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Co-producing just energy transition in everyday practices: sociotechnical innovation and sustainable development in the Thailand-Myanmar border

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ABSTRACT

Coupling innovations in everyday social and technological practices to close energy poverty delivers local sustainable development. Although case studies on the linkages between energy access and sustainable development had been far-reaching, we know very little about their interactions in everyday practices, such as cooking. A focus on access to renewable energy for everyday activities as cooking has substantial implications for the energy justice principles of equity, accessibility, and affordability. Energy justice underlines the necessity for all people to have access to energy services fairly. At the same time, one should ensure that these energy systems do not inflict damage upon the present and future generations. This paper used a Grounded Theory approach to show how an energy transition in everyday practices such as cooking can deliver just, local, sustainable development while emerging as a sociotechnical innovation in rural Thailand.

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1. Introduction

About 1.8 billion people still cook with polluting and unsustainable fossil fuels or health-degrading biomass (International Energy Agency (IEA) 2016: 22), which impacts the Sustainable Development Goals (SDGs), especially on modern energy access (SDG7). Improving upon SDG7 helps achieve the other SDGs (Nerini et al. 2018) at the same time that it addresses energy justice issues, including equity, accessibility, and affordability (Delina and Sovacool 2018). Energy access and transition to cleaner fuels even in everyday cooking matters, especially since the choice and use of unsustainable and polluting cooking fuels detriment climate action and affect human health. The challenges of just and sustainable development and climate action, thus, can also be pursued at the micro and local level, not only in large-scale electricity systems. It follows that energy transition can be introduced in households and communities via improvements in people's everyday cooking practices (Bazilian, Nakhoda, and Van de Graaf 2014; Delina 2017; Fri and Savitz 2014). This paper shows that this innovation in everyday practices could achieve several SDGs and assist in closing injustices, inequalities, and deprivations.

Despite many studies to understand energy and sustainable development linkages (e.g. Delina 2017; Güney 2019; Grubler et al. 2018), we still know little about how micro-energy transition occurs in households, particularly in rural areas in developing countries (Quinn et al. 2018; Muller and Yan 2018). What sociotechnical innovations in everyday cooking practices that close

energy poverty and, at the same time, achieves some SDGs and closes energy injustices are observed in these spaces? How did these rural communities perform and practice their indigenously produced energy transition innovations? What are the implications of these energy transitions towards just and sustainable development? This paper presents an empirical case study of a transition to sustainable cooking fuel observed from a rural community in the Thailand-Myanmar border. Using the Grounded Theory approach, this paper provides a critical analysis of how a modified biogas system has evolved into an accessible form of energy transition innovation that benefited rural poor people and provided a mirror to gaze at the intersections of energy justice and local sustainable development. This inductive study also offers evidence on the importance of inclusive and parallel social learning and reflexive experimentation in socio-technical innovations.

In section 2, the paper provides short briefings on Thailand and its energy challenges, the concept of “moderation society”, and the importance of rural development in Thai polity. This section also includes a short description of the rural community in the Thailand-Myanmar border where this study is situated and the highlighted energy system innovation. Section 3 describes the study’s multi-method research approach, which involved face-to-face interviews, focus groups, and site surveys. The collected data were then coded inductively to surface common themes. The coding yielded three themes on (1) user’s interaction with the technology, (2) the role of social learning and experimentation in this innovation, and (3) the co-impacts of the technology on various sustainable development goals as experienced by the users. Section 6 concludes the paper with a summary, its limitations, and some suggestions for future work.

2. Background

2.1. Thailand and its energy development challenges

Thailand (2018 population: 69.43 million), a continental southeast Asian country, is bordered in the north and the east by Laos, in the south by Malaysia, and the north and the west by Myanmar. Considered one of the fast-rising southeast Asian economies, Thailand’s GDP in 2018 stood at US\$ 505 billion, of which industry contributes 35% and agriculture 8% (Worldbank 2018). The Worldbank (2011) had already elevated Thailand’s economic status into an upper-middle-income country; yet, it is still home to several sustainable development challenges, including energy insecurity and energy poverty.

Energy security is understood most prominently in Thailand as related to energy supply reliability, stability, and affordability. After Indonesia, Thailand is Southeast Asia’s second-largest energy consumer (IEA, 2015: 29), meaning that energy security is crucial to the Thai policy issue. Although Thailand has domestic energy sources (e.g. coal in Lampang province and natural gas from the Gulf of Thailand), international energy trade remains important for energy security. To meet its energy demand, Thailand imports hydroelectricity from Laos, natural gas from Myanmar, and coal from Indonesia and Australia. Despite Thailand being close to achieving universal electrification, energy poverty, which is the reverse of access to reliable, affordable, sustainable, modern, and renewable cooking fuels, lingers (IEA, 2015: 12). About 24% of Thai households still use solid cooking fuels, particularly firewood and charcoal; this situation is more pronounced in rural areas where the proportion stands at 47% (The Global Alliance for Clean Cookstoves 2017). A rural Thai household would spend between US\$ 30 and US\$ 60 per month on imported cooking fuels such as liquefied petroleum gas (LPG) tanks. In Nigeria, where GDP was at the same level as Thailand, an LPG tank costs only US\$ 3 (Fraym 2021). For a Thai family in poverty, the amount for LPG represents a considerable burden. Choosing LPG tanks reduces that household’s ability to spend more on their food, education, health, and other productive purposes such as participation in small-scale industries.

2.2. Rural development in Thailand and the “moderation society” philosophy

Rural development is core to then King Bhumibol Adulyadej’s (1846–2016) – who, as the ninth monarch of Thailand, is also called Rama IX – development philosophy called “moderation society” (*moso*) or “self-sufficiency economy” (*sethakit phor piang*). Moso requires Thais to adopt the “true Buddhist way of life”, which means living in self-sufficiency and not overexploiting natural resources (Piboolsravut 2004; cf. Rigg and Ritchie 2002). The Thai Government translates this philosophy into practice through state-sponsored, rural, community-based development projects (United Nations Development Programme 2007). Having royal assent, these projects, which range from cattle raising to rice production, are often provided with state financing and capacity-building support.

One location that exemplifies the moso philosophy can be found in Pa Deng town in south-western Thailand. Located inside the Kaeng Krachan National Park on the Thailand-Myanmar southern border in Phetchaburi province, Pa Deng is a community of more than 100 households. Pa Deng can be translated into Deng Forest: Pa for the forest, and Deng referring to a dominant tree species found in the park. Most of the residents here thrive on agriculture (usually backyard gardening, husbandry, and raising fruit trees). Since Pa Deng is inside a national park, state laws prohibit electricity grid extension. Therefore, the majority of households would rely on household scale energy systems for their energy needs, such as diesel generators for lighting and powering small appliances such as radio and cellphones, and kerosene, charcoal, and LPG tanks for cooking. In the early 2000s, however, a moso community was created in Pa Deng, where providing access to affordable and sustainable energy sources was a primary goal. The most innovative of these systems is their plastic balloon biogas digester. This paper zooms into this innovation.

2.3. Innovating a cooking fuel resource and system

Biogas is made from anaerobic fermentation of solid wastes and may contain carbon dioxide and methane depending upon the feedstock (Surendra et al. 2014). Users can then harvest this biogas and use it as cooking fuel. Biogas digesters are often large-scale systems usually found in pig farms, but they can also be captured at the household level using cattle, pig, or human wastes as feedstock. In Thailand, biogas policy is predominantly geared towards large-scale systems (about a thousand cubic metres in volume) from pig farms (Aggarangsi et al. 2013). These larger systems fed onto a supply network for use in several households or even industrial operations (Suwansri et al. 2014). However, household-scale biogas systems (about ten cubic metres) are also available – such as those seen in Pa Deng – but large-scale adoption or diffusion remains low. On an average day, a small, household biogas plant would require at least twenty kilograms of feedstock to produce cooking gas for a household of five members (Bond and Templeton 2011). About three cows or six pigs can provide the required feedstock (Bond and Templeton 2011). Regardless of size, biogas digesters also produce sludge that users can turn into fertiliser (Aggarangsi et al. 2013; Sovacool, Kryman, and Smith 2015).

Solid waste anaerobic digestion to produce biogas traces its history to ancient China and Assyria (He 2010) with documented attempts to construct digesters in India, New Zealand, and the United Kingdom (Bond and Templeton 2011). In 1920s China, Luo designed a commercial biogas digester using household wastes (He 2010). During this decade, the technology spread to Europe, where it became popular in the 1970s following the oil price crisis (Bond and Templeton 2011), and the developing countries of Latin America, Africa, and Asia (Ni and Nyns 1996). China supported the scaled deployment of biogas digesters with funding such that by 2007, 26.5 million biogas digesters were in operation in the entire country (He 2010). India also popularised the technology through the National Project on Biogas Development in the 1980s. By 2007, over three million small-scale biogas digesters were installed in India (Bond and Templeton 2011).

A classic biogas system is a fixed dome unit typically made from bricks or reinforced concrete, with an inlet for feedstock, an outlet for slurry, and a network of pipes and valves for gas pressure regulation (Perez et al. 2014). Building this system requires spending for relatively expensive materials (e.g. cement, bricks, reinforcing steel bars, etc.), material transport, and labour cost for skilled builders (e.g. biogas technician, carpenter, masons, etc.) (Perez et al. 2014; Surendra et al. 2014). The digester must also be constructed with established and clear legal land ownership (Sovacool, Kryman, and Smith 2015). Fixed dome digesters are, therefore, expensive and inflexible. Their payoffs, nonetheless, are substantial: they are reliable, durable, low-maintenance, and with a longer lifetime (Surendra et al. 2014; Sovacool, Kryman, and Smith 2015).

3. Methods

3.1. Methods and data

A research team, comprising this paper's author and two Thai research assistants, collected qualitative data through interviews, focus groups, and site visits between November 2016 and January 2017 in ten villages in Pa Deng. The research team randomly selected the respondents using snowball sampling and spoke to them individually, in pairs, or in groups. The author interviewed the respondents in English, while research assistants provided simultaneous interpretation to Thai. Since all respondents spoke in Thai, the assistants translated them to English *in situ*. Altogether, there were eleven individual interviews, four in-pair interviews (i.e. eight respondents), and two focus groups (mixed gender and women-only). Participants gave their oral informed consent following the recommendations of the Internal Review Board of Boston University, which also stated that this project is not human subjects' research (Protocol No. 4103X on 29 April 2016, and Protocol No. 4696X on 12 December 2017). The interviews followed an interview guide, which included questions on: (1) user's access to energy systems, including the biogas digesters, the benefits from using these systems, and the challenges arising from their use; (2) the changes experienced before and after they had access to the technologies; and (3) the potential and challenges for replicating the energy systems outside their community. Although the conversations followed this guide, the respondents were allowed to elaborate on their responses, with new related issues permitted to be discussed as they arise. Table 1 summarises the description of the respondents whose data was used in this paper. The research team also paid attention to user interactions with their energy systems through participant observations and site walk-throughs. During these activities, the research team took notes and photographs with respondent oral permission.

Table 1. Summary descriptions of interviewees whose responses are included in this paper.

Respondent Codes	Brief description
Respondent 1	Pa Deng moso network leader, an adult man in his 40s, vegetable farmer, formerly working on rural development in Thailand, head of household
Respondent 2	Pa Deng moso network member, an adult man in his 30s, farmer and semi-skilled labourer, head of household
Respondent 3	Pa Deng moso network member, an adult man in his 20s, farmer, head of household
Respondent 4	Pa Deng moso network member, an adult man in his 30s, farmer, head of household
Respondent 5	Pa Deng moso network treasurer, an adult woman in her 20s, farmer, household member
Respondent 6	Pa Deng moso network member, an adult man in his 50s, farmer, head of household
Respondent 7	Pa Deng moso network member, an adult man in his 20s, farmer, head of household
Respondent 8	Pa Deng moso network member, an adult woman in her 40s
Respondent 9	Pa Deng moso network member, an adult woman in her 30s
Respondent 10	Pa Deng moso network member, an adult, indigenous woman in her 40s
Respondent 11	Pa Deng moso network member, an adult woman in her 30s, partner of Respondent 1
Respondent 12	Pa Deng moso network member, an adult woman in her 60s

3.2. Analytical protocol

This study adopted the Grounded Theory approach, which means that the author discovered the theory from data systematically collected from social research (Glaser and Strauss 2017) to explain social behaviours, in this case, energy end-users' behaviours towards their cooking technology. Grounded Theory is a useful approach to analysing Pa Deng residents' views on the use of their energy resources and their locally grounded innovation processes and concurrent social structures as shown for example in Süsser, Döring, and Ratter's (2017) work on energy transition in North Frisia (Germany). To make sense of the collected qualitative data, the author transcribed the English translations of the open-ended interviews and manually coded them. Using inductive, in vivo coding, the author uses the respondents' own words in discussing the results to avoid trying to infer meaning. *In vivo* coding, in this case study, was particularly useful since the data were derived from respondents who speak a different language and are from a different culture. This is important since some contexts are specific to this community that the author can loosely interpret. This paper, thus, presents the interview responses verbatim to avoid misinterpretation as much as possible (cf., Glaser and Strauss 2017). This inductive approach to data analysis is also helpful since it allows the findings to emerge from the dominant and significant themes inherent in the interviews without a structured methodology.

3.3. Concepts emerging from the data

In addition to the concepts of energy transition and energy access, sustainable development, distinguished according to the specifically defined goals and targets in the SDGs, is also prominent in our data. In addition, our study also surfaces themes around energy justice and energy democracy. Energy justice "entails holistic and reflexive processes, mechanisms, and exercises framed around inclusiveness and strong public engagement" (Delina and Sovacool 2018), while a complement concept, energy democracy, is a social agenda that requires multi-scale social mobilisation to achieve energy transition via active social participation in energy generation (Delina 2018a; Delina 2018c). The democratic sociotechnical innovation found and observed in Pa Deng's small-scale biogas digesters exemplifies how rural households could facilitate local energy transition via changes in their everyday cooking practices.

4. Results and discussion

This section discusses the coding results, which the author compiled into three themes: (Theme 1) the user's interactions with renewable energy technologies, particularly their biogas digesters; (Theme 2) the role of social learning and experimentation in the production of this sociotechnical innovation; and (Theme 3) user experiences of the co-impacts of the technology against various sustainable development goals. Photographs taken on-site are incorporated in these discussions.

4.1. Theme 1: user interactions with renewable energy technologies

As of 2018, the Pa Deng moso network was a self-sufficient community network comprising about 100 households and sustained without much state assistance since 2001. The network members conceived this organisation out of their need for accessible, reliable, and affordable cooking fuel and lighting, suggesting how personal necessities drive rural innovations (e.g. Magnani et al. 2017). Some Pa Deng households may have access to electricity via the national electricity grid, but Thai law disallows households located within the Kaeng Krachan National Park from connecting to it. The households would meet their cooking and lighting energy through kerosene, charcoal, gas tanks, and, in some instances, by illegally harvesting forest wood as mentioned by Respondents 2 and 3. Following the need for cheaper fuel options, Respondent 1 shared that these households

deployed multiple household-scale energy technologies, including improved cookstoves, solar home photovoltaic systems, solar irrigation, and biogas digesters for various uses (see [Figure 1](#) for some examples). Network members could readily and easily access these technologies through the Pa Deng moso network credit facility, where members would contribute around US\$ 2 every month, according to Respondents 1 and 3. The availability of project financing allowed ordinary householders to access these technologies, which is a pattern also observed in other cases (e.g. Terapon-Pfaff et al. 2014).

Of the multiple energy technologies that the network had deployed, users suggested that their biogas digesters have become the most technologically innovative. This innovation is found in terms of the materials used for building it, which strays from the conventional concrete structure described in 2.3. From a classic, fixed dome, concrete, or bricks system, the Pa Deng moso network improved on an alternative digester: **a floating balloon-type** (see [Figure 2](#)). The network started developing this system in 2007, revising the classic brick-based digesters they first saw from their farmer neighbours in Myanmar. The balloon-type digester, which used locally available polyethylene plastic materials, comprises three essential parts: the digester bag (where solid waste undergoes anaerobic digestion) that looks like a balloon, hence the name, and piping to move the biogas from the digester to the home kitchen, where it is used to produce fire for cooking. This type of digester can be regarded as a “traveling” innovation, having passed by Burmese farmers from the western border, who themselves could have learned about the technology from elsewhere.

The Pa Deng balloon biogas digester is not unique to Pa Deng since they are also used in several locations, albeit with varying degrees of success and failure. Examples can be found in central and northern Europe (Plochl and Heiermann 2006), India (Chanakya, Reddy, and Modak 2009), Africa (Mwirigi et al. 2014), and Latin America (Herrero 2007; Kumar et al., 2015).

Respondents 1, 3, and 4 shared that the lifetime of their balloon-type biogas digesters typically ranged between 5 and 7 years; this, however, is less than that of the classic brick or concrete system, which can reach up to 20–30 years. The technology’s life, nonetheless, can be extended, according to informants, by suppressing the speed of material wearing. Respondents 2 and 3 shared that they did this by placing their balloons under shade, while Respondents 1 and 4 covered them with tent-like structures. Although wear-and-tear may be a limitation, Respondents 1 and 4 overruled this concern, especially when one factored in the relatively low cost of their digesters. Respondents 1, 2, and 4 further shared that their digesters could also be constructed within a day since the required materials were readily available from their local public market and would require locally available feedstock. Respondents 3 and 4 attested to the technology’s versatility, saying that these are easily maintained and repaired in case of malfunctions. End-users, without additional training, can easily do basic repair, such as taping minor leaks, as Respondent 5 reported. By contrast, a dedicated technician should be available to maintain a classic concrete digester.



Figure 1. Multiple small-scale renewable energy solutions observed in Pa Deng: solar photovoltaic (a), improved cookstoves (b), and solar-for-irrigation (c). Source: Photographed by the author, November 2016.



Figure 2. The Pa Deng biogas digester is an innovation from classic brick or concrete digesters. Source: Photographed by the author, November 2016.

4.2. Theme 2: the role of social learning and experimentation in the production of the balloon digester as a sociotechnical innovation

The balloon biogas digester is a sociotechnical innovation since it was produced as an engineering or technological artefact while introducing changes in social behaviours. This co-production occurred when end-users were let to “experiment” with these technologies, reflect upon their own experiences of using them, and share these lessons with other end-users. Lesson-sharing through informal meetings and discussions with neighbours over glasses of wine and community cooking events had strengthened communal relationships, manifesting the moso philosophy. The sociotechnical innovation around the digesters was possible since Pa Deng end-users collectively considered their technologies incomplete, ongoing, and work-in-progress. As an emergent technology, these digesters were co-produced across time and stabilised as important objects for sustainable development by the end-users themselves (cf. Jasanoff 2004). As a dynamic sociotechnical system-in-development, end-users would, for example, report and share with neighbours how, at times, their digesters would experience mishaps – and effectively used these seemingly unfortunate experiences to experiment with the technology and to forewarn neighbours about them.

As end-users repaired their digesters, they would also test the efficiency of other feedstocks. Respondents 1, 3, and 6 found that locally available Napier grass (*Pennisetum purpureum*), used in Pa Deng as cattle feed, can be added to or even replaced conventional feedstock from cow manure, food scraps, and dried leaves. Respondent 7 further reported that this feedstock could even produce “more” biogas. This output of citizen-produced experimentation confirmed laboratory-based experiments on the use of mixed feedstocks, including Napier grasses, in biogas digesters in Thailand by, for example, Satjaritanun et al. (2016) and Wilawan, Pholchan, and Aggarangsi (2014). The resulting localisation of technological experiments evidenced a participatory approach to technology governance where end-users learn (Petts 2007). At the same time, the sustainable use of local resources also falls within the ambit of the moso philosophy.

Some end-users, such as Respondent 1, would experiment with the biogas produced from their digesters for electricity generation (see Figure 3). They found the capability of this system to provide electricity for intermittent lighting and powering small electric appliances such as radios and mobile phones. This social learning process reveals that users achieved knowledge



Figure 3. The biogas produced from the balloon-type biogas digester (shown in orange and blue coloured polyethylene plastic materials) can be connected to a generator set (the yellow equipment in the centre of the photograph) to generate electricity supplementing energy generated from a solar home system. Source: Photographed by the author, November 2016.

through informal yet meaningful and reflexive peer discussions that included information sharing with other users (Baker and Mehmood 2015). Social learning also underlined the capacity of end-users for reflexive learning (Wynne 1993; Chilvers 2013; cf. Stirling 2006), as shown most especially via learning-by-doing. Users reported, for instance, about an educational benefit in terms of the new skills that they had acquired. Through constant experimentation with biogas digesters, end-users would learn new skills to earn extra income in the future (cf. Morrison and Ramsey 2019). One farmer, Respondent 2, stated:

Each time I meet with my neighbors, we discuss our digesters and share stories about tweaking them. This way, we learn something new. This is important since I am learning a new skill that I can use in the future. For example, when other people decide to have this digester in their homes, I can help them build their own for some fee.

This first-hand experience with the technology highlighted the imperative of social learning in innovation where neighbours would mutually learn from each other's experiences (Baker and Mehmood 2015). These experiences revealed how energy could be governed in marginal locations such as poorer geographies (Bazilian, Nakhooda, and Van de Graaf 2014). In one way, this co-benefit contributes to the literature on energy justice, where everybody can participate in energy access and energy transition, and, at the same time, enjoy its benefits: new skills and employment prospects in this case (cf. Delina and Sovacool 2018; cf. Jenkins, Sovacool, and McCauley 2018).

As the case reveals, the availability of informal mechanisms by which end-users could share their reflections on their new technical systems had become a precondition for technology scale-up within this community (Fri and Savitz 2014; cf. Stirling 2006; cf. Chilvers 2013). As this new information travels by word of mouth, substantiated by an actual technological system, the floating biogas digesters were diffused in many Pa Deng households.

4.3. Theme 3: user experiences of the co-impacts of the technology against various sustainable development goals

For rural households previously suffering from energy poverty, the Pa Deng balloon-type biogas digester met household-level energy for cooking demand while contributing to local sustainability, exemplifying the moso philosophy and showing how small energy technologies can broadly impact the SDGs (cf. Goldthau 2014; Delina 2017). As the technology scaled, these benefits accrued from households to the community (cf. Moulaert and MacCallum 2019), providing verifiable benefits to local sustainable development (cf. Dóci, Vasileiadou, and Petersen 2015; Pel and Kemp 2020; Rein-sberger et al. 2015; Murphy 2015). End users reported these benefits in terms of the following: improved energy access (hence, contributing to SDG 7), climate benefits (SDG 13), improved health conditions (SDG 3 and SDG 6), expanded educational opportunities (SDG 4), empowered women (SDG 5), produced economic savings and improved productivity (SDG 8), and enhanced public engagement (SDG 16). I discussed these benefits in more detail in the following.

On improved health and sanitation (SDGs 3 and 6): The instantaneous transition from unsustainable cooking fuels to sustainable biogas led to an enhanced human health condition in the community. The digesters reduced, if not eliminated, the smoke and soot that used to pollute home kitchens, which increased mortality due to indoor house pollution discussed earlier in the paper. This improvement reduced the incidence of respiratory ailments in the family, as narrated by Respondent 8:

Cooking with firewood [was] a menace. There [was] smoke everywhere but now we can cook without coughing or tears on our eyes. We need not cover our nose and mouth too.

The digesters also promoted community health and wellbeing since these systems help to improve sanitation through the effective disposal and management of household and farm waste. Respondent 9 shared:

When we still buy our cooking fuel, we simply throw away our kitchen scraps. Sometimes, stray dogs and cats would eat it. If there are no cats or dogs, it will smell. With our digester, we don't need to worry about it anymore since they [the food scraps] go straight onto [the digester].

Community health, however, is an encompassing issue that goes beyond improving sanitation. It is critical to note the other health-related issues that the geographically isolated Pa Deng community faces, including access to hospitals, clinics, and modern medications. While these are still external to Pa Deng, the community provided a ready example of moso in practice.

On improved educational opportunities (SDG 4): The biogas system freed up time and money resources that households used to pursue and fund educational opportunities, especially for their children (cf. Sovacool, Kryman, and Smith 2015). Respondent 8 narrated:

I have two children. They go to school, but sometimes I could not buy the things they need because we don't have enough money. Money has to be spent first on food, then to purchase farm inputs. Education is always the last of our priorities here. But we were able to save some money, mainly because, for example, we do not need to buy charcoal anymore. It is a big help since we could then use that (money) to spend on my children's school supplies.

While monetary savings due to the availability of a local fuel had accrued, with anecdotal evidence pointing to the translation of use towards educational purposes, this study did not quantitatively measure the success of this co-benefit. For instance, we have not verified the children's attendance with educational institutions. That data may lead to new findings, but the present study did not include this in its design. Nevertheless, these improvements in education provided an example of how moso as a development philosophy can intertwine with the SDGs.

On gender empowerment (SDG 5): In a focus group discussion among some of the network's women members, informants shared how the biogas system improved the women's quality of life. For example, compared to using firewood, the digester did not require time-intensive activities

to search, collect, or harvest firewood for cooking, which they used to do. Therefore, the digester had reduced women's workload, leading to some freed-up time that they instead used to tend their families, help in farm work, or be involved in cottage industries (cf. Farhar, Osnes, and Lowry 2014; Sovacool et al. 2013). A lady end-user, Respondent 10, remarked:

Our biogas digester is a significant improvement in my life. It reduced the time I spend cooking. I no longer have to gather firewood or buy charcoal.

Respondent 8 also quipped:

It is already there. I mean, our cooking fuel is already built in. No need to look for it. No smoke too. But most importantly, I can now help my husband on the farm.

In a separate interview, Respondent 11 said:

It is a big help. I can now make more soap to help boost our household income.

The literature on gendered energy systems is vast and rich (e.g. Sovacool et al. 2013; Listo 2018). As shown in this case, women played essential roles in addressing energy poverty in the developing world (cf. Mwirigi et al. 2014). It is still crucial to note the nuances and complexities of gender-directed energy access programmes and energy poverty research. For instance, this case study failed to incorporate in its design the queer, transgender, and the diversity of gendered identities (other than the men-women binary), which are already seldom mentioned in the literature (Cornwall and Rivas 2015). Recent literature has also pointed out the problematics of describing women as "victims", "vulnerable", and "suffering from the burdens" of energy poverty, often in a tokenistic manner (Listo 2018). Consequently, these descriptions constructed women in developing countries as oppressed, submissive, virtuous, and hardworking, perpetuating the subordination of women in these places (Listo 2018), thereby hiding their contributions, especially to household decision-making (cf. Escobar 1995). The case study had rebutted these descriptions.

In situ observations from this community have shown that women are important decision-makers in energy choices and other vital household activities, including the use of household funds. For instance, the Pa Deng moso network's monthly meeting, which the author had observed one weekend, had most women in attendance, suggesting their primary role in household energy decisions. Women also held key positions in the network's organisational structure, including the membership committee and the treasurer's office.

On energy access and energy transition (SDG 7): The Pa Deng innovation directly benefited rural Thai households regarding their access to affordable and modern forms of cooking fuels and other energy services (e.g. lighting, communication, recreation, and agriculture). The cost to construct and maintain a balloon-type biogas digester appeared cheaper than the classic brick or concrete design, meaning that this technology could be affordable to rural poor people. The system, which builders could complete in less than a day, also increased the appeal of the technology. In addition, the system required little labour cost and minimal skills to put up, evidencing that energy transition, at the micro-level, can occur at a low price. A farmer, Respondent 3, stated:

We decided to adopt this biogas digester when we learned from our neighbors that this cooking system is cheaper to build and maintain than buying kerosene or LPG (tanks). We made a good decision to replace firewood gathered from the forest or LPG we purchased from the market with this one.

The farmer's remark shows how important peer comparison is in accelerating energy access programmes, consistent with other empirical evidence observed, for instance, in wealthier communities in Europe (Heiskanen, Nissilä, and Tainio 2017). The balloon-type biogas digesters ultimately became the primary mode for transmitting local energy transition. Respondent 6 remarked how its low cost contributed to this transition:

Although it [the digester] initially cost us a pretty good amount of money, it is cheaper in the long term ... of course, I mean, when you compare it against the way it used to be ... using charcoal for instance.

Feedstock versatility and low-maintenance, other vital aspects of this innovation and energy transition, further ensured that anyone who wanted the technology could have access to it as Respondent 8 shared:

It's [the biogas digester] easy to operate. You don't need formal technical training to fill in the balloon [referring to the biogas digester] with food scraps or cow manure. My children can even do it with ease.

Respondent 9 also followed up:

This system is a godsend. Unlike charcoal or firewood, we can quickly cook with manure [biogas], which we used to take for granted. It's incredible how easy it is to make cooking fuel without spending much money on it.

Low-cost and ease-of-use, therefore, are essential criteria for the shift, which then led to scaling. The technology could not have gained traction if local feedstock and cheap construction materials were not readily available (cf. Tawney, Miller, and Bazilian 2015). Along with their affordability, local availability of critical resources corresponds to one principle of energy justice, where end-users should have ready access to energy services (cf. Delina and Sovacool 2018). The innovation also corresponded with the moso philosophy by providing evidence on how self-sufficiency can be achieved with low-cost but sustainable energy fuels.

On economic savings and productivity (SDG 8): The cost avoided from purchasing polluting fuels and installing a relatively expensive classic brick or concrete biogas digester freed up some money that households could use towards other necessities. Interview data revealed that, on average, a Pa Deng household would spend up to about THB 2000 (US\$ 65) per month on traditional fuels. The digesters' meager operating costs, thus, also made a positive economic case for the technology. Fuel expense reduction resulted in monetary savings and increased productivity as Respondent 4 narrated:

My family has to stock up on LPG tanks in the old days, costing us several hundreds of baht. Today, we do not need to worry about our cooking fuel expenses anymore. It saves my family good money.

The biogas digester, which still required capital outlay, represented some freed-up money that end-users turned into savings. Some households used this freed-up money to start new small businesses, hence revitalising the community economy. Site visits revealed these new cottage industries, including soap making, backyard poultry raising, and local winemaking. A housewife, Respondent 12, shared:

I am an ordinary housewife with no regular job. Either I tend to our jackfruit farm, raise chickens, or clean the house, and, of course, gather firewood so that we can cook. That firewood had to be dried, collected, and stacked at the end of the day. With our balloon digester, I no longer have to do all that. Instead, I use my extra time to help on the farm and, sometimes, to make more wine, which we sell.

Some end-users also mentioned the potential for commercialising the digester. Respondent 3 said:

We would like our fellow Thais living in other rural areas or national parks to take advantage of the balloon digester. We saved a good amount of money because of it, and we hope they will also enjoy that kind of benefit. What we have here can be sold. I mean, we can help them install their balloon digesters, of course, at some minimal cost.

Respondent 1 revealed that plans were underway to exploit this market, including households and small and medium enterprises, by storing the biogas in tanks and then selling them to the domestic market (cf. Suwansri et al. 2014). Although not guaranteed, this entrepreneurial approach could scale innovation, as shown in other cases (e.g. Magnani et al. 2017).

On climate action and environmental benefits (SDG 13): The biogas digesters reduced the pressure on Kaeng Krachan forest through avoided deforestation related to firewood collection and charcoal production. The transition also benefitted the environment by preserving the local carbon sink, the Pa Deng Forest and avoiding greenhouse gas emissions from biomass and fossil fuel combustion. The fertiliser produced from the slurry had also displaced commercial fertiliser,

which, in industrial settings, are intensively produced using fossil fuels (cf. Sovacool, Kryman, and Smith 2015).

The Pa Deng moso network computed that their transition in cooking fuel resulted in the avoidance of 12,550 kg of LPG in 2015, saving them about 39 tons of carbon dioxide (see Figure 4). These carbon savings excluded unaccounted mitigation benefits accrued from trees not being felled for firewood and charcoal production, carbon avoided from commercial fuels such as kerosene and LPG, and the expansion of the network's other energy transition technologies, notably solar home systems.

The moso philosophy, by which Pa Deng network members firmly hinged their ways of life, put a premium on caring for the natural environment. Respondents 1, 6, and 8 suggested that the biogas digesters had scaled rapidly partly because of the members' innate appreciation of this development philosophy. Studies have shown that these cultural aspects are essential in energy transition and sociotechnical innovation (Stephenson et al. 2010).

On public engagement and democracy (SDG 16): The Pa Deng innovation also revealed a dynamic process for widespread mobilisation and participation that disrupted contemporary practices in Thailand (cf. Magnani et al. 2017). Respondent 1 narrated:

We do this [referring to the biogas digester] ourselves. We built it using our own money, our labor. We did not receive any help from outsiders, such as technical guidance, financing, supervision, you name it. When people know what we are doing here, often by word of mouth, they come over. We would then tell them how we do it. In some ways, what my neighbors and I are doing is very different from the usual dole-out practices that the government does here. I feel terrific doing this. It shows that farmers like us can also do new things.

This localised, democratic approach to innovation remade the lines between technology, innovation, and democracy (cf. Stirling 2014; Khandelwal et al. 2017), suggesting a move towards a more



Figure 4. Avoided carbon dioxide and LPG use in Pa Deng due to their biogas systems computed by the Pa Deng moso network. The horizontal axis denotes the year in the Buddhist calendar system, where the year 2558, for example, corresponds to the year 2015 in the Gregorian calendar. Source: Photographed by the author, November 2016.

reflexive, cosmopolitan, and pluralist platform for navigating energy access and energy transition (Delina and Janetos 2018). The case study exemplified how energy transition in everyday practices could also occur beyond state-led mechanisms in places far from the seat of power in Bangkok. Empirical studies had earlier revealed that when the public has the means to participate in charting the terrains of their energy transition, sociotechnical innovation extends upwards (e.g. Adesanya, Sidortsov, and Schelly 2020). The Pa Deng case study had shown the same: strong public engagement matters in energy transition, including in states where democracy fluxes, such as the case in Thailand (Delina 2018b).

5. Conclusion

A household-scale, relatively cheap to construct, and easy-to-operate, balloon-type biogas digester could not only convert household and farm waste into usable cooking gas but could also assist in electricity generation. As a result, this energy system addressed energy access and sustainable development challenges at the community scale. The Pa Deng biogas digester became an object of sociotechnical innovation, emerging from the co-production in social learning and reflexive experimentation. This case study showed that this technology opened up access to modern cooking fuel in rural Thailand and assisted in sustainable development, not only in underlining the practicality of the *moso* philosophy. Although local and rural, this innovation scaled from household to household, displacing unsustainable, imported, polluting, and expensive fossil fuels in the process. This innovation, however, could not have prospered in the absence of social learning through reflexive experimentation by ordinary farmers in their role as technology end-users. This co-production highlights how this innovation was both a technological and a social project that provided meaning to the concepts of energy justice and energy democracy as a practice in everyday life.

The success of Pa Deng's balloon-type biogas digesters as an object of sociotechnical innovation and as a mode of local energy transition can be attributed to several drivers. The innovation was borne out of the end-users needs, developed by the locals, and diffused in a community where people know and support each other that is almost free of external intervention (cf. Khandelwal et al. 2017). However, this arrangement and other conditions such as low cost and ease of use may not always be present in other rural communities. Replication, diffusion, and, consequently, scaling this technology and similar ones will still need adequate support in policy, capacity development, financing, and programmatic support (cf. Yousuf et al. 2017; Delina 2017, 2018a).

As this case study had shown, innovation is also co-producible in the fringes. It also underlines the capacity of ordinary, rural laypeople to co-produce objects of innovation *in situ*. In their social learning, rural people proved that ordinary citizens could produce exemplary experimentations and sociotechnical innovations scaled in similar contexts and geographies. Their innovation may be common, yet their indigenous solution is elegant. This local innovation, however micro, local, and ordinary, was a cause célèbre in the global project to improve quality of life, achieve just and sustainable development, and mitigate accelerating climate change.

The complexities, trade-offs, and uncertainties of this innovation further offer essential insights. Despite the absence of state support, the *moso* network thrived and evolved through continuous political negotiations and societal tensions (cf. Moolaert and MacCallum 2019; Pel and Kemp 2020; Westley and McGowan 2017). In short, the practice was never rosy. Notably, not every household in Pa Deng is part of the network, exemplifying its exclusionary characteristic, limiting the innovation's transformative power (cf. Arentsen and Bellekon 2014). As end-users continue to experiment with their technologies, it is also important to underline the risks and uncertain outcomes of their experiments (Hiteva and Sovacool 2017; Antadze and Westley 2012). Users should be aware of these technologies' trade-offs, unintended effects, and uncertainties (Delina and Janetos 2018).

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