



Research paper

Barriers and opportunities to bioenergy transitions: An integrated, multi-level perspective analysis of biogas uptake in Bali

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ABSTRACT

Renewable energy is expected to gain a larger share in the Indonesian energy mix by 2025. Biogas has not only the potential to contribute significantly to the country's renewable energy targets by mid-century, but also to provide a series of co-benefits to improve wellbeing of vulnerable rural communities. The challenge is to find pathways for biogas to overcome well-established technologies and practices in the current heavily fossil fuel based energy system. This paper focused on household-level biogas development in Bali, Indonesia, critically analysing four domestic biogas programmes that are currently under implementation. For our analysis, we adopted an integrated approach combining the multi-level perspective framework with a system-mapping exercise. Moreover, a series of semi-structured interviews as well as an interactive workshop was conducted which allowed us to place multiple stakeholder perspectives and experiences at the heart of the analysis to look at factors beyond the micro-system of the technology, and understand the broader socio-institutional context. Our analysis of enabling and hindering factors to biogas expansion identified opportunities for improving the design and implementation of policy, finance and technology measures. These findings are relevant not only for the Indonesian context, but also for other developing countries that are increasingly investing in transitioning to low-carbon energy futures.

1. Introduction

Indonesia is both rich in fossil fuels and alternative energies, but only uses the former to its full potential. In 2014, the country was the world's largest coal and the seventh largest liquified natural gas (LNG) exporter [1]. Before the fall of oil prices, its fossil fuel based industry contributed to roughly 30% of government revenues [1] and made the country the 7th largest greenhouse gas emitter in the world [2]. On the other hand, studies estimate its geothermal potential at 24 GW and, thanks to the large agriculture sector, its biomass potential at 50 GW [3]. Energy policy in Indonesia pursues both strategies for climate change mitigation and fossil fuel development in parallel. Indonesia pledged 26% emissions reductions by 2020 as signatory to the Paris Agreement and has a 23% renewable energy (RES) target for 2025, while its National Energy Plan (NEP 14) aims to simultaneously increase coal fired power from 26% in 2011 to 30% by the same date [3]. Against this backdrop, our paper analyses barriers and opportunities

concerning the uptake of one promising bioenergy alternative in Indonesia: biogas. This technology, based on anaerobic digestion of animal and agricultural waste products in a digester, is a well-established technology, which could contribute in several ways to Indonesia's development plans. First, biogas could help to reduce waste and greenhouse gas emissions [4,5]. Second, biogas can offer several co-benefits to adopting households such as additional revenue streams when marketing by-products, savings on energy expenditure to alleviate energy poverty, and reduced indoor air pollution, which according to World Bank estimates caused around 45,000 premature deaths in Indonesia in 2012 [6].

Although several studies have looked at barriers and opportunities for biogas adoption in developing countries, they tended to focus only on a specific dimension of the transition: household factors such as size or age affecting adoption [7,8], socio-economic constraints to adoption [9], the balance of greenhouse gas emissions [10], the effect on the farm economy or impact on adopters [11–13], or on one specific

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domestic biogas programme across different countries [14].

Our research differs from these studies in that we adopted an integrated approach, which included not only the analysis of factors affecting household adoption from the perspective of the users and potential adopters, but also of the broader factors influencing the transition from the perspective of policy-makers and the business sector. This approach was informed by the multi-level perspective (MLP) theory [15] aiming at understanding not only the niche, but also the regime and landscape dynamics. To empirically apply the MLP, we used a system mapping exercise [16] which helped us build on a participatory approach to look beyond the micro-system of the technology. Moreover, an interactive workshop in Bali as well as extensive stakeholder consultations helped to inform our study from a local perspective, placing stakeholder experiences and their perception at the heart of our analysis, allowing us to understand the broader socio-institutional context. As a result, our findings lead to specific recommendations taking into consideration perspectives on policy, technology and user behaviour that can inform a sustainable transition towards more low-carbon futures in Indonesia from the bottom up. In addition, we decided to focus not only on one domestic biogas programme, but instead to compare four biogas programmes operating in Indonesia with the aim to uncover lessons learnt and best practice examples from the different programmes.

Our focus is on the province of Bali where biogas has been promoted by different domestic programmes, each one driven by different institutions and influenced by several socio-institutional factors. Bali is also one of the rural areas in Indonesia with the highest potential for biogas production because of the large availability of livestock manure that can be used as potential feedstock.

2. Approach & methods

2.1. Conceptual framework

The combination of the multi-level perspective (MLP) framework [15,17] and the system mapping approach (SM, also referred to as ‘market mapping’ [16]) allowed us to analyse household biogas technologies from both the micro and the macro perspective of its wider socio-institutional context. The MLP is a theoretical framework which uses three analytical levels (Fig. 1). The first level is the ‘niche’ where ‘radical innovation’ is pursued [15] and where actors form networks and create common visions of how new technologies should develop [17]. Niches may emerge without coordination amongst networks of actors [18], or they may be actively protected, for instance, by government through policy support mechanisms [19]. In both instances, they may lack well-established norms and practices. Those well-established norms, practices and rules as well as a fully developed market for a specific technology are to be found at the ‘regime’ level, which presents the current status of a socio-technological system [17,20]. Although the definition of boundaries remains inconsistent in the literature [21] the understanding of the regime as a self-stabilising, inert system [21] with vested associated interests promoting its stability [22] is broadly held and is reminiscent of Indonesia's dominant fossil fuel sector. It is against this well-established fossil fuel system, with all its infrastructure, its political as well as private sector support and its public acceptance, that renewable forms of energy like biogas installations must compete. In the MLP framework, both niche and regime dynamics are influenced by the ‘wider context’ of the socio-technical ‘landscape’, which can be understood as the broadest level of organisation and trends, including demographical trends, political ideologies or macro-economic patterns, amongst other delineations [17].

The interplay between the three MLP levels is highly dynamic and technological transitions depend on windows of opportunity that stem from this interaction [15]. For instance, regime rules and practices may change, allowing for niches to become part of the regime or for niches to transform the regime and contribute to a new stability under

different circumstances (Fig. 1), i.e. a new socio-technical regime [23]. In this study, we are particularly interested in identifying factors that would enable and hinder this transition to a new socio-technical regime. However, it may also be the case that regimes are able to withstand pressures from the niche thus resisting change and maintaining the current state [22].

To complement our analysis and to mitigate the aforementioned problematic delineation of boundaries between the niche, regime and landscape levels of the MLP framework, our conceptual framework combined the MLP with the SM approach (Fig. 1), a tool for visualising and discussing the actors and factors influencing the enabling environment in which any given technology market chain (or value-chain) operates [16]. In our application, the tool represented the market chain of bio digester technology influenced by two inter-linked environments, namely the ‘policy environment’ (including actors developing decisions, policies and regulations, which can be part of the landscape and the regime) and the ‘business environment’ (including service providers, which can be part of the regime and the niche). The tool helped to place processes and actors within those environments, wherein interactions between processes and actors such as flows of information or flows of money were represented. This structured approach allowed us to identify and analyse barriers to and opportunities for biogas development in Bali in a systematic manner. These two theoretical approaches were combined with a series of interactive stakeholder consultations in Bali in 2016 (see 2.3.)

2.2. Case study description

As well as a popular tourist destination, Bali is an agricultural island where pockets of poverty exist and access to energy is not evenly distributed. About 528,000 people in the island are employed in the agriculture, fishery and forestry sector [24]. Biogas thus could help Balinese rural communities in several ways, starting from waste treatment and facilitating energy access to offering new economic and social opportunities.

Four household-level biogas programmes were operational in Bali at the time of the study (Table A1). While the technology used was similar, the programmes were managed by different entities and had their own unique features. All four programmes used concrete or fibre fixed-dome installations with a volume of between 2.5 and 11 m³ and the feedstock was pig, chicken or cow manure. The biogas generated by the digesters was used for cooking (one cookstove) and lighting (one lamp), which is the pathway investigated in-depth in this paper. Table A1 in Annex 1 describes the different programmes in more detail. The SIMANTRI programme, which was an integrated farming initiative launched by the provincial government under the ‘Bali Green and Clean’ programme¹, was introduced in 2009 to promote sustainable economic development and environmental protection, including zero waste practices from cattle farming. Biogas was included in this programme to deal with manure, rather than to fulfill cooking fuel needs, thus being different in motivation from the three other biogas programmes operating in Bali. The Indonesian Domestic Biogas Programme called ‘Biogas Rumah’ (BIRU) was also introduced in 2009 with the support from the Netherlands Embassy and two non-governmental organisations (NGOs), HIVOS and SNV. The BIRU programme used a market-based approach, including carbon credits, to promote the development and adoption of biogas technology as a way to reduce emissions. The second national programme was funded by the Ministry of Energy and Mineral Resources (MEMR) and implemented by provincial public works agencies in several provinces, including Bali. This national programme, which we refer to as the Public Works programme, was introduced to Bali in 2015. The third national programme, funded by the Ministry of

¹ <http://balicleanandgreen.blogspot.co.uk/2011/05/bali-clean-and-green-province-program.html>.

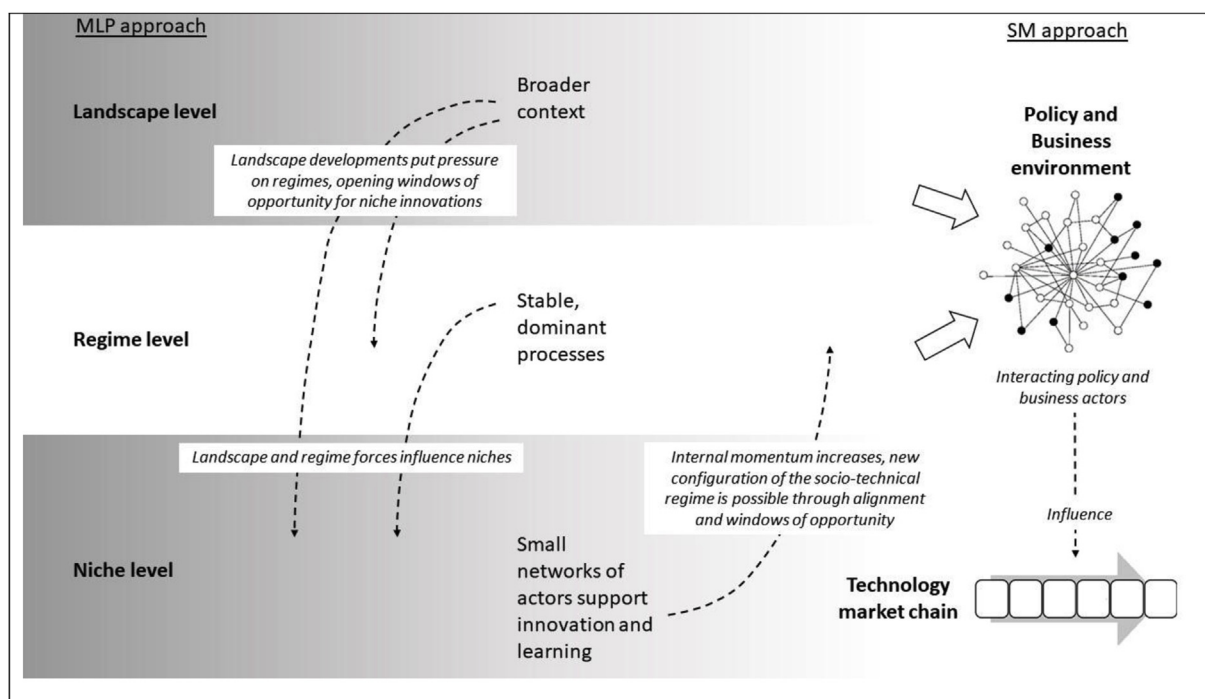


Fig. 1. Different levels of analysis included in the multi-level perspective (MLP) framework (adapted from Geels 2011) and the system mapping (SM) approach we used in this study.

Environment and Forestry and launched in 2013, provided biogas to farmers around the West Bali National Park as an alternative to reduce illegal deforestation and land-based emission of greenhouse gases. Thus, initial motivations of the four programmes range from waste treatment (SIMANTRI) to discouraging deforestation and greenhouse gas emissions.

2.3. Field methods

Our primary research approach was to place stakeholders of the biogas value chain at the centre of our analysis, thus complementing the prevailing research of household biogas in the literature with a user-centred approach, where stakeholders are given a voice to share their experiences. Three sets of stakeholder consultations were carried out, engaging a wide range of regional and national representatives from sectors such as policy, business, civil society and academia. Informed consent was obtained by all participants and consulted stakeholders. The first consultation was an interactive workshop with 68 participants in May 2016. Several group exercises² were conducted where participants discussed benefits, opportunities and barriers to biogas developments in Bali. The second consultation involved 20 semi-structured interviews that were carried out in Bali (Jembrana province) and Jakarta between October 2016 and November 2016, including a variety of stakeholders from different backgrounds.³

The semi-structured interviews included questions to: (1) identify stakeholders considered relevant to the biogas transition in Bali, (2) develop a biogas system map, (3) gather information on prevailing policies and strategies supporting biogas, (4) collect views on social acceptance, interests and expectations associated with the technology, (5) identify barriers and opportunities for the biogas technology development and use, and (6) understand the outcomes or transformations observed with the adoption of biogas technology. Interview

guidelines and templates tailored to each type of actor were prepared in advance to guide the interviewers and translators supporting the fieldwork. Interview responses were recorded and transcribed and, for those in Bahasa Indonesia or Balinese, were also translated and summarised in English for subsequent analysis.

The third consultation involved a focus group discussion in November 2016 with the aim (1) to validate the list of actors relevant to the biogas technological system, and their role in supporting the transition, and (2) to validate and develop the biogas system map using a participatory SM exercise. A total of 12 participants were engaged representing the different sectors and selected based on their knowledge of or their prominent position in the biogas system map. When referencing our interview sources throughout the following sections, we use the attributed code for each stakeholder listed in Table 2 in the Annex. We also indicate if information stems either from the workshop (WS) or the focus group (FG) discussion.

3. Results

The four biogas programmes deployed in Bali were complex and involved a variety of components and actors. Some actors are an integral part of the biogas value chain, while others influence it either through policy or business relationships (Fig. 2). The biogas system map for each programme is similar, with some variations in the market chain related to biogas processing steps as well as the programmes' sources and uses of financial resources. The combined system map for all four programmes in Fig. 2 was developed by the authors based on input from stakeholders during consultations. Arrows link the components across the market chain and the policy and business environments. The legend shows the meaning of different shapes used for the components in the system map, including process steps, actors, inputs, outputs and the direct and indirect flows between them. Coloured arrows are used to distinguish the financial flows related to the four biogas programmes in Bali.

It is important to note that 'environments' included in Fig. 2 are not necessarily separated from each other but instead they form a comprehensive whole. Actors situated in one environment might transcend

² Those exercises included: H-form exercise, a back-casting exercise as well as a value chain assessment.

³ A complete list of all stakeholders can be found in table 2 in the Annex.

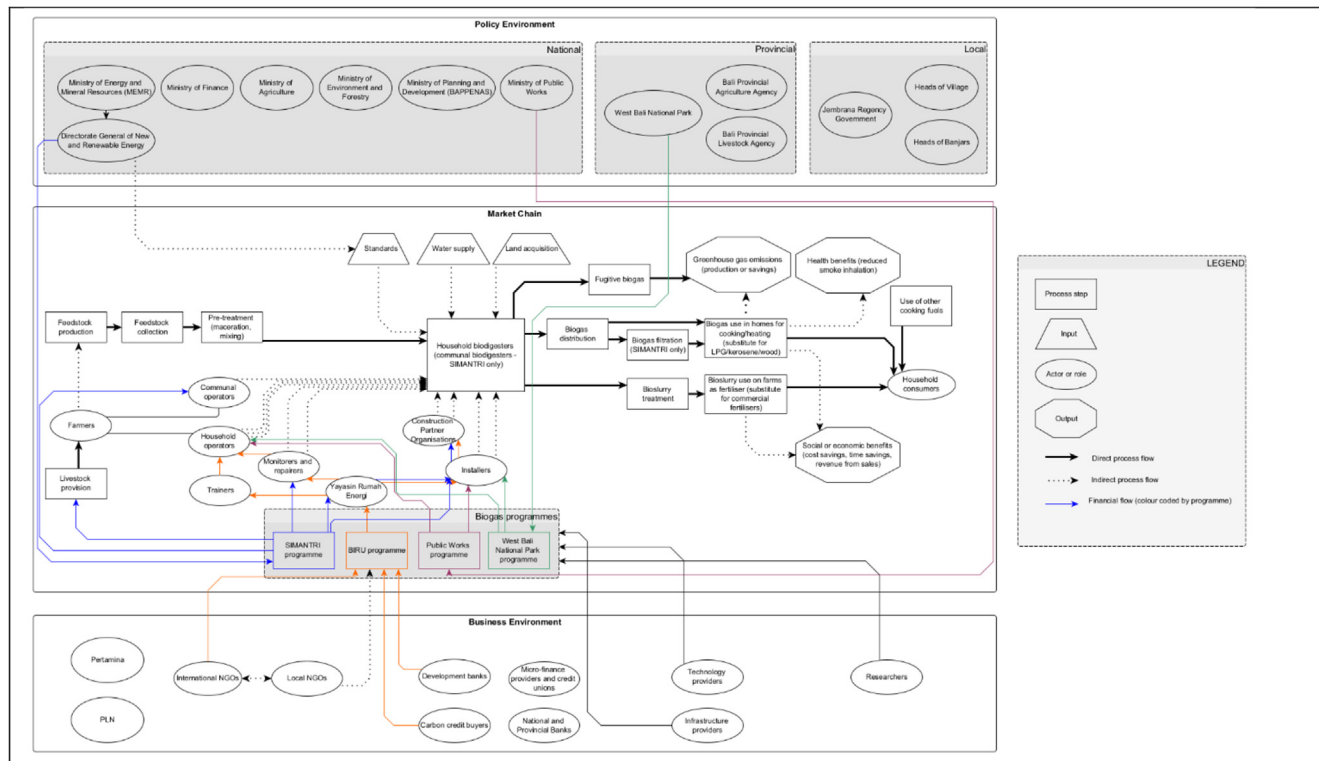


Fig. 2. Map showing the biogas technology market system in Bali, Indonesia. Colours indicate the financial flows of each of the four biogas programmes operating in Bali: SIMANTRI (blue), BIRU (orange), Public Works (purple), West Bali National Park (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

these boundaries depending on the role they play in the market chain. In a similar vein, barriers and opportunities tend to involve multiple actors and components across environments. For the sake of clarity, barriers and opportunities are nevertheless discussed following this three way structure.

3.1. Policy environment: barriers and opportunities

3.1.1. Barriers

A barrier identified by stakeholders in the policy environment was the complex bureaucratic governance structure in Indonesia. Indeed, government authority is decentralised and the country is administered by more than 77,000 sub-national government units [24]. While this decentralised system of governance helped facilitate a relatively peaceful transition to democracy in 1998 [25], it also facilitated rent-seeking behaviour and embezzlement of state funds by local power brokers [26], and brought uncertainty about policy authority between the local, regional and national levels [27]. These factors have also hindered the efficient administration of a biogas programme. We provide some examples below.

At the national level, a barrier identified was the misalignment of policies [28,29] since policies exist to boost both renewables and new coal power plants [30] thus strengthening the fossil fuel regime. Moreover, a stakeholder of the national government made the priorities of the Indonesian government clear: “The priority for the country is not to reduce greenhouse gas emissions, our priority is development.” [31]. The dominance of the fossil fuel regime is also manifested as another barrier, namely the prevalence of fossil fuel subsidies, while funding for renewable energy programmes has reportedly decreased [32]. Fossil fuel subsidies are discussed in Section 3.2.3 on the business environment.

At the regional level, processing applications for biogas installations was reported as being too lengthy and bureaucratic by stakeholders, mainly because they need to be reviewed and approved at several levels of

government [29,33]. This observation was corroborated by literature studying permits required for renewable energy installations [34]. The inefficiency was particularly pervasive in government-led biogas programmes, where permits usually have to be submitted first at regency level, and then again at regional level. The process was more streamlined in the BIRU programme.

At the community level, we noticed that sometimes funding support for biogas installations does not go to the best-suited candidates to manage the technology (e.g. based on selection criteria used by the programmes, such as available feedstock, past experience, etc.). Instead, candidates were sometimes selected because they were family members and people connected to the local power brokers. Corruption was therefore repeatedly identified by consulted stakeholders as a barrier in the policy environment [29,36,37].

The lengthy bureaucratic process to obtain biogas installations, and the associated nepotism, go hand in hand with poor communication between policy stakeholders. For example, one representative of a regional government unit admitted to not knowing the role of the National Energy Council in relation to biogas policy and planning [38,39] while other stakeholders described a lack of communication and a knowledge gap between government agencies [36].

3.1.2. Opportunities

Indonesia already has several climate mitigation policies in place which either aim at reducing emissions or increasing the share of renewable energy sources (RES) such as the National Energy Plan 2014 and specific Feed-in Tariffs (FiTs) for renewables. Those policies and support instruments present a rather solid basis for further action since RES targets and long term plans offer important political and market signals and indicate a potential medium- and long-term trajectory to stakeholders [40,41].

Existing policies within the renewable energy political framework could be improved. For instance, many stakeholders argued that a specific biogas target might help to incentivise private sector

stakeholders to invest in the technology and to increase the penetration and out-scaling of existing (and future) biogas programmes [42]. When it comes to support instruments such as FiTs, stakeholders suggested that there was a lack of transparency as renewable energy producers were required to negotiate with dominant state-owned electricity distributor PLN on a case by case basis, which discourages investment [29,32]. While household-level biogas technology does not necessarily require FiTs, strengthening transparency and reducing the negotiating power of state-owned companies via policies could create a RES-friendly environment which might spill-over into the bio digester market chain.

From a policy perspective, there is also an opportunity if the decentralised structure of Indonesian governance is seen not as a weakness, but as a strength. Regional governance units have significant policy making and budgetary powers [43]. For instance, the regional infrastructure development agency BAPPEDA could source financing for its regional development allocation plan (APBD) from local taxes and levies. This might open windows of opportunity for a regional “policy entrepreneur” to implement ambitious biogas support policies. One example is the current governor of Bali, who was the main driving force behind the SIMANTRI integrated farming programme. Here, the regional level presented an opportunity to go beyond national policies by adopting programmes that were tailored to regional contexts. However, several barriers along the value chain need to be overcome first.

3.2. Market chain: barriers and opportunities

3.2.1. Barriers

The first barrier we identified related to the feedstock collection and pre-treatment phase. BIRU stated that daily manure of two cows (or seven pigs) would be enough to ensure operation of their 4 m³ digesters and satisfy a household's daily cooking needs [44], a figure roughly in line with the literature [45,46]. However, stakeholders reported that it was difficult and time consuming to maintain a continuous flow of animal manure to feed the digester and maintain steady biogas production by anaerobic digestion. As a consequence, several stakeholders reported quantities of biogas insufficient to satisfy their cooking needs [33,47], with one stakeholder arguing that this was due to a lack of proper training given to the adopters [39].

Biogas distribution also proved to be problematic, particularly in SIMANTRI installations since this programme used communal digesters for the usage of many parties without adapting the size of the tank and without providing for storage or distribution solutions such as pipelines [33,48] although experimental storage in bags was explored, but inefficient in application. As a result, biogas generated by bio digesters in the SIMANTRI program was not used for household cooking, except for heating coffee during farmer group meetings [33]. In the same vein, the technology did not always seem to be well-adapted to user needs or the climate in Bali. Alternating wet and dry weather conditions led to cracks in the concrete dome of digesters in some households we visited. Moreover, we observed users venting the biogas valve to release pressure in the digester in cases where more gas was produced than could be used (i.e. in the SIMANTRI case where gas was not used for daily cooking). As a result, methane (CH₄), a potent greenhouse gas, was released into the atmosphere with studies suggesting that small methane leakages from faulty or improperly operating digesters could offset potential emission savings depending on geographical conditions, technology used, and fossil fuel source initially replaced by biogas [10].

In addition, there were potential health risks associated with high concentrations of hydrogen sulphites in biogas, which according to researchers we interviewed from Udayana University should be filtered to prevent the danger of inhalation [39]. The SIMANTRI programme had installed gas filters to more than half of their digesters, and they had the intention to cover all of their units. However, for the time being, this comes at a cost premium of up to 10% of the digester price

(see Table A1 in the Annex), although cooperation with universities is underway to help bring costs further down [39]. The biogas units of other programmes did not include gas filters and few adopting farmers seemed to be aware of this risk [33].

Many of the above technical difficulties can be attributed to poor information flows between biogas programmes and adopters and to a lack of training and capacity among operators and installers of biogas systems. Many adopters reported that they were neither properly informed about the benefits and the functioning of biogas digesters [39] nor properly trained on how to use and maintain the installations [49,50]. The literature identifies this lack of information as a main barrier to successful biogas adoption [51]. Furthermore, some stakeholders felt that the biogas programmes were implemented in a very top-down manner without prior consultation about local needs and interests [50,52], which often led to poor technology application and social acceptance of this technology.

Related to this lack of information and training, the absence of a comprehensive monitoring system of the biodigester performance constituted another barrier. Most government-supported programmes only offered a three-month monitoring period after installation, and usually data collection about performance was patchy. The BIRU programme included a longer-term monitoring system with a guarantee period of three years that involved maintenance of the biodigesters.

All of these shortcomings have led some adopters to supplement their cooking needs with conventional fire wood or LPG or not to use the digesters at all [44,47]. One stakeholder even argued that of all government-supported programmes, 60% would not work properly [38], a figure corroborated by a second stakeholder [50,53]. Not surprisingly, under-utilised and malfunctioning bio digesters sowed doubt amongst the farmers about technology's viability and usefulness. However, lessons learnt from the BIRU biogas programme clearly show the opportunities of well-designed biogas programmes.

3.2.2. Opportunities

Some technical barriers in the market chain might be easier to address than others. For example, one biogas adopter solved the manure availability and time-demand problem by keeping his animals in a stable, which improved the collection of the manure and therefore the steady feed of the bio digester. With regards to the digesters themselves and their resilience to local climate conditions, local NGOs and researchers were experimenting with other materials to build digesters such as PVC, promising significantly lower installation and maintenance costs.⁴

Besides those technical solutions, using inter-communal learning and capacity building might be a good way forward to spread information and awareness about biodigester technology in addition to government-led information campaigns. As argued by a community leader [52], farmers who have successfully adopted the biodigester technology could strengthen cooperation and learning even between villages, and facilitate a spread of the technology. This seems to be particularly appropriate in the Balinese context given the importance of communal management of resources, manifest for example in the rice paddy irrigation and cultural system *subak* [54].

However, the most salient opportunity might be in identifying ways to better exploit the market system where biogas is only one of several benefits. For many farmers, a major motivation to adopt the technology was the bio urine and bio slurry by-products from digesters which could be sold for additional revenues which might be an important co-benefit in Bali where many farmers still live in poverty [50]. Bio slurry was already marketed, albeit at a very small scale, with support from a local NGO [50] and strengthening this marketing activity could be a promising opportunity.

Using biogas and bio slurry can also have a positive impact on

⁴ <https://su-re.co/coffee/>.

household budgets by replacing expenses for fossil fuel energy such as LPG in the case of biogas or chemical fertiliser in case of bio slurry. This has been already proven by studies [5,13] while Balinese stakeholders confirmed the savings potential on household expenses from biogas usage [49,55]. After installing a bio digester, one household reported a drop of their daily expenditure for LPG by 50% thus saving the family around IDR 40,000 (\$3) per month [49]. With a farmer earning on average 1,000,000 IDR – 1,500,000 (or \$70 - \$105) per month in Bali [56], this is a non-negligible factor, a finding in line with other case studies where biogas uptake increased disposable household income [57].

Besides monetary benefits, other tangible opportunities may materialise as well. For instance, firewood used for cooking is primarily collected by women who spend up to 2 h per day performing this laborious task [58]. With less time spent on gathering firewood when using biogas, several stakeholders observed that this additional spare time was used for additional economic, social or even cultural activities [42,47]. In addition, using less fossil fuels to satisfy energy needs and using less chemical products to fertilise the land have environmental as well as health benefits, although measuring those benefits in exact numbers is a complex task [57].

3.3. Business environment: barriers and opportunities

3.3.1. Barriers

We found several barriers affecting the business environment. At the regime level, we found that the fossil fuel based energy system represented a main barrier for biogas development at the household level, particularly from a business perspective. State-owned companies such as oil and gas major PT Pertamina have a large market share of producing, distributing and selling fossil fuels [1] and from a systems perspective, those companies' dominance (and their pricing power) makes it difficult for small and independent bioenergy companies to compete [32,59]. In addition, fossil fuels such as LPG and electricity remain heavily subsidised, despite recent reforms carried out concerning diesel and gasoline subsidies [60]. In 2015, IDR 73.1 trillion (roughly \$5.4 billion in 2015 US dollars) was still paid in electricity subsidies and IDR 23.6 trillion (around \$1.7 billion) in LPG subsidies [60]. Many stakeholders including farmers [49,61], identified those subsidies as major challenges to successful biogas business and uptake [32,58].

But not only the regime harbours barriers, the niche level does as well. Many stakeholders criticised the lack of warranties and maintenance service of biogas programmes such as SIMANTRI [33,47]. Qualified technicians for maintaining the biogas units are few or sometimes not able to work on installations from other programmes for contractual reasons [35]. Moreover, there is no standardised certification programme for technicians, thus quality could not always be assured [62]. This lack of maintenance and repair capacity put a further strain on the viability of different biogas programmes.

Another barrier affecting the business environment concerned mainly the financial aspect, a problem which essentially transcends from the business- into the policy environment. At the time of writing, there were no specific lending policies in place to support Balinese biogas installations, despite the fact that state-owned banks control 38% of the banking market (incl. the country's biggest banks) [64]. This shortcoming was often considered a serious barrier by stakeholders [29,42,53,65] and has been identified to hinder biogas adoption in the literature [13], particularly since costs for a bio digester are still far beyond the reach of an average farmer. Digesters such as those used by the BIRU programme cost between IDR 6,000,000 and IDR 8,000,000⁵

⁵ Indications of costs varied with one stakeholder even claiming that BIRU digesters would cost US \$800. However, this value might be due to currency fluctuation and IDR 6,000,000–8,000,000 might be the more robust estimate.

[42,49] and an average farmer earned not more than \$1,500,000 IDR per month. In addition, banks are reluctant to lend to farmers since land tenure rights are unclear and farmers sometimes would lack collateral for banks in case of default on debt owed [38,53].

3.3.2. Opportunities

For technology providers, biogas programmes can be a viable business opportunity. One lesson learnt from the reportedly successful BIRU programme is that having adopters co-finance biogas installations improves the maintenance and thus longevity of the digesters. Farmers who participate in financing installations not only provide revenues for stakeholders installing the digesters but also see the biodigester technology as investment in their future. This is in line with findings of other studies, where co-financed biogas has been implemented rather than purely donor-based asset provision models that have failed in many contexts [66]. The introduction of this co-financing element might therefore be an opportunity for technology providers which could access additional revenue streams (and make use of a more market-based approach) instead of being dependent solely on government subsidies.

In addition to a participatory finance approach, the BIRU programme showed an extensive support system of monitoring, training and maintenance activities which was not found to this extent in the other biogas programmes. A three-year warranty period is provided while certified technicians educate adopters about maintenance issues, but also provide for repair services should adopters be unable to fix the problem themselves. This service is mainly provided for by Yayasan Rumah Energi (YRE), a NGO founded by the BIRU programmes co-financier HIVOS which has created additional jobs on Bali and beyond. While a detailed assessment of the employment potential of the programme went beyond our research, it is noteworthy that YRE plans to make this project a viable business model and envisions a break-even point at around 100,000 digesters installed nation-wide. Indeed, internal studies by YRE argue for a theoretical potential of 2 million biodigester units in the whole of Indonesia [42] which could likely create new jobs around those biogas systems.

4. Discussion

4.1. Seizing policy opportunities

The first policy recommendation is the adoption of a specific biogas target, which would help provide security among stakeholders, particularly investors, of a political will to support biogas development in the longer term. A biogas target could be enacted on the national level, or, if consensus does not emerge, on the regional and provincial levels using the decentralised governance system as an asset.

However, to facilitate the out-scaling of biogas technology, additional educational and training policies might be necessary which address the lack of knowledge about the technology's benefits and its maintenance requirements or which communicate the environmental, social and economic potential of biogas. Having those policies in place is likely to help wider adoption.

To further support biogas development, a biogas standards and certification regulation could be introduced at the national or provincial level. Such certification could improve the quality of biogas technology and increase consumer satisfaction thus boosting demand for the technology [66].

A further major issue which could be addressed with sound complementary policies is the lack of lending and financing opportunities for potential biogas adopters [13,67]. Tailor-made micro-credit lending policies for small-scale household biogas adopters could be made available to address the lack of access to finance for biodigester technology adopters. YRE has already begun working with stakeholders from the national government to design lending policies adapted to the needs of the farming community, an initiative which could be built

upon.

The niche-supporting policies recommended above might be reinforced with some measures that would make the fossil fuel-based regime more accommodating to niche technologies such as a fossil fuel subsidy reform, already tentatively under way [60] in order to level the playing field between fossil fuel and renewable energies.

4.2. Seizing market opportunities and making the technology fit for purpose

Several improvements could be made along the biogas value chain. First, size and building materials for digester construction should match user needs and strike a balance between digester size and feedstock availability. For instance, 4 m³ digesters proved insufficient to satisfy demand beyond single household size. Second, a continuous feed of manure (100–150 kg per day, depending on the livestock [45,46]) to ensure digester functioning could be facilitated by having animals in a stable, rather than relying on disbursed feedstock collection. Third, filtration should be installed on digesters to prevent health and safety issues associated with hydrogen sulphites that can be present in biogas, an area of ongoing research at local universities [39]. Finally, distribution or storage problems should be addressed to compensate for over- and underproduction as should the risk of fugitive methane, which has a significant environmental effect. If biogas installations are to be used, they need to respond to or fit with user needs and behaviour, not the other way around.

Training to build capacity amongst adopters could improve functioning of the digesters in order to seize their full potential. At the same time, training could be provided to third-party operators with the aim of building a functioning network of maintenance and monitoring services. This is particularly important to mitigate the emissions potential of faulty and improperly operated digesters [11]. Here, networks between all stakeholders should be supported to facilitate inter-community learning and the exchange of best-practice examples. Some co-operation already exist (e.g. SIMANTRI cooperates with local universities), but enlarging the circle and ensuring regular exchange between parties might further increase trust between stakeholders and in the technology.

Once these improvements concerning the biodigester technology and its maintenance have been made, the following steps to harness the full economic potential of the biogas system could be taken.

First, out-scaling the usage of the technology would significantly increase the economic viability of the whole system in Bali since creating a sufficiently large market would facilitate technology learning, economies of scale, long-term stability and therefore a more robust value chain. One example would be to collaborate closely with the tourism industry and create sustainable waste management solutions in an Island cherished by foreign tourists and harbouring significant eco-tourism potential [68,69]. Second, taking advantage of by-products from digesters, including bio slurry, bio urine or bio fertiliser would add value. Our stakeholder consultations revealed that many adopters of biogas were particularly fond of these by-products but marketing of those products remained tentative, and informal. Professionalising this secondary value chain might in turn strengthen the biogas value chain, if farmers can be sure to find markets for their bio slurry or bio fertiliser. Third, taking advantage of the time saved when using biogas compared to traditional biomass such as firewood for

cultural, social or business activities [42,47] might increase the attractiveness of the technology.

Only a comprehensive biogas system improving economic, environmental and societal parameters for adopters will make biogas attractive and fit for purpose. But seizing the full potential of such a well-established system requires an increased collaboration effort by all stakeholders.

5. Next steps

Overall, results showed that biogas is a promising technology in Indonesia. Biogas could increase its positive impacts if 1) the technology is best adapted to user needs and its market chain fully functional from feedstock collection to monitoring and maintenance and if 2) policy and business strategies are designed to harness co-benefits, such as energy savings (from LPG substitution), generation of additional income (through bio slurry and bio fertiliser markets), and/or time savings (less/no collection of firewood). Without a well-functioning value chain and these co-benefits, it is unlikely that more farmers will independently adopt biogas, given the slow return of investment and the high price of digesters.

It is therefore of utmost importance that all stakeholders from all environments (policy, business, market chain) collaborate in a constructive manner to create a well-functioning network. Technological shortcomings should be addressed and the right supportive policies should be in place in order to facilitate the emergence of a viable business model.

In addition, biogas adoption would greatly benefit from further, stakeholder-centred research. Several areas remain to be explored. The economic benefits and impacts on employment and welfare could be explored as well as the environmental benefits in actual saved emissions. Technological issues such as reducing leakage of methane, sulphates and the storing of gas would merit further attention and quantity and quality requirements of feedstock to scale the technology for electricity generation might be investigated. Finally, socio-cultural studies might further our understanding of how learning networks and knowledge exchange might be strengthened in rural communities willing to adopt biogas technologies.

Declaration of interest

None.

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Annex 1. Description of 2009–2016 biogas programmes in Bali, Indonesia

Table A1

⁶ 01.Pri_YRE; data gathered from our extensive stakeholder consultation are sourced using specific stakeholder identification codes to guarantee anonymity; see methods section.

The four biogas programmes in Bali, Indonesia.

	SIMANTRI	Public Works	BIRU	West Bali National Park
Introduction Description	2009 Integrated farming, biogas component included a year after introduction. Communal digesters installed for farmer associations, which also receive cattle. Livestock manure is fed into the biogas digesters. Guarantee period: 3 months.	2015 Individual biogas digesters are installed in farmer households that own livestock and show potential and interest. Guarantee period: 3 months.	2009 Individual biogas digesters are installed in farmer households that own livestock. Guarantee period including maintenance services: 3 years.	2013 Pilot project provided livestock and bio digesters to farmers around the West Bali National Park to discourage firewood collection.
Implementing Agencies	The project was initiated by the Governor of Bali. The Bali Provincial Agricultural Agency is the lead implementing agency. Others such as Udayana University and YRE (as Construction Partner Organisation) joined the programme in 2013 to provide backstop services.	Public Works is the lead implementing agency. It receives support from the Agricultural and Livestock agencies at the regency level.	SNV Netherlands and HIVOS launched the BIRU programme. In 2012 HIVOS created Yayasan Rumah Energi (YRE) to operationalise the programme. YRE is now a more independent entity and that has developed BIRU as a market-based approach.	The West Bali National Park authority is the lead implementing agency, with support from the forestry agency operating in Jembrana Regency.
Funding	Provincial budget, approx. IDR 42 billion between 2014 and 2017 Programme is 100% subsidised and farmers do not pay for the bio digester installation.	Funding comes from the national government (MEMR). Provinces can request the MEMR for budget to be allocated for biogas projects. Programme is 100% subsidised.	Multiple streams of funding, including HIVOS, credits from the EU carbon market (20% of funding), government (Dutch), and public-private partnerships. Adopting farmers pay part of the costs. 16,000 + bio digesters installed as of November 2016 in 9 provinces of Indonesia; more than 1000 in Bali. ⁶ Target: 100,000 units by 2020 at the national level (also the estimated commercial break-even point)	The Ministry of Environment and Forestry provides funds that go directly to the Jembrana regency where the national park is located.
Biogas Installations	632 bio digesters installed as of October 2016. Tentative target: 1000 by 2018. Farmers also produce bio urine and bio slurry as part of the integrated farming system.	57 bio digesters installed in Jembrana Regency as of 2016.		Only a few pilot projects have been implemented around the national park. Farmers also experimenting with vermiculture in the bio slurry with commercial purpose.
Biogas digester technology	Communal biogas digesters of capacity 5m ³ and 11m ³ Feedstock: cow manure Digester: fibre dome Gas filtration: yes End use: gas for cookstove in communal building and slurry as fertiliser Cost: IDR 200,000,000	Household biogas digesters of capacity 2.5–3m ³ Feedstock: pig and chicken manure Digester: concrete dome Gas filtration: no End use: gas for household cookstoves and slurry as fertiliser Cost: unknown	Household biogas digesters of capacity 4m ³ Feedstock: pig, cow and chicken manure Digester: concrete dome Gas filtration: no End use: gas for household cookstoves and lanterns and slurry as fertiliser Cost: IDR: 6–8,000,000	Household biogas digesters of capacity 4m ³ Feedstock: pig and chicken manure Digester: concrete dome Gas filtration: no End use: gas for household cookstoves and slurry as fertiliser Cost: unknown

Sources: Stakeholder interviews, FGDs, programme websites.

Annex 2. Stakeholders involved in 2016–2017 consultation in Bali, Indonesia

Table A2

List of interviewed stakeholders relevant to the biogas system in Bali, Indonesia

Code, type	Organisation, position	Location	Perspective
01.Gov.N	National Development Planning Agency (Bappenas), Indonesia Climate Change Trust Fund	Jakarta	National bioenergy policy and funding
01.Gov.S	Bali Provincial Agriculture Agency	Denpasar	SIMANTRI programme
02.Gov.S	Department of Forestry, Agriculture and Plantation, Plantation Division	Jembrana	SIMANTRI programme
03.Gov.S	Department of Forestry, Agriculture and Plantation, Agriculture Division	Jembrana	SIMANTRI programme
04.Gov.S	Public Work Agency	Jembrana	Public Works programme
05.Gov.S	Forestry Agency	Jembrana	West Bali National Park programme
06.Gov.S	Village Leadership	Tukad Aya Village	Village leadership involved in selection of potential farmer candidates
01.Pri	BIRU Construction Partner Organisation (CPO), Technician	Denpasar	BIRU programme
02.Pri	Gasifikasi Prima Energi	Denpasar	BIRU programme
03.Pri	DnD Consultant, Lawyer	Jakarta	Funding for bioenergy (biogas)
04.Pri	Udayana University, Researcher	Jimbaran	Research on biogas technology
05.Pri	Udayana University, Researcher	Jimbaran	Research on biogas technology
01.NGO	Bali Organic Association (BOA)	Denpasar	Support on biogas installation and use
02.NGO	Yayasan Rumah Energi (YRE)	Jakarta	BIRU programme
03.NGO	HIVOS	Jakarta	BIRU programme
01.Prod.A	Farmer (adopter)	Tukad Aya Village	Biogas adopter, support from Public Works programme
02.Prod.A	Farmer (adopter)	Tukad Aya Village	Biogas adopter, support from Public Works programme
03.Prod.A	Farmer (adopter)	Tuwed Village	Biogas adopter, support from SIMANTRI programme
04.Prod.A	Farmer (adopter)	Tukad Aya Village	Biogas adopter, support from Public Works programme
05.Prod.A	Farmer (adopter)	Blimbing Sari Village	Biogas adopter, support from West Bali National Park programme
01.Prod.NA	Farmer (not adopter)	Tukad Aya Village	Sent a proposal for biogas installation, still waiting for response
02.Prod.NA	Farmer (not adopter)	Tukad Aya Village	Sent a proposal for biogas installation, still waiting for response

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