BOTTLENECKS AND DRIVERS IN ETHIOPIA'S DOMESTIC BIOGAS SECTOR

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ABSTRACT

Ethiopia experiences an energy and environmental crisis due to the sustained reliance on woody biomass to satisfy its energy needs. A sustainable innovation that can improve this situation is domestic biogas. This paper analyses the current status of the domestic biogas sector in Ethiopia and identifies barriers and drivers that influence its development and further growth. The analytical framework used for the analysis combines the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM). The MLP consists of three levels: landscape, which contains national and global factors and trends; regime, which contains the current, traditional agriculture and energy sectors; and niche, in which the new innovation is being introduced. SNM looks into the niche level and investigates three processes: network formation, dynamics of expectations and learning processes.

The information sources are threefold: (1) desk study through literature and internet research; (2) online interviews and questionnaires with Ethiopian stakeholders; (3) an extensive field study including an extensive number of interviews with stakeholders inside and outside Ethiopia.

The biogas sector in Ethiopia started with the launch of the National Domestic Biogas (NBPE) programme in 2008, which has led to the dissemination of over 8,000 biodigesters up until now, about 60% of what was initially intended. At the landscape level, the use of domestic biogas has been triggered by Ethiopia's energy crisis as well as the suitability of the technology with the physical geography. However, the dissemination has been affected by factors such as economic instability, poverty and illiteracy. At the regime level, the inability of the traditional practices to solve the energy crisis has created a window of opportunity to provide alternative solutions that replace the use of firewood. However, many Ethiopian farmers are trapped in a lock-in, where due to their limited purchasing power they cannot afford the niche technology; at least in the way it is being disseminated. At the niche level, the NBPE designated a diverse set of actors to contribute to the implementation of the niche technology. However, their alignment is poor and the private sector is not involved. Expectations have had to be lowered because targets were not met. Also, learning processes are not optimal. Bottlenecks that were already identified in 2006, for example lack of involvement of the private sector, still remain unsolved.

The current research is innovative because (1) it is the first case study into biogas in Ethiopia; (2) it analyses multiple regimes (the energy and the agriculture regime) and their interaction with the landscape and niche levels; and (3) it shows more insight in how the SNM and MLP frameworks can be applied to a sustainable innovation in a developing country and what can be done to overcome

bottlenecks. Such insights in possible bottlenecks and how to overcome them contribute to sustainable growth.

Key words: Domestic Biogas, Ethiopia, Strategic Niche Management, Multilevel Perspective

1. INTRODUCTION

The largest segment of the population in Ethiopia is located in rural areas and their main source of income comes from agriculture (World Bank, 2014). This same segment of the population represents the main energy consumer in Ethiopia and satisfies most of their energy needs with woody biomass (Gebreegziabher, 2007; Wolde-Ghiorgis, 2002). The extensive demand for firewood has caused an energetic and environmental crisis since most of the forest coverage has been depleted over the last 35 years. This undermines firewood availability, soil fertility and the preservation of aquifers. Ultimately, Ethiopian farmers have to spend more resources (e.g. time or money) to have access to fuel wood. Meanwhile, their agricultural yield is reduced due to the lack of nutrients in the soil and the shortage of water (Boers *et al*., 2008). Sundried and combusted livestock manure is sometimes used as an alternative energy source to fuel wood. However, this is not an improvement since the resulting *'dung cakes'* have a low conversion efficiency to heat (≤ 8%) (Tauseef *et al.*, 2013) and inhibit the soil fertilisation that would have occurred if livestock manure would not have been combusted (Warnars & Oppenoorth, 2014).

Domestic biogas, in contrast, also utilises organic waste such as livestock manure, but it can achieve a conversion efficiency to heat up to 55% and provides an enriched fertiliser called bio-slurry (Tauseef *et al.*, 2013; Bond & Templeton, 2011)). Domestic biogas can be produced in domestic biogas plants, also known as domestic biodigesters (DBD). DBD's consist of small-scale microbially-controlled semi-batch reactors that process the organic compounds that are fed thereby producing a mix of 50-70% methane (CH_4) and 30-40% carbon dioxide (CO_2), among other gases (Bond & Templeton, 2011). Domestic bidogesters vary in size and shape but the principles behind their operation are similar. In the inlet, a one to one mix of manure and water is fed on a daily basis. The digester consists of an a sealed structure that hosts the microbial activity and yields the biogas. The resulting bio-slurry leaves the biodigester through an outlet and can be stored in a pit, installed next to the biodigester. The most developed DBD technology in Africa and Asia to date is the fixed-dome digester (Boers *et al*., 2008). The fixed-dome digester consists of a stationary underground structure made out of cement, bricks or stones, sand and aggregates. The biogas piping system can be constructed with PVC pipes, flexible hosepipes or metal pipes. Figure 1 depicts an example of a fixed-dome biogas digester.

Based on a daily manure production from four cattle heads, domestic biogas can replace the equivalent consumption of five kilograms of firewood, 1.5 kilograms of charcoal or 0.6 litres of kerosene per day (Boers *et al*., 2008; Warnars & Oppenoorth, 2014). The biogas that is produced is mainly used for cooking; however it can also be used in biogas lamps. Biogas can also be used to power internal combustion engines, refrigerators or radiant heaters; yet their application is even less widespread as lighting or cooking (Tumwesige, 2011). DBD's can raise the use of cleaner energy sources in Ethiopia and in parallel offer valuable co-benefits to their users such as increased agricultural productivity from the use of bio-slurry as fertilizer, reduced workload and time savings through the avoidance of firewood collection and reduced indoor air pollution.

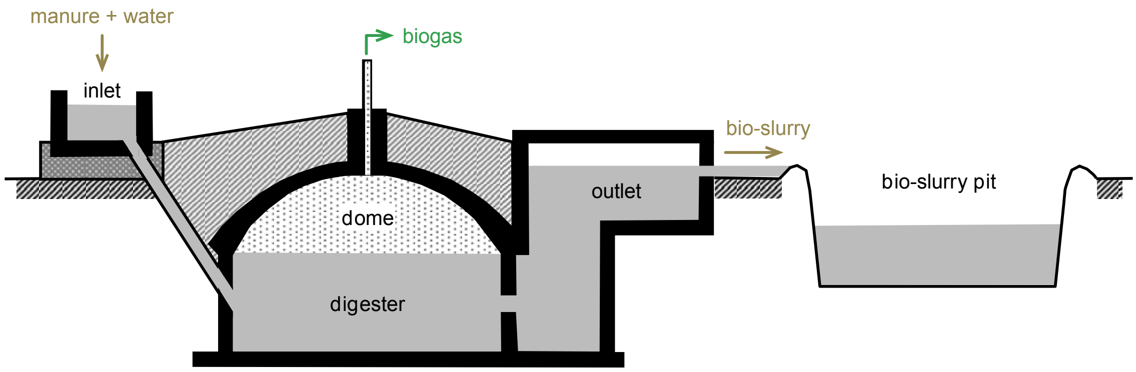

Figure 1: Schematic representation of a fixed-dome biogas plant, own elaboration based on Boers et al. (2008) and Tauseef et al. (2013)

In 2008, the Ethiopian Government with the help of the SNV Development Organization in The Netherlands launched the National Biogas Programme (NBPE) with the aim to up-scale the use of domestic biogas technology in the country. The NBPE started with a first implementation phase that concluded by the end of the year 2013 (Boers *et al*., 2008).

This paper analyses the current status of domestic biogas in Ethiopia and identifies barriers and drivers that influence its development and further growth. The analytical framework combines the Multi-Level Perspective (MLP) and Strategic Niche Management (SNM).This is practically relevant for two reasons. Firstly, despite the fact that comprehensive information resources were developed prior to the launch of the NBPE (Boers *et al*., 2008; Esthete, Sonder, & ter Heegde, 2006), currently no research or official statements have been published regarding the current status of development of domestic biogas or the obstacles to deploy it. Secondly, similar biogas programmes have been promoted by SNV Development Organization in Asia, Africa and recently in Latin America (SNV, 2013). Insights in current status and barriers and drivers in other countries may yield useful insights for these new programmes. Scientifically this paper is relevant for three reasons. Firstly, it is the first paper that provides a recent review of the case of the biogas sector in Ethiopia based upon primary data sources, mainly interviews. Secondly, it is one of the first papers that applies a combination of the Strategic Niche Management approach and the Multi-Level Perspective to a case study in a developing country. And thirdly, it is the first paper that includes two interacting regimes in the MLP analysis.

The paper is structured as follows. In section 2, we discuss the key notions of the analytical framework applied. Section 3 presents methodology. Section 4 describes the development and current status of the Ethiopian biogas niche. Subsequently, the important factors and dynamics within the niche are investigated in more depth in section 5 by using Strategic Niche Management. In section 6 and 7 we investigate the important factors and dynamics from outside the niche in more depth by using the Multi-Level Perspective. Section 8 presents our conclusions, theoretical findings and recommendations for actors involved.

2. ANALYTICAL FRAMEWORK

The analytical framework used in this paper is based on two sociotechnical approaches: Strategic Niche Management (SNM) and the Multi-Level Perspective (MLP). With the term sociotechnical we mean that the topic under study contains both technical and social elements, which are interlinked.

SNM is a theoretical framework that can be used to study the sociotechnical dynamics and factors within a niche around a new innovation (Raven, 2005; van der Laak *et al*., 2007) – in this case domestic biodigesters in Ethiopia. The MLP adds to the SNM framework by giving insight into the external environment in which the new innovation is developing – in this case the energy sector and the agriculture sector in Ethiopia and the Ethiopian society as a whole. The MLP approach studies how innovation is influenced by factors at three levels: the exogenous 'landscape'; the dominant way of providing a societal function or the 'regime'; and the 'niche', the level where the innovation emerges and develops (Geels & Schot, 2007). This framework provides more insight into which factors are relevant, and how they interact.

2.1 Strategic Niche Management

Strategic Niche Management (SNM) was developed as an analytical approach that can be used to review and analyze the development of innovative technologies in niches, which can be seen as incubation rooms or protective systems surrounding the new technology (Caniëls & Romijn, 2008; Schot & Geels, 2008; A. Smith & Raven, 2012).

In the niche, the innovation can grow and develop to become viable through gradual experimentation and learning by networks of actors. During this period, the emerging technology has to compete with the existing technologies which are technologically and economically superior to it (Geels & Schot, 2007) . These established technologies are part of large social networks, the regimes, which have certain rules such as price/performance ratio, engineering practices, user preferences and regulatory requirements .

In the initial stages, a niche technology finds itself within a technological niche, which is a space protected from the rules of the regime, e.g. by subsidies or regulatory exemptions. A technological niche can evolve into a market niche, a space where users start to recognize the values of the innovation and where it is able to compete over the established technologies. Market niches can eventually lead to the development of a new regime or become part of it (Caniëls & Romijn, 2008; Raven, 2005).

To analyze the development of a niche, researchers have proposed three niche processes which are dynamically interrelated: the voicing and shaping of expectations, network formation and learning processes (Raven, 2005) . We discuss them subsequently.

2.1.1 Dynamics of expectations

Expectations give direction to the technology development, influence design choices, and attract resources as well as new actors. According to Hoogma *et al*. (2002), expectations contribute to successful niche development if they become more robust (shared by more actors), more specific (give guidance) and have a higher quality (the expectations are validated by the actual developments). In the early niche stages, participants join the niche by investing effort, money and time because they have expectations of the future success. At that moment, actors have broad and unclear expectations about the technology and different visions of its future (van der Laak *et al*., 2007). During time, expectations can change because of external factors (regime and landscape) and internal circumstances (e.g. results from experiments within the niche) (Raven, 2005) .

2.1.2 Network formation

Actor networks are essential for niche development since they sustain development, attract resources and new actors, enable learning and carry expectations (van der Laak *et al*., 2007). Two characteristics are important when analyzing the actor network. First, the network composition is an essential factor. A good network requires a heterogeneous group of actors with different interests and roles (Raven, 2005) . Secondly, the network should be aligned. This characteristic refers to the degree to which actors' visions, expectations and strategies are in line with the niche development. This alignment can be achieved through regular interaction and co-operation between the different actors (van der Laak *et al*., 2007) .

2.1.3 Learning processes

Learning influences the niche by affecting the expectations and aligning them. A good learning process is reflexive and focuses on many aspects (van der Laak *et al*., 2007) . Furthermore, good learning processes should not be confined to individual learning by actors, but should also consist of interactive learning or, in other words, knowledge sharing among actors (Kamp *et al*., 2004). Interactive learning can be facilitated by, among other things, trust and proximity between actors or intermediary actors such as umbrella organizations which facilitate knowledge flows between other actors (Kamp *et al*., 2004; Kamp, 2008; Raven *et al*., 2008; A. Smith, 2007). Hoogma *et al*. (2002) gives two types of learning: first order learning and second order learning. First order learning refers to learning about the innovation's effectiveness in achieving pre-defined goals. It is directed on gathering facts and data. Second order learning is learning about the underlying norms and values related to the new technology. This type of learning enables changes in assumptions, approaches and cognitive frames, and has a larger contribution to niche development than first order learning (Schot & Geels, 2008). Furthermore, Hoogma *et al*. (2002) distinguishes learning with regard to the following five aspects: technical development and infrastructure, industrial development, social and environmental impact, development of the user context and government policy and regulatory framework.

2.1.4 Summary of niche indicators

Summarizing, we analyze the three niche processes by evaluating the indicators shown in Table 1.

Table 1: The three niche processes and their indicators

SOCIOTECHNICAL LEVEL	NICHE PROCESS	INDICATORS
NICHE	Network formation	Completeness of network of actors
		Alignment of network of actors
	Learning processes	Presence of first order learning
		Presence of second order learning
	Dynamics of expectations	Match between expectations and actual development

2.2 Multi-Level Perspective

The upscaling of an innovation is not solely the result of the above described internal niche dynamics, the external environment also exerts influence. The Multi-Level Perspective adds to Strategic Niche Management to analyze the major external developments that affect niche upscaling. It divides the socio-technical system into three different levels: the socio-technical landscape (macro level), the socio-technical regime (meso level) and the niche (micro level) (Geels, 2002).

The landscape consists of the deep structural trends and factors that are not part of the regime and niche, but influence them. A broad range of factors and processes can be taken into account at this level, amongst others macro-economic factors (e.g. oil prices, economic growth), population growth, level of corruption, cultural aspects such as status, power differences and presence of different tribes or classes; and availability of raw materials (Hofstede, 2005; Romijn *et al*., 2010). The landscape level has the slowest dynamics; these trends usually change relatively slowly and are hard to change. However, this level also includes unexpected events within or outside the country such as wars and oil price fluctuations (Geels & Schot, 2007). In this paper we also consider funding programmes or technology programmes from abroad as landscape factors. Situated below the landscape, the socio-technical regime is the level of the established technologies. The regime itself is generally stable and there is commonly resistance to the introduction of new technologies. This is because existing technologies are ‘locked-in’ or path dependent (Verbong & Geels, 2007). In niches, new technologies are developed, often to solve problems in the dominant regime. Because of its weak structuration (low stability and high uncertainties), the niche can easily be influenced by the regime and landscape (Geels & Schot, 2007). Often, more than one niche are in development at the same time.

The extent to which an innovation is able to upscale is influenced by the interaction between the three levels (landscape, regime and niche). As mentioned above, the room for niches in the regime is directly related to the stability within the regime. The actors in the dominant regime generally have an aversion against niche developments; the more stable the regime, the stronger the resistance for new technologies. A destabilized or weak regime offers windows of opportunity for niche breakthrough. Regime destabilization originates from pressurizing landscape factors and internal regime tensions. A niche can develop internal momentum through improved price/performance, support from powerful actors, increasing functionality of the innovation etc. When a niche expands and builds up momentum, it can exert influence on the regime through bottom-up forces (Geels & Schot, 2007) .

When the interactions between the levels are aligned they reinforce each other. This process depends on the timing and the nature of multi-level interactions. This offers windows of opportunity for the radical innovation at niche level to break through in the dominant regime (Geels & Schot, 2007).

2.1.4 Summary of MLP indicators

Summarizing, we analyze the three niche processes by evaluating the indicators shown in Table 2.

Table 2: The MLP levels and their indicators

SOCIOTECHNICAL LEVEL	INDICATORS
LANDSCAPE	Political and economic stability
	Suitability of economic climate for enterprises and innovation
	Extent of poverty
	Fit of physical geography and climate
	Availability of natural resources
	Education levels and literacy rates
	Presence of different population groups / tribes / mother tongues
	Funding programmes and technology programmes from abroad
REGIME	Stability in regime
	Suitability of sectoral policy
	Amount of lock-in in regime
NICHE	Completeness of network of actors
	Alignment of network of actors
	Match between expectations and actual development
	Presence of first order learning
	Presence of second order learning

3. METHODOLOGY

The case study material described in this paper was collected using the use of three research methods: (1) desk study through literature and Internet research; (2) online interviews and questionnaires with Ethiopian stakeholders; (3) an extensive field study including an extensive number of interviews with stakeholders inside and outside Ethiopia by the second author of this paper in the spring of 2014. Literature and Internet sources were used to collect qualitative information to analyze the relevant developments internal and external to the niche. The field study primarily consisted of open-ended, semi-structured interviews with 17 key informants: actors, experts and decision makers. The interviews focused on analyzing the current stakeholder configuration within the niche, the status of the niche and the dynamics within it. Based on observations and a questionnaire, additional cultural and social factors that influence the sector were found.

The analysis of the development of domestic biogas in Ethiopia was divided in its socio-technical levels based on the Multi-level Perspectives (MLP) theory. Hence, the landscape level and the relevant regimes where assessed as external socio-technical levels that influence the development in the niche. Strategic Niche Management (SNM) was applied to give a systematic overview of the niche level where domestic biogas technology is being deployed. The analysis of landscape, regimes and niche provided specific insights that allowed reconstructing the current development of domestic biogas and barriers and drivers for its further growth, which are stressed as concluding subsections at the end of the analysis of each level.

4. HISTORICAL DEVELOPMENT OF DOMESTIC BIOGAS IN ETHIOPIA

4.1 Introduction and early developments of domestic biogas

The early years of implementation of biogas in Ethiopia were not solely focused on small-scale domestic biogas; institutional and large-scale digesters were also deployed. A common characteristic was that the experiments were conducted on an isolated manner without proper means to up-scale the technology. Biogas was first introduced in Ethiopia by Ambo Agricultural College around 1957 to supply the energy for welding agricultural tools. During the 1970's, two biogas plants were introduced by the Food and Agriculture Organization (FAO) as pilot projects to promote the technology (J. U. Smith, 2011). During the last two decades, around 1,000 biogas plants were deployed in Ethiopia with sizes ranging between 2.5 and 200 cubic meters for households, communities and institutions (Boers & Esthete, 2008). During this period, different models were used (e.g. fixed-dome, Indian floating-drum and bag digesters). However, according to multiple consulted actors there was no local capacity to neither up-scale the technology nor sustain it. Hence, just 40% of the aforementioned biodigesters are still operational (Esthete *et al*., 2006).

Between 1999 and 2002, Christopher Kellner, a German biogas expert, built 60 fixed-dome biogas plants through a bottom-up implementation approach he titled *"From the Point to the Area"*. This deployment was partly done based on an Ethiopian-German development project titled "Land Use Planning and Resource Management, Oromia" (LUPO). His implementation method consisted of the construction of an initial biogas plant and the sub-sequent promotion within the close surroundings. This triggered local demand from neighbours and propitiated the construction of additional biogas plants. However, the rate of implementation was slow due to the limited size of the trained labour force (basically, Mr. Kellner and a technician he hired). In 2002, Mr. Kellner departed from Ethiopia and wrote a manual for the construction of LUPO digesters, which were adapted to the Ethiopian context. (Kellner, 2002, 2014)

Furthermore, since 2000, LEM-Ethiopia (a local NGO) started an awareness and promotion programme with latrine-fed biogas digester in schools and households in regions like Amhara, Oromia and SNNPR (Worku, 2014). To date, 22 and 25 of these digesters have been installed in schools and households, respectively. However, no data was found to determine whether those plants are still operational.

In 2006, a technical team integrated by experts from the EREDPC and SNV conducted a feasibility study to determine biogas potential in four Regions of Ethiopia which accounted for the largest number of inhabitants and livestock (Amhara, Oromia, SNNPR and Tigray). Table 3 presents a summary of the technical potential for domestic biogas in Ethiopia based on the aforementioned feasibility assessment. Two scenarios (low and high) were calculated based on the availability and access to water resources in each region. It was estimated that between 1.1 and 3.5 million households could benefit from the technology. Consequently, a 5-year pilot domestic biogas programme was proposed with an estimated cost of 11 million EU aiming to deploy 10,000 biogas plants over this period. (Esthete *et al*., 2006)

Table 3: Technical potential for domestic biogas in Ethiopia (Esthete et al., 2006)

Technical Potential	Amhara	Oromia	SNNPR	Tigray	TOTAL
Low scenario	255,361	641,033	159,340	75,591	1,131,325
High scenario	788,287	1,978,840	538,720	206,420	3,512,267

In 2007, Dutch experts conducted studies regarding technical potential of domestic biogas in several African countries, including Ethiopia. The rising interest in the technology led to the launch of *"Biogas for Better Life, An African Initiative"* in Nairobi in May 2007. Together with the launch of this initiative a business plan was developed with the aim to construct two million biogas plants by 2020, create 800 private biogas companies and 200 biogas appliance-manufacturing companies. (van Nes & Tinashe, 2007)

4.2 Deployment of the NBPE

Inspired by the positive environment with regard to domestic biogas in Africa and with the aim to up-scale domestic biogas in Ethiopia, the Ethiopian National Biogas Programme (NBPE) was developed and launched for a first stage of implementation between 2008 and 2013. From February to July 2007, a team from SNV and EREDPC conducted an extensive consultation process with relevant stakeholders in order to develop a Project Implementation Document or PID (Boers *et al*., 2008). On June 16th, 2007 the draft of the PID was presented and approved. Even though the assessment report suggested constructing 10,000 domestic biogas plants over a 5-year programme, the Ethiopian Government decided to set a more ambitious target. Consequently it was agreed to build 14,000 family-sized biogas plants between 2008 and 2013 and the NBPE was launched. (Boers, 2014)

Furthermore, a subsidy was provided to biogas users to compensate for the initial cost and hence improve the affordability of the biogas plants (Alemayehu, 2014). This was also important since the alternative, firewood, was freely available. The provision of the subsidy depended on the compliance of the technical criteria set by the NBPE. Hence it was limited to a single model for the biogas digester: the SINIDU model which is an adaptation of the Nepalese GGC-2047 fixed-dome digester (Boers *et al*., 2008). This subsidy is still been granted nowadays (Alemayehu, 2014).

The first years of implementation of the NBPE faced several obstacles in deploying the programme. Biogas was considered a new technology in the rural context and demand turned out to be lower than expected. In this period, SNV installed 98 biodigesters in the four regions for demonstration purposes and decided to expand the number of *woredas* where the NBPE could be implemented aiming to catalyse biogas dissemination (Teka, 2014).

The slow development of the NBPE was evidenced by the small amount of biogas plants that were built. Moreover, the situation was exacerbated by a cement crisis faced by Ethiopia between 2010 and 2011 (Alemayehu, 2014; Boers, 2014). Consequently, in 2010, during an intermediate revision of the NBPE, the African Biogas Partnership Programme (ABPP) decided to reduce the initial target from 14,000 to 10,000 biogas plants by end of the first phase in 2013 (Alemayehu, 2014; Pütz, 2014; Teka, 2014; Tsegaye, 2014). The first phase of the NBPE culminated on December 31st, 2013. Official sources have stated that 8,063 biogas plants were built during this phase and distributed as follows: 2,480 biogas plants in Oromia, 1,992 in Tigray, 1892 in Amhara and 1,699 in SNNPR (Alemayehu, 2014).

4.3 Present and future of the NBPE

The second phase of the NBPE takes place from 2014 until 2017 and aims to construct 20,000 additional biogas plants. In 2014 alone, the government expected to build 3,600 biodigesters in the four regions of implementation (Alemayehu, 2014). A significant goal for this second phase has been to enable private sector involvement, a goal that was not accomplished in the first stage of the NBPE (Asfaw, 2014; Oppenoorth, 2014; Teka, 2014).

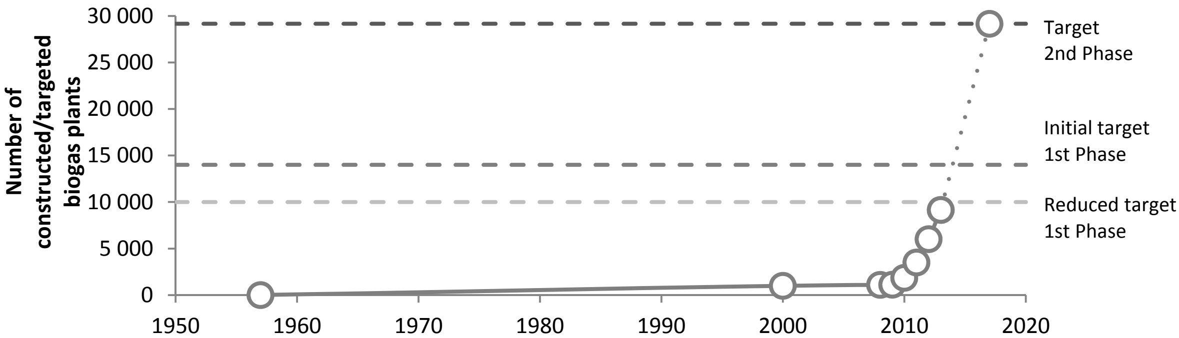

Figure 2: Number of domestic biogas plants constructed or targeted by the NBPE

Figure 2 presents a graphical summary of the number of domestic biogas plants constructed in Ethiopia since their introduction in 1957. Also the change in target in the first phase from 14,000 to 10,000 biogas plants can be seen, as well as the target in the second phase to build 20,000 additional biogas plants. The current status of the biogas sector will be deeper looked into in the subsequent sections.

5. ANALYSIS OF THE SOCIO-TECHNICAL NICHE

Biogas in Ethiopia is currently in the niche phase. It holds a small share of the market and it is sheltered by way of implementation programs. However, besides biogas also other niches around cleaner energy technologies exist in Ethiopia nowadays. For example, a large variety of improved cook stoves are being commercialised with the help of local actors such as HOA-REC&N and GIZ-Ethiopia. Moreover, other renewables, especially pico-solar is starting to spread in the country and private enterprises are beginning to appear for the installation and commercialisation of the technology (Sishuh, 2014). Furthermore, large-scale power plants, like the Grand Ethiopian Renaissance hydro project and Corbetti Geothermal also stand out as new innovations within the energy sector (Pusch, 2014). So, the development of domestic biogas is not an isolated effort. However, as the markets for part of these niches are still small (pico-solar, improved cook stoves) or because they aim for a different market (grid based electricity for the cases of hydro energy and geothermal energy), they are not in competition with biogas at this moment. Therefore, in this paper we will not look further into these other niches and their interaction with biogas. In the remainder of this section we will analyse the biogas niche in Ethiopia by focusing on the niche processes and indicators that we presented in Table 1 in section 2.

5.1 Network formation

Network formation looks into the composition of the network and alignment of the actors within it in order to assess their influence on the development of the niche (Hoogma, 2000; Raven, 2005). In the case of Ethiopia, the NBPE defined the actors that should be present in the development of the programme and assigned specific roles to each one of them (Boers et al., 2008). Moreover, it divided actors based on the different jurisdictional domains (federal, regional and local) and their respective backgrounds: government, NGOS, Micro-Finance Institutions, private sector, biogas users, etc.

Currently, the network of actors within the Ethiopian biogas niche is diverse and their alignment is poor. The current core of the biogas niche is formed by the NBPE . However complementing efforts and independent initiatives are also present and aim to fill the gaps left by the NBPE. Although cooperation linkages occur among actors, in many cases cooperation is weak or nonexistent. Figure 3 provides an overview of the main stakeholders involved in the domestic biogas niche in Ethiopia in 2014. In the following sub-sections, the alignment among stakeholders is revised at three different layers of implementation: (1) national and international, (2) regional and (3) local.

5.1.1 National and International level

At the federal level, the NBPE is led by the National Biogas Programme Coordination Office (NBPCO), which is hosted by the Ministry of Water, Irrigation and Energy (MoWE). The National Biogas Sector Steering Committee (NBSSC) was proposed since the implementation of the NBPE and allows integration of actors from the Ministry of Agriculture (MoA), Ministry of Finance and Economic Development (MoFED), Ministry of Environmental Protection and Forestry, as well a representatives from the private sector and NGOs (Alemayehu, 2014; Boers et al., 2008). However, weak linkages between the Ministry of Water, Irrigation and Energy and the Ministry of Agriculture undermines inter-ministerial cooperation (Araya, 2014).

The Ministry of Agriculture manages an extensive database of farmers, as well as the number and type of livestock they own (Araya, 2014), a resource that would be of high value to identify potential customers. Furthermore, the Ministry of Agriculture has a direct line of command with its extension officers who work at a local level and have direct contact with farmers. Meanwhile, the complex structure of the NBPE results in redundant hierarchies and bureaucracy (Oppenoorth, 2014). The fact that the Ministry of Agriculture does not play an active role in the implementation of the NBPE creates an institutional schism for the dissemination of domestic biogas.

At an international level, most of the stakeholders provide technical assistance and funding to the NBPE or other domestic biogas initiatives in Ethiopia. The funding for the NBPE is channelled by the African Biogas Partnership Programme (ABPP), based in Kenya. The ABPP allocates resources for each of the national biogas programmes it manages based on their yearly performance (Oppenoorth, 2014).

There is a strong consensus regarding the fact that the Government of Ethiopia is determined to play a strong role in domestic biogas dissemination – as well as other sustainable energy technologies – (Boers, 2014; Oppenoorth, 2014; Sishuh, 2014). However, this strong presence of the Government hinders private entrepreneurship and the lack of institutional capacity results in a slow rate of implementation of the technology (Oppenoorth, 2014). Furthermore, even though efforts have been made by international actors to improve the decision-making and the planning process, the actual implementation of those improved mechanisms does not happen.

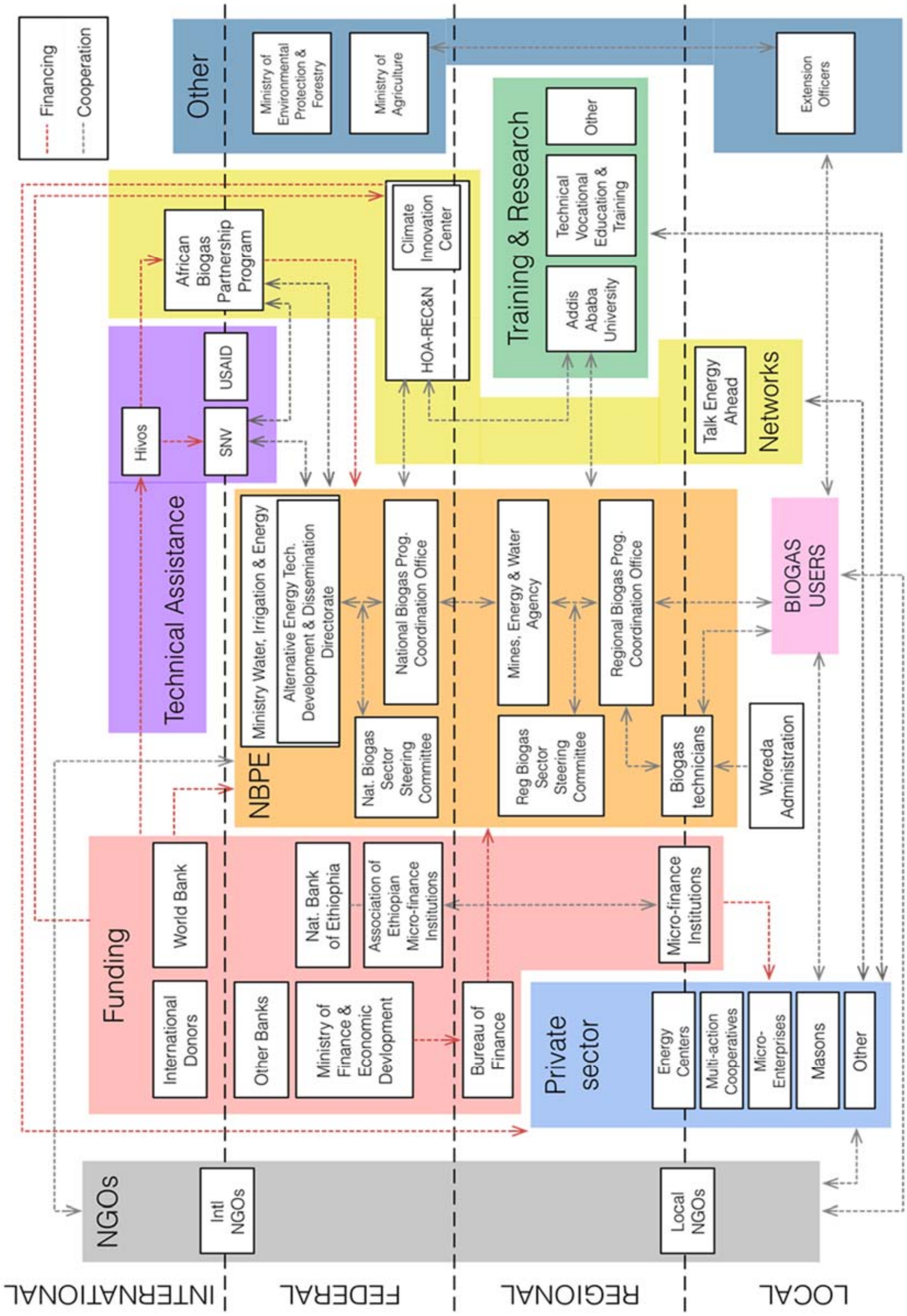

Figure 3: Stakeholder map for domestic biogas in Ethiopia in 2014.

5.1.2 Regional level

Although implementation is carried out at a local level, most of the activities are managed and supervised at a regional level. Most of the stakeholders are grouped at this level (as can be seen in the stakeholder map in Figure 3). The majority of the Universities operate at a regional level. The private sector related to domestic biogas is almost non-existent and most of the implementation is done by individual masons trained by the NBPE at the local level except from SELAM Group, a local private manufacturer and provider of most biogas stoves to the NBPE that is present in Addis Ababa and Awassa. Only two NGOs working with domestic biogas were found in Ethiopia. These are LEM-Ethiopia and the Institute for Sustainable Development (ISD) who work on promotion and awareness, and user training on bio-slurry utilisation, respectively. Furthermore, SNV Development Organisation plays a role as technical advisor in the implementation and is a continuous promoter of the programme since its beginning.

5.1.3 Local level

The implementation of domestic biogas happens at the local level and is usually managed and promoted at *woreda* (district) level. The NBPE appoints Energy Experts at each of the active *woredas* who are in charge for the training and supervision of the masons (Alemayehu, 2014). However, a hierarchy between the Regional Biogas Programme Coordination Offices (RBPCO) – appointed by the NBPE – and the Woreda Administration undermines the availability of the Energy Experts. The latter assigns the tasks to be conducted by the Energy Experts, which are not exclusive to biogas (Oppenoorth, 2014). This causes a constant negotiation between the Regional Biogas Partnership Coordination Offices (RBPCO) and the Woreda Administration and undermines implementation.

The masons are rarely grouped as local micro-enterprises, however there is consensus at the regional and federal level to leverage entrepreneurship. Furthermore, it is difficult to maintain trained masons within the NBPE, due to the fact that they do not work exclusively on biodigester construction and are usually attracted to other construction activities where they can find larger profit margins (Jijawo, 2014; Teka, 2014).

As explained before, even though extension workers from the Ministry of the Agriculture are present at the local level and work directly with the farmers, there is no linkage at this level between the NBPE and the extension workers (Oppenoorth, 2014). Consequently, the masons or the Energy Experts usually train biogas users on bio-slurry utilisation although the focus and expertise of this human resource is not agriculturally related (Araya, 2014).

5.1.4 Barriers and drivers at the niche level – network formation

All in all, the NBPE set a triggering institutional framework for the dissemination of domestic biogas in Ethiopia. Moreover, the programme identified and assigned roles and responsibilities for a diverse group of actors at the different jurisdictional domains. According to Raven (2005), the diversification of actors at the niche level is desirable to promote the development of the niche. Furthermore, according to Hoogma (2000) it is important for the network of actors to integrate stakeholders from the dominant regimes in order to increase the chances for the radical innovation to emerge. In the case of domestic biogas in Ethiopia, the NBPE set structures where actors from other governmental agencies could interact with the development of the programme. Although the composition of the network of actors is diverse, the alignment between the actors is weak. Moreover, the highly centralized and hierarchical nature of the programme hinders the contribution of an important actor type, namely the private sector.

5.2 Dynamics of expectations

5.2.1 Development of expectations

The launch of the National Biogas Programme in Ethiopia (NBPE) was a catalyser for the development of domestic biogas in the country. Prior to the NBPE, the development was scarce and limited to isolated efforts (J. U. Smith, 2013). The introduction of a systematic approach to disseminate the technology allowed the integration of several stakeholders and disrupt with the inertia imposed by the dominant regime with a predominant use of firewood. Nevertheless, the ambitions of the NBPE had to face and adjust to the constraints and challenges of the local context. Now, after the culmination of the first phase of implementation of the NBPE and in the first year of the second phase it is possible to compare and analyse how expectations have been shaped over this period.

Table 4 summarises some of the main targets set in the project implementation document of the NBPE before the start of the first phase and it is compared with the results after its completion. Given the nature of the NBPE, a strong interest has been focused on the number of biogas plants that can be deployed by the programme (Kellner, 2014).

Table 4: Targets and accomplishments of the 1st phase of the NBPE (Sources: Alemayehu, 2014; Boers, 2014)

.	Initial target	Actual implementation
Number of constructed biogas plants	14,000	8,063
Number of active woredas (districts)	28	130
Number of Biogas Construction Enterprises	≥ 20	?
Average cost of biodigester (6 m^3)	7,519 Birr	14,000 Birr
Percentage of cost covered by subsidy	57%	43%

Despite the initial enthusiasm, the NBPE promoters had to transform the promises and words written in the Project Implementation Document (PID) into real implementation structures, which meant: hiring staff, setting offices, training technicians and (most importantly) introducing a technology that was relatively novel to the country. At the same time, it was expected for the NBPE to start generating concrete results. Figure 4 shows the number of biogas plants that were built each year during the first phase of the NBPE. It clearly shows that the first years of the NBPE could not match the expectations.

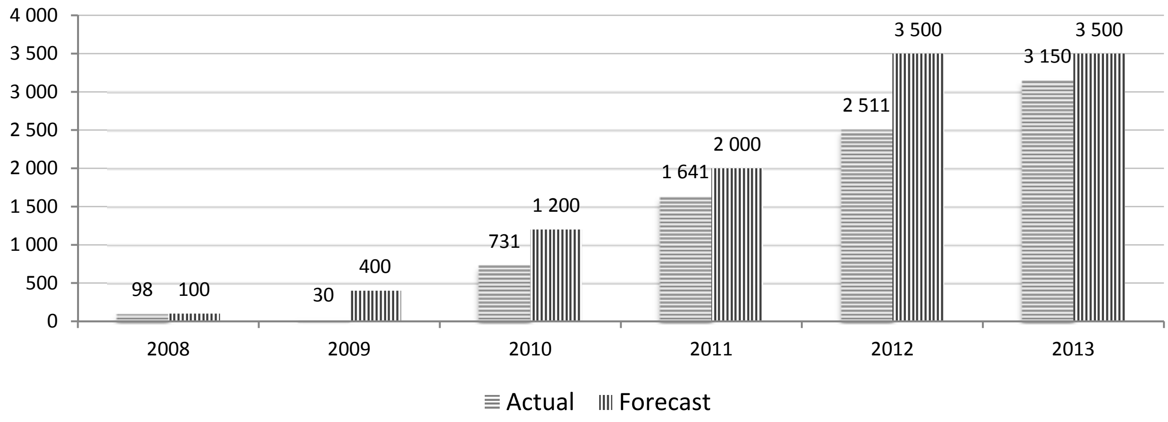

Figure 4: The number of installed biogas plants (per year) installed by the NBPE during the first phase of implementation, actual vs. target (Sources: ABPP, 2013; BIOGAS4ALL, 2014; Oppenoorth, 2014)

Although the NBPE faced a harsh environment, it was decided to extend the number of active *woredas* with the aim to increase the coverage of the programme and hence, reach more potential clients (Teka, 2014). By 2010, the NBPE gradually started to take off but it encountered another barrier: between 2010 and 2011, Ethiopia faced a cement crisis (Alemayehu, 2014).

From an outside perspective, it was difficult to appreciate the local efforts of the main promoters of the NBPE. Fund allocation by international donors is based on the periodical revision of NBPE's performance which is based on the number of biogas plants that are constructed. Actual implementation efforts were not able to comply with the targets. This mismatch deteriorated the overall expectations of the stakeholders involved and in 2010 (halfway through the development of the first phase), a silent decision was taken by the African Biogas Partnership Programme (ABPP) to reduce the initial target to 10,000 biogas digesters (Alemayehu, 2014; Teka, 2014). This decision shows how the expectations about the programme were significantly reduced.

From 2011 onwards, the NBPE started to deliver better results (as shown in Figure 4); however, it was still not possible to meet the yearly targets. After the completion of the first phase of the NBPE, the programme was able to deploy 58% of its initial target (8,063 biogas plants out of 14,000). Despite this bad performance, the NBPE significantly increased its area of coverage to 102 more *woredas* than the 28 *woredas* that were initially targeted (ABPP, 2013). In addition, fund allocation by international donors is based on the periodical revision of NBPE's performance which is based on the number of biogas plants that are constructed. Nevertheless, actual implementation efforts have not been able to comply with the targets. This mismatch deteriorated the overall expectations of the stakeholders involved and incurred in a silent reduction of the initial targets from 14,000 biogas plants to 10,000 biogas for the first phase of implementation (Alemayehu, 2014; Teka, 2014).

To date, another unaccomplished target has been the empowerment of local Biogas Construction Enterprises (BCEs) (Alemayehu, 2014). Several factors have influenced a poor private sector involvement but what is worrying is that so far, the NBPE has not been able to find a solution for this issue (Teka, 2014). Nowadays and especially for the implementation of the second phase of the NBPE, there is a general consensus among stakeholders that private sector involvement should actually take off during this period. But our interviews demonstrated neither a concrete understanding why this happens nor a plan on how to approach it (Alemayehu, 2014; Boers, 2014;

Oppenoorth, 2014; Teka, 2014). One exception is the case of HOA-REC&N in collaboration with (B) Energy, a local private biogas enterprise. This collaboration has evolved from the elaboration of an alternative domestic biogas technology (biogas backpacks fed by bag digesters) to the development of a business plan to disseminate this technology (Asfaw, 2014; Pütz, 2014; Tsegaye, 2014).

5.2.2 Barriers and drivers at the niche level – dynamics of expectations

According to Hoogma (2000), expectations can change in strength, quality or realism. In the case of Ethiopia the inability of the NBPE to deliver what was initially intended forced the actors to reduce their expectations according to the actual implementation in order for them to become more realistic. Nevertheless, it is paradoxical that although this change was performed for the first phase of the NBPE, the current (second) phase of implementation has an even more ambitious goal to deploy 20,000 additional biogas plants in the next four years. Figure 4 shows that the deployment during the last years of implementation of the first phase increased significantly. However, it is questionable whether the new expectations will be able to meet the actual implementation or will fail to become unrealistic again. Furthermore, analysing the performance solely based on the number of biogas plants may distract from an important fact that is whether the biogas plants that are being deployed actually meet the needs of its users or if they remain operational after they are deployed.

5.3 Learning Processes

After the development of the feasibility assessment in 2006, it was revealed that most of the by then existing biogas plants were not operational and the majority of them had been dismantled. Hence, a set of issues was identified and discussed so that it could be taken into consideration in the design of implementation of the NBPE. (Esthete *et al*., 2006)

Table 5 presents a set of lessons learnt based upon the aforementioned issues. They are divided into three categories as also distinguished by Hoogma (2002), as described in Section 2 of this paper: technical development, development of the user context, and government and regulatory framework. In the following sub-sections, an analysis of the current progress on the main issues from Table 5 is provided.

Table 5: Biogas issues identified by the NBPE's feasibility analysis (Source: Esthete et al., 2006)

CATEGORY	ISSUE
TECHNICAL DEVELOPMENT	Domestic biogas installations cannot supply the full domestic energy demand
	Non-local materials increase investment costs and maintenance problems
	In relation with the available dung, most installations are over-sized
	Without proper technical back-up, any plant will fail sooner or later
	"Single actor construction" weakens local technical back-up facility
	Standardization will improve quality

CATEGORY	ISSUE
DEVELOPMENT OF THE USER CONTEXT	Farmers need proper instruction to maximize the benefits from their investment
	Biogas installations as a "stand-alone" application are likely to fail
	The plant's water requirement shall not be underestimated
GOVERNMENT CONTEXT AND REGULATORY FRAMEWORK	EREDPC seems the best placed lead agency for a federal domestic biogas programme
	The Bureaus of Energy would seem the best placed coordinating, supervising and integrating agencies at regional level
	The extension network of the Bureaus of Agriculture would be an asset for a large scale dissemination programme
	The regional micro-finance institutions can play an important role in a large scale domestic biogas programme

5.3.1 Technical development

To date, domestic biogas systems are unable to attend a comprehensive share of a households' energy demand. Yet most worryingly, *injera* baking cannot be pursued using biogas since it does not provide sufficient energy to perform this task (Boers, 2014; Gebreegziabher, 2014; Pütz, 2014). As will be explained in Section 7.1, traditionally 50-60% of household energy demand is used to bake *injera*; a traditional fermented flatbread with a sour taste (Gebreegziabher, 2007, 2014). Although recent innovations have been developed to make *injera* baking possible using biogas, these innovations have not yet reached the commercial stage (Alemayehu, 2014; Pütz, 2014).

Furthermore, although the cement crisis from 2010/11 has been overcome (Alemayehu, 2014; Teka, 2014), other components of the biogas plants are often unavailable in the local markets or are prone to malfunction. This issue is exacerbated by the fact that these problematic components, specifically the biogas valves and the biogas lamp, are imported and have a poor quality (Jijawo, 2014; Pütz, 2014). Moreover, the biogas stoves manufactured locally by SELAM Group are scarce and their price and quality fluctuates considerably (Pütz, 2014).

Moreover, the role of after-sales service is key to assure the operability of the plants over their lifetimes. However, the only mechanism for quality assurance after the construction of the biogas plants is done through a sampling process by the Regional Biogas Technicians. When asked about the percentage of biodigesters deployed that are still operational, the answer was that the NBPE have not pursued a biogas inventory yet and there was no definite numbers on this topic (Jijawo, 2014). However, during our field study in Ethiopia some interviewees mentioned that a large percentage of biodigesters were malfunctioning or out of operation.

According to the NBPE promoters and especially SNV worldwide, one of the main drivers for biogas dissemination is the systematic approach which includes involving a broad range of stakeholders (Boers, 2014). The NBPE was able to transition from a "single actor" approach to disseminate biogas technology to a multi-stakeholder approach (Boers & Esthete, 2008). However, as described in subsection 5.3.1, this has not led to a significant increase of local technical backup facilities and the rate of operability of the biogas plants that are already installed is questionable.

Furthermore, the standardisation of the SINIDU fixed-dome model has eased the quality assurance procedures. Nevertheless, similarly to what happened in Nepal during its initial phases of implementation, at some point it became necessary to diversify the technologies for domestic biogas production (Silwal, 1999). Also, in Ethiopia isolated efforts outside the NBPE have started to appear trying to address the gaps or burdens of this single-technology approach by diversifying the models and business plans to disseminate domestic biogas (Asfaw, 2014; Pütz, 2014; Sishuh, 2014). However, it is still uncertain if these complementing initiatives will be considered by the NBPE (Alemayehu, 2014); which was eventually the case in Nepal, where it was decided to diversify the technological options for domestic biogas (NBPA, 2013).

5.3.2 Development of user context

According to Kellner (2014), it is common that due to lack of knowledge and awareness, many of the biogas users do not exploit the full potential of biogas plants. For example, bad habits such as irregular or insufficient feeding of the biodigester significantly hinder biogas production. Further, as reported by Araya (2014), bio-slurry utilisation is poorly taught to biogas users by masons and although extension officers from the Ministry of Agriculture could perform this task, it is not done due to abovementioned inter-ministerial misalignments

A significant challenge in many areas of Ethiopia is water scarcity and drought during certain times of the year. As explained in Section 1, under the traditional fixed-dome model an equal amount of manure and water has to be provided daily (Bond & Templeton, 2011). In order to remediate this issue, around 50% of the biodigesters that are being deployed include a toilet connection, which enables the use of urine to compensate for the lack of water (Jijawo, 2014). However this contribution is negligible in comparison to the daily amount of excretes or liquid that are required (Tauseef *et al*., 2013). Currently, some member countries of the African Biogas Partnership Programme (ABPP)are experimenting with Solid-State Digesters (SSD) (Veen, 2013). The SSD is a modification of the conventional fixed-dome model and allows using a 4:1 manure/water mix instead of 1:1, hence significantly reducing the water demand of the biodigester (SNV, 2013b). However, SSD has not yet been introduced to Ethiopia (Alemayehu, 2014; Oppenoorth, 2014; Teka, 2014).

5.3.3 Government context and regulatory framework

Although initially the Ethiopian Rural Development and Promotion Centre (EREDPC) was appointed as the leading organisation at the national level, this organisation ceased to exist due to a ministerial restructuration at the federal level (Alemayehu, 2014; Boers *et al*., 2008). No official data was found specifying the details of the transition of the NBPE from the former Ministry of Mines and Energy to the Ministry of Water, Irrigation and Energy (MoWE). Therefore, it remains uncertain if elements such as institutional capacity, human resources or allocated budget were altered due to this transition. On the other hand, the abovementioned institutional transformation did not affect the regional level, and the Bureaus of Water, Energy and Mines remained unaltered during this ministerial restructuration (Alemayehu, 2014; Jijawo, 2014).

In Table 5, it is interesting to see that prior to launch of the NBPE it was recommended to incorporate the extension officers from the Ministry of Agriculture to provide support in the implementation of the programme (Esthete *et al*., 2006). However, as explained before, the incorporation of the extension officers has not happened yet due to inter-ministerial misalignments between the Ministry of Agriculture and MoWE (Araya, 2014). On the bright side, micro-finance institutions have been gradually integrated within the NBPE and around 57% of the biogas plants that were constructed by the NBPE used micro-loans as a means to fund the initial investment. Moreover, the World Bank has allocated economic resources to improve micro-credit access for renewables, including biogas. These funds are being channelled by the Development Bank of Ethiopia and distributed to the regional and local micro-finance institutions. (Alemayehu, 2014).

5.3.4 Barriers and drivers at the niche level - learning

All in all, from a learning processes perspective, the NBPE was able to attain first order learning among NBPE actors and governmental actors; however, it was generally unsuccessful to generate second order learning. In other words, initially NBPE was able to determine several factors that could poses a risk for the implementation of the programme (hence creating first degree learning). Nevertheless, it was unable to effectively solve the issues it initially identified by changing its basic assumptions and approach. Furthermore, first order learning among masons, technicians and users has not been optimal because of unclarity about who is responsible for this training and problems with expertise among trainers, as explained in subsection 5.1.3, and high illiteracy rates among the population.

6. ANALYSIS OF THE SOCIO-TECHNICAL LANDSCAPE

At the landscape level, economic instability and poverty in Ethiopia constitute the most relevant barriers for biogas dissemination. The Federal Democratic Republic of Ethiopia is categorised as one of the poorest countries in the world, although the country has experienced a sustained economic growth over the last years and the gross national income (GNI) per capita has more than doubled over the last 20 years. Poverty goes beyond per capita income; it affects people's quality of life and their ability to overcome their misery, hence poverty itself becomes a trap (Sachs, 2011). Because of this widespread poverty, many people in Ethiopia do not have enough purchasing power to buy a biogas plant. Ethiopia has the second largest population in Africa after Nigeria. Moreover its population has followed an almost continuous trend of growth of 2.2% per year over the last 10 years. By 2011, 83.2% of the Ethiopian inhabitants resided in rural areas and scattered over a 1.1 million square kilometre territory (CSA, 2010).

Political instability constitutes an additional constraint, both internal and external to the country. From an internal perspective, although the country deposed the communist regime in the early 1990s and instituted a multi-party democracy there are still shadows from authoritarianism which are still present nowadays. According to the World Bank (2013b), despite the sustained economic growth, the current enormous public intervention overshadows and even hinders private sector investments. Other factors that hinder entrepreneurial activities are inadequate financing possibilities, a shortage of educated and skilled labour (Brixiova & Axaminew, 2010), and the inability of firms to convert part of their profit into investment (Bekele & Worku, 2008). Although the Ethiopian government launched market reforms in 1991, the country remains in a vicious cycle of low productivity, low-paid jobs, and poverty (Brixiova & Axaminew, 2010). From an external perspective, Ethiopia faces significant geopolitical issues since there are latent border conflicts with Eritrea and Somalia and wars in its neighbouring countries (e.g. Sudan and South Sudan, Somalia) that pose a constant threat to the political and economic stability of the country. The political and economic instability lead to a low overall level of competitiveness of the country. Nevertheless, the Ethiopian Government has ambitions and commitment to provide solutions for poverty eradication (World Bank, 2013a).

Another barrier is the low literacy rate in Ethiopia of 40% (CSA, 2010). This makes the training of masons, technicians and users more difficult. This problem is exacerbated by the fact that within Ethiopia more than 80 different mother tongues exist. Although Amharr is the first language and many people speak English, in rural areas many people only speak their mother tongue (CSA, 2010). Another barrier is the lack of basic infrastructure which is evidenced by, among other things, the low access rates to clean water and household sanitation. The availability and access to water can represent a barrier for the deployment of the technology (Dekelver & Ruzigana, 2006). The appropriate operation of biogas digesters can be threatened due to seasonal or geographical shortages of water. Nevertheless, according to Holm-Nielsen *et al*. (2009), and as described in Section 5 of this paper, the shortage of water can be complemented with the use of animal or human urine.

On the other hand, at the landscape level, there are also drivers that motivate the development of domestic biogas in Ethiopia. For example, the physical geography of Ethiopia complies with technical criteria for the biogas plants that are being deployed to operate in terms of temperature and availability of waste organic matter. According to Pütz (2014) this suitability of the Ethiopian climate is not being fully exploited since the main model for the biogas plants is situated underground where there is a lower temperature than in the surface. Hence, the microbial activity inside the biodigester could improve with a rise in the temperature of the digester chamber if it would be located above the surface (Kellner, 2002), hence causing an increase of the biogas yield. Another driver is the scarcity of firewood. The systematic depletion of the forest coverage to satisfy the energy needs has led to a systematic depletion of the forest coverage over the last 35 years and a shortage of traditional biomass resources. Nowadays, only 2.7% of the land is covered with forests (Boers *et al*., 2008). The main driver at landscape level for the growth of the biogas sector in Ethiopia is a driver that originates from outside the country: the NBPE programme.

7. ANALYSIS OF THE RELEVANT REGIMES

7.1 Energy regime

The Ethiopian energy regime is mainly based on biomass. According to IEA (2014b), 92.9% of the primary energy consumption comes from biofuels and waste; 81.2% of which is supplied by woody biomass (especially firewood), followed by dung cakes and crop residue with a contribution of 9.1 and 8.1%, respectively. Other types of biomass are charcoal, bagasse and bio-briquettes (Wolde-Ghiorgis, 2002). Electricity provides only 1.1% of the energy demand and it is mostly supplied by hydroelectric plants: 93.9% of the electricity comes from hydro and the remaining is supplied by geothermal and fossil fuel-based power plants. According to the World Bank (2014), electricity access reached only 23% of the Ethiopian population by 2010. One of the problems resulting from Ethiopia's limited electricity use is the increase in health problems due to smoke emissions resulting from indoor cooking and indoor use of kerosene lamps. Moreover, it is estimated that in rural areas, women and children spend 5 to 6 hours collecting fuel wood.

When looking at the demand side, the residential sector consumes 93.5% of the energy that is supplied (CSA, 2010). The rest of the sectors have a negligible contribution to the energy demand, including industry with 1.8% and the commercial sector with 1.1% (IEA, 2014b). At the household level, 98.6% of the energy is supplied by biomass. According to Gebreegziabher (2007, 2014), 50-60% of household energy demand is used for baking *injera*; a traditional fermented flatbread with a sour taste. *Injera* is baked on large batches using a clay plate covered with a lid made out of straw and dried cow manure (Simons, 2012). The baking process is highly inefficient and uses a significant amount of firewood (Esthete *et al*., 2006). The remainder of the consumed energy is used for cooking other foods and for lighting.

7.2 Agriculture regime

Agriculture represents the main economic activity in Ethiopia, accounting for 48.8% of the country's GDP in 2012 (World Bank, 2014). Moreover, Ethiopia is believed to have one of the largest livestock populations in Africa (CSA, 2012) and it is globally recognised as the cradle for coffee, a deeply rooted beverage within its culture. The majority of the agricultural production in Ethiopia is performed at a household level, 96.8% of which takes place in a rural context, where crop harvesting and animal husbandry activities are often combined. The main products are cattle and cereals. In These agricultural households are characterised by limitedly small land tenure and it is common for all household members to contribute to the farm's activities.

7.2.1 Agricultural crops

The agricultural activity in Ethiopia is divided in two main seasons. The *meher* season, which relies on the precipitations from June to September and it is when most of the crops are harvested. And the *belg* season, which offers a second opportunity to a harvest a smaller batch of crops thanks to rainfall between March and April (Megersa, 2014). Furthermore, by far, the vast majority of Ethiopia's agricultural land is utilised for temporary crops, mainly to grow cereals. The *injera* mentioned in Section 6 is the base of the Ethiopian diet and it consists on a fermented flatbread made out of a cereal named *teff*.

Agricultural crops are concentrated in the regions of Amhara, Oromia, SNNPR and Tigray, which account for 97.4% of the total annual crop production. It is no coincidence that the Ethiopian National Biogas Programme (NBPE) takes places in these four regions, since most of the crop and livestock production takes place there.

Ethiopian farmers employ different practices in order to improve their crops' productivity. The most commonly used practice is to fertilizer application, mainly during the *meher* season (second half of the year). These synthetic fertilizers are applied to almost half of the cropland area, while natural fertilizers are only applied to 10.2% of this land. Moreover, irrigation alleviates water scarcity during the dry seasons between October and March. However, just 1.8% of the total cropland area employs irrigation practices. (CSA, 2013a)

7.2.2 Animal husbandry

Livestock activity plays a number of roles in Ethiopia's economy. It provides food, force, soil fertility and a distinctive means of savings at the farm level (Solomon *et al*., 2003). It represents a "near cash" capital stock for the peasants which can be exchanged when the agricultural households face economic struggles (CSA, 2012). As mentioned before, due to the scarcity of firewood in the country, many farmers have been forced to use manure as an alternative energy source through "dung cakes" (sun-dried manure), causing soil depletion in exchange for an inefficient source of energy (Subedi *et al*., 2014; Tauseef *et al*., 2013).

Similarly to crop production, most of the livestock is concentrated in the regions of Amhara, Oromia, SNNPR and Tigray. Oromia is the region with the highest cattle population with almost 22.5 million cattle heads. Camels are usually found in the Eastern and Northern regions of Ethiopia (e.g. Amhara, Tigray and Oromia), and are mostly used for dairy and transportation (CSA, 2012). Other livestock present in Ethiopia are poultry and beehives. The total poultry population in Ethiopia accounted for 44.9 million by 2012, most of which were chicks (40%) and laying hens (33%). Meanwhile, apiculture represents a diversifying income for smallholder farmers and it represents an annual production of 39.7 million tonnes of honey and 3.8 million tonnes of beeswax. To put this in perspective, Ethiopia is the tenth largest producer of honey and the fourth largest producer of beeswax worldwide (Gebremichael & Gebremedhin, 2014).

7.3 Barriers and drivers at the regime level

As also mentioned for the landscape level, the inability of the traditional practices to provide a solution for the current energy and environmental crisis constitute a driver for domestic biogas dissemination. The energy and agriculture regime are well tied in Ethiopia and interrelate with each other. The largest share of the energy consumption and most of the agricultural activities are conducted at the household level in the rural context (CSA, 2010, 2013b; IEA, 2014a).

Based on this motivation, the Ethiopian Government has focused on deploying actions to alleviate the energy crisis by providing national frameworks of implementation to embedded the implementation of alternative energy sources such as domestic biogas (MoFED, 2010). The creation of such frameworks has also promoted the creation of a suitable sectorial policy which is a driver for the development of alternative energy technologies (Tsegaye, 2014).

However, albeit the unsustainability of the trends in the current dominant regimes such as the use of firewood a lock-in results in the perpetuation of traditional practices. Another barrier is the fact that current commercially available biodigesters are not suited for *injera* cooking, the traditional food in Ethiopia. Another important barrier in the regime is the poverty already mentioned in the landscape. The low purchasing power of Ethiopian farmers limits them to invest in a biogas plant. According to Oppenoorth (2014), an Ethiopian farmer faces the dilemma between investing in a biogas plant or increasing the number of cattle heads he or she poses. For the case of Ethiopia, a biogas digester costs the equivalent of four cows, whereas in Tanzania and Kenya it costs two and 1.5 cows, respectively.

8. CONCLUSIONS AND RECOMMENDATIONS

The current paper has looked into the development of domestic biogas in Ethiopia by analysing its current status as well as drivers and barriers for further growth. It has been found that the gradual emergence of the niche technology has been accomplished based on a systematic and centralized approach leaded by the Ethiopian National Biogas Programme (NBPE).

Our analysis shows that barriers and drivers for the deployment of domestic biogas in Ethiopia are present at the different socio-technical levels. Moreover, there are strong interdependencies within and between the levels, e.g. between the energy and agriculture regimes. The main drivers and barriers we found are represented in Table 6.

As can be seen in this table, at the landscape level an important driver for the current growth of the biogas sector in Ethiopia is the NBPE programme, largely funded by the Dutch SNV Development Organization. The deforestation resulting from the traditional use of firewood for cooking in Ethiopia is another driver, as is the climate which is very suitable for the operation of biodigesters. Barriers at the landscape level are the political and economic instability, the widespread poverty which results in insufficient purchasing power for most Ethiopians to invest in a biogas plant and the difficult circumstances for enterprises and innovation. Other barriers are the high illiteracy rate and the large number of mother tongues in Ethiopia which makes training of masons, technicians and users more difficult. In addition, water shortages may also become a barrier since a daily 1:1 ratio of manure and water needs to be fed into the biodigesters in order to assure there adequate operation.

As a consequence of the NBPE program, suitable sectoral policies were set up at regime level, which are a driver for the further growth of biogas in Ethiopia. A barrier at this level is the deeply rooted practice of *injera* cooking, an Ethiopian staple food, which is not possible on the currently commercially available biogas cookers.

At the niche level, drivers are (1) the fact that many different actors are present in the network, among whom governmental actors at many different levels and also regime actors, and (2) the presence of first order learning about biogas technology, at least among NBPE actors and governmental actors. However, at this level also quite some barriers exist. Although many different actors participate, the private sector, which should play an important role, is currently not active in the Ethiopian biogas niche. Also, the alignment between the actors that are present in the niche is weak, especially between the different governmental bodies. Furthermore, because the actual implementation rate of biodigesters is severely lagging behind the initial goals, expectations had to be lowered during the recent years. Also, first order learning among masons, technicians and users has not been optimal because of problems with training and high illiteracy rates. Furthermore, second order learning is lacking – issues that were already identified before the start of the NBPE programme, e.g. regarding technical problems, the user context and the regulatory framework, are still not resolved.

Table 6: The main drivers and barriers for further growth of the biogas niche in Ethiopia

SOCIOTECHNICAL LEVEL	BARRIERS	DRIVERS
LANDSCAPE	Political and economic instability	
	Low suitability of economic climate for enterprises and innovation	
	Widespread poverty – therefore most farmers have insufficient purchasing power to invest in a biogas plant	
		Suitability of the climate
	Lack of natural resources – water shortages	Lack of natural resources – depletion of firewood
	High rate of illiteracy	
	Presence of different tribes with different mother tongues	
		Presence of NBPE programme
REGIME		Stability in regime – deeply rooted practices of firewood use
		Suitability of sectoral policy
	Amount of lock-in in regime – deeply rooted practice of *injera* cooking which is currently not possible on biogas	Amount of lock-in in regime – deeply rooted practice of firewood use
NICHE	Not fully completeness of network of actors – private sector is missing	Almost completeness of network of actors, including regime actors
	Poor alignment in network of actors – many mismatches between governmental bodies and levels	
	Mismatch between expectations and actual development – implementation goals have not been reached; private sector is still not involved	

SOCIOTECHNICAL LEVEL	BARRIERS	DRIVERS
	Problems with first order learning among masons, technicians and users	Presence of first order learning among NBPE actors and governmental actors
	Lack of second order learning – issues present at start of NBPE programme are still not resolved	

Our recommendation for actors involved is to focus quickly on addressing the abovementioned barriers, part of which have already been known for years. One aspect here form the emerging initiatives that are focused on solving the technical issues such as the inability of the biogas systems to satisfy a significant share of the household energy demand (in simple words, being able to bake *injera* with biogas). Another important aspect is the empowerment and inclusion of the private sector by rethinking the way the technology is disseminated. A third recommendation is to pay special attention to training and awareness of masons and users in the rural areas especially adapted to circumstances with high illiteracy rates and many different mother tongues. A fourth aspect to mention here is the price of the biodigesters and the price differences between different countries. In this respect, starting to disseminate different designs and sizes of biodigesters, as has also been done in Nepal, seems worth considering. These actions combined would improve the further dissemination of this technology and in that way contribute to innovation for sustainable growth. This also provides the direct link between this article and the theme of the IAMOT 2015 conference: Technology, innovation and management for sustainable growth.

From a scientific perspective, the combined application of Strategic Niche Management (SNM) and the Multi-Level Perspective (MLP) added to the deep insights into the status and dynamics of this case and adds to the body of literature about innovation in the developing world. Moreover, the analysis of multiple relevant sociotechnical regimes allowed to better understand the interrelationships between them as well as the influence that they exert on the niche technology.

REFERENCES

ABPP. (2013). ABPP: Ethiopia. Retrieved January 12, 2014, from http://africabiogas.org/ethiopia/

Alemayehu, T. (2014). Interview with Tesfaye Alemayehu, Chief Engineer at the NBPE 30/4/2014. Addis Ababa, Ethiopia.

Araya, H. (2014). Interview with Hailu Araya, Ecological Organic Agriculture Advisor for ISD 1/5/2014. Addis Ababa, Ethiopia.

Asfaw, A. (2014). Interview with Dr. Araya Asfaw, Executive Director of HOA-REC&N 30/4/2014. Addis Ababa, Ethiopia.

Bekele, E., & Worku, Z. (2008). Factors that affect the long-term survival of micro, small and medium enterprises in Ethiopia. South African Journal of Economics, 76(3), 548–568.

BIOGAS4ALL. (2014). Forecast and Actual biogas plants. Retrieved May 17, 2014, from https://sites.google.com/site/biogas4all/2012

Boers, W. (2014). Interview with Willem Boers, former Lead Renewable Energy Advisor for SNV-Ethiopia 13/3/2014. Lelystad, The Netherlands.

Boers, W., & Esthete, G. (2008). Biogas in Ethiopia: From Skepticism to Enthusiasm (pp. 1–5).

Boers, W., Workneh, K., & Esthete, G. (2008). National Biogas Programme Ethiopia Programme Implementation Document.

Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. Energy for Sustainable Development, 15(4), 347–354. doi:10.1016/j.esd.2011.09.003

Brixiova, Z. & Asaminew, E. (2010). SME Start Ups in Ethiopia: Which Incentives Matter? ADB, Ethiopian Economic Association, Addis Ababa, Ethiopia.

Caniëls, M. C. J., & Romijn, H. A. (2008). Actor networks in Strategic Niche Management: Insights from social network theory. Futures, 40(7), 613–629. doi:10.1016/j.futures.2007.12.005

CSA. (2010). Census 2007.

CSA. (2012). Annual Agricultural Sample Survey 2012/2013: Livestock and Livestock Characteristics (Vol. II).

CSA. (2013a). Annual Agricultural Sample Survey 2012/2013: Farm Management Practices.

CSA. (2013b). Annual Agricultural Sample Survey 2012/2013: Land Utilisation.

Dekelver, G., & Ruzigana, S. (2006). Implementation Plan: National Programme on Domestic Biogas in Rwanda.

Esthete, G., Sonder, K., & ter Heegde, F. (2006). Report on the Feasibility Study of a National Programme for Domestic Biogas in Ethiopia .

Gebreegziabher, Z. (2007). Household Fuel Consumption and Resource Use in Rural-Urban Ethiopia. Wageningen University.

Gebreegziabher, Z. (2014). Interview with Dr. Zenebe Gebreegziabher, Senior Research Fellow at EDRI 1/5/2014. Addis Ababa, Ethiopia.

Gebremichael, B., & Gebremedhin, B. (2014). Adoption of improved box hive technology: Analysis of smallholder farmers in Northern Ethiopia. International Journal of Agricultural Economics and Extension, 2(2), 077–082.

Geels, F. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8-9), 1257–1274. doi:10.1016/S0048-7333(02)00062-8

Geels, F., & Schot, J. (2007). Typology of sociotechnical transition pathways. Research Policy, 36(3), 399–417. doi:10.1016/j.respol.2007.01.003

Hofstede, G. (2005). Cultures and Organizations: Software for the Mind: Intercultural Cooperation and its Importance for Survival. New York: McGraw-Hill.

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. Bioresource Technology, 100(22), 5478–84. doi:10.1016/j.biortech.2008.12.046

Hoogma, R. (2000). Exploiting Technological Niches: Strategies for Experimental Introduction of Electric Vehicles. Twente University Press. Retrieved from http://books.google.nl/books?id=X8SIAAAACAAJ

Hoogma, R., Schot, J., & Truffer, B. (2002). Experimenting for Sustainable Transport Experimenting for Sustainable Transport: the approach of strategic niche management. London: Spon Press.

IEA. (2014a). Ethiopia's Energy Balance (2011). Retrieved May 27, 2014, from http://www.iea.org/Sankey/index.html#?c=Ethiopia&s=Balance

IEA. (2014b). Ethiopia's Final Consumption (2011). Retrieved May 27, 2014, from http://www.iea.org/Sankey/index.html#?c=Ethiopia&s=Final consumption

Jijawo, T. (2014). Interview with Tamirat Jijawo, Regional Biogas Coordinator for SNNPR 12/5/2014. Hawassa, Ethiopia.

Kamp, L. M. (2008). Analyzing the introduction of renewable energy technologies in The Netherlands with the FIS approach – possibilities , limitations and additions. In DIME International Conference "Innovation, sustainability and policy" (pp. 1–27). Bordeaux.

Kamp, L. M., Smits, R. E. H. M., & Andriesse, C. D. (2004). Notions on learning applied to wind turbine development in the Netherlands and Denmark. Energy Policy, 32, 1625–1637. doi:10.1016/S0301-4215(03)00134-4

Kellner, C. (2002). Manual for The Construction of a Bio Digester , " LUPO " Design. Edition for Ethiopia (pp. 1–30).

Kellner, C. (2014). Interview with Christopher Kellner, Regional Technical Advisor at BORDA 22/4/2014. Zambia.

Megersa, G. (2014). Genetic erosion of barley in North Shewa Zone of Oromiya Region, Ethiopia. International Journal of Biodiversity and Conservation, 6(3), 280–289. doi:10.5897/IJBC2013.0673

MoFED. (2010). Growth and Transformation Plan 2010/11 – 2014/15. Volume I: Main Text. Addis Ababa.

NBPA. (2013). Biogas Technologies. Retrieved February 17, 2014, from https://sites.google.com/site/nepalbiogas/biogas/biogas-technologies

Oppenoorth, H. (2014). Interview with Harrie Oppenoorth, Senior Advisor in Energy and Climate Change for Hivos International 17/4/2014. Den Haag, The Netherlands.

Pusch, Z. (2014). Interview with Zachary Pusch, Regional Environmental Assistant at the US Embassy in Ethiopia 6/5/2014. Addis Ababa, Ethiopia.

Pütz, K. (2014). Interview with Katrin Pütz, Co-owner of (B) Energy 2/5/2014. Addis Ababa, Ethiopia.

Raven, R. (2005). Strategic niche management for biomass: a comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark. Technische Universiteit Eindhoven, Eindhoven. Retrieved from http://w3.tm.tue.nl/fileadmin/tm/TDO/Rob_Raven.pdf

Raven, R., Heiskanen, E., Lovio, R., Hodson, M., & Brohmann, B. (2008). The contribution of local experiments and negotiation processes to field-level learning in emerging (niche) technologies: Meta-analysis of 27 new energy projects in Europe, 1–19. doi:10.1177/0270467608317523

Romijn, H., Raven, R., & de Visser, I. (2010). Biomass energy experiments in rural India: Insights from learning-based development approaches and lessons for Strategic Niche Management. Environmental Science & Policy, 13(4), 326–338. doi:10.1016/j.envsci.2010.03.006

Sachs, J. (2011). The End of Poverty: How We Can Make it Happen in Our Lifetime. Penguin UK. Retrieved from http://books.google.nl/books/about/The_End_of_Poverty.html?id=DnoaoaPbBzQC&redir_esc=y

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy, 20(5), 537–554. doi:10.1080/09537320802292651

Silwal, B. B. (1999). A Review of the Biogas Programme in Nepal.

Simons, L. (2012). Fortune Cooker: Leon Simons at TEDxUtrechtUniversity. Utrecht, The Netherlands: TEDx Utrecht University. Retrieved from https://www.youtube.com/watch?v=fr4PKeI5C14

Sishuh, B. G. (2014). Interview with Benjamin G. Sishuh, Executive Director of 4R Energy 2/5/2014. Addis Ababa, Ethiopia.

Smith, A. (2007). Translating Sustainabilities between Green Niches and Socio-Technical Regimes. Technology Analysis & Strategic Management, 19(4), 427–450. doi:10.1080/09537320701403334

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. Research Policy, 41, 1025–1036. doi:10.1016/j.respol.2011.12.012

Smith, J. U. (2011). The Potential of Small-Scale Biogas Digesters to Alleviate Poverty and Improve Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa.

Smith, J. U. (2013). The Potential of Small-Scale Biogas Digesters to Improve Livelihoods and Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa.

SNV. (2013). Domestic biogas. Retrieved February 15, 2014, from http://www.snvworld.org/en/sectors/renewable-energy/about-us/snv-energy/domestic-biogas/snv-and-domestic-biogas

Solomon, A., Workalemahu, A., Jabbar, M. A., Ahmed, M. M., & Hurissa, B. (2003). Livestock marketing in Ethiopia: A reviw of structure, performance and development initiatives. Nairobi, Kenya: International Livestock Research Initiative. Retrieved from http://tiny.cc/ytwofx

Subedi, M., Matthews, R., Pogson, M., Abegaz, A., Balana, B., Oyesiku-Blakemore, J., & Smith, J. (2014). Can biogas digesters help to reduce deforestation in Africa? Biomass and Bioenergy, 1–12. doi:10.1016/j.biombioe.2014.02.029

Tauseef, S. M., Premalatha, M., Abbasi, T., & Abbasi, S. A. (2013). Methane capture from livestock manure. Journal of Environmental Management, 117, 187–207. doi:10.1016/j.jenvman.2012.12.022

Teka, M. (2014). Interview with Melis Teka, Renewable Energy Advisor for SNV-Ethiopia 30/4/2014. Addis Ababa, Ethiopia.

Tsegaye, F. (2014). Interview with Fitsumbrhan Tsegaye, Energy Expert at HOA-REC&N 29/4/2014. Addis Ababa, Ethiopia.

Tumwesige, V. (2011). Small-Scale Biogas digester for Sustainable Energy production in Sub-Saharan Africa.

Van der Laak, W. W. M., Raven, R. P. J. M., & Verbong, G. P. J. (2007). Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies. Energy Policy, 35(6), 3213–3225. doi:10.1016/j.enpol.2006.11.009

Van Nes, W. J., & Tinashe, D. N. (2007). Biogas for a better life: An African initiative. Retrieved June 20, 2014, from http://www.renewableenergyworld.com/rea/news/article/2007/07/biogas-for-a-better-life-an-african-initiative-51480

Veen, M. (2013). Interview with Martijn Veen, Sector Leader Renewable Energy at SNV-Tanzania 1/11/2013. Arusha, Tanzania.

Verbong, G., & Geels, F. (2007). The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). Energy Policy, 35, 1025–1037. doi:10.1016/j.enpol.2006.02.010

Warnars, L., & Oppenoorth, H. (2014). Bioslurry: a supreme fertiliser.

Wolde-Ghiorgis, W. (2002). Renewable energy for rural development in Ethiopia: the case for new energy policies and institutional reform. Energy Policy, 30(11-12), 1095–1105. doi:10.1016/S0301-4215(02)00061-7

Worku, M. (2014). Interview with Mogues Worku, Executive Director of LEM-Ethiopia 29/4/2014. Addis Ababa, Ethiopia.

World Bank. (2013a). Second Ethiopia Economic Update: Laying the Foundation for Achieving Middle Income Status.

World Bank. (2013b). The World Bank Implementation Status & Results The World Bank (pp. 1–4).

World Bank. (2014). World DataBank: Ethiopia. Retrieved January 13, 2014, from http://data.worldbank.org/country/ethiopia