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Taboos, toilets and biogas: Socio-technical pathways to acceptance of a sustainable household technology

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ABSTRACT

Toilet-linked anaerobic digesters (TLADs) can provide users with a clean gaseous fuel and a fertiliser product as well as offer waste management services. Socio-cultural resistance towards domestic TLADs, due to the use of human excreta as a feedstock, is often articulated as a finite barrier to adoption. However, no research has specifically investigated the issues associated with TLADs separately from those associated with domestic digesters without toilet connections, consequently, there has been little attempt to discover what motivates users to use TLADs. Drawing on qualitative data from Nepal this paper explores how socio-cultural resistance impacts TLAD adoption and subsequent use of the biogas, and how adoption and transition pathways evolve. We argue that socio-cultural resistance is not a finite barrier to adoption and the opportunity to observe or trial a TLAD can positively influence adoption, especially amongst the older generations. Technical issues affected how TLADs were utilised more than socio-cultural norms and we discuss how socio-technical factors might co-evolve to influence sustainable adoption and use of TLADs. Caste and gender were not found to influence adoption pathways as much as the leadership or 'risk-taking' characteristics of specific adopters. Adoption of TLADs can occur within a year of a user first observing or trialling a TLAD; however, most users still do not use biogas for ritual cooking, despite having had a TLAD for many years. Grassroots initiatives that understand the diversity of localised socio-cultural norms will likely be imperative for successful TLAD dissemination.

1. Introduction

Globally it is estimated that three billion people, predominantly in low and middle-income countries (LMICs), cook using kerosene and solid fuels such as wood, crop wastes and dung in open fires and inefficient stoves [1]. These fuels and practices can lead to high levels of indoor air pollution, which is estimated to cause up to four million premature deaths from associated illnesses [1]. These health burdens disproportionally affect women and children who, due to gender norms, perform both the majority of the cooking and fuel collection [2–4]. The harvesting and burning of solid fuels for domestic purposes can also lead to deforestation which has a negative effect on a range of ecosystem services, with subsequent negative impacts on those people who rely on forests for their livelihoods.

Domestic biogas is considered to be a clean cooking alternative for rural populations in LMICs [5–7]. Adopting biogas can reduce the amount of time spent collecting solid fuels and reduce the health burdens associated with the burning of solid fuels [2,3,8]. Biogas is generated when organic materials are decomposed in the absence of oxygen in an anaerobic digester [9–11]. Typical household feedstocks include animal dung, food and agricultural waste, and toilet waste. Animal dung is the most commonly used feedstock and users are often required to have a minimum number of livestock before adopting biogas technology [12,13]. Domestic biogas technology thus provides a waste management service in addition to providing energy. A typical set-up of a fixed-dome anaerobic digester, common across China, Nepal and India [5,11,12,14] is illustrated in Fig. 1.

In addition to biogas, domestic anaerobic digesters also produce

Abbreviations: TLAD, toilet-linked anaerobic digester; DFAD, dung-fed anaerobic digester; HE, human excreta.

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slurry as a liquid by-product. The slurry can be used as a plant fertiliser because the process of anaerobic digestion converts nutrients into a form more readily available to plants than the feedstocks from which it is derived [15]. Further waste management benefits are gained when a household connects their domestic toilet to the anaerobic digester, which improves sanitation provision and can increase biogas production [5,14,16,17]. Inadequate sanitation is estimated to cause 432,000 diarrhoeal-related deaths annually and is linked to the transmission of many diseases such as cholera, hepatitis A, typhoid and polio [18]. The leaching of faecal waste from basic latrines and toilets into the environment is a common hazard in LMICs where there can be inadequate means of disposal [19] or where high groundwater and/or monsoon rains increase the risk of human pathogens contaminating drinking water sources [20]. The process of anaerobic digestion can also reduce the odour of feedstocks, which is perceived as an additional benefit of the waste management service [21,22]. Users of domestic anaerobic digesters have the flexibility to manage fluctuating health, labour availability and markets because they can choose between expending labour on running a digester to obtain the biogas and slurry, or purchasing gas fuel or fertilisers depending on their circumstances [23].

A summary of the potential benefits that TLADs could offer are presented in Fig. 2. Despite the additional services that connecting a toilet provides, TLAD adoption is much lower globally compared to domestic dung-fed anaerobic digesters (DFADs). This has been ubiquitously attributed to socio-cultural resistance by users due to the use of human excreta (HE) as a feedstock [12,25–27] which is often articulated as rejection and an insurmountable barrier to adoption for new users. Consequently, there is a need to broaden our understanding of the meaning of socio-cultural resistance and its drivers.

The research gaps can be reductively grouped into two areas with the first being about adoption of the technology. Importantly, no studies have explored how existing users of TLADs have overcome socio-cultural resistance, what motivated them to do so or what the perceived benefits and challenges posed by TLADs were. Additionally, despite the differences between DFADs and TLADs previous studies have not differentiated between them and so the specific socio-technical opportunities and challenges facing TLADs, from the adopter perspective are unclear. The second research gap is about the technology use; households use a range of fuels to meet their energy needs, which is known as fuel stacking, where selection for use is based on factors such as traditions in cooking practices, availability, perceived costs and benefits, labour and income [28–30]. Despite this broader understanding of the complexity of household decision-making around fuel use, the rejection of TLADs and the biogas they produce is often reported as being a binary decision. Whether varying levels of socio-cultural resistance of TLADs exist across different cooking practices has not yet been determined. This paper seeks to address our lack of understanding about the drivers of socio-cultural resistance towards TLADs and the complex decision-making process associated with the adoption of the technology by investigating TLAD uptake in a case study area in Nepal. Whilst extensive literature exists around why traditional fuels are maintained over improved fuels and stoves like biogas [31–33], this study investigates how socio-cultural norms have been navigated or overcome to identify potential adoption pathways of the whole TLAD system, which can include additional health, sanitation and sustainable livelihood benefits.

Many Asian and African countries have had notable national domestic biogas programmes [5,34], but Nepal's is commonly credited with being a success story [14,34] especially in regards to the number of toilet connections it achieved. In 2015 Nepal's domestic biogas programme had installed approximately 350,000 domestic biogas units and of these up to 79% had a connected toilet [35,36]. Nepal's relatively high uptake of toilet connections challenges the perception that biogas and slurry made from HE are not acceptable due to cultural beliefs as Hinduism, the dominant religion in Nepal, has a strong cultural grounding in purity and pollution practices [14,37]. Nevertheless, neighbouring India, which has similar demographics and socio-cultural norms, has much lower levels of TLAD acceptance and adoption [12,25]. To date, no research has investigated how pathways to TLAD adoption were forged in Nepal, how the biogas and slurry are used and if and how socio-cultural resistance has shaped these decisions.

Thus, the overarching aim of this case study was to explore the socio-technical pathways and barriers to adoption and acceptance of TLADs in the cultural context of Nepal and make recommendations for future approaches to the transition to TLADs in similar contexts. Specifically, our objectives were to determine: 1) the motivation, and pathways to acceptance, of users who have adopted TLADs and therefore overcome socio-cultural resistance; 2) How socio-cultural norms shape the ways that TLAD biogas and slurry are used and the reasons why; and 3) the socio-technical opportunities and challenges associated with TLADs.

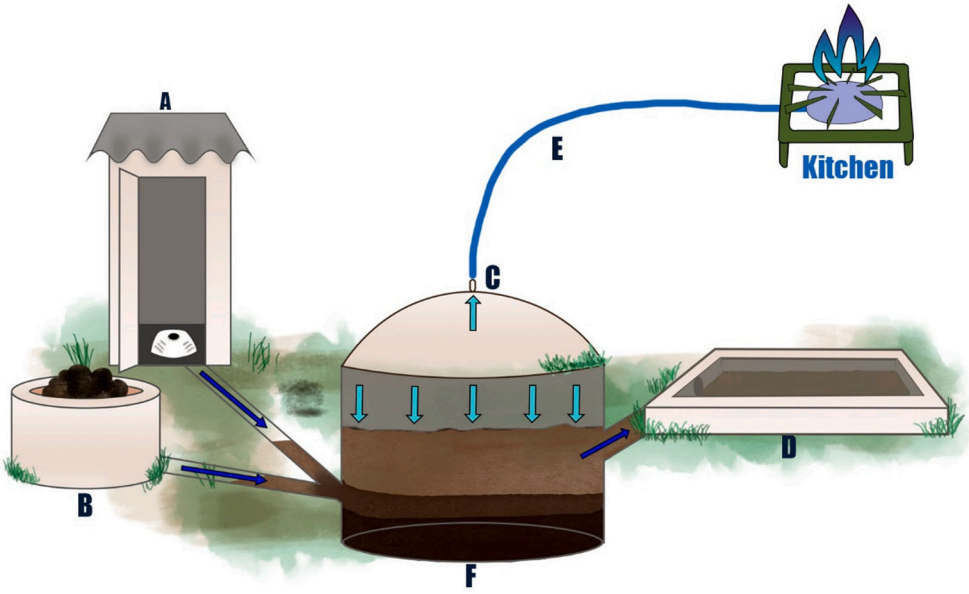

Fig. 1. Illustrated schematic of a fixed-dome toilet-linked anaerobic digester (TLAD). Dark blue arrows depict the flow of feedstock and the light blue arrows, show the flow of biogas. The feedstocks from A) the toilet and B) the cow/animal dung and other organic waste inlet flows into the digester (F) after mixing with water. As the organic waste decomposes biogas builds up inside the digester and flows through a pipe (E) directly to the kitchen stove via a pressure gradient. The production of biogas increases the pressure inside the fixed dome structure (C) and forces the by-product of the process (a nutrient rich, and predominantly liquid product called slurry that can be used as a plant fertiliser) out and into the slurry storage area (D). Typically, the biogas dome (C) is all that can be seen above ground of the main digester, though in some cases both (F) and (C) are buried underground. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

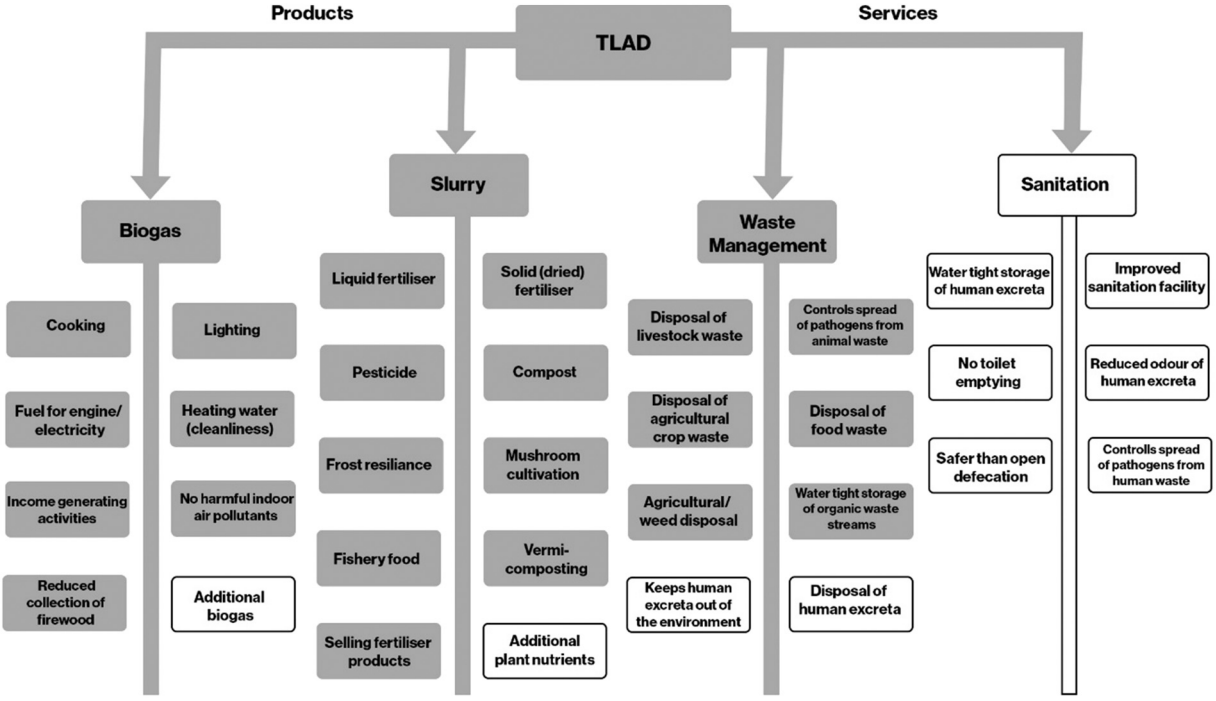

Fig. 2. Summary of the benefits of a toilet-linked anaerobic digester (TLAD) adapted from [24]. The benefits offered by domestic dung-fed anaerobic digesters (DFADs) are shown in grey and the additional benefits offered by a toilet connection are highlighted in white.

2. The Nepal context and literature review

2.1. Biogas in Nepal – programme and policy evolution

Nepal is predominantly a rural society where farming practices complement the use of domestic biogas technology [36]. More than 80% of the population relies to some extent on subsistence agriculture and many have cattle living in stalls adjacent to their house [14,36] providing a regular and easily accessible supply of dung. Nepal's nationwide biogas programme began in the 1970s and is still in continuation today though the programme has evolved over time. The programme pioneered a public-private approach to biogas dissemination and was supported in later years (1992–2010) by the Netherlands Development Organisation (SNV) and other international donors [36]. During this phase, the Biogas Support Programme (BSP) was launched to promote biogas, train skilled staff, and set up regional biogas companies. They also provided subsidies that helped users cover costs and incentivise good construction. Biogas companies were only reimbursed the subsidy if they built satisfactory models [38].

From 2003 to 2010 a government ministry, called the Alternative Energy Promotion Centre (AEPC), became the main executing body and was set up to fully take over promotional activities, policy development and funding coordination in 2010 when the SNV phase came to an end [36]. While the subsidy model remained, the execution of the programme became more state-led, and top-down, with less quality control checks, more focus on annual targets and had a reduced overall budget [36,39].

Despite its perceived success, the biogas programme in Nepal has been criticised for its ineffectiveness at reaching the rural poor. Though regulated, the private sector involvement does not incentivise private contractors to approach poor households who are less likely to adopt the technology [13]. The subsidies are criticised as biogas remains unaffordable for poorer households. Uptake has also slowed in recent years due to modernity and migration changing the shape of village life; migration is leaving many villages depopulated (leaving just the elderly), the land uncultivated and the livestock population diminished [40].

2.2. Geographical and cultural context

Nepal was never colonised and although it has been the recipient of much foreign aid money it has managed to keep some autonomy in its socio-political life [41]. Subsequently, Nepal has experienced several grassroots development success stories in addition to the BSP such as the community forestry initiative [42,43]. It is, however, a country affected by natural hazards and periods of inconsistent political leadership [44]. Nepal has the capacity to generate all its required electricity (and more) from its hydropower potential but has never accumulated the political will nor economic and knowledge capital to achieve this [8,45,46]. Thus, it has remained dependent on India for fossil fuel imports. As a result, Nepal's people have historically had to manage both manmade, and natural hazard-induced energy deficits such as the Indian fuel blockades of 1989 and 2016 [47], frequent load shedding, and earthquakes and landslides, which can cut off fuel and other supplies delivered by road. Such disruptions to the energy supply often result in significantly inflated energy costs, which in the past has increased interest in biogas [36].

In addition to the geographical landscape pressures, it is important to understand more localised and day-to-day socio-cultural norms that characterise the adoption context and shape adoption pathways. In Hinduism, physical and ritual purity are not synonymous with each other [48,49]. Cow dung for example, which could contain human and zoonotic pathogens, is revered and is often used as a purification agent [48,50]. In contrast, a toilet within the home, despite being physically clean, can still be interpreted as ritually polluting [49]. The ritual pollution of an individual is associated with the caste they are born into

within the Hindu social system, (the caste system[1]) and is reinforced by occupational practices [51–53]. Occupations such as toilet cleaners have been traditionally forced upon groups from lower castes, and to avoid perceived pollution, people of higher castes segregate themselves from these occupations and the people that perform them [54,55]. People belonging to the higher castes will sometimes refuse to invite people of lower castes into their homes and refuse to accept water or cooked food from them [48,56]. There have been instances in Nepal where neighbours of TLAD adopters are reluctant to visit or eat food at their neighbour's house [31]. Open defecation (OD), the practise of defecating in fields and water bodies can be prevalent in rural populations where socio-cultural norms together with necessity, perpetuate this behaviour [57,58]. Adoption pathways could be shaped by these complex taboos and socio-political implications around toilet use and emptying.

TLADs offer diverse benefits across multiple household domains suggesting that adoption pathways will interact with socio-cultural norms inherent within a diverse range of day-to-day practices. In Hindu village life, religion is not confined to the realm of the personal but cascades into practical life [56,59,60] where many daily acts are performed to maintain the purity of the home and body. It is useful to contextualise how villagers might understand ritual pollution surrounding cooking, eating and defecation, all of which may influence TLAD adoption. Some of the day-to-day practices that will interact with TLAD adoption pathways in various household domains are shown in Fig. 3, which illustrates where the use of biogas and slurry derived from HE could oppose traditional socio-cultural norms and influence user's decisions to adopt a TLAD.

2.3. Transitions: caste and gender

The adoption of new energy technologies is often not linearly correlated to the needs of the adopter, affordability or health agendas [26,32], for example, in India people use liquefied petroleum gas (LPG) because it improves their social status [32]. Caste has also been shown to have an important role in influencing adoption pathways to improved cookstoves in diverse ways [51]. Some higher caste households, for example, have chosen to maintain high smoke-producing cooking practices due to associations with ritual purity, whereas some lower caste households were motivated by the increased cleanliness of their homes offered by improved cookstoves. Alternatively, lower caste households may implement more stringent traditional cooking practices, to show commitment to purification and ritual practices as a way of improving social status [67].

Group membership and social status can also ensure access to resources [68], whereby access to a variety of energy technologies in Hindu contexts can be dependent on caste-based relations that favour higher castes [12,69,70]. An individual's caste and social status are more than a title, they embody them, and their positions within the social system can be fluid. People of lower caste, through a process referred to as Sansritisation, seek to increase their social position by adopting the practices and behaviours of higher castes [67], for example, through conducting certain religious rites and abstaining from alcohol and eating meat (which is traditional for the priestly Brahmin caste). A Hindu can also lose their caste status for various reasons including breaching caste boundaries, such as through marriage to someone of a lower caste [52,56]. Thus, through embodiment of caste an individual's behaviour could affect their ability to obtain access to resources. Understanding this is imperative to explaining why an individual might not change their behaviour or adopt a new technology despite there being an economic incentive. Theories of practice can help explain this complex decision-making within the social context [71–73] and clarify why the needs of an adopter are not always correlated to adoption. Bourdieu [74] theorised that there are three types of capital; economic, social and cultural and that when people make a decision, they are weighing up these forms of capital [73]. Social and cultural capital help people gain access to resources; they can be gained and lost, not by individuals alone but in terms of collective status, and have a direct impact on survival and quality of life that may or may not be convertible to economic capital [52].

Women in Nepal often hold the responsibility of collecting solid fuels and cooking [14,56,62] and thus stand to benefit the most from the reduced labour and indoor air pollution offered by TLADs [34]. Women are also more vulnerable to attack and sexual harassment during OD [20,75]. However, women often do not have the purchasing power to obtain new technologies and are subject to different social pressures than men such as maintaining the purity of the kitchen and family meals [32,56,76,77]. Traditionally, women in Nepal are the primary cooks, which means that women will be able to provide detailed insights into how TLAD biogas is adopted and socio-cultural norms around cooking navigated. Transitions to TLADs are complex as the main beneficiaries are not always the buyers.

3. Study site and methodological approach.

3.1. Case study location and context

Fieldwork was conducted in four rural villages outside Pokhara, the second largest city in Nepal. Pokhara is situated in the Hilly region of Nepal within the Kaski district of Province 4 (Fig. 4), where high levels of biogas penetration have been reached [23]. There are seven provinces in Nepal and Table 1 compares Province 4 to other provinces across several categories. Province 4 has the highest food security of all provinces and falls somewhere in the middle of the seven provinces in terms of educational attainment and wealth. The Kaski district was the first to be declared open defecation free (ODF) suggesting high levels of sanitation awareness and adoption in the area [78] although there are similar numbers of toilet-connected biogas in the Hilly and Terai regions [35]. In diverse societies like Nepal, where adoption contexts will be shaped by ethnic group, geography, ecology and socio-economic status more research studies will be necessary to explore and generalise the TLAD adoption pathways identified in this paper [31]. This study represents how adoption pathways could be forged around socio-cultural norms in a geographical context that supports TLAD adoption. The study sites were selected due to the prevalence of functional TLADs, which was informed by using local actors with grassroots knowledge of construction locations.

All households had (or once had) cattle in stalls adjacent to their homes and practised subsistence agriculture. A total of 88% of participants listed agriculture or dairy farming as a source of income but no household listed it as sole income. Due to the proximity to Pokhara some had businesses or worked in the city. In addition, 30% of participants listed remittance income from abroad as a main or secondary form of income. Migration for work is common in Nepal with 47% reporting that at least one person had migrated from the household in the last ten years

[1] Caste may be defined as a named group of persons characterised by endogamy, hereditary membership, and sometimes the involvement in a particular occupation [53]. However, it is important to understand the historical implications of colonialism on interpretations of caste and that the system is not universally the same across South Asia. In a reductive summary, Nepal's caste system constitutes the elite Indo-Aryan Hindu castes such as the Brahmin/Chetri castes, Janajati/Janjati castes who are Nepal's Tibeto-Burman indigenous groups (corresponding to what are officially classed as Scheduled Tribes in India) and the Dalit caste; those historically most stigmatised and who have been forced to perform the roles of manual scavengers because they are considered 'untouchable' [54,55,64,65]. High caste groups are historically the landowners and the priest castes. They maintain a high state of purity that means they often do not eat meat, cannot accept water or cooked food from lower castes and do not engage in polluting occupations such as working with leather, meat and cloth [48,66,67]. Other religions have places in the caste system depending on the ethnic origin of members [64].

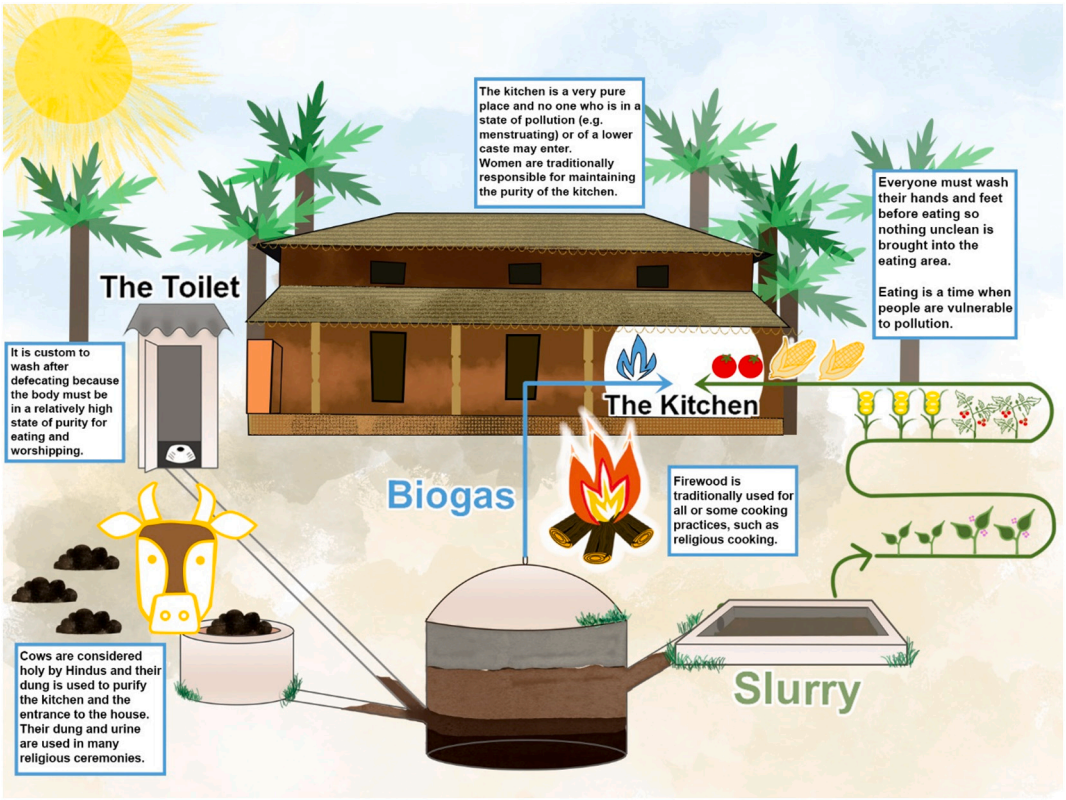

Fig. 3. A toilet-linked anaerobic digester (TLAD) within a traditional Nepali village home showing how TLADs connect human excreta with cooking and eating. The text boxes describe some socio-cultural practices around, cooking, eating and defecation that are performed to maintain purity in rural Hindu Nepal [56,61–63]. The illustration contextualises how these socio-cultural norms might influence decision-making across household domains when adopting or using a TLAD.

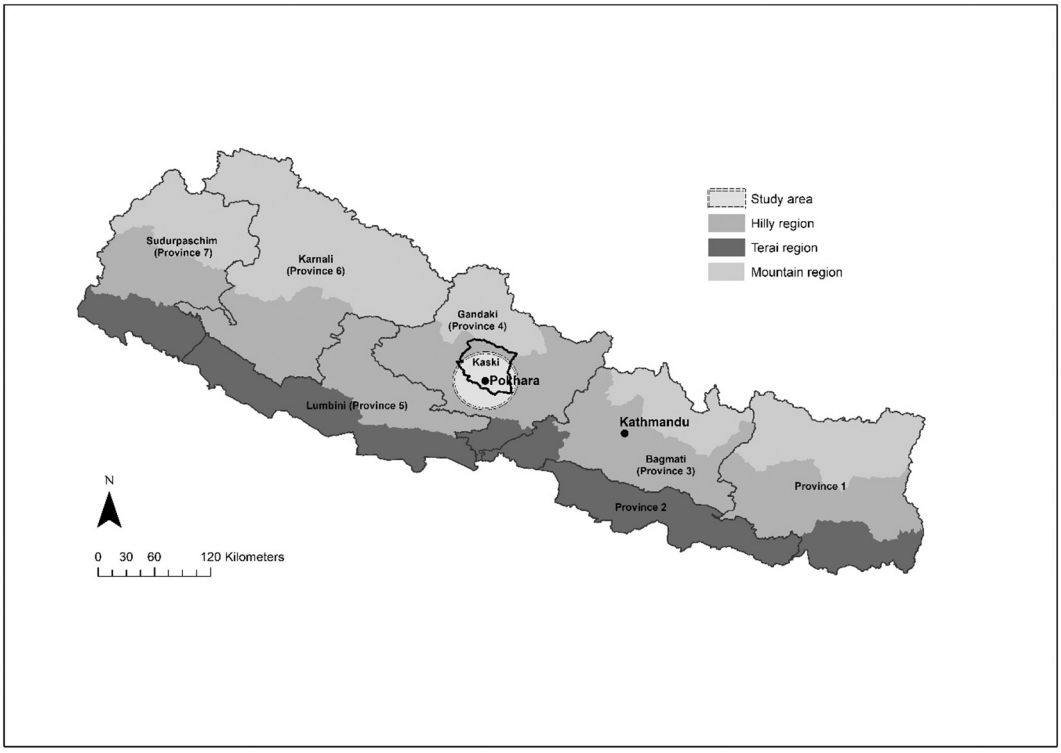

Fig. 4. Map of Nepal and location of the study area sourced from [79].

Table 1
Demographic statistics for Province 4 compared to highest and lowest value of same category in other provinces taken from the 2016 Demographic and Health survey in Nepal de facto population [37].

Category (% of province)	Province 4	Lowest value across all provinces	Highest value across all provinces
Classed as severely food insecure	6	6	17.5
Classed as food secure	56	22.5	56
In the lowest wealth quintile	22	3.9	69.1
In the highest wealth quintile	20.4	2.6	41.6
With no education (F/M)	34.5 / 17.2	33 / 15	52.9/ 30.6
With higher than secondary education (F/M)	11.1 / 13.5	3.3 / 8.3	17.7 / 22.4

[37]. All participants in this study had a TLAD, and access to LPG or biogas (two TLADs were broken and no longer producing biogas), they also had drinking water within their premises and an improved sanitation facility (TLAD or septic tank if TLAD was no longer functional) and all were electrified. In comparison, at the national level, almost all households (95%) (rural and urban) have access to an improved source of drinking water and 69% of households have drinking water on their premises. Overall, 63% of households in rural areas use improved toilet facilities and 21% have no toilet facility. In total, only 11.5% of rural households use either LPG/natural gas/biogas compared to 77.3% of households that use wood fuels and 10.5% who use other solid fuels [37].

3.2. Data collection and analysis

Data collection was carried out in August 2019. Due to the explorative nature of the research questions, in-depth semi-structured interviews with 17 participants were used as the main data collection method to obtain detailed narratives of experiences of TLAD adoption. The interview schedules were structured around the adoption and use of TLADs within village and household socio-cultural norms. The questions were broad and did not attempt to direct participants to any one experience of TLADs to ensure decisions around adoption were collected from the user perspective without framing TLADs predominantly as an energy technology. Participant observations, pictorial evidence as well as conversations with two biogas technicians that had installed TLADs in some of the households visited were also collected and used to supplement the data (Fig. 5).

The recruitment criteria for this study was necessarily broad due to the exploratory nature of the research questions; the overarching selection criteria was that participants had a functional or non-functional TLAD. Although producing generalisable results was not an aim of this study, to ensure different socio-demographic perspectives were captured, purposive sampling was applied to include both male and female participants from a variety of caste backgrounds. Of the 17 participants, 10 were female and seven were male (all were of Hindu faith, of whom 10 identified as Brahmin, five as Dalit and two as Janajati). The age of participants ranged from 24 to 80 with the majority being between 40 and 60. Interviews 1–11 were conducted in village 1 where the fieldwork team were met on arrival by a local male gatekeeper and introduced to other members of the village where they used a snowballing technique to recruit participants. Additionally, the female fieldwork team walked around the village independently recruiting female participants. This allowed for in-depth conversations with females where they could freely talk about what they considered important and how they use biogas. The research team visited villages 2, 3 and 4, which closely neighboured each other, with two male biogas technicians who introduced the fieldwork team to households where they had installed TLADs. The research team requested that they be taken to households from various ethnic backgrounds.

The interviews were conducted and recorded in Nepali and transcribed into English for thematic analysis using NVivo 12 software. Braun and Clarke's [80] phases of thematic analysis were followed and the identified themes were taken from the explicit surface meanings of the data rather than looking beyond what participants said. The research objectives were used to generate initial themes. To reduce researcher bias, open coding was subsequently applied to the data to identify emerging themes beyond the research questions. This ensured that the data was captured and coded from the participant's perspective. Because the interviews were loosely structured and the study aimed to collect qualitative experiences of TLAD adoption to describe and hypothesise how pathways to adoption can be forged and not to generate generalisable results, it was not considered appropriate to base analysis on any quantification of results [81]. However, numbers of participants that contributed to a theme have been presented occasionally when it was felt appropriate to draw attention to, and contextualise, a particular finding for the reader. As this is a qualitative scoping study, quotes have been included to recognise the diversity of participants and individual voices, and to add richness to the narratives provided [82]. TLAD adoption has been rarely reported within academic literature therefore the authors felt that it was important to contextualise the lived experience of TLAD adoption from the participants perspectives [83]. We have used quotes only to clarify or describe discussed themes, which is a common method for showcasing individual lived experiences of participants [28,32,72,83,84].

All participants gave written consent to participate. Ethical approval was obtained from the University of Stirling General University Ethics Board before commencement of fieldwork.

4. Findings

4.1. Motivations for, and pathways to, adoption of TLADs

The socio-technical motivations for TLAD adoption were diverse. Respondents liked the improved health, cleanliness and reduced wood collection offered by the biogas compared to wood fuel and the reduced cost compared to LPG. Several female respondents also mentioned that when cooking with biogas they can leave to do other activities whereas with wood they must stay and tend it. All respondents felt that having a TLAD had made their lives more comfortable. However, with loss of cattle and migration from the villages TLADs were not universally seen as a long-term solution that people will keep investing in, although many appreciate TLADs for their sanitation benefits even without much biogas production.

The toilet connection specifically motivated six participants to adopt a TLAD, and others listed the toilet connection as a key benefit. The socio-technical reasons given encompassed practical aspects such as reduced smell and emptying costs as well as emotional benefits. Perceived benefits of the toilet connection were the same regardless of gender or caste, but female participants spoke in more detail about emotional benefits of the toilet connection.

> *"Emptying a latrine is stressful as we need to call a vacuum truck for emptying it but with TLAD there is no such issue, so it is more comfortable than a latrine"*

Fig. 5. a: TLAD in a rural household in Nepal. The components of the system are as follows; Cow dung and food waste inlet (A) Toilet (B) Animal holding close to house and digester (C) the main TLAD digester dome is situated underground (D). **b:** Two cow dung and food waste inlets. (A) shows the inlet with cow dung prior to users mixing with water and moving a stone that blocks the inlet pipe to the digester so the liquid mix can fall via gravity into the digester, (B) shows an empty cow dung and food waste inlet next to the toilet (blue door) and rice field behind the house, the slurry exits the digester and flows freely into the rice fields or can be composted first. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Female #12 V2 Janajati 48)

"Everyone has a TLAD here. Before there were no toilets at home and I had to go in the field for toilet [and] … we had to cover our face with cloth which was really shameful and hard. After we had TLAD at home it is like a palace for us."

(Female #9 V1 Brahmin 62)

Two participants from village 1 also mentioned that ODF programmes in the local area, that include fines for practicing OD, encouraged them to install a TLAD as a toilet. However, it was observed that, at least for some villagers, females were not allowed into participant's houses or to touch anyone when menstruating and in a state of pollution. This example shows that traditional practices around purity and pollution were not abandoned when TLADs were adopted, instead a new equilibrium has been found.

Adoption pathways were shaped by individual personalities and experiences. Analysis revealed the respondents to be on a spectrum from risk-takers or leaders to more hesitant adopters, but most could be loosely sorted into two groups. The remainder fall somewhere on the spectrum or not enough information was obtained to place them in a group. The first group of respondents (3/17) were risk-takers or leaders of TLAD adoption. They adopted a TLAD before they had experienced its benefits or before they had the support from their families and villages. For this group loss of social and cultural capital was not heavily factored into decision making and the decision to adopt was because they were convinced by the practical benefits of TLADs.

"Yes! That time was hard for me. People who used to pass by my home always used to say in this house they eat foods cooked from the [HE]

smoke. I was not discouraged with what villagers thought. I just wanted my life to be comfortable which it was after installing biogas
I was a policeman and when I was in Pokhara and I met people from a national biogas company. They told me about TLAD in detail…. and I was convinced to have one."

(Male #4 V1 Brahmin 60)

One of the participants in the risk-taker group was the wife of a local biogas technician (not a technician involved in this study), they were one of the first households to install a TLAD in their village area. In addition, another member of the risk-taker group was a policeman who met biogas company representatives whilst working, which suggests that risk-takers could include people that have had access to more detailed knowledge of TLADs. The second group of respondents (9/17) adopted a TLAD or chose to eat food cooked on biogas once TLADs had become more normalised for them through direct or indirect experience.

*"**Participant 17:** My husband he used to hesitate to have food cooked in biogas. He used to ask me to cook in wood fire and said 'I will not eat food cooked from [HE]'*

***Husband of participant #17 who was present for the interview:** I changed my mind over time. After a year it did not take long time since I had it in my home, I saw the process of biogas and I was OK"*

(conversation with Female #17 V4 Dalit 54 and her husband)

"Before when the first man used biogas [#4] as a fuel, we also did not like it. We used to think how they can eat [food] cooked from HE. But I found it interesting thinking of how that house is facilitated and I went to see it. After using LPG, we just thought about the process of LPG production…. and we convinced ourselves that biogas is also just a gas there is no difference to use biogas as a fuel"

(Female #5 V1 Brahmin 40)

The comparison of biogas to LPG was mentioned by four participants and a 'gas is gas' mentality helped them to accept biogas. One participant mentioned that they did not know how LPG was made but thought it was very similar to biogas, and after observing priests using LPG he was convinced that biogas must be acceptable for religious cooking.

Many responses revealed that in general, the older generation needed more opportunities to observe TLAD before they overcame their socio-cultural reservations. However, some never accepted TLADs even after having one in their home.

"[In reference to his mother] I tried to convince her saying that LPG gas is the same so don't hesitate to eat [from] biogas but she used to say 'I have not seen the process of LPG production but I know about the production of biogas and that it is made from HE and dung so I cannot eat food cooked from biogas"

(Male #6 V1 Brahmin 65)

Despite this, the initial adoption of TLAD systems took less time than transitions to using biogas for religious cooking. Participant 4 who was the first to get a TLAD in village 1 observed that within a year other villagers were installing TLADs. The husband of participant 17 also shared that within a year he had accepted having a TLAD at home but was not using biogas for religious cooking. Many other participants were also not using biogas for religious cooking despite having one for many years.

4.2. How socio-cultural norms shape the ways that TLAD biogas and slurry are used and the reasons why

The uses of biogas and slurry were restricted for some participants depending on a range of socio-technical influences. Biogas was used by all participants for some cooking practices although the majority across all caste groups did not use it for religious cooking practices, where cooked food is offered to the gods [14], and some did not use it for boiling milk or ghee. These decisions were linked to tradition and socio-cultural norms.

"I don't use biogas for boiling milk and ritual cuisine because of traditional practices that have been going on since our ancestors"

(Male #2 V1 Brahmin 51)

"I don't use biogas for ritual cooking because everyone in the village and our parents also say to cook ritual foods in wood fire"

(Female #16 V4 Dalit 29)

However, three participants said they have no reservations using it for ritual cooking and a further two suggested they possibly use it or could use it.

"Before I didn't cook food for ritual or worshipping purposes. Now everyone is educated and open minded, so we don't hesitate to cook things used for worship also"

(Female #5 V1 Brahmin 40)

Decision making about which cooking practices to use biogas for resulted in complex social interactions between the cook and their recipient. This often resulted in the cooks' selecting fuels based on what they were cooking, and for whom, adding consideration beyond food preferences. These individual aversions resulted from strong negative perceptions of biogas, such as the perception that food may be contaminated, rather than to negative experiences from cooking with biogas.

"My mother-in-law she doesn't like to eat bhaat [rice] cooked from biogas, but she will eat other things. It is because she thinks that the bhaat may absorb the smell of HE from the biogas, so I cook bhaat on LPG for her"

(Female #16 V4 Dalit 29)

In one instance, strong individual feelings around biogas use resulted in deception, whereby one participant pretended to use wood fuel to appease a family member.

"When my mother was alive, she would only eat when the cooking utensils were black [cooking utensils are clean if biogas is used but black when wood is used]. I used to pretend by just showing her black utensil, but I used to cook in biogas"

(Male #6 V1 Brahmin 65)

Slurry was discussed in less detail than biogas and had fewer restrictions placed on it. All participants that discussed the slurry indicated that it was a good fertiliser. However, some mentioned that they did not like to apply it when it touches the edible parts of food (author interpretation) such as vegetables and salad items. This decision was not articulated in the context of disease or bad experiences but just strong intuition that users had.

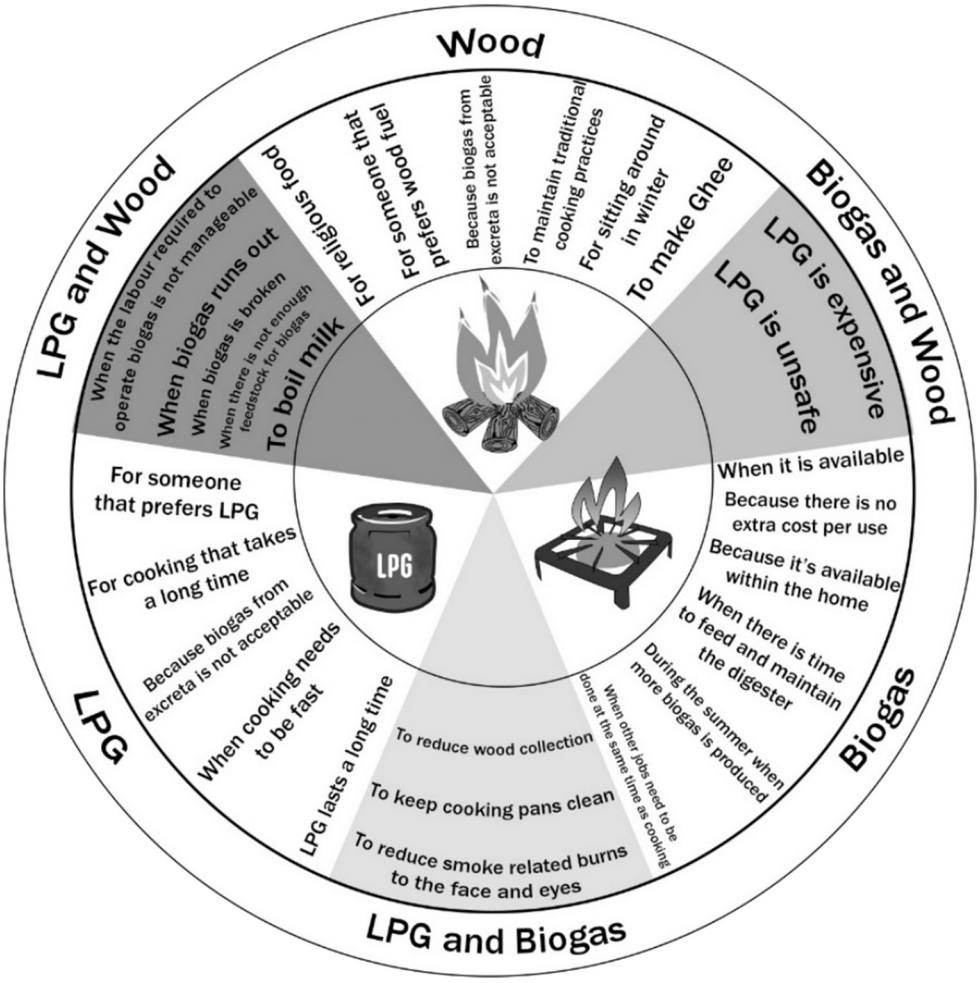

Fig. 6. An interpretative summary of why participants choose to use either biogas from toilet-linked anaerobic digesters, wood or LPG.

"I do not use [slurry] on vegetables because vegetables are smaller and I feel it will get directly absorbed in vegetables … so I just hesitate to use on vegetables"

(Male #6 V1 Brahmin 65)

"Fertilisers are not used for vegetables because … of the toilet waste. [We] hesitate to use it though it is a good fertiliser. It's just a thought nothing else"

(Male #1 V1 Brahmin 55)

It is evident that a wide range of socio-technical factors influence how biogas was used. A socio-technical interpretation of user choice relating to biogas, LPG or wood fuel is illustrated in Fig. 6. The quantity of biogas produced by the TLADs made a significant impact on when biogas was used. Many participants communicated that they only used LPG and wood when there was not enough biogas. Biogas reduction due to winter temperatures, breakages or loss of cattle and manpower all affect how much is available. Many of these circumstances are brought about by social factors; loss of cattle and manpower can be a result of migration and changing lifestyles [40] and repairs are carried out when they are affordable or when time can be prioritised.

"Since my biogas is only dependent on toilet waste…. it only lasts for half an hour, I cannot cook whole meals"

(Female #16 V4 Dalit 29)

Operational knowledge was lacking, and a few participants stated that they had received training when the TLAD was first installed but none since, although they would like more. Cattle loss results in a significant drop in biogas production but only some respondents knew about alternative feedstock such as goat dung and food waste, and others indicated they are not knowledgeable or confident trying different feedstock. Four respondents mentioned they feed animal bones in the TLADs which the biogas technicians confirmed can cause blockages.

4.3. Opportunities and challenges

The socio-technical opportunities and challenges facing TLAD adoption are interpreted and summarised in Fig. 7. The challenges most discussed by participants were affordability and technical issues commonly associated with domestic anaerobic digesters in general [4,25] rather than anything specific to TLADs. Although socio-cultural resistance was articulated as a challenge by some and does restrict the use of biogas, it does not prevent users from perceiving TLADs as beneficial overall. The biggest challenge to the continued adoption and use of TLADs is the resultant loss of livestock and labour due to urbanisation and migration. This is compounded by a lack of knowledge of other feedstocks to boost biogas production and the prevalence and affordability of LPG.

Fig. 7. Interpretive summary of the socio-technical opportunities and challenges for the adoption of toilet-linked anaerobic digesters from the responses in this case study and arranged into most frequently and less frequently talked about by the participants.

The most frequently discussed opportunities specific to TLADs were the improved ease and comfort together with the potential for improved health and sanitation. Participants also mentioned the practicality of installing a TLAD rather than a DFAD and a separate toilet in terms of saving money and space. Combining messaging on OD and sanitation with TLAD and domestic biogas marketing presents an opportunity for TLAD adoption. The widespread use of LPG also presented an opportunity for increased biogas adoption as people often compared biogas to the more socially acceptable LPG.

5. Discussion

Socio-cultural resistance is the most commonly reported barrier for TLAD adoption yet findings from this study suggest there are more complex socio-technical factors influencing acceptance or resistance. Biogas use was based on socio-cultural norms as well the quantity available, the slurry was used based on its performance and where users were confident using it. The rate of acceptance of both biogas and slurry varied with technical performance and perceived motivations [72]. Usage was also continually monitored against shifting social norms as well as external stimuli (such as breakages, migration) and thus transitions are continually evolving rather than being driven by binary decisions. Adoption therefore cannot be considered as a one-off decision; there is the initial decision to adopt a TLAD and then the incremental secondary adoption decisions where biogas and slurry are used for more practices. We identified a possible connection between user knowledge, technical performance and available alternatives and the combined effect they have on biogas and slurry selection. For example, if there was insufficient biogas, and LPG or wood were available, there is little motivation or necessity to overcome socio-cultural norms and use biogas for religious cooking. Similarly, if alternative fertilisers were available there is little incentive to use TLAD slurry on vegetable and salad crops. Although outside of the scope of this study, the application and use of slurry from TLADs is also a potential hazard to human health [85,86], and education on the safe handling and application of slurry could facilitate safer transitions. Previous studies have identified that factors such as technical performance, training and marketing are important in forging adoption and sustained use of domestic biogas [10,24,25,87,88]. However, TLAD adoption should not be solely interpreted as a technological transition where socio-cultural acceptance or resistance occurs separately as it is not reflective of the adoption pathways that are evolving. Transitions to TLADs are socio-technical transitions whereby society and technological relationships co-evolve [89–91] and due to the additional complex socio-cultural norms around HE, the socio-cultural interactions with TLAD adoption are heightened. Even though socio-cultural resistance did not universally lead to permanent barriers to adoption, it played a significant role in shaping how the biogas and slurry were used. Notable, however, is that these socio-cultural sanctions were not interpreted as additional barriers to adoption in themselves. There was no evidence that TLADs were rejected because biogas could not be used for all cooking purposes or the slurry for all growing needs, instead, they were used for activities that were perceived as being within the bounds of socio-cultural norms. This can be compared to many other improved cookstove and fuel adoption studies that find adoption does not mean that the new stove or fuel replaces traditional fuels or even becomes the dominant one [31,32]. It means that the adoption of TLADs cannot be assumed to result in maximal use of all the products and services TLADs offer. As Bennett's [56] observations show the practicalities of Nepali Hindu village life are driven by ritual undertones. Still, the common interpretation of religion, which is grounded in Western ideals, sees it as something restricted to the personal and not the physical and political realms of life [59,92,93]. This standpoint perpetuates the idea that technological and social evolution occur separately and that technologies solely fulfil a function [94]. When socio-cultural resistance encounters the practical realm of technology adoption and is interpreted through a lens of 'not belonging', it could be more easily interpreted as an insurmountable barrier to TLAD adoption. The unpacking of socio-cultural resistance in this study offers an alternative interpretation. It suggests that with time, socio-cultural norms shape adoption and use, as they do many other aspects of village life, but

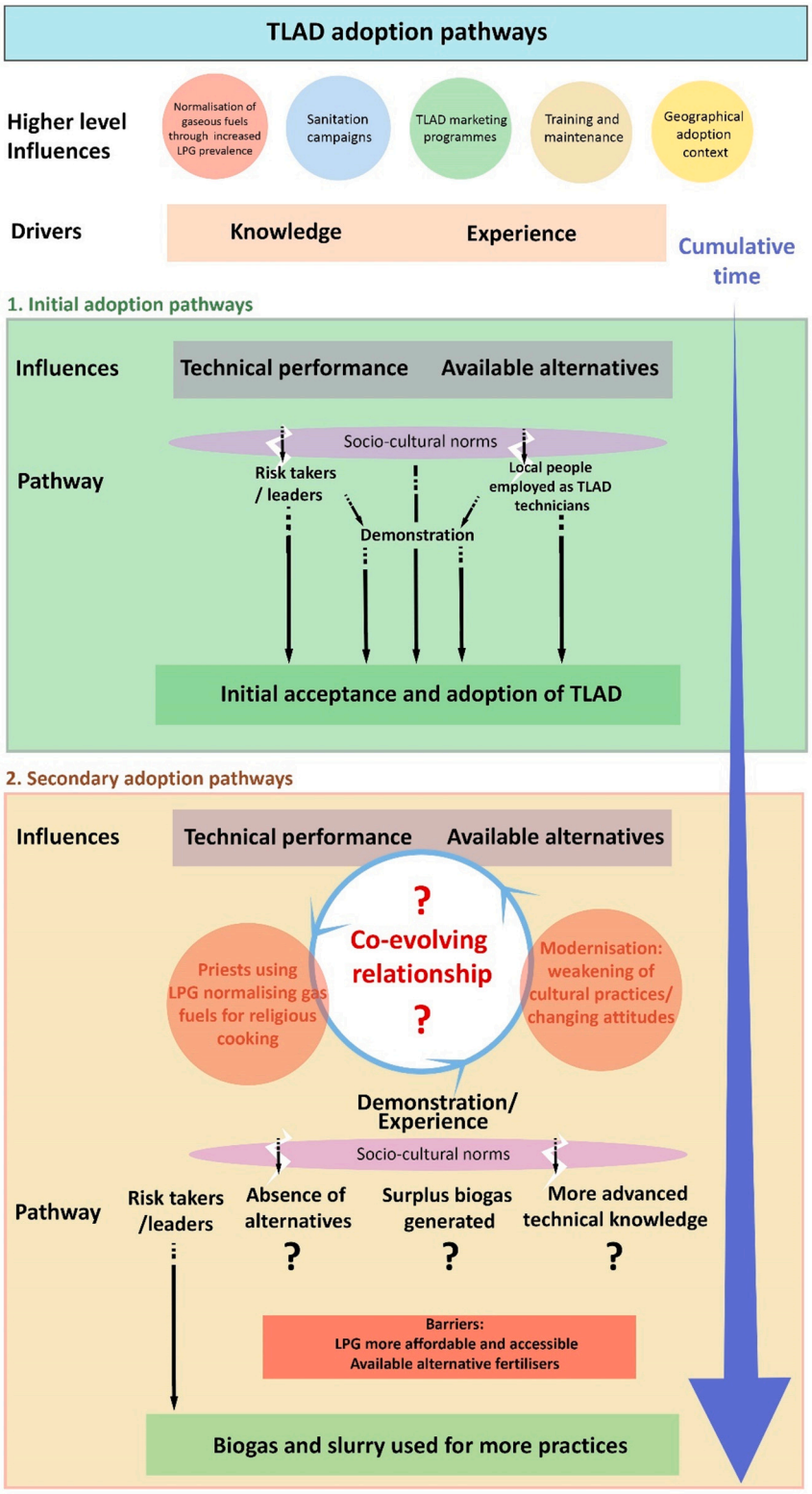

Fig. 8. Adoption pathways to initial adoption of toilet-linked anaerobic digesters (TLADs) and secondary adoption (increased or diversified use of TLAD biogas and slurry).

do not directly and irrefutably oppose it. Transitions to TLADs will be diverse socio-technical transitions that are unique to the context, but which may nevertheless follow similar pathways.

We have identified several pathways leading to the initial adoption of TLADs as well as increased or diversified use of TLAD biogas and slurry (i.e., secondary adoption) that are summarised and illustrated in Fig. 8. These overarching factors, that shape the adoption environment from a top-down or wider contextual angle, are shown as 'higher-level influences' and 'drivers' (Fig. 8). The first two identified pathways are 'risk-takers/ leaders', and 'demonstration', which encourages adoption as people see the benefits of TLADs. A third pathway identified was 'employment of local actors' who have TLADs within their own homes.

The fourth and fifth pathways were identified as the subsequent 'demonstration' (or ripple) effect that the risk-takers and employed local actors have on their communities by showcasing the benefits of TLADs. Demonstration and trialability are key drivers for technology and product adoption [95–97]. Due to the perceived risks TLADs pose to social and cultural capital, opportunities for trialability may be more important than with other technologies, and even with DFADs.

Risk-takers, participants who risked social and cultural capital in favour of adoption, played an important facilitation role in their communities adopting TLADs and using biogas, which suggests that they could be used to build pathways to acceptance [23]. Due to these locally specific pathways to adoption, grassroots initiatives will be important for disseminating information about TLADs. However, initiatives that use local actors should be careful not to accentuate existing socio-cultural and economic disparities [12,13,69] if they favour or exclude certain beneficiaries, and hetero- and homogenous community structure could affect adoption pathways [43]. The risk-takers were the only group willing to use biogas for religious cooking and thus were the only identified pathway to secondary adoption, although further research is required to determine how socio-technical factors co-evolve for secondary adoption. To encourage wider societal adoption of a new technology incentives are sometimes offered to influential members of a community to adopt and promote the technology to their neighbours [13]. Whilst it is possible that the identified risk-takers could have received such incentives there was no evidence of this occurring in the villages visited. Nevertheless, with or without incentives, adopting a TLAD risks an individual's social and cultural capital [31] due to opposing socio-cultural norms. Whilst no participant indicated they received such an incentive they did report social difficulties either within their household or village when they initially adopted TLADs. Therefore, the hypothesis that risk-takers could create pathways for community adoption of TLADs is valid, but more research must be conducted to test the hypothesis's generalisability and what factors beyond risk-taking motivated the first adopters of TLADs.

This case study was not intended to determine demographic influences on TLAD adoption, and the size of the respondent group means that generalisations are not appropriate. The literature suggests that socio-economic backgrounds (caste and gender) would likely influence adoption pathways based on different motivations and perceived benefits and challenges. However, we found that caste and gender did not shape adoption pathways in an obvious way and risk-takers were represented by all caste and genders within this group. The findings from this case study suggest that more emphasis should be placed on understanding diversity amongst demographic groups and its subsequent effect on adoption. A significant amount of research on the effects of gender norms and caste on decision making originates from India, see for example references [33, 51, 68, 69, 98]; however, the caste system in Nepal is different to India's and rural development has evolved differently in Nepal. The religion, caste or gender of the adopter might not always influence TLAD adoption as much as how religious they are or how caste and gender norms are embodied locally or generationally (older generations in this study required more opportunities to observe TLADs before they accepted them) as well as how much importance they give to how they, personally, are perceived. The adoption pathways that were identified were strongly dependent on individual personalities or core values [99] suggesting that pathways to TLAD adoption will be localised but could nevertheless, have patterns. Local participation in community forestry initiatives in Nepal, another successful grassroots development initiative, was negatively affected by economic and land inequalities amongst the groups as well as local perceptions of the initiative and its governance [43]. Ethnic diversity was not found to significantly impact success as it is so often reported to do in literature [43]. Supported by these results, the findings from this case study suggest that the adoption of TLADs will be affected by localised norms and differences within the community structure. Future research and dissemination of TLADs should now consider both overarching socio-cultural norms as well as localised norms and their effect on TLAD adoption pathways.

6. Conclusion and recommendations

Attempting to scale up transitions to sustainable livelihood practices and energy sources in LMICs is important for addressing the 'energy trilemma' [100], a term used to encompass the three challenges of energy security, climate change mitigation and energy access and equity. Thus, understanding transitions to decentralised renewable energy technologies [23,101,102] such as TLADs, which can facilitate more equitable access to energy as well as offer other sustainable benefits, is a necessity. Understanding consumer rejection of recycled products, which can elicit strong negative emotions is imperative if a more sustainable circular global economy is to be realised [103]. This paper is the first to inform an academic and wider understanding of socio-cultural resistance towards domestic TLADs and how pathways to adoption evolve within the Hindu context of Nepal. It provides a strong grounding from which further studies can explore adoption pathways to HE derived products.

Demonstration and trialability were found to play a pivotal role in facilitating users in contextualising benefits and overcoming socio-cultural resistance. Good technical performance, as well as training and maintenance services, fostered sustainable use of TLADs, especially when they are competing with available alternatives. Caste and gender did not shape adoption pathways in an obvious way but generational differences, and people with risk-taking personalities who were the early adopters and catalysed community adoption, did. Thus, adoption pathways will be diverse, and we recommend that grassroots initiatives are utilised in disseminating TLADs. In addition to this, a top-down vision of TLADs is needed to inspire change from a grassroots level as users required information, time and opportunities for demonstration to accept TLADs. A programme without commitment to promoting and installing TLADs will likely not be successful. More research must be conducted to test the generalisability of the hypothesised adoption pathways in other contexts, within and outside of Nepal. When conducting research in other geographical locations studies should consider the impact of environmental and social contexts on motivating users to adopt TLADs. For instance, local sanitation campaigns, number of cattle and climatic conditions. This study refrained from framing TLADs as an energy technology in order to learn more of the holistic motivations users had for adopting TLAD systems. Biogas production and its use is often the primary focus of biogas programmes and now adoption pathways are better understood, further studies are needed to investigate how TLAD biogas is used and stacked with other stoves and fuels. Similarly, substantial literature has drawn attention to the difference between adoption and use of technologies [31,32], with post-installation functionality rates of household biogas ranging from 30 to 90% [7,104]. Further investigation is needed to assess the role of different adoption pathways in the sustainable use of the technology.

Socio-cultural resistance, in most instances, was found to be a complex socio-technical phenomenon that evolved with time and exposure to TLADs and although it was not a finite barrier to adoption [96] it did significantly shape how TLADs, biogas and fertiliser products were used. The paper supports the idea that we must challenge and transcend the commonly conceived idea that culture stifles positive change, and; move towards seeing it as something that can enable adaptation [105]. While we accept the findings from this case study in Nepal cannot be generalised, our results do suggest that a lack of research that specifically unpacks the important role socio-cultural norms play in the adoption of TLADs, has led to an over-simplification of the barriers to adoption, and resistance being interpreted as rejection. Researching TLADs separately from DFADs reveals specific information about the adoption of TLADs that had previously been overlooked within the literature. If TLADs are to be promoted in more effective ways, they must be acknowledged as a unique biogas technology that requires a different approach that

understands localised socio-cultural norms and does not seek to homogenise groups.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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