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Empowerment Pathways: Assessing the Impact of Small-Scale Biogas Technology on Rural Women in Sub-Saharan Africa

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled **Empowerment Pathways: Assessing the Impact of Small-Scale Biogas Technology on Rural Women in Sub-Saharan Africa** independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 18. 4. 2024

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Klára Kohoutová

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Abstract

This thesis evaluated how small-scale biogas technology contributes to rural women's empowerment in Sub-Saharan Africa. By utilizing a comprehensive literature review, the study synthesized secondary sources about the economic, social, environmental, and health benefits of biogas technology. Additionally, it assessed the benefits' contribution to women's empowerment within the region by utilizing Kabeer's women's empowerment framework and identifying empowerment pathways of biogas.

The findings indicated that small-scale biogas technology had shown potential to empower rural women through various benefits. Economically, biogas adoption provided financial savings, income generation opportunities, and increased agricultural production, leading to enhanced decision-making power and long-term poverty mitigation. From a health perspective, benefits included improved pollution and waste management practices, and deforestation mitigation, leading to awareness about sustainable practices and their promotion, resulting in greenhouse gas reduction and sustainable management of natural resources. Additional, biogas technology decreased indoor air pollution, improved food safety, prevented injuries, and subsequently, improved community health outcomes. Socially, biogas technology facilitated time and labour savings, increased access to education, fostered more equal household and community relationships, enhanced skills and knowledge, and increased decision-making power, ultimately promoting the adoption of sustainable cooking practices and enhancing women's status within communities.

Additionally, the study highlights potential obstacles of biogas technology adoption, including economic, operational, and maintenance challenges, energy stacking, cooking preferences, intra-household gender dynamics, and potential employment loss. Altogether, the thesis contributes to understanding the role of renewable energy in promoting gender equality and empowerment.

Keywords: gender equality, renewable energy source, bioenergy, poverty, digester, bio-slurry

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ABPP	Africa Biogas Partnership Program
AD	Anaerobic digestion
GHG	Greenhouse gas
GII	The Gender Inequality Index
IEA	International Energy Association
NGO	Non-governmental Organization
Pro-WEAI	Project-level Women's Empowerment in Agriculture Index
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
ToC	Theory of change
UN	United Nations
WB	World Bank
WBA	World Biogas Association
WE	Women's empowerment
WHO	World Health Organization
WOCAN	Women Organizing for Change in Agriculture and Natural Resource Management

1 Introduction

To address the most urgent problems in today's world, the United Nations (UN) established seventeen Sustainable Development Goals (SDGs) in 2015. So-called Agenda 2030, framed with the motto “Nobody is left behind” aims at ensuring that Planet Earth becomes a more pleasant place to live for everyone. The SDGs tackle pressing issues such as poverty, hunger and inequality; they are necessarily interconnected and, thus, the change in one influences other (Lindgren 2021). The topic of this thesis is bridging SDG 5 addressing explicitly gender equality, and SDG 7 aiming at the provision of affordable and clean energy for everyone. Achieving these two goals contributes to socio-economic development (Gafa & Egbendewe 2021; Kabir et al. 2022); with a high priority for developing and newly industrialized countries, many of which can be found in Sub-Saharan Africa (SSA) (Terrapon-Pfaff et al. 2018), a region with over 1.21 billion inhabitants (O'Neill 2024) and 35.4% of the population living under the poverty line[1] (World Bank 2019).

Nowadays, most of the energy in the developed world comes from centralized systems, that provide energy to consumers with no obvious discrimination. However, the misconception often is that there are no inequalities within this system, as particular requirements remain hidden (Stai et al. 2023). In developed countries, these requirements are e.g. the need to buy and maintain certain devices or the payment of the electricity bill. Women are often left behind when it comes to large-scale energy systems because they are commonly seen 'only' as caretakers and stay in the informal or even unpaid sector. Therefore, it is important to pay attention to how and who has access to energy resources and how this access is influenced by social gender norms (Njenga & Mendum 2018).

In contrast to the developed world, the energy in developing countries often comes from decentralized sources. Also, even when some centralized grid exists (which is not very common), it is often not affordable or accessible for all people (Stritzke & Jain 2021). The affordability of this energy is necessarily tied to the generation of sufficient income. The capacity to create such income is different for men and women and depends greatly on local social norms (Njenga & Mendum 2018).

[1] Daily income USD 2.15 or lower (World Bank 2019)

Where a centralized energy grid is not accessible, most of the energy used for cooking, heating or lighting comes from the use of traditional biomass, such as charcoal, firewood, or occasionally dung (Ifegbesan et al. 2016; Njenga & Mendum 2018). Over 85% of the households are dependent on these energy sources in the case of rural SSA. According to the International Energy Association (IEA), these habits are not only energy inefficient, but also very unclean and harmful to health (Murshed 2022).

Today, it is generally agreed that access to clean energy technologies has different impacts on the lives of men compared to women and girls, which is caused by the traditional social norms assigned to each of the genders (Terrapon-Pfaff et al. 2018). Women's empowerment (WE) is both the goal and the facilitator of development in many important areas of life, and the adoption of clean fuels could help with its achievement (Odo et al. 2021). An example of a recently emerging, renewable, and clean fuel is biogas, which has a significant potential to contribute to WE (AlQattan et al. 2018). However, the empowerment process is not simple or easy, and many variables influence the final impact.

Thus, a comprehensive analysis of the specific benefits brought by the use of biogas technology, particularly for rural women, is provided in this thesis. In addition, the concept of empowerment is examined in connection to these benefits. Specifically, **are the benefits of using small-scale biogas technology supportive of the empowerment process of rural women in SSA?**

2 Aims of the Thesis

The primary objective of this thesis was **to evaluate whether the benefits of small-scale biogas technology brought to rural women in SSA contribute to their empowerment process**. The evaluation was done through a comprehensive literature review synthesizing secondary sources' results into a study which could serve as a foundation for further research.

To achieve the main objective, three specific objectives were formulated:

1) To determine and comprehensively synthesize the results of published studies related to the benefits brought to rural women in SSA after the implementation of biogas technologies, while considering economic, social, environmental and health perspectives;
2) To link these benefits to the three-dimensional WE model (Kabeer, 1999);
3) To point out potential obstacles connected to the adoption of biogas technologies for rural women in SSA.

3 Methodology

This chapter discusses the methodological approach, describing the specific methodologies employed in the research and the rationale behind their selection. Additionally, it discusses the conceptual approach, which explains the theoretical frameworks and conceptual models guiding the research. Lastly, the limitations of the thesis are briefly discussed.

3.1 Methodological Approach to Literature Review

This thesis utilized a comprehensive literature review approach to explore the connection between small-scale biogas technology benefits and WE in SSA. The secondary data used in this work originated from scientific and grey publications. The scientific literature reviewed for this study was searched on academic databases, primarily ScienceDirect between June 2023 and February 2024. The literature retrieved from ScienceDirect was used for the core of the thesis.

To select scientific papers relevant to the thesis, the suitable keywords, such as *gender, equality, energy, biogas, bio-slurry, women, empowerment, rural, Sub-Saharan Africa, economic, social, environment, health* and *benefits* and their combinations with the use of Boolean operators, mostly AND, but also OR, were used. An example of a combination used was *"Women empowerment" AND biogas AND Africa.* Only sources in English were considered, which can be seen as one of the limitations of this thesis. However, the English language is widely used in communicating research results (Chandra Sekhar Rao 2018).

The specified timeframe of the literature was selected to be 2013-2024 for the sake of topicality, except for the study published by Kabeer in 1999, which was used to create the WE framework. However, an interesting finding was that in the earlier years, there were usually only a few papers published, and in more recent years, their numbers have increased significantly, implying that the topic of this thesis is also getting more recognition among the researchers. An example from the ScienceDirect database is provided in Figure 1.

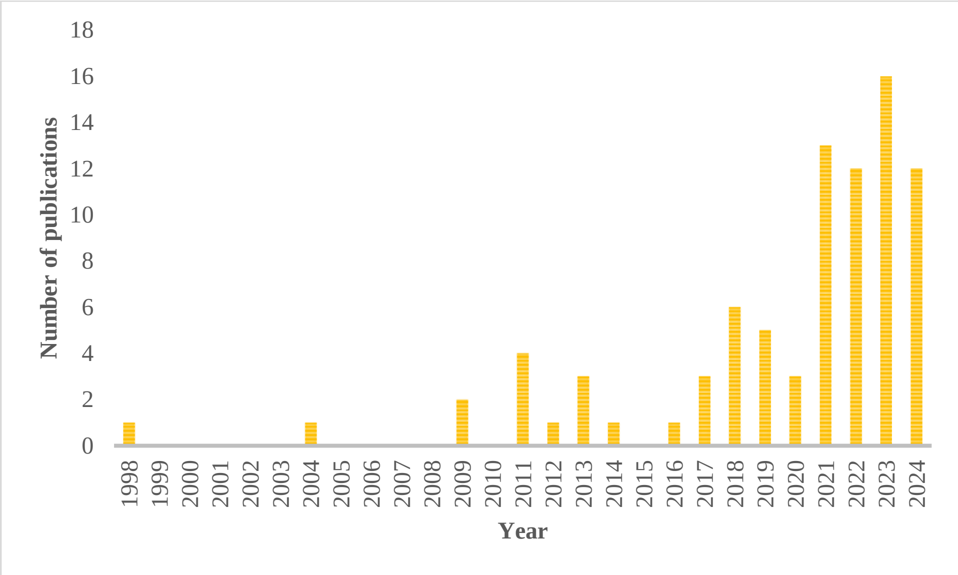

Figure 1. Results for "Women's empowerment" AND biogas AND Africa on ScienceDirect (15/04/2024).

The inclusion criteria for the papers retrieved were: 1) the paper addressed biogas to at least some extent, even if it was not the main focus of the paper; 2) the term "women's empowerment" or "gender equality" (or their combination) was used in the paper; 3) the paper focused on SSA or a specific country within the region. For the paper to be included in the review, at least two out of these three criteria needed to be met. Next, abstracts were also screened for relevancy. Initially, 336 results were retrieved during the primary search, from which 43 were considered relevant based on inclusion criteria and abstract content.

After the primary search, a complementary search took place on Scopus, Wiley, and Google Scholar, and ended in April 2024. Additionally, some complementary resources were retrieved from the references of the studies found during the primary search, or from the official websites of the UN, World Bank (WB), and World Biogas Association (WBA). No sources included were published before 2013 as well. Literature retrieved during the complementary search was used for clarification of some concepts as well as for obtaining more examples from particular countries. An additional 22 papers and 4 other sources from WB, UN, and WBA were included during the complementary search, adding up to **69 sources in total**. The literature selection process is described in Figure 2. The methodology of the thesis adopts a qualitative approach, prioritizing in-depth exploration and analysis of the gathered information over quantitative measurements.

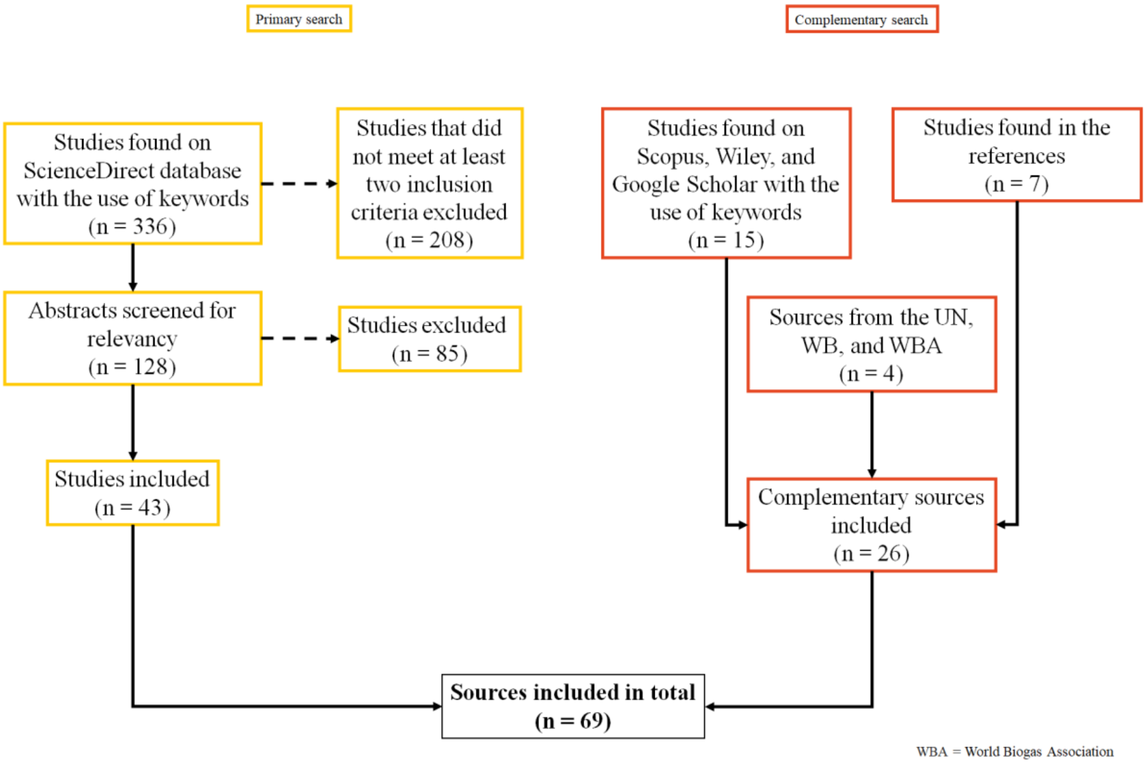

Figure 2. Literature selection process.

3.2 Conceptual Approach to Literature Review

In the thesis, the transition from traditional fuels to biogas, mainly used for cooking, will be substantial for the assessment of empowerment. No commonly accepted definition of transition is used by scholars. However, according to Elasu et al. (2023), the most important part is that the energy transition concerns either energy technology, energy fuel or energy pattern (or a combination of these) and a shift among them. A crucial part of the transition is the change on several levels, including economic, political, demographic, institutional, ethical, ecological and socio-cultural factors. These factors are important for the households to determine if the transition will be advantageous for them. In this case, the **transition from traditional biomass** (e.g. fuelwood, coal, dung) used for cooking **to biogas technology** was considered.

Studies focusing on biogas often distinguish the benefits brought by its implementation into several categories. For instance, Piadeh et al. (2024) delve into the impacts through economic, environmental and social perspectives with the health implications being discussed across these chapters. On the other hand, a study from rural areas of Colombia by Pizarro-Loaiza et al. (2021) primarily examines the environmental and health benefits of biogas technologies. However, the economic and social benefits are briefly mentioned as well. Within the scope of this thesis, the **benefits** of the small-scale biogas technology proposed by the reviewed literature were thus assessed from **economic**, **social**, **health,** and **environmental** perspectives, since positive impacts of biogas were found within all of these categories. However, it is important to mention that some of the benefits discussed further fit into more than one of the categories since none of them exist in a vacuum and can influence many different parts of women's lives.

Next, a concept of **Theory of Change** (ToC) was included in the conceptual framework. ToC outlines how interventions can lead to specific development outcomes and helps to identify effective solutions to address underlying issues. Thus, it generally consists of inputs, activities, **outputs**, **outcomes**, and **impacts**, which are, respectively, linked up to each other. ToC also highlights underlying assumptions and **risks** which could hinder the desired change (United Nations Development Group 2017). An example of ToC of biogas implementation is provided in Figure 8.

By connecting Kabeer's empowerment framework and the ToC model, it was possible to identify empowerment pathways through which biogas contributes to positive impacts on rural women in SSA. More specifically, resources, agency and achievements were identified in Chapter 4.4.5. Different benefits were associated with outputs, outcomes and impacts in the ToC process, by which it was possible to identify the "journey" from the transition to biogas technologies to WE – **empowerment pathways**.

The **obstacles** identified in Chapter 4.5. were, in this sense, assigned to the risks which are part of the ToC as well. These obstacles appear during different phases of the empowerment (in another way, change) process. They prevent the desired goals from being reached. Finally, an illustration of the conceptual framework, including the processes described above, is provided in Figure 3.

3.3 Limitations of the Study

To understand the impacts of small-scale biogas technology, it is also important to understand human behaviour. Several factors, such as religion, education, or social networks, influence the way biogas technologies (and their impacts) are perceived, and there is no universal motive for every household (Lindgren 2021). However, most of the existing literature focuses on the technological, environmental, and economic part of the problem, completely overlooking the human factors (Iessa et al. 2017).

In recent articles on this topic, most of the authors are white men typically coming from North America. Also, the degrees of these authors are often in science, engineering or economics, but just a few are trained in human studies. Of course, their research is very important and valid, however, the limited perspectives are evident (Sovacool 2014). In the last 15 years, only 15% of the authors in energy studies identified themselves as women, and only about 0.5% of these authors had training in development studies or affiliations in anthropology or communication. Authors that would have training in gender studies were missing completely (Lindgren 2021).

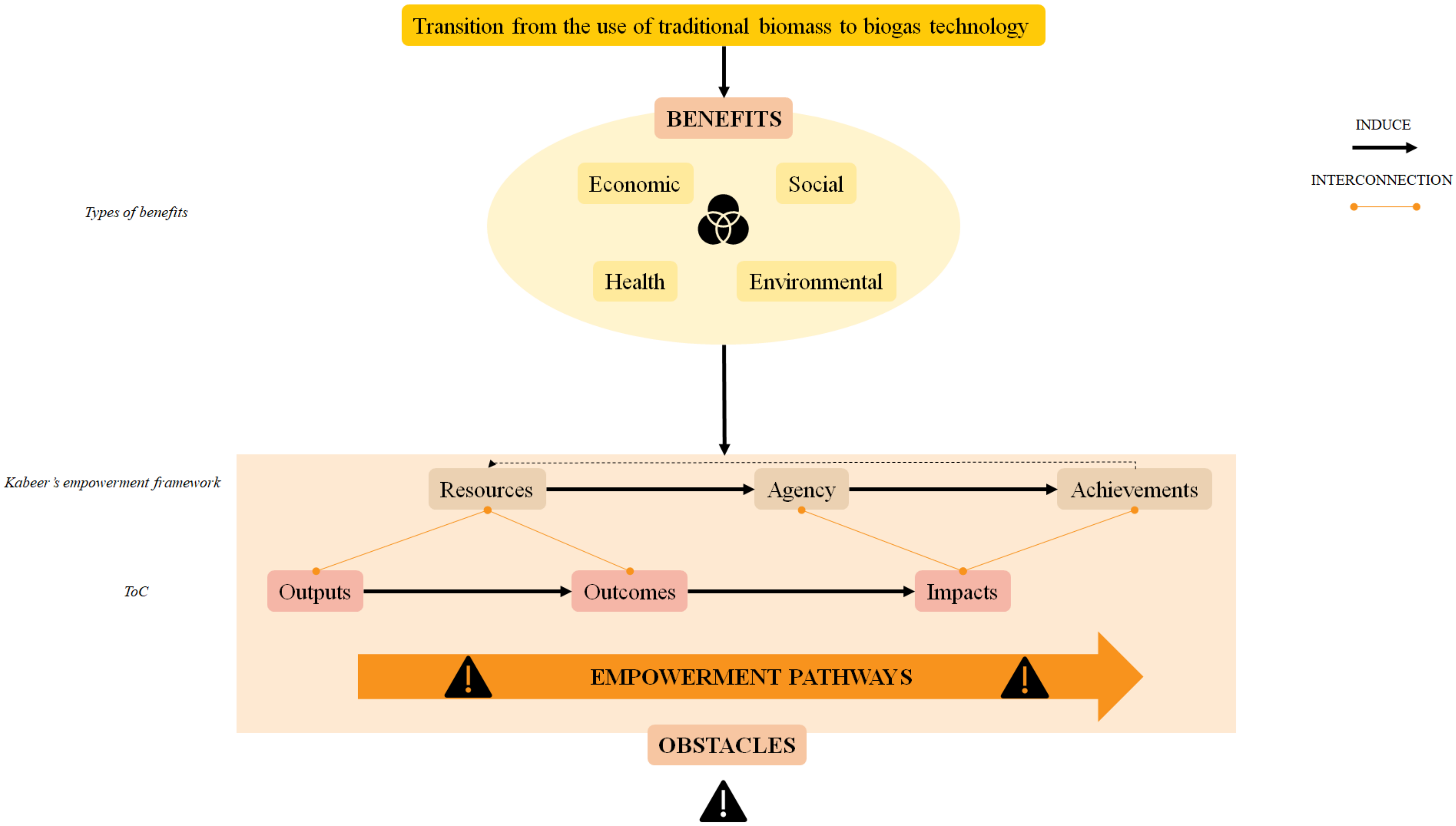

Figure 3. Conceptual framework of the thesis.

4 Literature review

The literature review section of the thesis delves into various aspects related to WE. It also provides an overview of traditional energy sources and biogas technologies in SSA, along with their expected benefits for women from the economic, environmental, health and social perspectives. Additionally, the benefits are connected to the WE framework and empowerment pathways are identified. Potential obstacles that rural women in SSA might face regarding the adoption of biogas technologies will be explored at the end of this chapter (Lindgren 2021).

4.1 Women's Empowerment and Energy Justice

In feminist circles, it has been hard to find precise definitions of WE, and it has been even more complicated to find how to measure it. Kabeer (1999:437), for instance, defined it as "*the expansion in people's ability to make strategic life choices in a context where this ability was previously denied to them*", implying that empowerment is necessarily bound to disempowerment – denial of the ability to make choices. It is the process of change where the previously disempowered individuals obtain the ability to choose. In addition, certain alternatives must exist for one to make a choice, and it should be possible to transition freely between these alternatives if needed. Moreover, not all choices have the same impact on the lives of people. Some choices are strategic and have a severe impact on people's lives.

To make decisions freely about one's life, the acquisition and control of certain *resources* - whether material, financial, human or social - is typically deemed essential. However, some studies prefer to use the *agency* as the main proxy of empowerment. Agency manifests itself as, for example, control over finances, decision-making authority, or freedom of movement. Empowerment is often closely connected to power relations among different actors. In the case of women, intra-household and familial dynamics are also involved (Yasmin & Grundmann 2020; Odo et al. 2021). Thus, besides the ability to "make a choice", it is important to consider the mutual interdependence of women and their husbands, families, communities, or society (Meinzen et al. 2019). Nevertheless, the absence of a proper definition of empowerment is often welcomed by many feminists, since it gives certain mobility (Kabeer 1999).

For this thesis, the model (as well as the definition of empowerment) introduced by Naila Kabeer (1999) is used, as it is crucial to have a unified understanding of the concept to properly evaluate the benefits discussed further in the thesis. This model comprises of two dimensions mentioned above – resources, and agency. In addition, it takes into account also a third one – achievements.

As the first dimension, **resources** comprise both economic/material and human/social parts, and they can manifest themselves as actual allocations, but also as future expectations and claims (Kabeer 1999). Therefore, they are often divided into tangible and intangible. Many rules and norms influence access to such resources, which gives some actors authority over others. Assets and property rights are some of the indicators of resources (Meinzen et al. 2019). Another example of resource division can be found in the study conducted by Sinharoy et al. (2023), where eight sub-domains of resources were identified. These domains included bodily integrity, health, safety and security, privacy, financial and productive assets, time, critical consciousness, knowledge and skills, and social capital. However, different researchers often develop their own indicators to identify resources depending on the particular aims of their research (Sinharoy et al. 2023).

Then, the dimension of **agency** refers to the capacity to act upon defined goals. Its meaning can be positive (in the sense of the "power to", "power with" and "power within") or negative (in the sense of the "power over") (Kabeer 1999; Meinzen et al. 2019). Measuring agency is often challenging; thus, the project-level Women's Empowerment in Agriculture Index (pro-WEAI) introduced three domains of agency; instrumental (power to), intrinsic (power within), and collective (power with). Although pro-WEAI introduced 12 specific indicators of agency (Sinharoy et al. 2023), Meinzen et al. (2019) decided to focus on less specific aspects which are connected to the three domains. In the case of ***instrumental agency***, these aspects are decision-making (in agricultural production), control over income, control over assets, mobility, and time. The domain of ***intrinsic agency*** includes intrahousehold relationships and intimate partner violence against women. Lastly, leadership and group participation are part of the ***collective agency*** domain. Some of these aspects were also identified in the study by Sinharoy et al. (2023).

Capabilities are made up of both resources and agency and refer to the ability of individuals to live the lives they want. The results of the agency's exercise are described as **achievements** (Kabeer 1999), which could be measured in different areas such as income, productivity, nutrition, and health. Achievements also present the sphere where empowerment is usually pointed out most often by the participants and external observers in different studies. They can sometimes lead to the creation of new resources (Meinzen et al. 2019). All the dimensions, domains and aspects mentioned above will be used for the conceptualization of the benefits further in the thesis, and their connections are demonstrated in Figure 5.

Empowerment is a complex process which can be influenced by many variables. The availability of new resources does not necessarily manifest as empowerment when the social setting does not allow the individual to use these resources to achieve desired goals (Bryan & Garner 2022). Many power imbalances in social structures can obstruct the agency of certain social groups and make them unable to make decisions freely. The study conducted by Tsagkari (2022:41) states: "*Just by assuming that access to electricity or renewable energy will translate women empowerment and gender equality, fails to acknowledge the structural problems that have traditionally shaped gender roles*." This argument supports the idea that resources alone are often not enough to fully empower women. In addition, it refers directly to renewable energy, which is important for this thesis.

Tsagkari's study also points out the fact that the introduction of renewable technologies can even reinforce women's inferior status if the project does not consider gender inequalities. Therefore, a three-dimensional **energy justice** concept was introduced. The concept includes (a) procedural justice, which emphasizes disparities within the process and governance, (b) distributive justice, which addresses the uneven allocation of advantages and disadvantages resulting from energy development, and (c) recognition justice concerning the acknowledgement of different stakeholders and the diverse range of their needs (Figure 4) (Tsagkari 2022). The concept examines the unequal health and welfare effects caused by energy sources, disparities in access to renewable energy, environmental racism and disproportionate impacts of climate change on marginalized groups. Energy justice is closely connected to the ongoing discussions about incorporating principles of climate justice, fairness, and equity into energy sector transformation (Allen et al. 2019). Thus, it provides a theoretical framework to contextualize the research of this thesis. It acknowledges the connection between SDG 5 and SDG 7, thus supporting the assumption that biogas technology adoption influences WE.

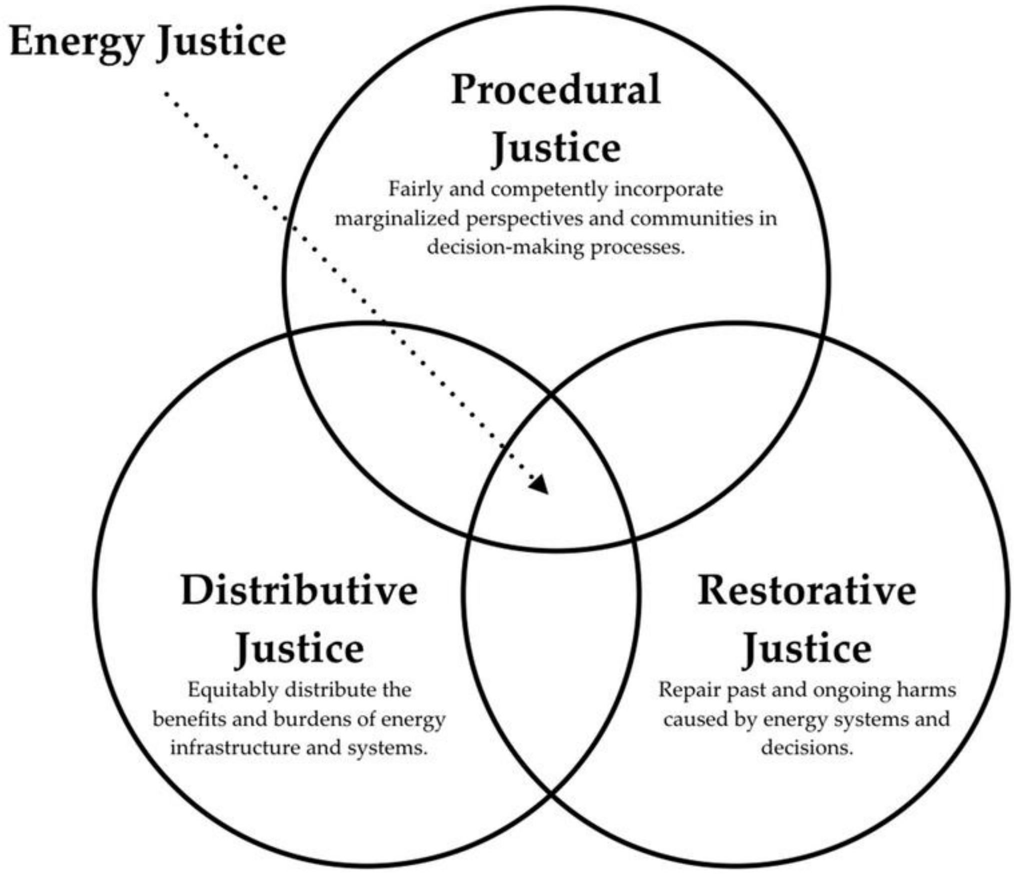

Figure 4. Energy justice principles (Wallsgrove et al. 2021).

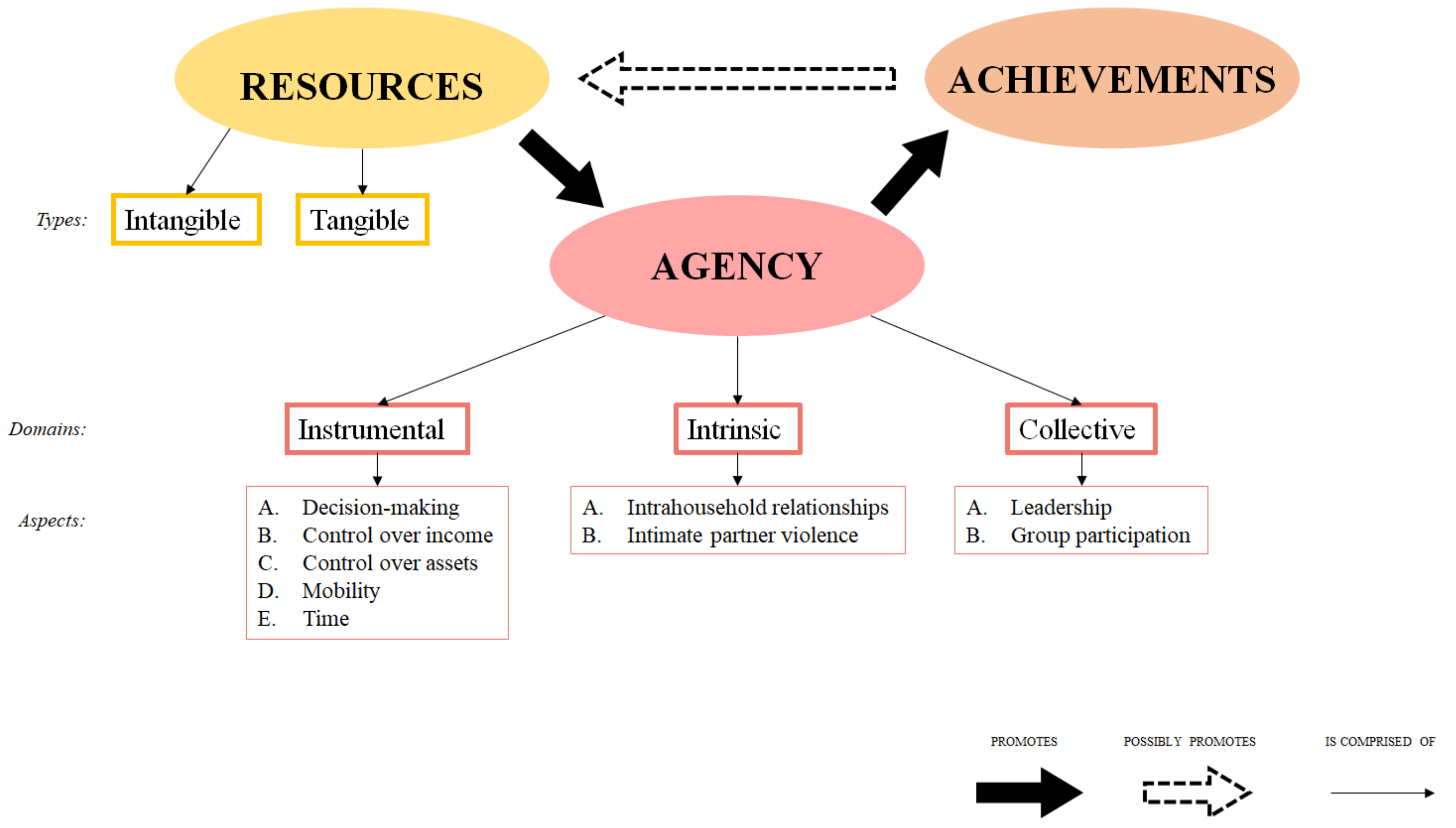

Figure 5. Empowerment dimensions and their interconnections (adapted from Meinzen et al. 2019).

4.1.1 Addressing Gender Inequality in Energy Sector

SSA region continues to be one of the most energy-poor regions in the world, even though there are significant differences between individual countries (Gafa & Egbendewe 2021). Energy poverty causes several indirect outcomes, including air pollution, poor environmental quality, and more time spent on fuel collection and preparation. This harms people's health, but it also encourages gender inequality, which, in the long term, contributes to slow economic growth and hinders poverty reduction (Krishnapriya et al. 2021).

Gender inequality remains a problem all over the world. However, in developing countries, specifically the ones lying in SSA, it is even more apparent. Many of these countries rank low in the Gender Inequality Index (GII)[2]. For example, out of 193 countries, Rwanda was in the 98th place in 2022. Ethiopia and Zambia ranked even lower, 125th and 137th, respectively. Out of the countries in the SSA region, Cabo Verde ranked the highest, on the 75th place, and Nigeria the lowest, on the 165th place (UNDP 2022). According to many reports, women are the major group of people affected by energy scarcity (Yasmin & Grundmann 2020). In addition, only access to renewable energy technology does not necessarily guarantee a positive impact on women's livelihoods. Many sociocultural, economic and institutional aspects play an important role as well (Terrapon-Pfaff et al. 2018).

There is some evidence resulting from renewable energy projects proving that the benefits for men and women differ. In Zambia, the distribution of benefits among the local community was not equal after the implementation of solar mini-grids. Women saved more time than men on fuelwood collection since it was their primary responsibility. However, the spare time was expected to be used on different domestic activities instead. Men, on the other hand, didn't spare as much time as women, yet, they were able to rest more (Johnson et al. 2019). Similarly, the gendered dynamics of micro-hydropower projects in Sidama, Ethiopia, were investigated by Wiese (2020). The findings suggest that women were less involved in the process, received fewer benefits, and their energy requirements were not sufficiently acknowledged or met. In addition, a study conducted

[2] GII is a combined measure of gender inequality that consideres three aspects: reproductive health, empowerment, and labour market. A lower GII values signifies minimal inequality between genders, while a higher value indicates the opposite (UNDP 2022). For more information, see https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII.

in South Africa, Brazil, India and China reports that local energy transition policies are not concerned with fair benefit allocation for women either (Tsagkari 2022). Understanding the possible pathways to assist WE as a result of development interventions is, therefore, the focus of a growing body of research (Bryan & Garner 2022).

4.2 Traditional Energy Sources in Sub-Saharan Africa

Many environmental and health threats, together with the increasing prices of fossil fuels, have been recently connected to the use of solid biomass, including charcoal, firewood, or animal dung, for the production of traditional energy (Njenga & Mendum 2018). These energy sources are not only responsible for indoor air pollution, but they also have very low thermal efficiency, ranging from only 13% to 15% (Wassie & Adaramola 2021).

Around 780 million people in SSA are estimated to use traditional biomass for energy production (Karanja & Gasparatos 2019). In addition, due to the fast population growth in the area, this number is estimated to more than double by 2050, to approximately 1.8 billion people, which will account for roughly 65% of the population by that time (Elasu et al. 2023). Today, around 2.5 billion people rely on biomass fuel for their cooking needs worldwide (Adams et al. 2023). More than 80% of people living in SSA still use predominantly solid fuel stoves (Yasmin & Grundmann 2020; Guta et al. 2022), with the number being even higher in certain countries, such as Ethiopia, where it reaches 93% (Negash et al. 2021; Yalew 2021).

Furthermore, there are severe differences between urban and rural areas, with the need for the use of traditional biomass being higher for the latter (Krishnapriya et al. 2021). For example, 7.2 million (predominately rural) households in Kenya are still primarily using woody biomass for cooking (Karanja & Gasparatos 2019). Biomass is used for heating and cooking by 70% of the population in Cameroon, of which 90% live in rural areas (Zieba Falama et al. 2024). In Ethiopia, biomass constituted more than 91% of total primary energy usage. In rural regions, which are home to about 80% of Ethiopia's population, almost all cooking energy requirements are met by the use of solid biomass fuels (Wassie & Adaramola 2021). Women are usually much more affected by the negative impacts of traditional cooking fuels than their male counterparts, since they are, traditionally, more involved in cooking activities (Elasu et al. 2023).

Historically, there is a strong connection between white patriarchy and the use of fossil fuels (so-called "petro-masculinity"). The energy transition, however, creates space for projects that are more small-scale and decentralised, and that focus on rather inclusive, bottom-up approaches (Tsagkari 2022). Thus, modern renewable energy technology has become increasingly accessible and available even in developing regions in recent years, which ensures the supply of sustainable energy. Many of these technologies are based on biogas production, which is, in fact, one of the most advanced renewable energy sources with the potential to fight the global energy crisis (AlQattan et al. 2018). These technologies have already been proven to have net benefits for society (Rahman et al. 2017) and represent a small-scale solution that is particularly suitable for the region due to the decentralized supply they provide (Terrapon-Pfaff et al. 2018; Zieba Falama et al. 2024).

4.3 Biogas Technologies in Sub-Saharan Africa

Traditional energy sources have, as mentioned above, several negative effects. Biogas technologies offer an alternative solution, which, besides providing energy, can also contribute to other challenges. Yet, its utilization in SSA remains inadequate.

The biogas production process is called anaerobic digestion (AD). Organic matter is converted into gases and manure using microbial reactions during this process. Around 250-350 l of biogas per 1 kg of biodegradable material can be generated this way and can be used for cooking, lighting or fueling electric generators (AlQattan et al. 2018). The definition of small-scale biogas digesters depends on the volume, which is usually 200 m^3 and less in this case[3] (Issahaku et al. 2024). Additionally, small-scale biogas digesters typically operate without the need for constant mixing and heating (Luo et al. 2016), thus, the expertise required to operate them is quite low in comparison to other technologies (Jabeen et al. 2020). The small-scale biogas systems usually generate adequate gas for household cooking. However, sometimes surplus gas can be used in heating or as energy for productive assets (IPE Triple Line 2020).

[3] Average size of small-scale digestors used by rural households in SSA is, however, much smaller. For example in Ethiopia, average digestor has a volume of 6 m^3 (Yalew 2021).

The most typical design utilized in SSA is the fixed dome digester, which has its origins in China (Figure 6). However, flexible balloon models are sometimes promoted because of the lower upfront cost (Clemens et al. 2018; IPE Triple Line 2020). A mixing tank, an airtight underground digester tank, a gas holder and gas regulator valves are the components of a typical biogas plant (Rahman et al. 2017).

Biogas is a fuel that consists of 50-70% methane (CH_4) and 30-50% carbon dioxide (CO_2). The exact composition depends on the particular input, which can be different types of biomass, animal slurry, or other organic waste (Karanja & Gasparatos 2019; Jabeen et al. 2020). Sometimes, small amounts (max. 10%) of nitrogen, hydrogen, oxygen, water, ammonia, or hydrogen sulphide can be present as well (Rahman et al. 2017; Uhunamure et al. 2019). With this composition, it is considered to be a higher grade analogous to natural gas (Jha & Schmidt 2021).

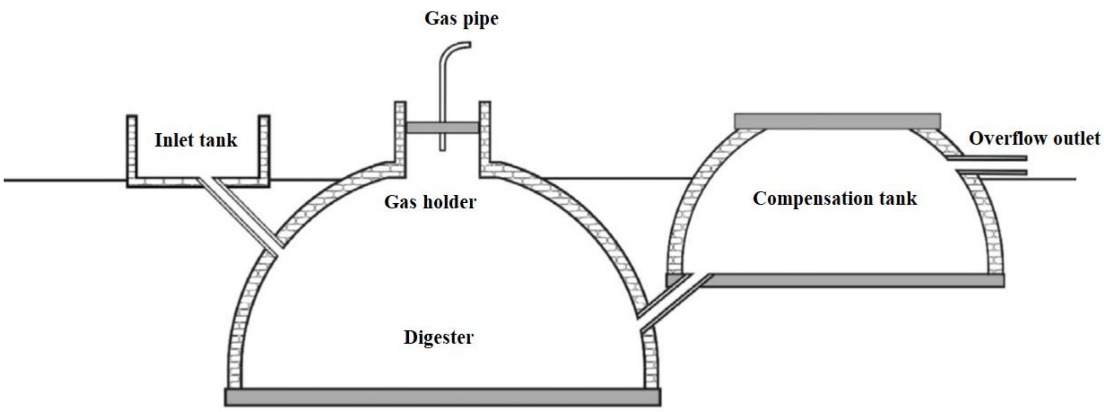

Figure 6. Biogas digester scheme (fixed-dome type) (Roubík et al. 2020).

The byproduct of AD is called bio-slurry and can be used as a clean alternative to chemical fertilizers to be applied into soil or used in aquaculture (Karanja & Gasparatos 2019; Xia et al. 2023). Biogas is often referred to as “clean energy” and can be utilized as a fuel for so-called “improved cookstoves” (Krishnapriya et al. 2021).

Although approximately 50 million biogas systems have been installed globally, particularly in Asia, just a small fraction of them can be found in SSA (Clemens et al. 2018). In 2017, the total number was estimated to be 27,612 digesters. This includes digesters installed in Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cote D'Ivoire, Ethiopia, Ghana, Kenya, Lesotho, Malawi, Nigeria, Rwanda, Senegal, South Africa, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe. About 85% of them can be found in the Eastern parts of SSA (Dahunsi et al. 2020).

Unfortunately, biogas technologies remain unattainable for many people in the region. An analysis conducted in Nigeria by Ifegbesan et al. (2016), which used data from the Nigeria Demographic and Health Survey conducted in 2013 across the nation, revealed that only 0.3% of the respondents use biogas as cooking fuel. Out of these biogas users, only 15% lived in rural areas and 71% acquired some form of education above secondary level. In addition, 93% of the respondents were classified as the "richest" by the researchers. These trends imply that biogas is a fuel used by the most privileged citizens (Ifegbesan et al. 2016). This argument was later confirmed also by Murshed (2022) revealing that there is a higher probability of the implementation of biogas for cooking among the richest households in Ethiopia. In addition, it states that there are significant differences even among countries in the SSA region. Clean cooking fuels and technologies[4] are accessible to 93.34% of people in Mauritius, but only to 0.57% in Rwanda.

Around 18.5 million households could technically use biogas for cooking due to factors like population density, climate, fuelwood shortage, water availability, and livestock ownership. Tanzania, with 1.8 million families, Uganda, with 1.3 million households, and Kenya, also with 1.3 million households demonstrate some of the biggest potentials (Clemens et al. 2018). Because of the number of livestock raised by local small-holder farmers, between 1.1 and 3.5 million households could technically install small-scale biogas digesters in Ethiopia (Yalew 2021). These figures highlight the potential for widespread adoption of biogas technologies in the region. However, it is expected that the use of more sustainable energy sources that focus on recycling and reuse will grow in the coming years in this part of the world (Njenga & Mendum 2018).

4.3.1 Expectations from Biogas Technologies

Besides SSA, other regions have already experienced positive impacts of biogas technology and set up examples for SSA (Dahunsi et al. 2020). Thus, there exist several

[4] In the study by Murshed (2022), a definition of clean cooking fuels by WHO was used. According to WHO, clean cooking fuels include, besides biogas, solar energy, electric energy, LPG, ethanol, and some improved types of biomass stoves (Murshed 2022). For in-depth understanding, see https://www.who.int/tools/clean-household-energy-solutions-toolkit/module-7-defining-clean.

past evaluations of the impacts of biogas technologies, many of which are discussed further in this thesis. These evaluations not only summarize the impacts but also determine the future expectations people have from the technology. With their help, it is possible to propose a Theory of Change in biogas technology.

Biogas technologies are expected to contribute significantly to SDGs, particularly in regions like SSA. According to the WBA, biogas holds the potential to help achieve nine out of seventeen SDGs, including goals number 2, 3, 5, 6, 7, 9, 11, 13, and 15 (World Biogas Association 2018). However, a report by IPE Triple Line (2020) conducted for Shell Foundation suggests a slightly different outcome. According to the report, biogas also contributes to SDGs number 1 and 8. On the other hand, it does not mention SDGs number 6, 9, and 11 (Figure 7). Nevertheless, the wide range of biogas impacts is clear.

Figure 7. Comparison of biogas contribution to SDGs proposed by WBA (left) and IPE Triple Line (right).

IPE Triple Line (2020) additionally suggests a ToC which illustrates the relationship between SDGs and biogas. The ToC visualizes the impact pathways and highlights the causal relationships involved, offering valuable insights into what can be expected from the adoption of biogas not only in SSA. However, this ToC is quite general and does not distinguish between men and women. The expectations from biogas technology are necessarily influenced by personal preferences. Moreover, it was proven by several studies that the expectations, as well as the ultimate benefits, are different for men and women (Tsagkari 2022). The benefits from women's perspective will be the main focus of the next chapter.

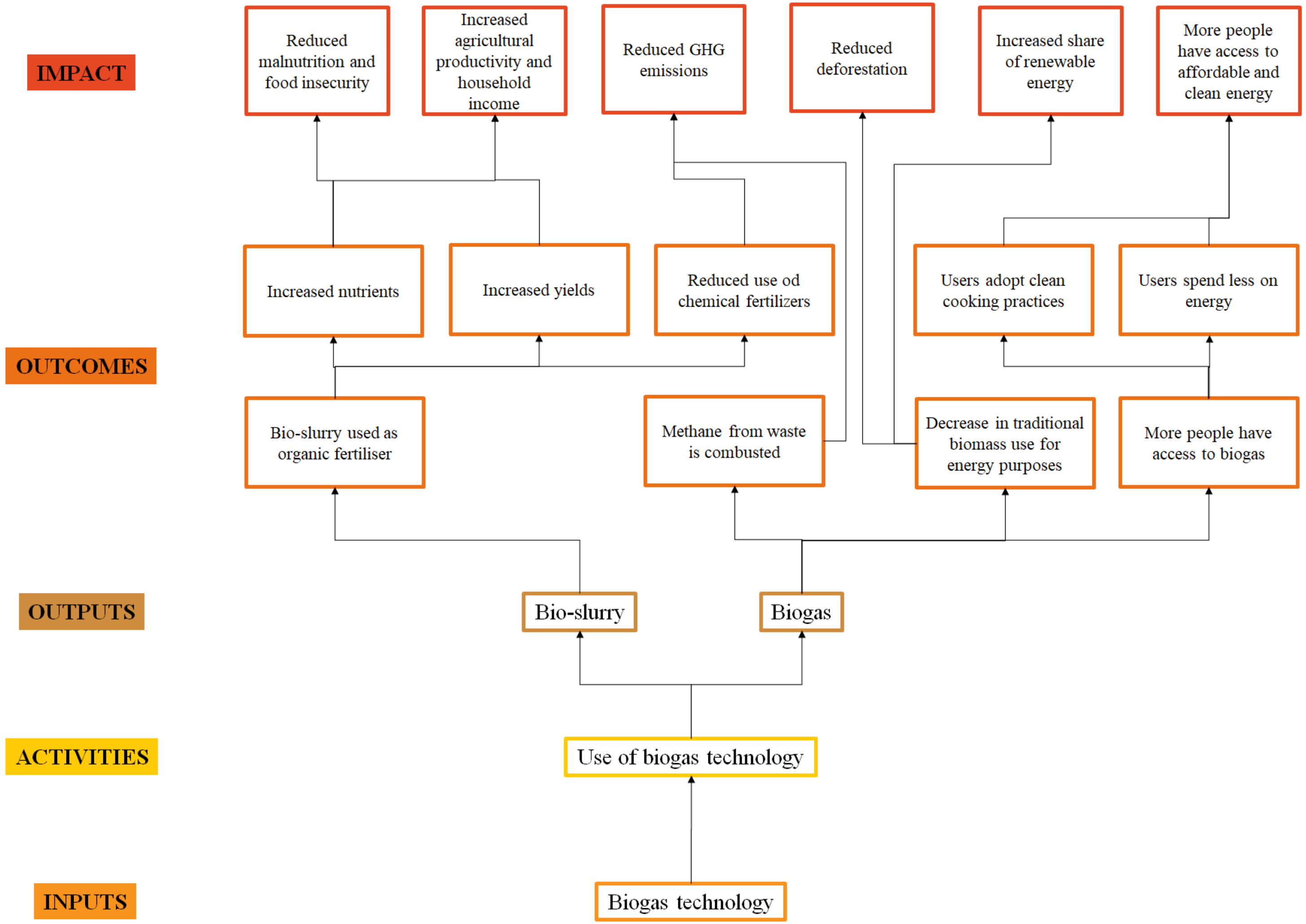

Figure 8. ToC proposed by IPE Triple Line (2020).

4.4 Overview of Biogas Technology Benefits for Rural Women in Sub-Saharan Africa

As mentioned above, people in SSA rely primarily on traditional energy sources, unlike those in developed nations. The use of such sources, predominantly low-cost biomass, comes with various challenges. Biogas is one of the alternative resources with great potential to fight these challenges. Women especially are said to benefit from the implementation of biogas technology (Njenga & Mendum 2018).

The use of biogas is a low-cost and decentralized solution (Piadeh et al. 2024), thus it complies with the standards most local people have for cooking and heating. In addition, it makes use of waste, such as crop residues or manure, which decreases the cost of production. Lastly, it is a much cleaner option in comparison to traditionally used coal or wood, with almost no incombustible particles (Njenga & Mendum 2018; Jabeen et al. 2020). It is an alternative energy source with demonstrable benefits, especially in the case of rural areas (Uhunamure et al. 2019).

Particular benefits are discussed further in the thesis. Table 1 presents a comprehensive outline of these benefits, categorized according to the benefit type. Furthermore, examples sourced from the scientific literature are sorted into tables, which can be found in the Appendices. Notably, these examples include instances facilitated by biogas (indicated in **orange** in the tables) and also those mitigated through biogas utilization (highlighted in **yellow** in the tables).

Table 1. Overview of biogas technology benefits for rural women in SSA according to benefit type.

Benefit types:	**Economic**	**Environmental**	**Health**	**Social**
Particular benefits:	Financial savings	Improved pollution and waste management practices	Decreased indoor air pollution	Time and labour savings
	Income generation opportunities	Deforestation mitigation	Injuries prevention	Increased access to education
	Increased agricultural production	Sustainable management of natural resources	Food safety	Increased decision-making power
	Increased decision-making power	GHG emission reduction	Reduced occurrence of health-related problems	More equal household and community relationships
	Poverty suppression	Awareness about and promotion of sustainable practices	Improved community health outcomes	Sustainable cooking practices adoption
				Skills and knowledge enhancement
				Enhanced status within communities

4.4.1 Economic Benefits

The economic implications of biogas adoption are significant. A study conducted by Clemens et al. (2018) reveals that “money” is considered to be the most important benefit of biogas use among respondents from Kenya, Tanzania and Uganda. Biogas adoption is connected to benefits such as cost savings, income generation opportunities, and increased agricultural productivity, which are discussed further.

The adoption of biogas is tied to financial savings since it uses mainly waste materials that could not be utilized otherwise and disposal of which often means a challenge (e.g. dung, especially from zero-grazed animals) to generate heat. This allows women with no or very low incomes to change to this alternative with no requirement for additional finances. The amount of money a household spends on other biomass resources decreases significantly. For example, the average weekly expenditure on firewood per household declined by 71% in Kenya after the shift to biogas (Njenga & Mendum 2018). In Ethiopia, approximately USD 87, 28, and 3[5], can be saved annually on fuelwood, charcoal and dung cake, respectively (Negash et al. 2021).

In addition, household expenses connected to health problems caused by indoor pollution, also decrease (Njenga & Mendum 2018). Furthermore, demand for traditional biomass, mainly charcoal and firewood, is increasing rapidly due to the growing population, and the supply remains relatively low. Thus, the prices of these fuels are rising, which makes biogas an even more affordable option for many people (Karanja & Gasparatos 2019), especially the ones living in desert or riverside areas, where wood resources are scarce and thus often need to be purchased for a lot of money (Zieba Falama et al. 2024).

Other savings can be achieved with the use of bio-slurry, which reduces the need for synthetic fertilizers by increasing the carbon content in the soil, subsequently enhancing soil fertility and increasing crop yields (Gabisa & Gheewala 2019; Negash et al. 2021; Piadeh et al. 2024) In Ethiopia, approximately USD 16[6] were saved on chemical fertilizer annually (Negash et al. 2021). Expenditures on chemical fertilizers were

[5] ETB 3833, 1243, and 129 (average exchange rate in 2021)
[6] ETB 718 (average exchange rate from 2021)

reportedly reduced in the case of many households from Kenya and Tanzania, as revealed by (Clemens et al. 2018).

Bio-slurry can also be used as feed for pigs; a case study from Kenya states that bio-slurry can decrease pig feeding costs by 25% (Njenga & Mendum 2018). Additionally, there is a potential for bio-slurry to be used as feed in aquaculture. It is a fast-acting fertilizer rich in nutrients (e.g. phosphorus and nitrogen), suitable for both growing fish and fingerlings, as shown in studies predominantly conducted in Asian countries (Ataei et al. 2020). However, studies about this potential benefit of bio-slurry focusing on SSA are missing, thus, more research needs to be conducted.

Many different businesses can be established in connection with biogas technology utilisation. One of them can be capacity building. If a woman has her own experience with biodigesters, she can train other women in her community to maintain and operate the systems. A certain price should be paid for this service. Next, women can also work as dealers or suppliers of the technology and appliances connected to it. Lastly, women can sell the bio-slurry from biogas production as an organic fertilizer, which is another small-scale business opportunity (Njenga & Mendum 2018; Gabisa & Gheewala 2019). In addition, the use of biogas facilitates other business activities, such as the sale of fruits and vegetables, grains, or dairy products. A survey conducted in Tanzania, which, however, didn't distinguish between men and women, revealed that 84% of the respondents experience this benefit (Clemens et al. 2018).

There are several employment opportunities connected to biogas technology, creating many jobs that can be appointed to local people (Kabir et al. 2022). Then, there are job opportunities related to the technology that utilize biogas. For example, clean bioenergy stoves, including biogas stoves, have a rather long value chain. The job opportunities are diverse, from stove design and manufacturing to marketing, distribution, and sale of the appliances (Karanja & Gasparatos 2019). Regarding biogas technology overall, not distinguishing between small-scale and large-scale, other employment opportunities can be found in the waste collection and management sector (Piadeh et al. 2024).

When women do have sufficient control over finances and can generate income, their power and status in decision-making increases, and vice versa (Murshed 2022). This trend was confirmed by a study conducted in the Ivory Coast, which found out that when local women earned income, their decision-making power was higher. Consequently, it was more likely for households where women participated in income generation to implement clean cooking fuels, which in consequence improved the lives of all household members (Yasmin & Grundmann 2020). Also, it is important to note that electrification allows women to spend more time on income-generating activities overall, especially when utilizing off-grid systems such as biogas since fixed connections are less accessible to them in comparison to men (Pueyo et al. 2020).

The link between increased income generation and the implementation of biogas technologies was also shown in studies from other regions. In Nepal, 0.9 million jobs arose from the segment between the years 1992 and 2006. In the Punjab region of Pakistan, biogas users were found to have much higher per month income in comparison to non-users (Jabeen et al. 2020). Overall, the creation of income-generating opportunities has the potential to suppress poverty, not only in the energy sector (Gafa & Egbendewe 2021).

While applying bio-slurry in liquid or dry form, or mixed with other organic matter as fertilizer, crop productivity and diversity can be increased, making the household less prone to food insecurity (Karanja & Gasparatos 2019; Jabeen et al. 2020). Additionally, it can also be utilized as an organic fertilizer in aquaculture (Xia et al. 2023).

A study conducted by Clemens et al. (2018) in Uganda, Kenya and Tanzania revealed that up to 91% of households in Uganda that use bio-slurry as a fertilizer claim that their crop yields increased. In the case of Kenya and Tanzania, the increase in crop yields was reported by 84% and 86% of respondents, respectively. A farmer from Kenya stated that her production of coffee increased by 20% after the introduction of bio-slurry and she hoped it will increase even more in the future. In addition, less chemical fertilizers needed to be purchased (Njenga & Mendum 2018).

4.4.2 Environmental Benefits

The use of traditional biomass for energy purposes is connected with several negative environmental impacts, which, together, contribute to climate change (Murshed 2022; Elasu et al. 2023). According to Jeuland et al. (2021), around three-quarters of studies examined in their review of biogas technology impacts focused primarily on the environment. These studies explored the impact related to for example air quality, climate, or ecosystem effects. The review suggests that there is a strong link between biogas technologies and positive environmental impact. The environmental benefits for women include for example ecosystem preservation, greenhouse gas emission reduction, and pollution and waste management.

Harvesting of fuelwood is connected with deforestation (Elasu et al. 2023; Piadeh et al. 2024) and different kinds of land degradation, such as soil erosion, deprivation or drying. Floods, biodiversity loss, a decrease in soil fertility, or a decrease in the capacity to store carbon in affected forests are just some examples of associated negative outcomes (Jabeen et al. 2020). For instance, illegal logging for domestic energy purposes is tied to the loss of 45,000 ha of Nigerian woodland each year (Ifegbesan et al. 2016). In Ethiopia, approximately one-third of fuelwood originates from unsustainable harvesting of woodlands and forests (Yalew 2021). Local demand for fuelwood was 88.9 million m^3 in 2014, which was ten times higher than the annual sustainable supply (Wassie & Adaramola 2021). Firewood exploitation contributed to climate change by 30% in Chad. Additionally, it caused a 28% reduction in soil fertility, a 29% decline in flora and fauna, and a 27.5% increase in desertification and soil degradation (Zieba Falama et al. 2024).[7]

The biogas technology could play a significant role in the reduction of unsustainable use of wood and different solid fuels (Yasmin & Grundmann 2020; Jabeen et al. 2020; Yalew 2021). Since biogas provides an alternative to fuelwood, it was proven to contribute to slow down deforestation, soil erosion, soil degradation and other harmful effects (Jha & Schmidt 2021). Biogas technology systems have even the potential to restore and rehabilitate land. For instance, degraded or marginal lands could be repurposed for energy crop cultivation, which would mitigate the risk of further deforestation or desertification, particularly in areas already affected by unsustainable agricultural practices (Piadeh et al. 2024).

Additionally, fuelwood and other traditional biomass combustion produce excessive amounts of greenhouse gases (GHGs), such as carbon monoxide (CO) or nitrogen oxides (NOx). The same applies for the inefficient combustion of charcoal and other biomass (Karanja & Gasparatos 2019; Dahunsi et al. 2020). On average, countries

[7] These examples are not directly connected to biogas, however, it is important to pay attention to them, since biogas can help fight these negetive effects, as mentioned in the next paragraph.

in SSA do not produce such high amounts of GHG emissions compared to the rest of the world. Carbon dioxide emissions stand at only 0.8 metric tons per capita. The world average is almost seven times higher, 5.4 metric tons per capita. However, there exist countries which are above the world's average even in the SSA region. For example, South Africa produces 9.1 metric tons of CO_2 per capita (Uhunamure et al. 2019). For such countries, the reduction of GHG emissions is especially crucial. GHG emissions could be cut by 1.9 t of CO_2 equivalent per year with the use of typical anaerobic digesters (Yalew 2021). Biogas technology also captures CH_4 (Baruah & Enweremadu 2019; Dahunsi et al. 2020), which is 21 times more potent GHG in comparison to CO_2 (AlQattan et al. 2018; Piadeh et al. 2024).

In addition, the use of improved cookstoves utilizing biogas can minimize the occurrence of household air pollution and reduce overall GHG emission levels (Ravindra et al. 2021). A review by Phillip et al. (2023), including eleven different SSA countries, revealed that although improved cookstoves generally reduced indoor air pollution levels, the decrease was the most significant in the case of CO emissions. The highest emission reduction was found in cookstoves with chimneys. Additionally, Zieba Falama et al. (2024) discovered that an installation of 6,715 new improved biogas cookstoves carries the potential to reduce CO_2 emissions by 54,901,840 $kgCO_2$/year in Cameroon (considering the households that only used firewood for cooking purposes before).

Adoption of biogas technologies can reduce the release of organic waste leakage into surface and groundwater reservoirs, consequently decreasing water pollution levels and making the water safer for consumption. Water pollution can be decreased by the use of bio-slurry as an alternative to conventional chemical fertilizers, which, when applied improperly or in excess, can cause nutrient leaching, a common contributor to water eutrophication (Piadeh et al. 2024).

Biogas production is one of the cleanest ways to utilize waste since CH_4 is released into the atmosphere during the waste decomposition in landfills. Also, the need for open burning, one of the unsustainable waste disposal methods, is decreased. Thus, the use of biogas technologies contributes to safer waste management, which helps improve sanitation and reduce environmental pollution (AlQattan et al. 2018; Piadeh et al. 2024).

Several small-scale biogas projects were implemented in Kenya, using organic waste such as manure, slaughterhouse residues, and vegetable residues, and subsequently preventing this waste from ending up in landfills (Jha & Schmidt 2021) However, a study focusing on the willingness of cassava processors to utilize biogas production as a waste management technology conducted in Nigeria by Mukaila et al. (2024) found out that only 21.25% of processors were aware of improved cassava waste management technology. The study also states that 92.08% of these processors were women, thus, increased awareness about the utilization of biogas for this purpose would be particularly beneficial for them.

4.4.3 Health Benefits

The important link between health and biogas technology is discussed further. It delves into the effects of indoor air pollution caused by traditional biomass and how biogas technologies can prevent these effects. Additionally, the risks connected to biomass collection are mentioned. The health benefits include reduced occurrence of health problems, injury prevention, or food safety.

The air pollution created by solid fuel cookstoves causes various health problems, which are particularly dangerous for women and children, since they spend more time indoors (Yasmin & Grundmann 2020; Lindgren 2021; Gafa & Egbendewe 2021), especially in kitchens, which often have poor ventilation (Karanja & Gasparatos 2019). For example, women and girls from Mozambique spend several hours a day cooking, which means they are directly exposed to indoor air pollution (Ugembe et al. 2022). Findings from Uganda indicate that 95% of cooking responsibilities are carried out by women and children, while men contribute 5% only (Nalunga et al. 2019).

This pollution can cause various respiratory and cardiac diseases, and, in the case of women, issues during pregnancy and birth (e.g. stillbirth). The issues can be fatal (Guta et al. 2022). Around 1.3 million people in the developing world die each year due to indoor air pollution caused by conventional biomass fuels (Yasmin & Grundmann 2020). In SSA, it is one of the top three causes of death. For instance, in Ethiopia, indoor air pollution accounts for approximately 5% of the overall disease burdens (Yalew 2021) and approximately 72,400 people die from this cause each year (Negash et al. 2021). In 2016, indoor air pollution caused 32,636 deaths in Mozambique, with a slightly higher mortality rate among women compared to men (Ugembe et al. 2022). Children are also at high risk;

burning solid biomass in African households leads to nearly 600,000 premature deaths annually, according to research by Ifegbesan et al. (2016).

In addition, other complications, which are not fatal, but still can cause many troubles, are connected with exposure to harmful air particles. Some of these issues are for instance eye irritation, burns, or headache (Yasmin & Grundmann 2020). Additionally, among children under five years of age, being underweight prevails as an issue when frequently exposed to these pollutants (Murshed 2022). The use of biogas technologies significantly reduces these risks by mitigating indoor air pollution (Njenga & Mendum 2018; Dahunsi et al. 2020).

Some studies provide individual testimonies demonstrating the health benefits of using biogas technologies. For instance, a quote by Mr. Salongo, a farmer from rural Uganda who was interviewed during a field visit, was pointed out in the study by Clemens et al. (2018:27). The quote runs: *"My wife no longer cries in the morning as she prepares for us breakfast."* Mr. Salongo added that the distress his wife was experiencing was caused by smoke produced when she was using firewood for cooking. The quote demonstrates how women's lives could be changed for the better after the introduction of biogas technologies. It is also revealed in the same study that nearly half of the respondents interviewed in Tanzania experienced reduced frequency of respiratory symptoms and/or irritated eyes, although only 5% actually appreciated this change. In Ethiopia, participants pointed out the smokeless nature of biogas as a major benefit during a focus group discussion as well (Negash et al. 2021). Eye irritation caused by smoke can be almost eliminated with the use of biogas stoves (Gabisa & Gheewala 2019).

Using biogas as fuel prevents women from injuries caused by carrying heavy loads of firewood on their backs, usually for very long distances (Njenga & Mendum 2018). SSA women often need to carry 20 kg of fuelwood on average per day (Yasmin & Grundmann 2020). In addition, the probability of experiencing safety risks such as violence or rape is much higher during fuel collection (Karanja & Gasparatos 2019). This danger is particularly pronounced in settings like refugee camps, where instances of these risks are, unfortunately, frequent. Thus, when there is no need for the collector to go out, often alone, and the fuel is available within the safer space they are living in, gender-based violence declines (Njenga & Mendum 2018). In addition, electrification overall increases the amount of public lighting, which enhances safety during nighttime hours.

However, biogas is used for electrification only in case of excess production (Woollacott et al. 2023).

Also, the overexploitation of forests leads to fuelwood scarcity, which is linked to many harmful cooking habits (Karanja & Gasparatos 2019). For example, people with limited access to fuelwood cook their meals for a shorter time and often eat them undercooked, which can cause many health problems. The same applies to water cooking time (Dohoo et al. 2015). Biogas cookstoves make it easier to regulate the temperature of cooking, and the meals prepared on them were proven to often have higher nutritional quality (Karanja & Gasparatos 2019).

4.4.4 Social Benefits

This chapter delves into the social implications of biogas technology for rural women in SSA. The first group of benefits discussed are time and labour savings, which are, especially in case of women, evident. An aforementioned study by Clemens et al. (2018) states that time savings are the second most important benefit of biogas technology for the respondents from East Africa, right after financial savings. Participants of the focus group discussion in Ethiopia appreciated the time savings as well (Negash et al. 2021).

Yet, this benefit is usually overlooked when it comes to research about clean energy, probably because the collection of time-use data is not only difficult but also expensive. In addition, it is hard to measure the value of time (Krishnapriya et al. 2021). Nevertheless, several examples were found among this benefit group. The benefits discussed further are concerning the relationships and decision-making in households, and community development and education.

When it comes to the responsibility to acquire energy resources, their price plays a significant role. If there is a need to purchase biomass for money, the primary responsibility falls onto the household members who earn incomes (traditionally men). In contrast, if biomass is available for no financial cost, the responsibility usually shifts to individuals who are not wage-earners (traditionally women and children). For these household members, the cost is not money, but their free time and, potentially, health, social status, and well-being. Additionally, unpaid work, such as childcare, cooking or house cleaning is not usually considered “real” work as it does not create any income (Njenga & Mendum 2018).

As stated above, fuelwood collection (finding, transfer, and storage) is a time-consuming activity that is generally assigned to women (or children) (Njenga & Mendum 2018; Yasmin & Grundmann 2020; Gafa & Egbendewe 2021). Women in SSA commonly spend twice as much time on this activity as men (Lindgren 2021). This phenomenon can be explained by the traditional gender roles norm, which prevails not only in the SSA. The social norms often force women to spend their time on unpaid domestic labour and caregiving (Krishnapriya et al. 2021). In rural Kenya, women gather fuelwood for a minimum of one hour daily (Karanja & Gasparatos 2019), but the time usually exceeds two hours and can be even up to five hours per day (Yasmin & Grundmann 2020). In Mozambique, women and young girls spend 1.4 hours collecting fuelwood daily (Ugembe et al. 2022). The use of clean cooking fuels (including biogas) was proven to shorten the length of the trips and also decrease their frequency (Karanja & Gasparatos 2019).

In addition, biogas technology can decrease the time and effort required for cooking itself, since there is no need for fuelwood management (Yasmin & Grundmann 2020). Another huge benefit is the “readiness” of these technologies since biogas stoves provide heat immediately. Lastly, the use of biogas was proven to result in cleaner kitchens. For instance, more than three-quarters of surveyed households in Tanzania pointed out this benefit (Clemens et al. 2018). A case study done in Kenya suggests that biogas utilization encourages men to participate in cooking, reducing the amount of women's daily work. The reasoning behind that is not clear, but it is most probably because the whole process is easier, faster, and cleaner (Njenga & Mendum 2018).

An article by Krishnapriya et al. (2021) states that there exist several studies focusing on time-saving due to improved cooking technologies. However, they often do not distinguish between cooking time and collection time savings and often focus on different household members. Additionally, there are differences between the measurement methods and conceptualisations used in the existing studies. The article provides data focusing on several different improved cookstove technologies utilized in Zambia, Rwanda and Ethiopia. In general, the time saved thanks to improved cookstoves can reach up to 190 minutes per day (with the mean being 67.9 minutes per day). In the case of biogas, the maximum time savings were slightly lower, but still significant.

The use of biogas for cooking can bring benefits to the entire household. Firstly, it makes the conditions in the house cleaner and more sanitary. Secondly, the relationships among the household members can be improved (Yasmin & Grundmann 2020). A study from Kenya suggests that biogas utilization improves the relationships in families and allows children to participate safely (with some caution) in cooking. This is not typical for the area, so the shift after the installation of biodigesters is clearly visible (Njenga & Mendum 2018).

Also, more free time for women allows them to focus on diverse leisure activities, such as community development, which, as a result, improves community relationships (Njenga & Mendum 2018; Karanja & Gasparatos 2019; Krishnapriya et al. 2021). An example of a community development project is COWAN, which is a women-led NGO in Nigeria focusing on WE from economic, social and political perspectives (Olaniran & Perumal 2021). Next, MUVA is a program that focuses on WE by emphasizing the importance of small business establishment in Mozambique (Quak et al. 2022). In fact, business establishment is another way how women can make use of their spare time. Usually, women in SSA establish businesses such as restaurants, hair salons, retail trade, or textile trade (Swid et al. 2023). The spare time can also be used for education. For instance, the training which took place in the Northern Cape Province of South Africa helped 2083 women achieve a 41% increase in their education and knowledge levels about reproductive health, leadership and other work-related skills (Arora-Jonsson & Gurung 2023). Finally, the spare time can be used also simply for resting (Ugembe et al. 2022).

Children, particularly young girls, are usually forced to help their mothers with cooking and traditional biomass collection. As a result, these girls do not have time to do their homework or to attend school at all (Yasmin & Grundmann 2020). Also, busy parents do not have time to help them prepare for school. The use of biogas shortens the time needed for these activities rapidly, allowing the children to attend school and achieve better results as an outcome (Krishnapriya et al. 2021). In the long run, women who attended school for longer gain bigger bargaining power during household decision-making (Yasmin & Grundmann 2020).

4.4.5 Applying Women's Empowerment Lenses on Expected Biogas Technology Benefits

The adoption of small-scale biogas technology in SSA brings multifaceted benefits to rural women, as summarized in Chapter 4.4. When viewed through the lens of Kabeer's WE framework, it is possible to connect the anticipated benefits to the dimensions of resources, agency, and achievements, as outlined in Chapter 4.1. Moreover, this chapter seeks to evaluate how these benefits may contribute to the empowerment pathways of rural women in SSA, considering the outputs, outcomes, and impacts articulated in the ToC. Table 2 categorizes the benefits according to the WE framework dimensions.

Table 2. Overview of biogas technology benefits for rural women in SSA according to WE framework dimensions.

Dimensions:	**Resources**	**Agency**	**Achievements**
Particular benefits:	Financial savings	Increased decision-making power	Poverty suppression
	Income generation opportunities	Reduced occurrence of health-related problems	Sustainable cooking practices adoption
	Increased agricultural production	Skills and knowledge enhancement	Sustainable management of natural resources
	Improved pollution and waste management practices	More equal household and community relationships	GHG emission reduction
	Deforestation mitigation	Awareness about and promotion of sustainable practices	Enhanced status within communities
	Decreased indoor air pollution		Improved community health outcomes
	Injuries prevention		
	Food safety		
	Time and labour savings		
	Increased access to education		

4.4.6 Resources Dimension

One of the primary dimensions of WE are access to and control over resources (Kabeer 1999). Firstly, biogas technology provides two resources by its nature, as discussed in Chapter 4.3. These resources are biogas as an alternative fuel, and bio-slurry as an organic fertilizer. These resources are provided to both men and women; however, they influence their lives differently, with particular significance for women. The following resources have distinct impact on women's lives.

Biogas technology offers tangible economic benefits to rural women by reducing their expenditure on traditional biomass fuels (Njenga & Mendum 2018).The financial savings resulting from the use of biogas can free up resources that were previously allocated to purchasing fuel, thereby enhancing women's decision-making power (Negash et al. 2021). Additionally, the generation of income opportunities, such as selling bio-slurry, crops, or providing training in biogas technology maintenance, can further empower women by increasing their control over financial resources (Gabisa & Gheewala 2019; Njenga & Mendum 2018). Lastly, increased agricultural productivity, facilitated by the use of bio-slurry, increases women's economic agency as well (Karanja & Gasparatos 2019; Jabeen et al. 2020).

Moreover, biogas technology contributes to improving women's health by reducing their exposure to indoor air pollution associated with traditional biomass cooking methods (Yasmin & Grundmann 2020). The decreased incidence of respiratory illnesses and other health problems among women and children result in fewer healthcare expenses, further boosting their financial resources and economic autonomy (Njenga & Mendum 2018). Additionally, biogas technology enhances food safety and prevents injuries related to fuelwood collection, further promoting overall health of women (Karanja & Gasparatos 2019).

Environmental benefits of biogas technology, such as deforestation mitigation and improved pollution and waste management, contribute to WE (Jabeen et al. 2020; Piadeh et al. 2024). Lastly, by reducing the time and effort required for fuel collection and cooking, biogas technology also contributes to the redistribution of intangible time resources, enabling women to engage in education, or community development (Karanja & Gasparatos 2019).

4.4.7 Agency Dimension

Biogas technology has the potential to enhance women's agency by providing them with greater decision-making power and autonomy within their households and communities. The reduction in time spent on fuel collection and cooking time liberates women from traditional gender norms, allowing them to pursue alternative activities and interests (Njenga & Mendum 2018). Additionally, the improved health outcomes associated with reduced indoor air pollution contribute to women's agency by enabling them to live healthier lives (Yasmin & Grundmann 2020).

Moreover, the environmental benefits of biogas technology indirectly empower women by enhancing their resilience to climate change impacts by increasing their awareness about sustainable practices, which they can further promote among their community (Jabeen et al. 2020; Piadeh et al. 2024).

Furthermore, the income generated from biogas-related enterprises can enhance women's bargaining power within the household, enabling them to participate more actively in decision-making processes. This results in more equal household, and potentially community, relationships (Gabisa & Gheewala 2019). Increased access to education resulting from time savings enhances women's skills and knowledge, which also increases their decision making power (Krishnapriya et al. 2021).

4.4.8 Achievements Dimension

The achievements dimension of the empowerment framework encompasses the tangible outcomes and impacts resulting from women's enhanced access to resources and agency (Kabeer 1999). Biogas technology holds the potential to facilitate positive achievements for rural women in SSA across various domains (Njenga & Mendum 2018). Economically, the financial savings and income generation opportunities associated with biogas can lead to improved household well-being and economic security, leading to decreased poverty rates (Negash et al. 2021).

Socially, the redistribution of time resources and increased participation in decision-making processes can enhance women's status and recognition within their communities (Yasmin & Grundmann 2020). By alleviating the burden of fuel collection and cooking, biogas technology allows women to engage in community development initiatives, participate in social gatherings, and pursue educational opportunities, thereby strengthening their social networks and influence and challenging traditional gender norms. By this, they gain a power to further promote sustainable cooking practices within the community (Karanja & Gasparatos 2019).

Furthermore, the adoption of biogas technology can contribute sustainable management of natural resources (Jabeen et al. 2020; Piadeh et al. 2024). Biogas technology thus helps create more sustainable and resilient environment for current and future generations. Additionally, greenhouse gas emissions are mitigated in the long run by biogas adoption (Dahunsi et al. 2020). The environmental achievements resulting from biogas adoption not only benefit women directly through improved health and environmental conditions, but also contribute to the broader goal of sustainable development in SSA.

4.4.9 Empowerment Pathways

By examining the expected benefits of biogas technology through the lens of WE framework, several empowerment pathways emerge. These pathways describe how the adoption of biogas technology can induce empowerment among rural women in SSA, as outlined in ToC framework. The pathways identified align with the types of benefits proposed in the Chapter 4.4. – economic, health, environmental, and social. Through the connection of the empowerment framework and ToC principles, these empowerment pathways indicate how the process goes on (Figure 9).

Beyond merely providing alternative energy source, these pathways underscore the transformative potential of biogas technology. By alleviating the burden of traditional cooking practices, biogas provides more free time to women, which allows them to pursue education, engage in income-generating activities, and actively participate in decision-making processes in their households and communities. Moreover, the economic benefits of biogas not only further increase women's decision-making power, but also alleviate poverty within the communities in the long run. Additionally, biogas technology directly impacts women's health and ecological resilience, as shown in the pathways.

Furthermore, the empowerment pathways fostered by biogas extend beyond individual women and their households. They shape broader social dynamics and challenge traditional gender norms. Ultimately, biogas technology emerges as a powerful tool for advancing WE in SSA.

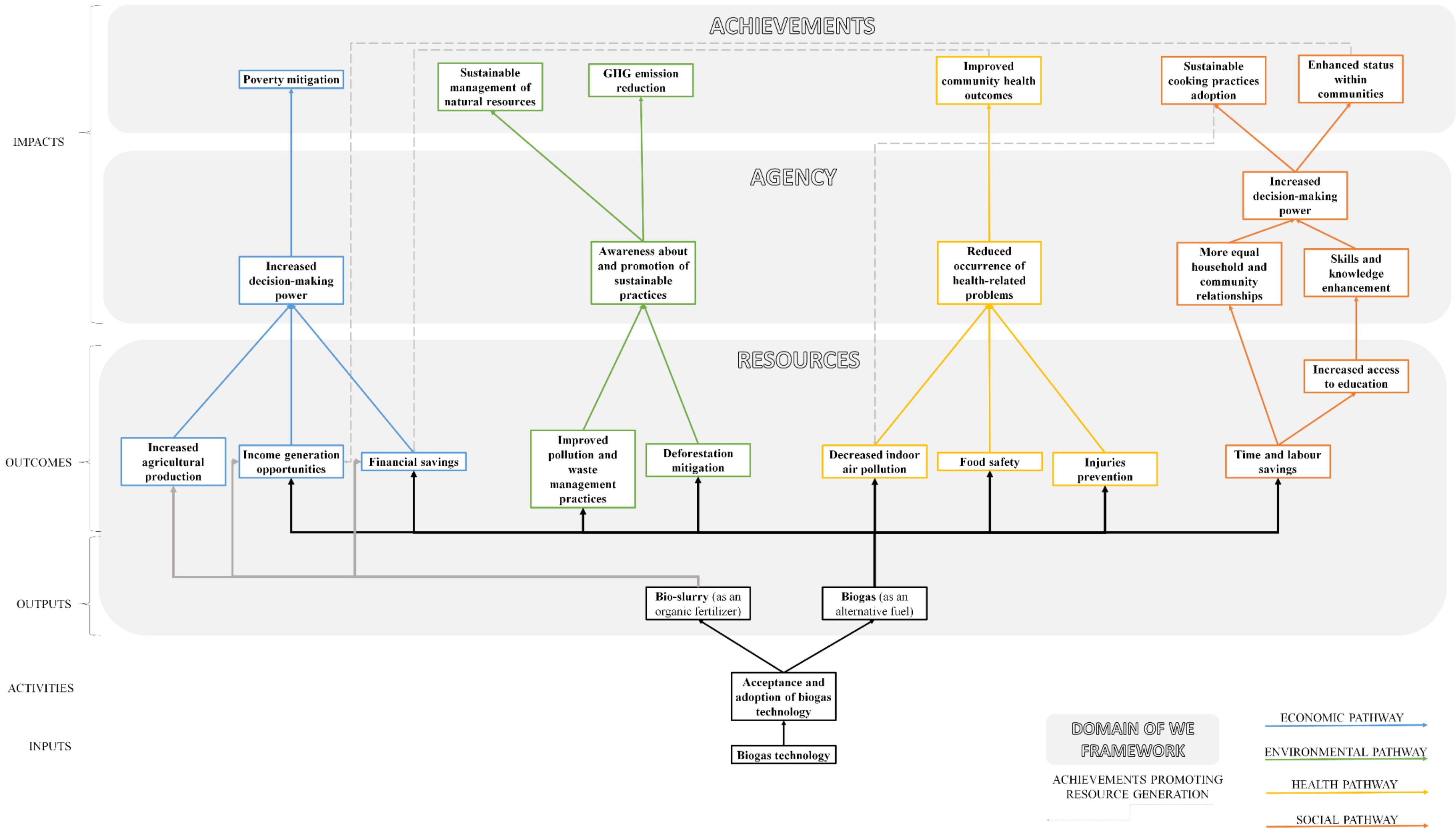

Figure 9. Visualization of the empowerment pathways.

4.5 Potential Obstacles of Biogas Technology for Rural Women in SSA

The biogas technology provides many benefits for rural women in SSA. However, there also exist several obstacles that prevent them from being empowered in reality. It is crucial to consider that several conditions need to be fulfilled, including physical access, economic access and adoption, for the technology to have an impact on women's lives (Gafa & Egbendewe 2021). Obstacles appear during different stages of the empowerment process or sometimes do not allow the biogas technology to be adopted at all, thus the empowerment process does not even start, despite its theoretical potential. These obstacles are sometimes technological, yet, the social dynamics often play an important role as well (Lindgren 2021).

4.5.1 Economic, Operational, and Maintenance Challenges of Biogas Technology

The biogas sector faces various economic constraints, such as investment requirements, operational expenses, and maintenance needs (Jha & Schmidt 2021; Yalew 2021). Despite the potential benefits, the price of biodigesters poses an obstacle for many people in rural SSA. For instance, in Kenya, the price starts at around USD 700[8] for the cheapest digesters (Njenga & Mendum 2018), while in Ethiopia, the average expense for the construction of a standard-size ($6m^3$) biogas plant is around USD 780[9] (Yalew 2021). These costs highlight the financial barriers that limit widespread adoption among rural areas in SSA.

Biogas units, improved cookstoves and similar technologies are commonly offered to rural communities through the so-called “credit model”. In this model, the payments are done in the form of instalments and collateral needs to be provided, which is often not possible for poor families (Sovacool 2013). Moreover, numerous reports have highlighted the scarcity or lack of suitable bioenergy feedstock as a significant issue in the African region (Dahunsi et al. 2020). Furthermore, biogas utilization is technically viable only for households that own (or have access to) at least three heads of cattle and have access to water (IPE Triple Line 2020).

[8] KES 70,000 (average exchange rate from 2018)
[9] ETB 16,465 (average exchange rate from 2016)

Next, appropriate and regular maintenance is needed for an effective biogas plant operation. Findings of several studies show quite a high rate of biogas plants not being in operation; in Kenya around 30% (Karanja & Gasparatos 2019), and in Uganda and Tanzania 21% and 33%, respectively (Clemens et al. 2018). The reasons may vary, but the most probable is inappropriate management of the biogas units by end users. Further, poor construction can shorten the lifespan of these technologies rapidly. Generally, SSA suffers from the lack of qualified workers and quality control. Additionally, some households suffer from low water supply, which is necessary for biogas units to function properly (Karanja & Gasparatos 2019).

Women need to be involved in the planning of biogas projects since they often offer new or different perspectives, which could otherwise be omitted (Terrapon-Pfaff et al. 2018; Kabir et al. 2022). Furthermore, they should be included in the assessment phase, which is usually carried out by managers, technicians, or governments. This often leads to a "gender-blind" approach, in which the different impacts on men and women are not considered. Gender-sensitive language is crucial for the assessment as well (Tsagkari 2022).

4.5.2 Energy Stacking and Cooking Preferences

The improvement of health is necessarily bound not only to the active use of biogas cookstoves but also to the abandonment of traditional biomass use. However, several studies discovered that the health benefits are not as high as originally expected after laboratory results or that there is no improvement whatsoever. The explanation could be the fact that traditional techniques are often not abandoned completely (Lindgren 2021). In fact, so-called **energy stacking**, which could be defined as a combined use of modern and traditional energy fuels, is typical for many developing countries (Ravindra et al. 2021; Elasu et al. 2023; Adams et al. 2023).

Only one hour of traditional cookstove use per week increases the emission levels above the World Health Organization's (WHO) recommended amount[10]. Thus, the benefits can often not reach their full potential (Lindgren 2021). Additionally, the household needs to invest in both traditional biomass and biogas technology in case of

[10] Amount recommended by WHO guidelines for indoor air quality from 2010 (Lindgren 2021). Available at https://www.who.int/publications/i/item/9789289002134.

energy stacking, which can lead to even higher costs than just the biomass itself (Lindgren 2021).

The persistent use of traditional biomass could be explained by the inappropriate design of the cookstoves. Users tend to favour fast cooking times and comfort. However, the design is more often focused on the technical side. Even health benefits and lower fuel expenses are not determinative for the end users. On the other hand, the right size, simple utilization, portability, and durability of the stove, together with the possibility to prepare traditional dishes efficiently and safely, can be convincing (Lindgren 2021). For example, the possibility to easily bake '*Injera*', a traditional bread, is very important for Ethiopian women when deciding about technology adoption and they also prefer to use biogas for the preparation of liquid food (e.g. sauces) or water boiling (Jabeen et al. 2020; Negash et al. 2021). Naturally, the particular requirements are household-specific, and they differ according to the locality, culinary habits, food preferences, rituals, ethnobotanical knowledge, or house materials (Zieba Falama et al. 2024).

4.5.3 Intra-household Gender Dynamics

In developing countries, decision-making about capital expenditures, including the installation of biodigesters, is shaped not only by access to resources but also by social and cultural norms, which often put men in the position to decide about household matters (Yasmin & Grundmann 2020). This is an issue mainly because men often do not consider the benefits brought to women a priority, since it does not influence them directly (even though they could also benefit from it indirectly). Moreover, men often tend to make technologies such as biogas sound more complicated than they are in reality, which creates the illusion that men need to control them since they are often considered to be more knowledgeable about such technology (Njenga & Mendum 2018). Because of that, they seldom decide to purchase biogas technology without proper education and deeper knowledge about the benefits (Lindgren 2021).

Furthermore, as a study from rural Uganda shows, women are usually not allowed to participate in decision-making due to their low education levels and low or non-existent incomes (Nalunga et al. 2019; Yasmin & Grundmann 2020). In South Africa, men predominantly exert influence over decision-making, ownership, access, and control concerning household resources and investments, which impacts the acceptance and utilization of biogas technology significantly (Uhunamure et al. 2019). On the other hand, a study conducted in Ghana by Adams et al. (2023) discovered that the decision-making process is dominated by women in the case of cooking energy.

Women are usually more willing to invest in biogas technology since they expect them to increase the well-being of their households (Yasmin & Grundmann 2020). In fact, women in low and middle-income countries (including SSA) are investing up to 90% of their earnings into products that they consider beneficial for their families, such as nutrition, health and education. This is different for men, for which these investments account for 30-40% of their incomes (Lindgren 2021). To illustrate, a study conducted by Gafa & Egbendewe (2021) in rural Togo states, that local women usually allocate more of their resources to energy in comparison to men (Jabeen et al. 2020).

However, a minority of households are female-headed in SSA. For instance, only 39.4% of households sampled in the research conducted by Uhunamure et al. (2019) in South Africa were considered to be female-headed. On the other hand, the same study also discovered that there is no significant difference between men and women when it comes to their willingness to adopt biogas technology in South Africa, although hierarchical family relationships remain in the country. A review written by Guta et al. (2022) found several studies stating that there is a higher probability for male-headed households to implement biogas technology. Thus, it is hard to clearly claim who is more open to their adoption.

Nonetheless, intra-household gender dynamics play an important role during budget allocation and decision-making (Karanja & Gasparatos 2019) and promotion strategies should differ for men and women (Lindgren 2021). The aforementioned study by Gafa & Egbendewe (2021) (which does not focus on biogas per se, but on the reduction of energy poverty) suggests, that the households where men and women decide together about energy use receive greater benefits and are less prone to be energy-poor. The individual decisions, no matter who made them, usually come with fewer benefits. This shows how complex the decision-making can be (Yasmin & Grundmann 2020). Nonetheless, consultation with other household members, ideally of different genders, can often make the final decision more favourable. However, in Ghana, for instance, men and women decide jointly about the type of cooking energy only in 7.7% of the households (Adams et al. 2023).

Next, adjustment to the use of new technology takes away the time women need for other (mostly domestic) duties. Thus, even though the use of technology spares time in the long run, it is not always realistic for rural women to start using the technology in the first place due to their already very time-demanding routines, which are hard to adjust (Rhodes et al. 2014). On the other hand, even if they can adjust and implement the technologies into their routines, it is not guaranteed that the time spared could be used for some income-generating activities. Market access is quite restricted in rural communities. In addition, husbands usually expect women to spend their time doing chores, thus, the time women save is usually converted into more household work. As a result, gender inequalities and biases are even strengthened (Lindgren 2021).

4.5.4 Potential Employment Loss

The adoption of new technology usually leads to labour displacement (Bryan & Garner 2022). In rural Africa, fuelwood and charcoal sectors are creating many jobs (not only) for women, and they are also an important part of the economy of SSA. However, the shift to clean cookstoves, which are often imported, can cause a loss of local job opportunities (Karanja & Gasparatos 2019).

Additionally, it is important to note that although biogas energy is responsible for creating new employment opportunities, those jobs do not have to be assigned to local people, and, even less so to women. If the local policies allow so, foreign investors and their workers can take over these new jobs (Kabir et al. 2022). The participation of women in paid employment is often viewed as a consequence of poverty in rural areas, rather than being considered advantageous, thus, new job opportunities are primarily assigned to men (Pueyo et al. 2020).

5 Conclusions

This thesis aimed to explore the empowerment pathways enabled by the adoption of small-scale biogas technology among rural women in SSA. The study was based on a comprehensive literature review that synthesized findings across economic, social, environmental, and health domains to assess whether and how biogas technology contributes to WE. The findings revealed that biogas technology significantly contributes to rural WE by providing reliable and sustainable energy sources that reduce time and labour spent on biomass collection and cooking.

Economically, biogas adoption has enabled women to save money on fuel costs and generate income through various means, thereby enhancing their financial independence and decision-making power within households. Environmentally, the shift to biogas has mitigated deforestation and improved pollution and waste management, leading to positive environmental impacts. Socially, the technology has increased women's opportunities to engage in education and community activities, further promoting their social status and influence.

The study also identified several challenges to the widespread adoption of biogas technology, including initial installation cost, maintenance knowledge, cultural preferences, and inequalities in resource access within household. Addressing these barriers is crucial for maximizing the empowerment potential of biogas technology. Policies aimed at subsidizing initial costs, providing technical training, and fostering inclusive communities are recommended to enhance the uptake of biogas technology. Additionally, it is important to integrate insights from human behaviour to avoid “gender-blind” approaches in further research.

In conclusion, small-scale biogas technology has demonstrated a substantial impact on the empowerment of rural women in SSA by addressing all three dimensions of WE framework – resources, agency, and achievements. However, the full realization of these benefits requires continued policy support and community engagement to overcome existing obstacles. This thesis contributes to the understanding of renewable energy's role in gender equality and sustainable development in rural SSA.

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Appendices

List of the Appendices:

Appendix 1: Overview of economic benefits of biogas technology for rural women in SSA.

Group of benefits:	Benefit:	Example:	Country:	Source:
Financial savings	Decreased expanditure on traditional biomass	*The average weekly expenditure on firewood per household declined by 71%.*	Kenya	(Njenga & Mendum 2018)
		Approximately USD 87, 28, and 3, can be saved annually on fuelwood, charcoal and dung cake, respectively.	Ethiopia	(Negash et al. 2021)
	Decreased expanditure on health problems	*Household expenses connected to health problems caused by indoor pollution decreases.*		(Njenga & Mendum 2018)
	Decreased expenditure on synthetic fertilizers	*Approximately USD 16 were saved on chemical fertilizer annually.*	Ethiopia	(Negash et al. 2021)
		Expenditures on chemical fertilizers were reportedly reduced in case of many households.	Kenya, Tanzania	(Clemens et al. 2018)
	Decresed expanditure on animal feed	*Bio-slurry application can decrease pig feeding costs by 25%.*	Kenya	(Njenga & Mendum 2018)
		There is a potential for bio-slurry to be used as feed in aquaculture.		(Ataei et al. 2020)
Income generation opportunities	Business establishment	*Women can train others to maintain and operate the systems, they can work as dealers or suppliers of the technology and appliances, or the can sell the bio-slurry.*		(Njenga & Mendum 2018; Gabisa & Gheewala 2019)
		The use of biogas facilitates business activities such as the sale of fruits and vegetables, grains, or dairy products for 84% of respondents.	Tanzania	(Clemens et al. 2018)
	Employment opportunities	*The job opportunities are diverse, from stove design and manufacturing to marketing, distribution, and sale of the appliances.*		(Kabir et al. 2022)
		Job opportunities are created in waste collection and management sector in connection to biogas.		(Piadeh et al. 2024)
Increased agricultural production		*Up to 91%, 84%, and 86% of households in use bio-slurry as a fertilizer claim that their crop yields increased.*	Uganda, Kenya, Tanzania	(Clemens et al. 2018)
		A farmer from Kenya states that her production of coffee increased by 20% after the introduction of bio-slurry.	Kenya	(Njenga & Mendum 2018)

Appendix 2. Overview of environmental benefits of biogas technology for rural women in SSA.

Group of benefits:	Benefit:	Example:	Country:	Source:
Ecosystem preservation	Natural resources (fuelwood) preservation	*Illegal logging for domestic energy purposes is tied to the loss of 45,000 ha of woodland each year.*	Nigeria	(Ifegbesan et al. 2016)
		Approximately one-third of fuelwood originates from unsustainable harvesting of woodlands and forests.	Ethiopia	(Yalew 2021)
		Demand for fuelwood was 88.9 million m³ in 2014, which was ten times higher than the annual sustainable supply.	Ethiopia	(Wassie & Adaramola 2021)
		Firewood exploitation contributed to climate by 30%.	Chad	(Zieba Falama et al. 2024)
		Biogas technology could play a significant role in the reduction of the unsustainable use of wood.		(Yasmin & Grundmann 2020; Jabeen et al. 2020; Yalew 2021)
		Biogas provides an alternative to fuelwood.		(Jha & Schmidt 2021)
	Mitigation of land degradation	*Firewood exploitation caused a 28% reduction in soil fertility, a 29% decline in flora and fauna, and a 27.5% in desertification and soil degradation.*	Chad	(Zieba Falama et al. 2024)
		Biogas technology utilization slows down soil erosion, soil degradation and other harmful effects.		(Jha & Schmidt 2021)
Greenhouse gas emission reduction	Emission mitigation by digesters	*GHG emissions could be cut by 1.9 t of CO2 equivalent per year with the use of typical anaerobic digesters.*		(Yalew 2021)
		Biogas technology captures CH_4.		(Baruah & Enweremadu 2019; Dahunsi et al. 2020)
	Emission mitigation by improved cookstoves	*Although improved cookstoves generally reduced indoor air pollution levels, the decrease was the most significant in case of CO emissions.*		Phillip et al. (2023)
		An installation of 6,715 new improved biogas cookstoves carries the potential to reduce CO2 emissions by 54,901,840 kgCO2/year.	Cameroon	(Zieba Falama et al. 2024)
Improved pollution and waste management		*Water pollution can be decreased by the use of bio-slurry as an alternative to conventional chemical fertilizers.*		(Piadeh et al. 2024)
		The use of biogas technologies contributes to safer waste management.		(AlQattan et al. 2018; Piadeh et al. 2024)
		Several small-scale biogas projects were implemented, using organic waste such as manure, slaughterhouse residues, and vegetable residues, and subsequently preventing this waste from ending up in landfills.	Kenya	(Jha & Schmidt 2021)

Appendix 3. Overview of health benefits of biogas technology for rural women in SSA.

Group of benefits:	Benefit:	Example:	Country:	Source:
Reduced indoor air pollution-related health problems	Decrease of fatalities	*Indoor air pollution caused by conventional biomass fuels it is one of the top three causes of death in SSA.*		(Yalew 2021)
		Approximately 72,400 people die due to indoor air pollution each year.	Ethiopia	(Negash et al. 2021)
		In 2016, indoor air pollution caused 32,636 deaths.	Mozambique	(Ugembe et al. 2022)
		Burning solid biomass in African households leads to nearly 600,000 premature deaths annually.		(Ifegbesan et al. 2016)
	Decreased disease occurrence	*Indoor air pollution accounts for approximately 5% of the overall disease burdens.*	Ethiopia	(Yalew 2021)
		Indoor air pollution causes eye irritation, burns, or headaches.		(Yasmin & Grundmann 2020)
		Underweight prevails an issue for children under 5 years old when frequently exposed to indoor air pollution.		(Murshed 2022)
		"My wife no longer cries in the morning as she prepares for us breakfast."	Uganda	Clemens et al. (2018:)
		Respondents experienced reduced frequency of respiratory symptoms and/or irritated eyes.	Tanzania, Ethiopia	(Negash et al. 2021)
		Eye irritation caused by smoke can be almost eliminated with the use of biogas stoves.		(Gabisa & Gheewala 2019)
Injuries prevention	Shorter and less frequent carrying of fuelwood	*Using biogas as fuel prevents women from injuries caused by carrying heavy loads of firewood on their backs, often for very long distances.*		(Njenga & Mendum 2018)
		SSA women often need to carry 20 kg of fuelwood on average per day.		(Yasmin & Grundmann 2020)
	Decreased incidence of violence	*The probability of experiencing safety risks such as violence or rape is much higher during fuel collection.*		(Karanja & Gasparatos 2019)
		When there is no need for the collector to go out, often alone, and the fuel is available within the safer space they are living in, gender-based violence declines.		(Njenga & Mendum 2018)
		Electrification overall increases the amount of public lightning, which enhances safety during nighttime hours.		(Woollacott et al. 2023)
Enhanced food safety		*People with limited access to fuelwood cook their meals for a shorter time and often eat them undercooked, which can cause many health problems. The same applies to water cooking time.*		(Dohoo et al. 2015)
		Biogas cookstoves make it easier to regulate the temperature of cooking, and the meals prepared on them were proven to often have higher nutritional quality		(Karanja & Gasparatos 2019)

Appendix 4: Overview of social benefits of biogas technology for rural women in SSA.

Group of benefits:	Benefit:	Example:	Country:	Source:
Time and labour savings	Savings on fuel collection	*Women in SSA commonly spend twice as much time on collecting fuelwood as men.*		(Lindgren 2021)
		Women gather fuelwood for a minimum of one hour daily, but the time usually exceeds two hours and can be even up to five hours.	Kenya	(Karanja & Gasparatos 2019;Yasmin & Grundmann 2020)
		Women and young girls spend 1.4 hours collecting fuelwood on average daily.	Mazombique	(Ugembe et al. 2022)
		The use of biogas as a clean biofuel was proven to shorten the length of the fuelwood collection and also decrease its frequency.		(Karanja & Gasparatos 2019)
	Savings on cooking	*Biogas technology can decrease the time and effort required for cooking itself, since there is no need for fuelwood management.*		(Yasmin & Grundmann 2020)
		Biogas stoves provide heat immediately.		(Clemens et al. 2018)
		More than three-quarters of surveyed households pointed out cleaner kitchens as a benefit of biogas.	Tanzania	(Clemens et al. 2018)
		The time saved thanks to improved cookstoves can reach up to 190 minutes per day (with the mean being 67.9 minutes per day). In the case of biogas, the maximum time savings were slightly lower, but still significant.	Zambia, Rwanda, Ethiopia	Krishnapriya et al. (2021)
		Biogas utilization encourages men to participate in cooking, reducing the amount of women's daily work.	Kenya	(Njenga & Mendum 2018)
Improved household and community relationships	Improved household relationships	*Biogas utilization improves the relationships in families and allows children to participate safely (with some caution) in cooking.*	Kenya	(Njenga & Mendum 2018)
	Community development opportunities	*Women can participate in community development projects, such as COWAN, which is a women-led NGO.*	Nigeria	(Olaniran & Perumal 2021)
	More leisure time	*The spare time can also be used on income generation and education, or simply on resting.*		(Ugembe et al. 2022)
Increased education level and decision-making power		*The use of biogas shortens the time needed for cooking and fuelwood collection, allowing the children to attend school and achieve better results as an outcome.*		(Krishnapriya et al. 2021)
		Women who attended school for longer gain bigger bargaining power during household decision-making.		(Yasmin & Grundmann 2020)