle to grow mushrooms due to lack of knowledge of straw pre-treatment and spore planting. If straw digestate and mushroom growth training were made available to farmers, this business model would be their first choice.

Access to compost was seen as favourable throughout all business models. The agricultural authorities encourage organic farming. Farmers using organic practices are more likely to get support in the form of seeds, plants, and (for co-operatives) machinery. The potential opportunity to reduce mineral fertiliser use was therefore seen very favourably.

For agricultural entrepreneurs BM3 was favoured as this is the business model most relevant to provide energy for productive uses such as rice drying or milling or generating electricity for various commercial uses, e.g. lighting for buildings or running equipment. However, as they would just be end users of the energy and not like farmers feedstock providers, their main criteria for the business models was not so much the origin but the cost of energy. They would only use the biogas based energy if it was cheaper the current fuel or energy provided. The additional, non-energy benefits of the business models were less relevant for this stakeholder group and they would not directly benefit from other services and opportunities like straw management, compost or mushroom growing.

Policymakers and agricultural authorities did not have any particular preference of the business models. Their main criteria were preventing straw burning, improving the access to energy, especially for farm households, and supporting the development of a green economy. For this stakeholder group, similar to the rice farmers, wider benefits, beyond energy were highly relevant as this could address several problems at the same time. Additionally, many households in the case study region are linked to farming through direct or supply chain activities or employment opportunities. Introducing interventions that benefit the farming community could therefore provide benefits for the wider community.

3.3 Multi-criteria assessment and sustainability performance

Figures 7-9 present the results of the multi-criteria assessment (MCA) evaluating the sustainability performance of the different business models. The results are collated following the three sustainability pillars: environmental, economic, and social implications. The environmental implications (Figure 7) for all four business models are identical to the point of biogas production and therefore presented as one trajectory. The evaluation beyond the point of biogas production was outside the scope of this assessment as this would need to consider possible energy applications that would have been replaced by the bioenergy. At this stage of a pilot project such an assessment would have been subject to assumptions and high variations and uncertainties. As a baseline, the business models are compared to the current practices of straw burning and straw incorporation.

The main environmental benefit from biogas production is related to providing a renewable energy carrier that can replace fossil-based fuels and traditional solid biomass such as fuelwood and charcoal. Other environmental benefits relate to straw management as air pollution and emissions are avoided from straw burning and methane from decaying straw incorporated into flooded paddy fields. There can also be environmental benefits from straw digestate or compost when it replaces some of the mineral fertiliser during crop production. However, with the bioenergy system the transport, handling and storing of straw becomes necessary and emissions will be released during these activities. There can also be a risk of fugitive emissions form the biogas facility. Overall, biogas production is seen as environmentally beneficial, but there are also emissions from the system, which would need to be comprehensively identified and accounted for in a detailed lifecycle assessment, which is being undertaken.

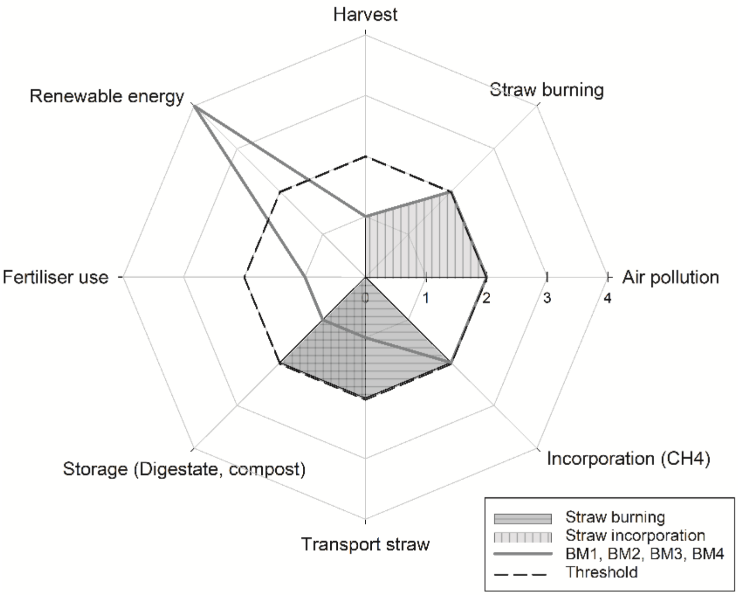

Figure 7 Environmental implications of business models. Trajectories based on relative scale 0 to 4; 0 being the most negative impact, 2 the threshold (neutral) and 4 the highest benefit. Shaded areas illustrate the impacts of straw burning (horizontal pattern) and incorporation (vertical pattern) with overlaps at some criteria (checked pattern). The black line presents the environmental impacts of the four biogas business models in one trajectory.

The economic implications (Figure 8) vary more significantly between the different business models and the current practices of straw burning and straw incorporation. The presented results focus on three main economic aspects: employment; cost and access/dependence on services. These aspects will affect different groups of people differently; therefore, the economic implications have been split into two graphs illustrating the farm household and the AD operator (Figure 8a, b). Current harvesting practices offer employment opportunities to a large number of people. During the interviews it was raised several times that this is ensuring a regular and important income for workers. While the on-farm employment might reduce with the introduction of mechanised harvesting, the biogas business model would provide new employment opportunities for example for straw collection, at the AD facility, or in mushroom production (farm or retail activities). The tangible costs related to current practices and the different business models may vary. While costs related to harvest activities might be similar for all options and cost for straw incorporation will reduce with the bioenergy business models, BM4 can create new costs and potential revenues for farm households from mushroom production and retail. BM4 would also bear a higher financial risk for the farm household as it would rely on services and loans to establish and run mushroom production or the franchise. From an AD operator perspective there are various costs related to labour, straw and product handling, transport, AD operations, and mushroom production. At the same time biogas, compost and mushrooms provide an income and a full economic assessment considering commercial scale would be necessary to evaluate if the system is profitable.

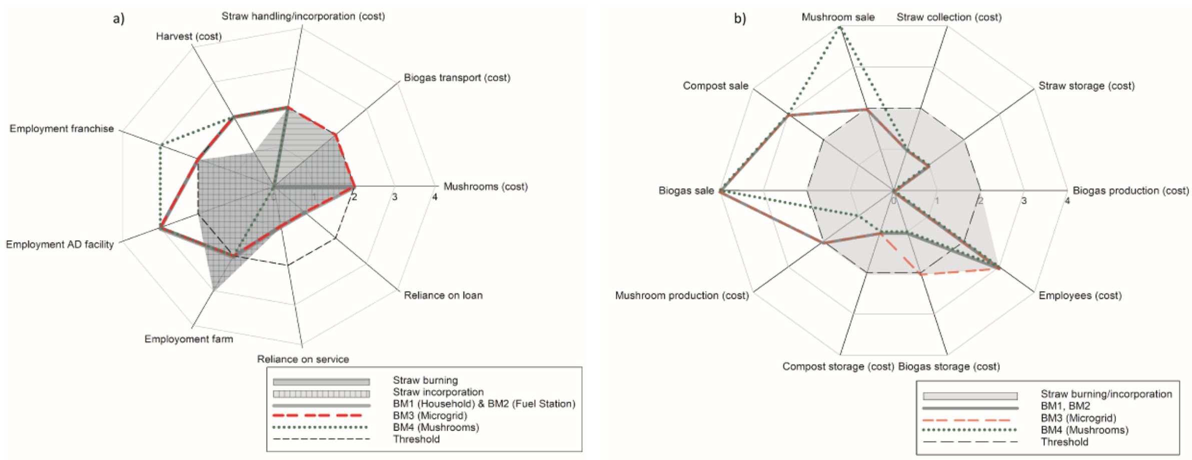

Figure 8 Economic implications of business models from a farmers' (a) and AD operators (b) perspective. Trajectories based on relative scale 0 to 4; 0 being the most negative impact, 2 the threshold (neutral) and 4 the highest benefit. Shaded areas illustrate the impacts of straw burning (a) horizontal pattern) and incorporation (a) vertical pattern) with overlaps in some criteria (a) checked pattern, b) grey area with no pattern). The different lines present the economic impacts of the four biogas business models. BM1 and 2 are represented as one trajectory (grey line).

While the environmental and economic implications indicate benefits and trade-offs for the bioenergy business models compared to the current practices, the MCA for the social implications indicates the bioenergy business models would create benefits or at least no negative impacts throughout the assessed criteria (Figure 9). All business models offer some form of improved energy access as well as the participation of the farming community with improvement and diversification of practices. However, an improvement of ownership, decision-making, and empowerment could not be proven as there were no obvious changes to these criteria at the level of a pilot-scale project. During the first set of research fieldwork, farmers emphasised that they would like to be part of a new technology intervention in their community that would help them with straw management and offered new opportunities. While monetary and material benefits through product and service return were viewed favourably, there was an even stronger interest in "being part" of the technology intervention and related activities and to have solutions for the "straw problem". During the second set of fieldwork farmers spoke about their participation in the project and expressed that they felt part of it as they would know and could see what happened to their straw. Some had the opportunity to test some of the biogas at home, recognised the employment opportunities at the pilot site, and highly valued testing and sharing of knowledge for mushroom production that was set up alongside the pilot site to test straw treatment before and after the digestion process. During the first set of interviews most farmers were interested in participating if the bioenergy system could offer solutions to straw burning. However, there were also sceptical voices from farmers about straw becoming a valuable feedstock for the biogas facility and that farmers should be paid for the straw collected from their fields. With the operation of the biogas facility, all interviewed farmers were in favour of providing the straw free of charge. This change of perception was mainly based on farmers seeing in practice how straw was removed from the fields, that this new form of straw utilisation reduced air pollution or cost for incorporation, that some farmers or family members had started working at the biogas facility, and that mushroom production training became freely available for the community.

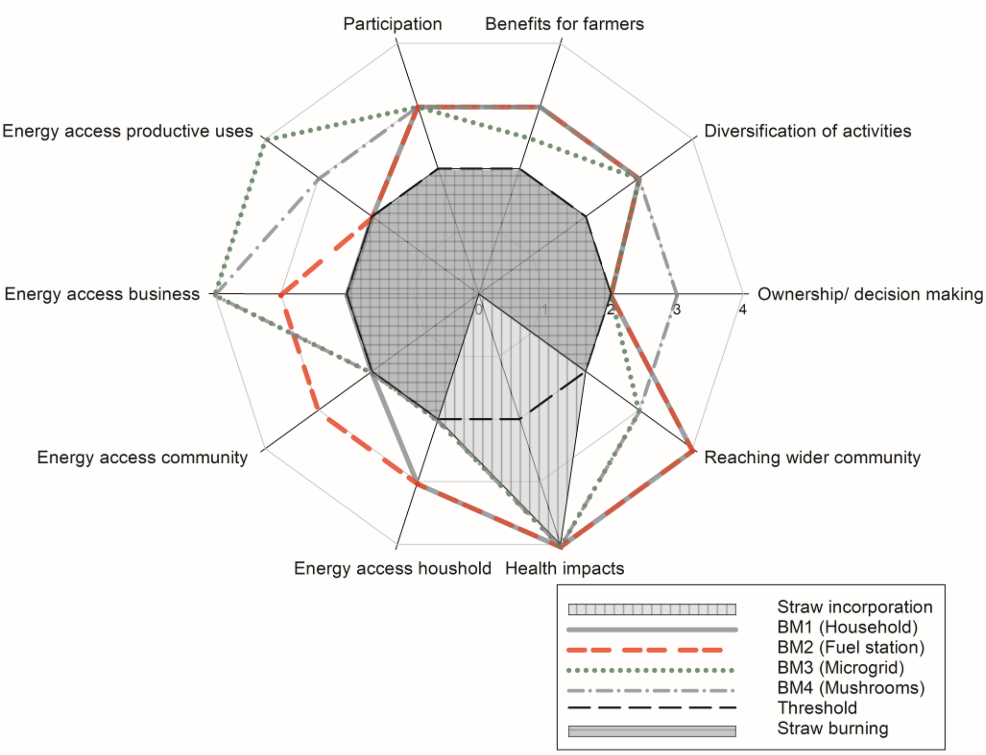

Figure 9 Social implications of business models. Trajectories based on relative scale 0 to 4; 0 being the most negative impact, 2 the threshold (neutral) and 4 the highest benefit. Shaded areas illustrate the impacts of straw burning (horizontal pattern) and incorporation (vertical pattern) with overlaps in some criteria (a) checked pattern). The different lines present the social impacts of the four biogas business models.

4 Discussion - Trade-offs and synergies of bioenergy business models and energy interventions

The objective of this research was to develop and assess business models that introduce bioenergy as a solution to improve access to energy, agricultural practices, and empower local rice farming communities. Improved access to affordable and renewable energy is understood as a key enabler for economic development [38-40]. In the context of bioenergy, domestic energy use for cooking is one of the most discussed topics in the development context. This is mainly due to the large share of traditional biofuels for domestic use, its negative impact on health and environment and a shift to modern and sustainable technologies [22]. However, within the context of this project the discussions with the farming community showed that there is a limited demand and perception for modern bioenergy approaches for cooking compared to other energy uses, co-benefits, and diversification of existing farming systems. This is partly a result of the relatively good energy access in the case study location, the potentially higher price of bioenergy compared to existing fuels like LPG, and the daily and livelihood activities of the interviewed farm households. While participants were aware of the need to replace existing solid and fossil fuels with renewable energy carriers to reduce climate change impacts, they also saw a higher need to support economic and income activities beyond energy use as well as providing energy in flexible ways for various uses. This became apparent in the discussion of the business models that offer a certain degree of flexibility and choices of how and when energy is used. This shows the importance of understanding energy as an enabler rather than a product, which has also been shown by others [38-41].

Figures 7-9 illustrate the trade-offs of the different criteria of the business models. Research by others [38, 42, 43] has shown that a change of one or more aspects of a system affects other aspects. This is also apparent for this research and relevant for decision-making and project planning. For example, with an environmental focus, a renewable energy intervention might improve energy access and provide a renewable energy carrier. Still, there will be other environmental implications that have not been there in the previous system like energy and fuel requirements for transport and plant operation. Research [43-45] has shown that different bioenergy applications and practices lead to different environmental impacts and that it is imperative to understand and evaluate emissions of the full supply chain with its allied activities and practices to ensure emission reductions are achieved. While the qualitative assessment indicates the environmental benefits of biogas, this is subject to assumptions and high uncertainties. In particular in a development context, it is important to consider that an energy intervention potentially increases energy supply and therefore the amount of related emissions. Nonetheless, it is also relevant to consider wider impacts like the possible reduction of air pollution from residue burning and traditional biomass use.

Similarly with economic and social trade-offs, farmers mentioned several times the importance of manual agricultural practices to provide employment. Even though bioenergy interventions may offer new opportunities, it is important to consider social dynamics and relationships: the introduction of the bioenergy system and more mechanised agricultural practices creates new employment opportunities for skilled workers and potentially physically less demanding work. Still, such interventions and changes will affect other aspects of the society and livelihoods as this might reduce the available workers for other activities, change relationships between individuals and groups, or alter expectations within a community. Research by others [41, 46-49] has shown how technology intervention and changes in practices can affect social dynamics, relationships and the importance of understanding how change will affect existing systems. It is also important to ensure that sufficient training and upskilling is provided for existing communities if they are to take advantage of opportunities.

The synergies between the three different sustainability pillars, environmental, economic, and social sustainability, are relevant for developing solutions for transforming energy access. Energy access interventions often aim to address the energy trilemma of environmental sustainability, energy security and affordability to support Sustainable Development Goal (SDG) 7 - Ensure access to affordable, reliable, sustainable, and modern energy for all [50]. Many have argued that modern bioenergy has been slow to be implemented to date because it does not fall into one specific policy area and needs to be addressed across departments: agriculture, food, land ownership and communities, waste disposal, energy, climate change, etc. Bioenergy, especially in the development context, is closely linked to agricultural systems and therefore to the livelihoods of rural communities. This requires consideration beyond just energy, involving the different aspects of the environment, economy, and society at the same time.

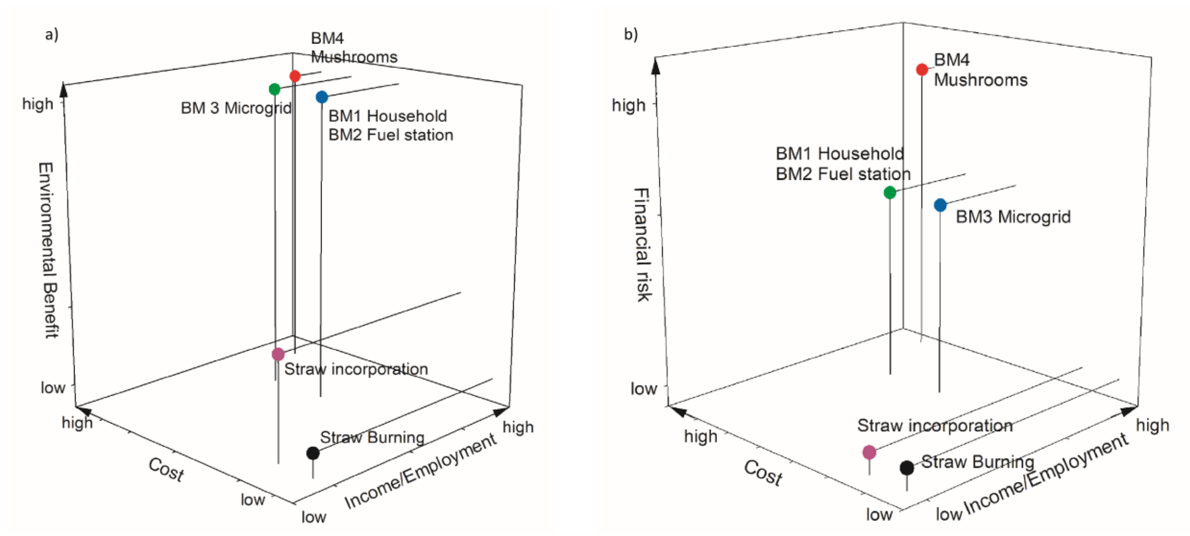

Figure 10 Synergies between the different sustainability categories of the four business models and two reference cases of rice straw burning and incorporation

Based on the empirical research of this project, Figure 10 illustrates the synergies between the different sustainability pillars of environment, economy (represented by the example of cost in Figure 10 a,b) and financial risk in Figure 10b), and society (represented by income/employment). The graphs show that the biogas business models compared to current practices offer improved environmental benefits and increased opportunities for skilled employment with higher incomes and diversified activities. However, the bioenergy business models also have higher costs than current practices, which is the most relevant for the AD operator and commercially oriented stakeholder. Even though there are income opportunities from biogas, compost, and mushrooms, there are also related capital and opportunity costs.

The bioenergy business models, and in particular BM4, would have a higher financial risk (Figure 10b) for the AD operator but also for the farm households starting to invest in and depend on mushroom production. This means BM4 offers the best income and employment opportunities, but is also the business model with the highest costs and financial risk. Most of the interviewed farmers were in favour of BM4 as it provides opportunities for diversification and additional income. Production of straw mushroom is not new to the Philippines, but requires an appropriate location and environment, energy and time for straw pre-treatment and knowledge and skills for spawning. Using the straw digestate would cut out some of the requirements for straw pre-treatment, but would still need investment for spawn, skills and knowledge of mushroom production, and a reliable market for the mushrooms with a shelf life of a day. Hence, to make BM4 work for poor farming households, measures would be needed to support farmers and reduce some of the costs and risks.

This project highlighted the cross-sectoral nature of bioenergy and the synergies between the different sustainability pillars. The main aim of the initiative was delivering energy access to poor people in rural communities, but a by-product was that it inspired entrepreneurs within that community to investigate new business activities around mushroom production and even production and local retailing of mushroom burgers. This goes beyond delivering the original project objective, supporting not just energy access but livelihoods within the community, delivering sustainable products that unlock trading opportunities all integrated with the low carbon energy provision. It could be argued that the energy access delivered by BM4 is potentially more resilient in the long term as it focuses on a more diversified market base and set of income streams that co-support the energy access objective. However, it also has a wider set of stakeholders than the other business models, so there is perhaps a greater risk that benefits may not be returned to the core participants in the community. Stakeholder network analysis might help yield some insights into which actors and links are key to improve the return of benefits and how resilient those benefit pathways can be to future change.

While BM4, with the right support mechanisms, would directly benefit individual farmers and their households; the interviewees pointed out that BM2 and BM3 would enable benefits for a wider group of community members. BM2 would offer a direct supply of different products from the biogas facility on the market. Depending on their assets, a larger group of community members could have direct access to these products and a discount scheme would provide access to products for poorer participating farmers. As Figure 9 has shown, there would be a lower direct energy access for farm households in BM3 (dotted trajectory) compared to BM1 and BM2 if the energy is used commercially. However, BM3 could provide indirect benefits through improved services for a large group of farmers, when used in rice processing and this is the business model with the lowest overall cost of the four bioenergy options.

Agricultural entrepreneurs and more commercially-oriented stakeholders indicated during the interviews that cost would be their main driver for AD operations or biogas use, while non-monetary co-benefits would be less relevant. As these are important stakeholders for the deployment and potentially investment in new technology and supply chains, it is important to provide evidence or approaches to understand the trade-offs and synergies of the intervention as this will also minimise the risk of failure not just in terms of cost but also community perception and acceptance of new products and services.

This shows the challenge of deploying sustainable energy systems, enabling benefits, and reducing risks while minimizing negative impacts. Understanding barriers as well as drivers, opportunities, and synergies clarifies, which community members will benefit and how.

Access to affordable and renewable energy is an enabler for economic development. Although this was the primary project focus, the discussions with farmers, community groups, and authorities showed that energy is not their central interest. There was a high awareness of the need for affordable and clean energy, but the main need of the community was to find solutions to stop the straw burning without creating new financial and labour burdens on farmers. Previous research has shown that bioenergy often provides opportunities and solutions beyond energy as it is closely linked to agricultural practices and livelihoods [38, 51, 52]. The limited direct demand of energy in this particular project site was also apparent in the business model discussion with the farmers and the wide support for BM4 because of the integrated mushroom production, diversification of activities and increased income. This raises the question of what other solutions might address that need. However, the results show that sustainable system integration can offer these and other benefits whilst at the same time supporting access to renewable energy. Nevertheless, the key to maximizing those benefits and minimizing negative impacts is to take a holistic approach to the business models and to their potential benefits and impacts. Focusing too narrowly on energy access alone is unlikely to realise the wider benefits: energy is linked to many other SDG's and aspects of life. In intervention programmes, it is important to recognise that support for wider activities can support energy access and vice versa.

It must be kept in mind that this research was part of a pilot project focussing on testing a new technology and investigating possible business models for the project location that offer sustainable solutions for energy access, straw management, and enable socio-economic benefits. Interviewees and participating farmers were highly engaged in the project and showed enthusiasm at all levels. Discussing and testing possible solutions with them allowed the project team to understand the community needs and which aspects are the most relevant for the community for potential solutions and business models. At the same time, the community was continuously informed about the progress and was offered practical engagement opportunities. While the pilot plant was set up and operated successfully, this required management of expectations in the community as the current project is a test facility and activities fully depend on public funding, therefore wider application is contingent on future commercialisation. Still, the project demonstrated that a people- and solution-centric approach can result in a change of practices and enable environmental and socio-economic benefits.

The layout of the fieldwork allowed a high-level observation of a change in community perception from the early stages in this project to the later work. Physical demonstration of the project in an appropriate setting with community involvement changed mind-sets from viewing rice straw as a difficult problem to solve, through to a greater appreciation of the concept of rice straw to biogas as a working solution. This yields another important learning point that physical demonstration in a positive, engaging manner is critical for the rapid deployment of low carbon and accessible energy systems. Providing capital funding to support demonstration facilities (which often need to be at scale but pre-commercial) is a critical component of creating a more positive environment for acceptance of modern bioenergy systems, which can support long term carbon reductions.

5 Conclusion

This work has shown that bioenergy can provide solutions for improving access to energy for agricultural practices and empowering local rice farming communities. However, to enable positive impacts, these solutions must be understood beyond energy and technology. The wider technical, environmental, socio-economic, and socio-cultural aspects play an important role, as well as the links and synergies between them. For this, a multi-level approach is required, recognising that support for wider activities can also enhance energy access, and that energy access can in turn be achieved in multiple ways beyond just technology.

The capital investment for a pilot facility at scale demonstrated that it is technically feasible to produce biogas from rice straw and solve environmental challenges. However, to transform energy use as well as agricultural practices sustainably, local communities need to be included in the development process as they are the suppliers, participants, and end users. Developing and assessing the business models together with the community, allowed technical and non-technical challenges to be identified from the start, along with barriers and needs for change. It also showed that providing context-specific and demand-driven solutions can lead to transformation and rapid change of practices. This study provides an evidence base of changes in perception through stakeholder engagement at different stages of the technology intervention and development of the business models. It shows how this approach supports transformational processes, generates trust, increases participation and inclusion, which in turn can bring long-term sustainability benefits for stakeholders. The project also showed that is does not necessarily need an optimised technical process or supply chain, if the intervention demonstrates potential benefits for the community and the local community is participating in the further development of the interventions to create wider benefits in line with the needs and demand of the community.

Acknowledgment

This research was funded by Innovate UK under the Energy Catalyst Round 4 programme (Project Reference: 102769) and the Engineering and Physical Sciences Research Council (EPSRC); Grant Ref: EP/P030874/2. The authors would like to thank all participating stakeholders who shared their expertise, knowledge, and views, in particular the rice farmers who provided invaluable input. A special thank-you to Yevgeny Honrade and Angeli Castalone for managing the fieldwork and providing local guidance and translation.

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