Biogas backpacks

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Table of Contents

List of Abbreviations and Units

h	–	hour
kg	–	kilogram
kWh	–	Kilowatt hour
kWh_e	–	Kilowatt hour electrical
LPG	–	liquefied petroleum gas
m^3	–	cubic meters
NGO	–	non-governmental organization
PE	–	poly ethylene
SWOT analysis	–	Analysis of Strengths, Weaknesses, Opportunities and Threats
US$	–	US Dollars

List of Tables

List of Figures

List of Pictures

Introduction

The GEF-funded project “Reduction of GHG emission through Promotion of Commercial Biogas Plants” jointly implemented by the United Nations Industrial Development Organization (UNIDO) and the Cambodian Ministry for Environment, Ministry of Agriculture, Forestry and Fisheries aims at utilizing biogas as a clean energy source to reduce greenhouse gas emissions that are related to the use of diesel generators at pig farms and methane emissions from pig manure. It further aims to demonstrate and promote biogas-based energy services as a financially viable, reliable, effective and sustainable mechanism to address on-farm animal waste management while reducing greenhouse gas emissions.

Within the framework of this project, an “Analysis of alternative uses for biogas in Cambodia” is carried out, which intends to address existing challenges for alternative uses for biogas in Cambodia by analysing and elaborating tailored solutions for certain animal farm types and sizes. In this light, this report focuses on the application of biogas backpacks and strives to answer the question in how far the use of biogas backpacks can serve as a means of distribution of biogas in the Cambodian context in order to support alternative uses of biogas.

In order to analyse the use of biogas backpacks, this report starts out by introducing the concept of biogas backpacks. The second chapter elaborates various factors that play a role in the feasibility of implementing the use of biogas backpacks. Several business models based on biogas backpacks are presented in the third chapter of this report. After providing an overview of characteristics in the relevant Cambodian context in the fourth chapter, a SWOT analysis is carried out in the fifth chapter showing strengths, weaknesses, opportunities and threats of the use of biogas backpacks in Cambodia. The last chapter subsequently provides concluding recommendations in this regard.

It should be kept in mind that biogas backpacks generally cannot be analysed in complete separation from the production of biogas, that is to say biogas plants, when it comes to questions of feasibility of their usage or business models. This report nonetheless attempts to focus as much as possible on biogas backpacks as such by taking a perspective that revolves around biogas backpacks as a means of transport for biogas.

1. The Concept behind Biogas Backpacks

Biogas is a renewable energy, which has several direct and indirect uses in commercial and domestic contexts: Its major applications are the generation of electricity, heat and fuel as well as the use of digestate as fertilizer. In many developing and emerging countries, one important use is the direct utilization of biogas for cooking or lighting purposes in rural domestic settings.

Typically, biogas plants can be installed at domestic, agricultural or industrial locations. At many of those locations the available feedstock and the corresponding biogas potential exceed the need for energy at those locations. While it is generally an option to sell the surplus biogas or the surplus electricity generated on basis of biogas, in Cambodia the conditions to do so are difficult because the grid operator does not allow the feed-in or sets unfavourable conditions, e.g. by accepting electricity only in summer time (dry-season) or offering only a very low price. Thus, when biogas is not or only partially used directly on-site of the generating plant (however small- or large-scale that might be), the question of transportation and distribution of the biogas becomes essential to make a biogas investment financially viable. While in many countries a gas or electricity grid exists, different solutions for the distribution of biogas need to be found in countries where a grid is non-existent and no other type of transport option has been established. Predominantly in developing and emerging countries, biogas backpacks can pose an alternative method of transportation for biogas. To introduce this particular technology, this chapter sheds light on the general background of biogas backpacks, takes a look at their safety as well as advantages and disadvantages.

1.1 The technology of biogas backpacks and its application

The biogas backpack is a low-tech pillow-shaped container for the temporary storage and transport of biogas. Made out of gas tight material, plastic and fabric, it is light-weighted with approximately 3.5 kg in an empty state up to 4.5 kg in inflated state and can thus be carried manually by one person.[1] Straps facilitate the transport and the container can be carried like a backpack which is where it receives its descriptive name from. Several layers ensure gas-tightness of the product, which is sometimes described as a balloon: There are two inner layers, which are made out of gas tight poly ethylene (PE) material. The materials of the biogas backpack are very endurable.

[1] empowering people Network 2018 (for details, see *Chapter 7 References*).

Picture 1: Example biogas backpack in Ethiopia, Africa[2]

In addition, a biogas backpack is equipped with a welded, threaded flange including a ball valve that enable emptying and filling without a pump or compressor. The system makes use of simple pressure equalization when connected to a biogas plant or consumer device via rubber hose. Weights such as stones or wood are put on top of the biogas backpack in order to push out the gas. Typically, around 1-1.5 m^3 of biogas are held within a biogas backpack, which is enough to support two to four hours of cooking with a simple gas stove.[3] This, in turn, is the major application of the biogas backpack: to provide small amounts of biogas for domestic devices like gas-burning cooking stoves or gas-fueled lamps.

Picture 2: Biogas backpack with weights on top for deflation[4]

[2] Source of image: Jeffrey 2018.
[3] Diermann 2018; De Decker 2018; (B)energy 2018.
[4] Source of image: empowering people Network 2018.

1.2 Safety of biogas backpacks

Biogas is a highly flammable mixture of gases, which can also be toxic to humans. It is thus essential to identify dangers and take appropriate measures to prevent possible dangerous circumstances. These remarks are particularly important for the operation of biogas plants. For the typical utilization of biogas backpacks, experience has shown that the use is considerably safer and easier to control: As the gas is not pressurized and the amount of energy is limited (typically below 10 kWh), the risk of an explosion is very low and the effect would be limited. Should the backpack get into contact with fire, it rather burns down slowly and in a controlled manner in contrast to an explosion.[5] Nevertheless, for safety reasons, biogas backpacks are stored outside of buildings and closed rooms to prevent accidents when gas is leaking.

1.3 Gender Dimensions

In many developing countries the task of looking for firewood is left to women and children. This can have negative impacts on their health, safety, as well as social and economic engagement. When using biogas instead of firewood and depending on the biogas distribution network, women can save time, since the gathering of firewood can be tedious having to look at different locations, while biogas can always be received at the same spot – the biogas plant. Saving time is an important social advantage. With the usage of biogas backpacks and more available time, women can concentrate on other economic activities and children can go to school.

1.4 The costs of biogas backpacks and the related transport of biogas

The costs for biogas backpacks range between 20 and 50 US$.[6] Additional equipment such as pipes, valves or hoses that are needed to charge the biogas backpacks at the biogas plant and discharge at the point of utilization are assumed to cost an extra 20 US$. This equipment is needed for each backpack that is in use, i.e. is being charged or discharged. The equipment, however, can be re-used to fill or empty several backpacks after one another. Hence, a set including the biogas backpack and relevant equipment is estimated to cost around 60 US$. Moreover, it needs to be taken into account that import costs might apply if biogas backpacks are not available on the local or national markets, such as in Cambodia, where the biogas backpacks are not on the market yet. Thus, a further investment of around 20 US$ can arise for shipping costs. As the material is very endurable, biogas backpacks have a high lifetime and maintenance is very limited since the filling with gas does not create a need for cleaning. All of the mentioned costs are typically incurred by the owner of the biogas backpack, which is typically the user of it as well.

Assuming maintenance costs of 2 % of the total investment, Grope et al. have looked at the cost of biogas transport by biogas backpacks per kWh by carrying out calculations for two

[5] empowering people Network 2018.
[6] Grope et al. 2018.

different biogas production capacities: 100 and 10 m³/h raw biogas production and a methane content of 58 %.[7] The findings are summarized in the following table[8]:

Table 1: Cost of biogas transport by biogas backpacks

Biogas production	100 m³/h	10 m³/h	Unit	Comments / sources
Number of households	1,600	160	[-]	[9]
Investment cost				
Biogas backpacks	60	60	US$ per household	
Connection to stove	20	20	US$ per household	Own assumption
Overall investment	128,000	12,800	US$	
Amortization	25,600	2,560	US$/year	Over 5 years
Interests	5,920	592	US$/year	9.25 % p.a.
Maintenance	2,560	256	US$/year	2 % of investment
CAPEX	31,520	3,152	US$/year	
OPEX	2,560	256	US$/year	
Yearly overall cost	34,080	3,408	US$/year	
Specific cost	**0.008**	**0.008**	**US$/kWh**	No economy of scales, because every cost occurs for each family

The results in this table[10] are based on the assumption that each household needs to buy one biogas backpack. However, there are other models possible as well, such as a community buying several biogas backpacks collectively and getting a discount for bulk purchase or a lease system operated by the biogas provider or an intermediate, e.g. an NGO.[11]

[7] The value of 58 % is used here to represent the methane content of a typical mix, since manure has a methane content of about 60 % while other feedstocks like starch containing plants range between 50 and 55 % in regard to methane content. Further information can also be found in the report by Grope et al. (2018).
[8] Grope et al. 2018.
[9] Based on the assumption that an average household consumes 1.5 m³ of biogas per day (see Grope et al. 2018).
[10] Grope et al. 2018
[11] A selection of business models is elaborated in Chapter 3.

Taking these cost-related aspects into account, the transport of biogas via biogas backpacks appears to be a promising low-cost option in order to provide energy to households.

1.5 Advantages and disadvantages of biogas backpacks

The use of biogas backpacks can be viewed from various perspectives, such as from a technological stance or under social aspects. This brings forward different advantages and disadvantages which are presented in this chapter. Some of these aspects also play an important role when evaluating the feasibility of the use of biogas backpacks. This, however, is looked at in more detail in Chapter 2 Factors in Feasibility of Biogas Backpacks.

Advantages of the use of biogas backpacks

The technology of a biogas backpack is **simple and easily usable** which entails that it can be used by practically anybody. Transporting biogas with a biogas backpack does not require lengthy and sophisticated training, instead its use is straightforward and can indeed be described similar to the usage of a balloon. Therefore, the usability is a major advantage, as biogas backpacks can be utilized widely and there are no challenges to spread the product in terms of training.

Looking at the biogas backpack from an environmental perspective, several rather indirect advantages become clear: The use of a biogas backpack helps to substitute other types of cooking fuel such as firewood or fossil options which is a very important advantage for **environmental protection**. Additionally, the replacing fuel – biogas – is made from renewable sources and significantly **reduces CO_2 emissions** in comparison to conventional options. By supporting the avoidance of the use of firewood, biogas backpacks also contribute considerably to the **reduction of deforestation**.

In connection to the replacement of fossil fuel, different health aspects prove to be advantageous about biogas backpacks. Since there is no black smoke from firewood or charcoal, the users are **not exposed to indoor air pollution**. An additional health advantage of the use of biogas backpacks is the fact that its weight is below five kilograms, even in filled state. Thereby, the **carrying weight is far less**, particularly compared to firewood, as the loads of the latter on the back of the carrier can sum up to almost ten times as much in comparison to the backpack's weight in inflated state.

Next to these advantages, the users of biogas backpacks can also **save time**, since the gathering of firewood can be tedious having to look at different locations, while biogas can always be received at the same spot – the biogas plant. Saving time is an important social advantage, since in many developing countries the task of looking for firewood is left to women and children. With the usage of biogas backpacks and more available time, women can concentrate on other economic activities and children can go to school.

A further advantage of biogas backpacks and the corresponding equipment such as rubber hose, valve, pipes or stoves is that the **costs for the devices are low**. While the prices for biogas backpacks range from 20 to 50 US$, an additional 20 US$ are estimated to be necessary for additional equipment.[12] Grope et al. calculated the price for biogas when transported with biogas backpacks per kWh:

- 0.038 US$/kWh if the biogas production is 100 m^3/h;
- 0.058 US$/kWh if the biogas production is 10 m^3/h (typical size for pig farms in Cambodia).

In comparison, the LPG retail price in Cambodia is about 0.06 US$/kWh.

Disadvantages of the use of biogas backpacks

One technological disadvantage of the biogas backpack as a means of transportation is its **limited volume**. Due to the size restrictions of the container and also due to the fact that the gas is not pressurized, the user can only carry up to 1.5 m^3 of biogas.

Moreover, it seems obvious that the use of a biogas backpack presupposes the availability of biogas, or to put it differently the existence of a plant with excess biogas, close-by. While this precondition can be perceived of as self-evident and can be applied in analogy to other sources of energy (e.g. firewood necessitates trees in proximity), it is a disadvantage in so far that biogas backpack as such is only a means of transport and cannot provide energy on its own.

Additionally, taking a closer look at the biogas backpack from a social point of view, it has to be considered that walking or cycling distances are physically restricted. Thus, the **range of transport is limited** and can be identified as another disadvantage as well as the fact that the **source of biogas has to be in proximity**.

Furthermore, as with any technology, it has to be considered that materials are used to produce the biogas backpacks and also have to be disposed of in a sustainable and environmentally friendly way. The latter, however, depends highly on the country of usage and the corresponding rules and practices. Thus, an appropriate disposal cannot be guaranteed.

Social/ cultural acceptance

[12] Grope et al. 2018.

Table 2: Overview: Advantages and disadvantages of biogas backpacks

Overview: Advantages and disadvantages of biogas backpacks	
Advantages	**Disadvantages**
- Technological aspects o Simple and easy-to-handle technology - Environmental aspects o Substitution of cooking fuel such as firewood or fossil option o Supports usage of renewable energy that reduces GHG emissions o Considerable reduction of deforestation - Health aspects o No indoor air pollution through reduction of black smoke o Less weight to carry - Social aspects o Saving of time in comparison to gathering of firewood o Low cost	- Technological aspects o Limited in volume due to size restrictions and non-pressurization o Presupposes availability of biogas in proximity o Use of materials - Social aspects o Limited transporting distances due to limited walking or cycling range o Frequency due to need to reload every day o Appropriate disposal necessary

2. Factors in Feasibility of Biogas Backpacks

In the decision-making process on the usage of biogas backpacks several factors have to be considered to evaluate whether their application is feasible. This chapter gives insights into the most important feasibility factors. They are evaluated on basis of the degree that they constitute a challenge to the use of biogas backpacks and how much effort it takes to overcome the impediment. While in the green and yellow category, potential challenges can be overcome with differing degrees of impediment and corresponding effort needed for the remedy, the red category shows deal breakers with the potential to halt projects.

An overview of the various factors and their evaluation is given at the end of this chapter, see Feasibility Factor Overview on page 13. In any case it has to be considered that individual situations when thinking about introducing biogas backpacks as a means of transport may differ and other factors might play a role than those elaborated here.

2.1 Availability of biogas backpacks

One factor for the decision of whether the use of biogas backpacks is feasible is the availability of the biogas containers as such. If the biogas backpacks are not available on the local or national market, it can be a minor challenge to get hold of them. In spite of that, there are easy solutions to overcome this impediment: It is possible to establish a cooperation with a company or organisation in a country where biogas backpacks are available and import them. In such a case, NGOs can serve as an intermediate or organizer and help keeping the costs as low as possible, maybe even reaching economies of scale. Of course, the standard way of importing goods is possible as well but might entail higher costs. As there is no company offering biogas backpacks in Cambodia, for example, it is assumed that this will bring the cost of a biogas backpack up to approximately 60 US$ (in contrast to 20 to 50 US$ without costs for import).[13] Another option can of course also involve the founding of a business that – in cooperation with companies selling the biogas backpack – locally produces the container. However, the efforts for the latter option can be comparatively high and the economic sense of this option depends on the importing efforts needed in each individual country.

In sum, the availability of biogas backpacks constitutes a rather minor challenge and there are multiple and easy ways to overcome it such as providing funding for pilot projects and pilot users, also to foster acceptance and a positive reputation. Hence, it is rated as a green factor.

2.2 Financial capability to invest into biogas backpacks and equipment

The financial capability to invest into biogas backpacks and necessary equipment is another factor relevant to the feasibility of the use of biogas backpacks as a means of transport for biogas. As pointed out in *Chapter 1.3 Gender Dimensions*

In many developing countries the task of looking for firewood is left to women and children. This can have negative impacts on their health, safety, as well as social and economic engagement. When using biogas instead of firewood and depending on the biogas distribution network, women can save time, since the gathering of firewood can be tedious having to look at different locations, while biogas can always be received at the same spot – the biogas plant. Saving time is an important social advantage. With the usage of biogas backpacks and more available time, women can concentrate on other economic activities and children can go to school.

The costs of biogas backpacks and the related transport of biogas, biogas backpacks are rather inexpensive. Nevertheless, the costs have to be considered as a challenge, since often biogas backpacks are used in rural domestic contexts and one container is used per household. Subsequently, *one* household needs to be able to afford at least one biogas backpack, which can be a notable challenge in developing and emerging countries.

Several options exist to counter this impediment: A leasing system can be introduced in order to reduce the immediate costs for the user of a biogas backpack, as only a rent is paid for the container. Other options include financing in form of microcredits or subsidies from public or private funds. Additionally, an NGO can serve as an intermediate facilitating the distribution of biogas backpacks to individual households or as the organisation running the leasing system.

Thus, while there are ways to overcome the challenge of financial capability and the effort is feasible and plannable to do so, it is yet evaluated to be in the yellow category of feasibility

[13] As mentioned before, additional equipment would approximately cause another 20 US$ of investment.

factors, as the degree of impediment can majorly vary in individual cases and needs to be checked thoroughly beforehand.

2.3 Appropriate source of biogas in proximity

Another factor that is very important to the feasibility of the use of biogas backpacks is an appropriate source of biogas in proximity, that is to say a biogas plant with excess biogas that can be sold and then transported in biogas backpacks. This aspect is already introduced in *Chapter 1.5 on the Advantages and disadvantages of biogas backpacks* and is elaborated subsequently. When using biogas backpacks as means of transport, it has to be considered that there are physical limits to the reach of the user carrying the container. Hence, the source of biogas needs to be rather close-by. Additionally, the plant producing the biogas needs to have excess biogas that it can sell to the users of biogas backpacks. Certainly, the amount of available or rather sellable biogas has to be sufficient in order to make the use of a biogas backpack or several ones feasible. Moreover, the amount should not exceed the demand and what can be carried in all available biogas backpacks – otherwise the biogas needs to be stored (also see *Chapter 2.5 Availability of storage*), dedicated to a different purpose or, in a worse case, burning it with a gas flare to avoid gas venting into the atmosphere. For urgent environmental reasons, it has to be mentioned here that it should always be avoided that biogas escapes into the atmosphere due to the contained methane which has a climate change potential approximately 25 times higher than that of CO_2.[14]

This feasibility factor with all its connected aspects constitutes a very considerable challenge and needs to be taken into account in advance. It should be among the very first points to consider when starting a decision-making process about the use of biogas backpacks, as it can be a deal breaker. In the following, light is shed on different cases connected to this feasibility factor.

In case there is no biogas plant and no biogas available close-by, the use of biogas backpacks is not possible. Of course, the option exists to become a *prosumer*, someone who produces *and* consumes the relevant product, which is in this case biogas. However, the impediments to establish a biogas plant of any size necessitate separate feasibility studies and highly depend on the setting, the potential operator etc., the discussion of which goes beyond the scope of this study.[15] To provide some rough ideas on this question, it is possible to refer to a solution for up to three households (see *Chapter 3.1 on Model 1: Biogas backpacks in solely domestic contexts).*

In case there is a biogas plant located close-by but no excess biogas, since all the biogas is used for other purposes by the operator, the options to overcome this challenge are limited as well. Nevertheless, there are some solutions: one of them could be the provision of additional feedstock to the plant operator by the potential users of the biogas backpacks (see *Chapter 3.2 Model 2: Biogas backpacks used at a farm business* and *Chapter 3.3 Model 3: Biogas backpacks for industrial biogas plants*).

[14] IPCC 2007.

[15] More detailed insights are provided in the *Initial Assessment Report* in which several biogas plan locations are evaluated (Hofmann and Bontempo 2018 [1]).

Typically, biogas plants in Cambodia have excess gas available, since their captive energy demand is lower than the available biogas. If the amount of biogas available exceeds the demand (for own purposes as well as from other users), such as is typical for biogas plants in Cambodia, a possible remedy for this impediment is to store it. Since this option is crucial, it can be seen as an individual factor of feasibility and a separate section has been dedicated to it (see *Chapter 2.5 Availability of storage*). The other typical actions implemented to deal with excess biogas are using it for a different purpose or just burning it in a gas flare.[16] For the first case, it is highly likely that the biogas would have already been dedicated to a different purpose if that was available and there was any excess biogas beforehand. Consequently, if this has not been done, the option most likely does not exist anyway. The latter situation, that is letting the excess biogas burn in a gas flare, is a loss of potential income and renewable energy. However, from an environmental perspective, burning excess gas in a flare is the preferred option to what unfortunately appears to be common practice in Cambodia, namely to let the excess gas escape into the atmosphere.

For these reasons, the appropriate source of biogas in proximity is rated as a red feasibility factor – a potential deal breaker that is not at all easy to overcome. Furthermore, this factor of feasibility along with the questions that need to be answered to remedy it are particularly important for any of the business models presented in *Chapter 3.*

2.4 Availability of buyers and sellers

The availability of buyers and sellers of biogas that use biogas backpacks is another feasibility factor for the introduction of this means of transport for biogas. The selling side is already addressed in the section about the issue of having an appropriate source of biogas in proximity (see *Chapter 2.3*). In turn, the buyer side can also constitute an impediment that needs to be remedied. If there are no users with a demand for biogas, the investment into biogas backpacks is pointless for either side. Therefore, it is necessary to have or create a demand for the biogas to subsequently have buyers that utilize biogas backpacks. However, this is not an easy task to solve and can certainly be a deal breaker. If the potential users are reluctant to switch to the biogas and biogas backpacks option and keep using conventional fuels such as firewood or LPG, it takes considerable effort to create the demand needed, e.g. informative events, awareness raising campaign etc. that could be carried out by an NGO. Considering this, the underlying feasibility factor is also rated into the red category.

2.5 Availability of storage

In case there is more biogas available than is used on a plant site and it can be sold to users of biogas backpacks for other purposes such as domestic cooking and lighting, it is important to consider that the availability of a storage can play an important role. Biogas is produced permanently and not only during daytime when buyers come to pick up the biogas and

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[16] For urgent environmental reasons, it has to be mentioned again that it should always be avoided that biogas escapes into the atmosphere due to the contained methane which has a climate change potential approximately 25 times higher than that of CO_2 (IPCC 2007).

transport it in their backpacks. Thus, the availability of a storage possibility for the biogas produced during night-time or more generally during time periods where there is no demand by carriers of biogas backpacks can be considered a notable challenge. Building an additional permanent storage if needed can be an option to remedy this feasibility factor but can be quite expensive and potentially falls short as an option for small businesses and farms as well as households. However, e.g. covered lagoons have sufficient gas storage. Another possibility is to plan the biogas plant as such in a way to be capable of bridging the times when there are no buyers with biogas backpacks to pick up the biogas. Moreover, using biogas backpacks to store the biogas on the plant site or at another location until pick-up is another solution.

Therefore, it can be concluded that overcoming this impediment necessitates some efforts but can be remedied by planning and a structured approach within a tolerable amount of time and at bearable costs. In consequence, it is categorized as a yellow factor of feasibility.

2.6 Bridging of maintenance times and other downtime of the plant

As the use of biogas backpacks clearly depends on the availability of biogas, it is necessary to consider maintenance times of the biogas plant and other downtimes of the biogas plant as well as seasonal variation in gas availability. In order to operate a biogas plant safely and reliably, regular checks and maintenance are essential, e.g. repairs on the digester. This, however, partially entails times in which less biogas is produced and hence, cannot be sold to the users of biogas backpacks. Additionally, other downtime has to be taken into account as well, e.g. when the availability of feedstock such as manure from pigs is temporarily not available due to certain farming strategies in use in Cambodia.[17] Since users of biogas backpacks – particularly those using this means of transport to provide fuel to their cooking stove or lamps on a daily basis – rely on the availability of biogas, maintenance times and other downtime pose another factor in the question of feasibility. There are several remedies to this challenge: First of all, the plant needs to be operated well and in a safe manner. Second, there is the possibility to anticipate maintenance and down times by having a storage tank or storage biogas backpacks in order to provide consumers with stored biogas during those times and thereby bridge the potential absence of biogas production. While the solutions are quite clear they involve further investment and need to be well planned by the operator. Therefore, this feasibility factor is rated as belonging to the red category.

[17] Please also refer to *Chapter 4 The Cambodian Context*.

2.7 Feasibility Factor Overview

Having looked at the various feasibility factors in previous chapters, the evaluation according to the three categories is summarized in the following table. The evaluation system is set as follows:

- Green:
  Green factors constitute a minor challenge to the application of biogas backpacks, but are easy to overcome by quickly available means and at rather low cost.
- Yellow:
  Yellow factors constitute a notable challenge and some effort is needed to overcome them. However, this effort is feasible and plannable within a tolerable amount of time and at bearable costs.
- Red:
  Red factors constitute a very considerable challenge and the effort needed to overcome them is very high in terms of time and finances. Red factors can be crucial deal breakers and should be considered first in the decision-making process on using biogas backpacks.

Table 3: Overview of Feasibility Factors for Biogas Backpacks and their Evaluation

Feasibility Factor	**Evaluation Category / Degree of Impediment**
Availability of biogas backpacks	Green
Financial capability to invest into biogas backpacks and equipment	Yellow
Source of biogas in proximity	Red
Availability of buyers and sellers	Red
Availability of storage if necessary	Yellow
Bridging of maintenance times and other downtime of the plant	Red

3. Business Models for Biogas Backpacks

Several business models for biogas backpacks as a means of transporting biogas are conceivable. They are, of course, closely linked to the production of biogas in a biogas plant. Whereas the variety of possible business models by far exceeds the scope of this study, in this chapter three basic business models are presented that involve the use of biogas backpacks and also give information about the biogas plant from which the transported biogas is retrieved. Any of the models presuppose the check of the feasibility factors elaborated in the previous chapter.

It has to be noted that, since this report focuses on the application of biogas backpacks, the business models do not consider in-depth the sale of digestate as fertilizer which, however, is an important part of business concepts revolving around biogas plants. In any of the models presented below, the use and/or sale of digestate can be kept in mind as a profitable option.

3.1 Model 1: Biogas backpacks in solely domestic contexts

One business model that is commonly applied in relation to biogas backpacks in developing and emerging countries is set in a solely domestic context. It usually involves up to three households in various roles.

One household owns a domestic biogas plant and produces biogas with manure from a small number of animals (cows, pigs, chicken etc.) that are owned by the household as well or other organic household waste. The biogas is then used for own purposes. Excess biogas is sold to one or two neighbouring households, either for a small fee or in exchange for additional feedstock for the biogas plant. The biogas is transported by biogas backpacks that are either owned collectively or each household owns one container. An important precondition in this context is the availability of feedstock for the production of biogas such as manure from livestock, food waste or other organic materials. Typically, around 20 kg of e.g. cow dung need to be put into a domestic plant in order to receive approximately 1 m^3 of biogas per day serving one household. Moreover, this business model presupposes as well the financial capability to invest into the plant, the biogas backpacks as well as needed equipment for cooking or lighting.

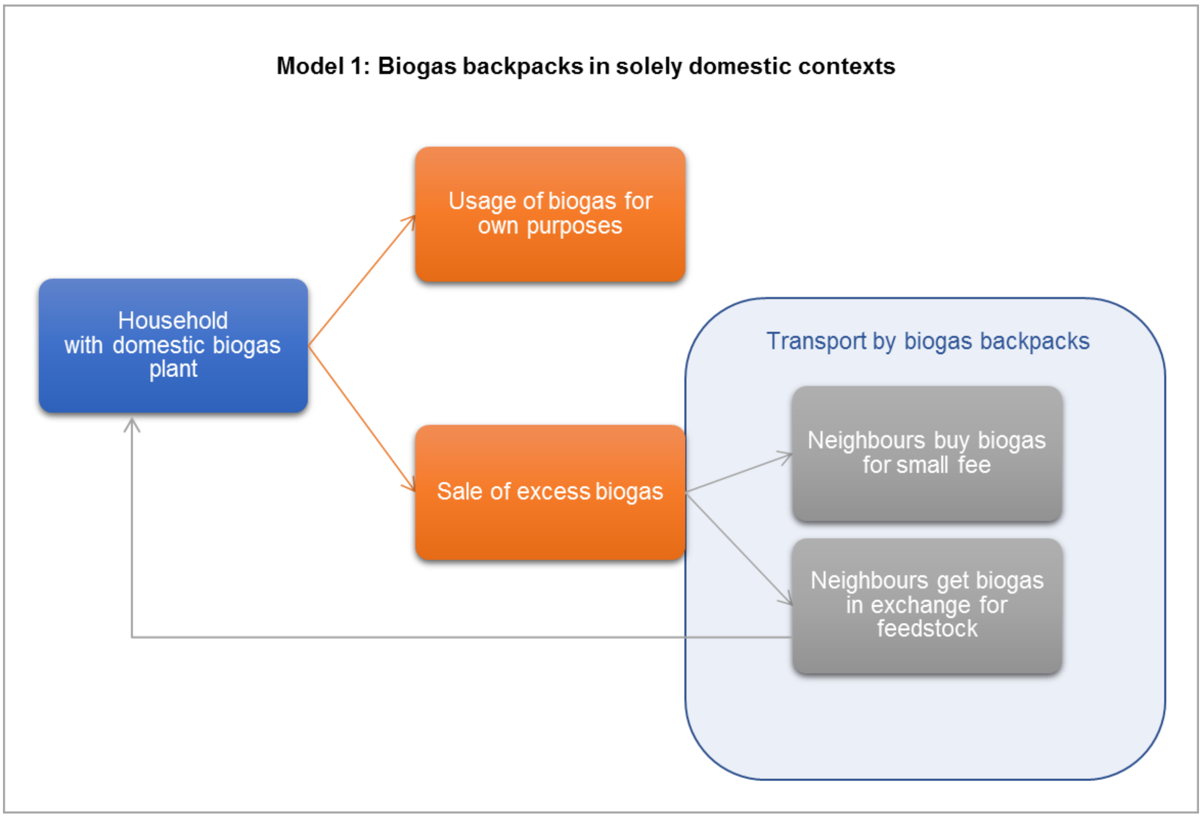

Figure 1: Structure of Business Model 1 (Biogas backpacks in solely domestic contexts)

3.2 Model 2: Biogas backpacks used at a farm business

A second business model is set up around a small farm business. While the focus of the farm is on agriculture (in contrast to energy production), there are sufficient amounts of feedstock available at the farm such as manure from livestock or vegetable wastes. Those organic materials are then digested in a biogas plant. The farm can use electricity produced from the biogas for capacitive use, e.g. lighting and pumping. Selling the (excess) biogas is a secondary business for the farmer whose primary focus remains to be set on agriculture and maybe the production of valuable fertilizer. A precondition here is self-evidently sufficient amounts of feedstock as well as resulting biogas and interested buyers that can pick up the biogas and transport it via biogas backpacks. One option in this business case is bartering between the farmer and the users of the biogas: It is possible to reduce the fee paid for the biogas or even suspend it in exchange for the delivery of additional feedstock materials by individuals or business customers such as neighbouring farmers, thereby having additional biogas available.[18] Furthermore, the farmer can certainly also use the biogas and the fertilizer for her/his own purposes on the farm or farmstead.

[18] If there are animals on the farm, hygene is a relevant topic since animal diseases could potentially be introduced tot he farm with the sold feedstock and the people visiting for delivery. However, this can be solved by organisational measures such as handing over oft he biogas backpack at the entrance.

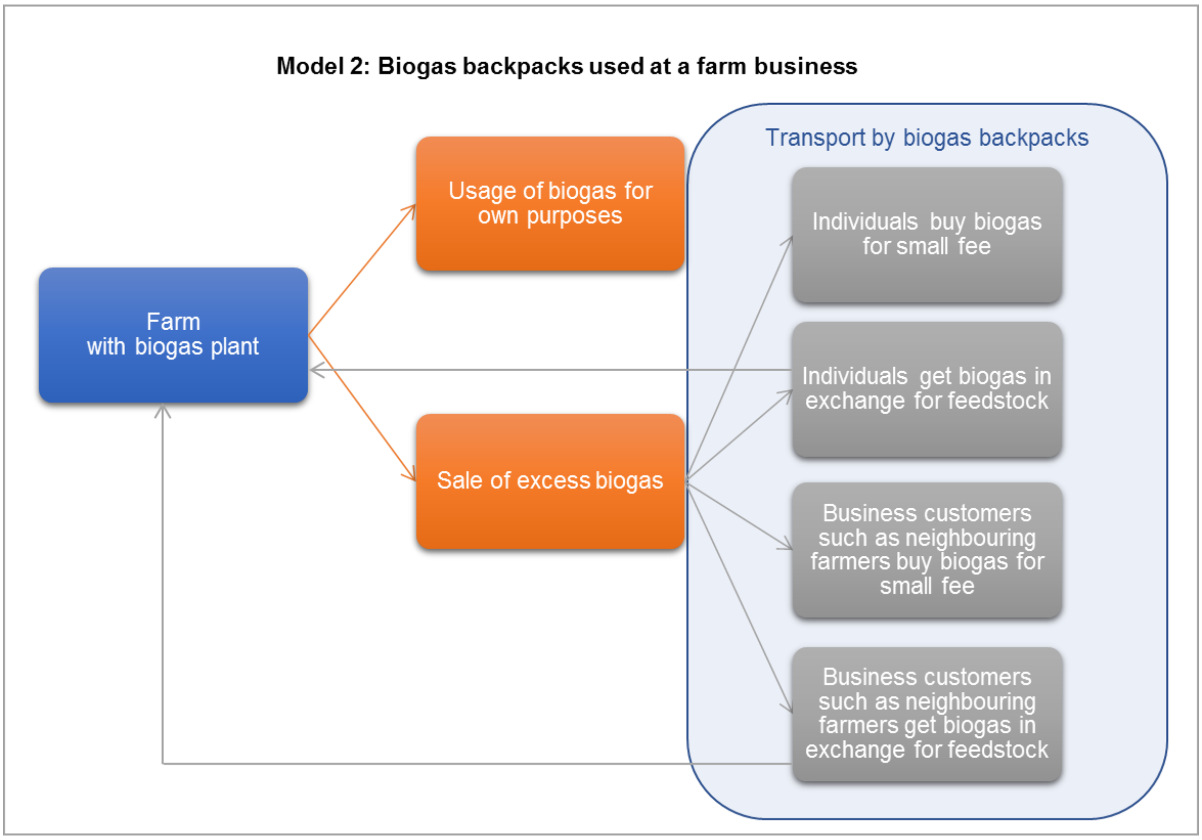

Figure 2: Structure of Business Model 2 (Biogas backpacks used at a farm business)

3.3 Model 3: Biogas backpacks for industrial biogas plants

This business model has at its centre an industrial biogas plant with the capability of producing more biogas than needed for own purposes or business processes. This possible excess biogas can – as a secondary business – be sold to consumers in the close-by area via the utilization of biogas backpacks. Similar to Business Model 2, the transaction takes place with the help of biogas backpacks and is based on either a small fee or a trade-off for the delivery of feedstock. In addition to this and taking into consideration the size of the plant, another business option is possible for an industrial-scale business: Depending on the amount of surplus biogas available for the local sale, an intermediate could help facilitate the distribution of biogas by using biogas backpacks for transport to neighbouring businesses or farms as well as to a possible local selling points for individuals who then continue transporting the biogas to their homes in biogas backpacks as well. A lease system for the biogas backpacks could be an additional characteristic of the intermediate's business model that lowers the cost for the end consumers. This intermediate position could be taken up by NGOs in developing and emerging countries. Moreover, a flat rate price could be arranged between the biogas seller and the intermediate in order to enable low pricing for end consumers. Potentially, in this business model the operator of the biogas plant can also have the sale of biogas as a primary business.

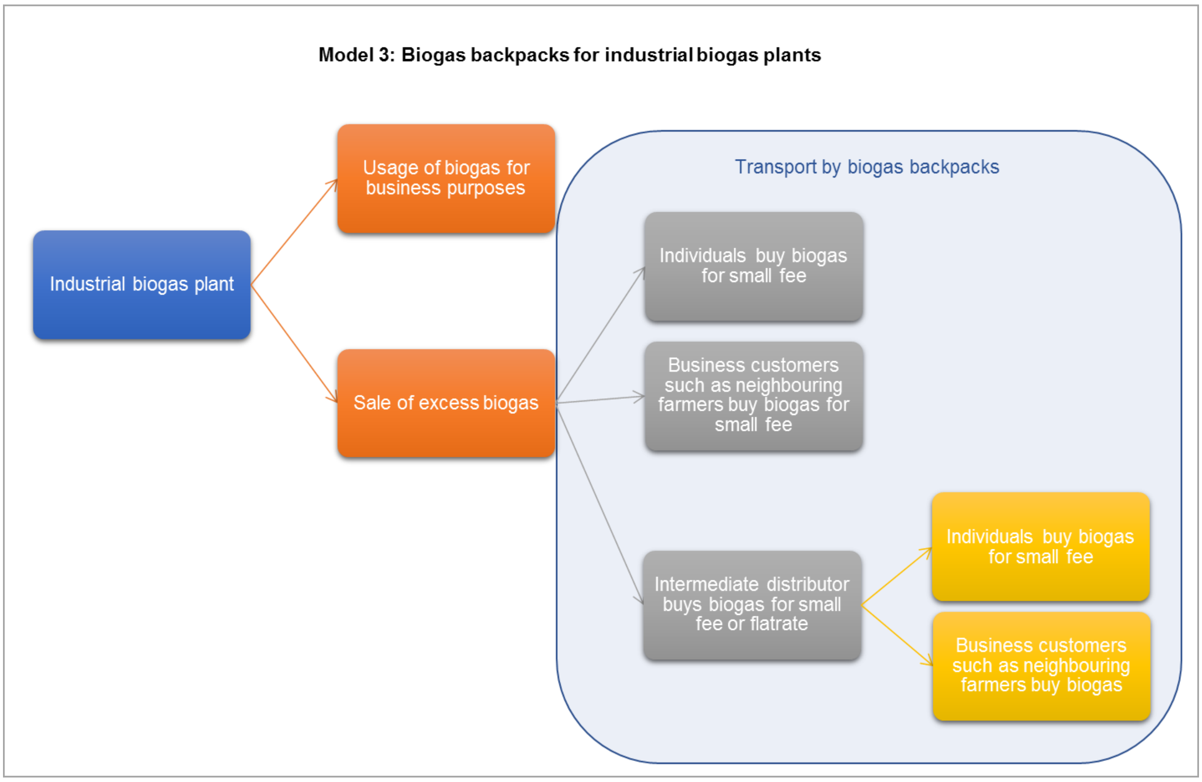

Figure 3: Structure of Business Model 3 (Biogas backpacks for industrial biogas plants)

4. The Cambodian Context

As part of the project "Reduction of GHG emission through Promotion of Commercial Biogas Plants" a field mission to Cambodia has been carried out including visits to various farms and factories (some of them already with biogas production) next to workshops with national stakeholders in order to determine the feasibility of alternative uses of biogas in the given locations.[19] Within the framework of the resulting *Initial Assessment Report*, general remarks are made about the visited sites that are applicable to all or most locations. Furthermore, specific findings are presented and analysed. This chapter summarizes the most important aspects of the aforementioned report in order to provide insights into the Cambodian context. The provision of background information about Cambodia is necessary at this point in order to apply the information from previous chapters in combination with the said findings in a SWOT analysis of the use of biogas backpacks in Cambodia in the following Chapter 5.

4.1 Background information from field mission to Cambodia

In Cambodia, pig fattening farms apply an "all in – all out" strategy meaning that the process starts with small piglets and ends with the fattened, grown pigs. After this fattening period of 5-6 months, the pigs are sold and the stable cleaned and sanitized which approximately takes

[19] Extensive details can be found in the *Initial Assessment Report* prepared by Fachverband Biogas e.V. (Frank Hofmann and Giannina Bontempo) within the framework of this project.

another month. This is important for two reasons in regard to the production of biogas: Firstly, small piglets produce less manure than grown pigs. Hence, the amount of available feedstock differs, as the pigs grow, and consequently, the biogas production varies as well. Secondly, there is a gap of a month during which no manure is available at the farm at all.

Another important aspect found during the field mission is the reluctance of electricity providers to accept electricity produced from biogas into the grid on a permanent basis. Among others, there is a difference between wet and dry season, as the generation of hydro energy is low during the latter and electricity providers might be more prone to let biogas-based electricity be fed into the grid. Some energy providers do not offer the possibility to feed in the electricity at all. As a consequence, most Cambodian locations would concentrate on using the biogas and the generated energy for their own purposes and on-site – either for electricity, heat or fuel replacing fossil-based energy, e.g. in order to substitute diesel. The reduction of their own energy costs would thus be put in focus.

Out of the Cambodian sites visited, some already had begun with biogas production by means of covered lagoons. Low investment costs for this technology and the simplicity of its operation are the major reasons to construct this type of plant. Regardless of these advantages, lagoon biogas plants present serious risks to the environment and people.[20]

Several owners and personnel from the visited sites expressed no interest in investing into a biogas plant and no one was interested in the sale of potential excess biogas via biogas backpacks. Among others, the reasons included:

- Concentration on core business and no desire to expand by creating a side business;
- Sites with an existing biogas production have no interest in diversifying their biogas utilization which is now solely used in a genset engine;
- Selling produced energy is not an option, focus is set strictly on using energy for own purposes;
- Other energy sources are more economical;
- Biogas production (or the corresponding potential) is very limited due to the small size of the farms;
- Other economic factors not related to biogas but rather linked to the operative business of the companies (e.g. no available staff).

These statements confirm that there is a direct connection between the investment into or existence of a biogas plant and the potential usage of biogas backpacks. As pointed out before, looking at biogas backpacks as a means of transport for biogas presupposes examining the presence of a biogas plant and the corresponding availability of excess biogas that can be sold and transported. Therefore, it is necessary to keep this important condition in mind when discussing the application of biogas backpacks.

[20] Further information can be found in the aforementioned *Initial Assessment Report*.

4.2 Example locations from field mission to Cambodia and their biogas yield

Despite the aforementioned hesitancy by stakeholder in Cambodia to expand or build a biogas plant which is a precondition to the (extended) usage of biogas backpacks, an analysis of the (additional) biogas potential at each visited location has been carried out within the *Initial Assessment Report*.[21] A short overview of this analysis for each site is presented in this chapter summarizing the situation at each location and the biogas potential in regard to biogas backpacks.

Considering the characteristics of biogas backpacks in general, such as their volume of only up to 1.5 m^3, as well as the presented business models, it has to be taken into account that industrial, large-scale projects based on distribution solely by biogas backpacks are likely to be unattractive to investors. The latter are more prone to invest into a project when the production costs for energy supply are advantageous in comparison to the LPG retail price, charcoal or any other established fuel supply, and the biogas production exceeds a certain scale and margin.[22] Thus, biogas backpacks with their limited volume and reach are potentially not an appropriate means of distribution for industrial, large-scale projects. Consequently, this study and the field mission have rather been focused on sites with existing biogas plants with potential excess energy or e.g. an energy demand that could be covered with biogas from feedstock available at the location.

<u>Farm No1</u>

On the farm No 1, a biogas plant is installed with a biogas production of about 11 m^3/h. The annual biogas energy production is about 670,000 kWh per year, the annual electricity production could potentially be 180,000 kWh_e if the genset would work reliably and convert all of the biogas to electricity. During the field mission, information was neither available about the actual electricity production nor about the electricity demand on the location. Yet, experiences from other locations indicate that considerable potential for excess biogas is likely which could hence be sold via biogas backpacks. A reliable estimation in regard to the amount of excess biogas is however not possible at this point.

<u>Farm No 2</u>

On the farm No 2 about 49,500 m^3 of biogas per year could be produced or 5.7 m^3 biogas per hour. Thus, about 326,700 kWh per year could be generated resulting in about 88,209 kWh_e of electrical power per year. As the actual demand for electricity on the farm is about 10,000 kWh_e, only about 40,000 kWh biogas are needed to produce this amount. Thus, the potential of excess biogas is about 287,000 kWh. One typical biogas backpack can hold about 6 kWh (at the size of 1 m^3). It can be concluded that potentially nearly 50,000 biogas backpacks per year can be filled with the excess biogas.

[21] Hofmann and Bontempo 2018 [1].
[22] E.g. higher than 10% WACC included in the cost calculation mentioned above.

Farm No 3

A biogas plant is installed on the farm No 3 with an estimated biogas production of 5.7 m^3/h, resulting in about 326,700 kWh per year and in about 88,209 kWh_e of electrical power per year. According to the owner, the electricity demand on that farm is about 12,000 kWh_e per year. About 48,000 kWh of biogas are needed to cover the electricity demand and consequently, the excess biogas potential is 278,000 kWh. With that about 46,000 biogas backpacks can be filled with 6 kWh each per year.

Farm No 4

At the location Farm No 4 about 112,500 m^3 of biogas per year can be produced or 12,8 m^3 biogas per hour. This equals 742,450 kWh per year. The resulting electricity production is about 200,475 kWh_e per year. No exact information was available about the energy demand on this site. Hence, by comparison, it is only possible to assume a considerable potential of excess biogas for the use of biogas backpacks as on similar locations described in this chapter.

Farm No 5

On the farm No 5 a biogas plant will be installed with an estimated biogas production of 3 m^3/h. It will produce about 27,000 m^3 of biogas per year. This amounts to about 178,200 kWh per year and therefore, around 53,460 kWh_e of electrical energy per year. According to an electrical bill of the farm, the monthly consumption is 7,191 kWh, adding up to an estimated annual demand of 86,292 kWh_e. This estimated demand, however, is considerably higher than the electricity demand on comparable farms and a more exact recalculation on basis of further energy bills is not only interesting but also recommended. If the electricity demand is actually as high as estimated, the consumption cannot be covered by the expected amount of electricity produced with biogas which would entail the absence of any excess biogas that could be sold via biogas backpacks. It has to be kept in mind that these estimations are theoretical and the actual situation – and the actual biogas potential – might be different in reality.

Farm No 6 (tapioca factory)

At the time of the field mission, the factory once producing tapioca had stopped operation. Subsequently, the biogas plant that is installed on the site with an estimated biogas production of 450 m^3/h is also not operating anymore. Within the framework of this project, an extensive *Analysis of using biogas from Tapioca starch effluent for various options*[23] has been conducted which indicates the probable existence of substantial potential for the use of excess biogas. In the absence of reliable data regarding the consumption on the site and as the biogas plant is not in operation, it is not possible to calculate the potential biogas to be used in biogas backpacks at this point.

Farm No 7 and Farm No 8 (rubber factories)

At the Farm No 7 and Farm No 8 rubber factories, no biogas plant had been constructed at the time of the field mission and hence, no estimation of the biogas production can be carried out in regard to biogas backpacks.

Farm No 9 and Farm No 10

Even though there is no biogas plant on the farm No 9 and the farm No 10 yet, the potential for biogas is known: It is about 5 m^3/h. The electricity demand of both farms is rather low with about 5,000 kWh_e. Consequently, the field mission and subsequent analysis could not identify a viable business case that included the investment into a biogas plant. As a result, there will not be excess biogas that could be used in biogas backpacks.

Farm No 12 (dump site)

At the farm No 12, the data for the biogas potential was not available. Nevertheless, the potential was estimated to be roughly around 480 m^3/h.[24] In order to make use of any biogas application, a gas collecting system would have to be installed. However, the investment is not possible and hence, there is no potential for the usage of biogas backpacks. Even if the Battambang dump site was to be equipped with a gas collecting system in future to reduce the methane emissions, the biogas production of 480 m^3/h is high and necessitates further uses of the biogas than the sale and transport via biogas backpacks. Otherwise, 480 biogas backpacks had to be filled up each hour of the year. If other options are applied (e.g. upgrade to biomethane), the leftover, excess biogas could be used for biogas backpacks.

The total potential of these exemplary Cambodian locations is considerable, not only in regard to the potential amounts of biogas, but also in regard to economic and environmental aspects. Many similar locations also exist with additional potential. Thus, it remains interesting to analyse biogas backpacks as a means of transport for biogas for the case that this potential is exploited with the help of investors, incentive programs and similar supporting options, since they could enable the sale of excess biogas and facilitate overcoming reluctancies by stakeholders at the locations. Consequently, strengths, weaknesses, opportunities and threats are identified in the following chapter (see Chapter 5 SWOT for Utilization of Biogas Backpacks in Cambodia).

5. SWOT for Utilization of Biogas Backpacks in Cambodia

This chapter applies the information given in previous chapters of this study to a SWOT analysis for the utilization of biogas backpacks in Cambodia. Where necessary and possible, the analysis is completed with additional information. Keeping particularly the presented factors of feasibility and the introduced business models in mind, strengths, weaknesses, opportunities and threats are thereby examined, highlighting the most important aspects.

5.1 Biogas backpacks in Cambodia: Strengths, weaknesses, opportunities and threats

Strengths

In a SWOT analysis, the category of strengths considers factors that will lead to success by identifying aspects of the product that are better in comparison to other options. What is a unique selling point of the product? For the biogas backpacks, this has to be done through a comparison of other means of transport for biogas and also in the context of its use as described in previous chapters.

A clear strength of biogas backpacks is the simplicity of its introduction and use – the threshold to start using biogas backpacks for the transport of biogas is very low. They are not only inexpensive but the technology is also very simple and it is thus easy to handle. Out of the advantages described in *Chapter 1.5*, the aforementioned appear to be the most relevant for the category of strengths. While other means of transport for biogas necessitate investment in infrastructure or additional equipment as well as possible training for proper utilization, biogas backpacks are ready for usage at once and no complicated introduction to the technology is needed. Moreover, another strong point about biogas backpacks is that first experiences in other countries already exist with the usage of biogas backpacks which makes it more likely for people to use the product instead of having to be early adopters of a completely new and never used product.

In combination, these strengths are an important unique selling point in regard to Cambodia where no gas or electricity grid exists to distribute biogas or the electricity generated on the basis of biogas across the country.

Weaknesses

To analyse the weaknesses of a product, a SWOT analysis looks at factors potentially leading to failure – which aspects are perceived as worthy of improvement, particularly by others? It also considers points that could entail situations that should be avoided. In case of the biogas backpacks, this does not only relate to the mere product as such in comparison with competitive options for transporting biogas (e.g. pipes or gas/electricity grids), but also the surrounding settings in which they are used.

A major weakness that has also been considered in more detail among the disadvantages of biogas backpacks (see *Chapter 1.5*) is the dependency on appropriate biogas production in proximity. Connected to this is the limited range of biogas backpacks in terms of physical restrictions of the users. The combination of these two aspects is a potential deal breaker in regard to the utilization of biogas backpacks. Therefore, these aspects are likely to be perceived as a crucial weakness for the further introduction of biogas backpacks, as competitive transporting options have a further range and thus do not necessitate biogas close-by.

In Cambodia, these weaknesses play a substantial role, as the production of biogas is mainly implemented in domestic small-scale biogas plants. Therefore, in many cases, the lack of appropriate amounts of (excess) biogas from plants in proximity will bring forward the described weaknesses of biogas backpacks as a means of transport. However, other distribution options such as pipes or grids face the same challenges – probably even at a more severe level, since the investment is higher and typically, those distribution systems are meant for larger amounts of biogas than transported via biogas backpacks.

Opportunities

In regard to opportunities, a SWOT analysis takes into account new trends, changes in the legal framework, developments in society or local events. Such aspects might influence the success of a product positively and provide chances for the introduction – in the underlying case – of biogas backpacks. Thus, looking at opportunities for biogas backpacks does not only involve the technology but also beneficial aspects such as Cambodian policies.

Two Cambodian ministries (the Ministry of Environment and the Ministry of Agriculture, Forestry and Fisheries) in cooperation with UNIDO (United Nations Industrial Development Organization) are currently considering the promotion of commercial biogas plants on small farms.[25] As biogas backpacks can be used in this context as pointed out e.g. in *Chapter 3 on Business Models for Biogas Backpacks* this impetus certainly provides a chance for an increased use of biogas backpacks in Cambodia. However, it is necessary to intensify these

[25] Grope report

efforts in order to develop targeted policies that deliver sufficient results and thereby create appropriate incentives for farmers and further stakeholders such as from the food processing industry etc. to invest into biogas plants.

Moreover, another opportunity can be seen in the activity of NGOs in Cambodia. As some business models regarding biogas backpacks suggested the possible involvement of an intermediate, NGOs could take up this role and facilitate the use of biogas backpacks, particularly with small farms that have biogas plants or are in a decision-making process about investing into one. In order to seize this opportunity, a goal-oriented collaboration between all stakeholders is crucial, particularly in regard to policy makers and NGOs as forerunners of the process of introducing biogas plants and the corresponding use of biogas backpacks on a non-domestic small-scale level.

Threats

Within the framework of a SWOT analysis, the threats category looks at risks and competition as well as potential changes in law, policies or the market situation in general that can cause immediate failure. Hence, this section analyses aspects that would not only impede but that could stop the use of biogas backpacks or rather its introduction.

One major threat to the increased use of biogas backpacks is the reluctance of farmers and other entrepreneurs to invest into biogas plants and/or biogas backpacks, as found in the field mission carried out within the framework of this project (see *Chapter 4 The Cambodian Context*). This conservative perspective could also cover the potential cooperation with an NGO which contributes to the degree of severity of this threat. In this regard, it is substantial to provide for sufficient incentives to counter this reluctance. This could be done by well-defined policies giving economic stimulus and thus helping to enable interest in the investment into biogas plants and in connection biogas backpacks.

Moreover, the biogas production and use in Cambodia has mainly been realised by means of small-scale domestic plants.[26] In this light, the market is said to be quite well covered at the moment in regard to domestic biogas plants.[27] While the opportunities mentioned above could provide a chance nevertheless, the inexistence of considerable market potential in this segment is a considerable threat. Therefore, it is fundamental to clearly define the target group and corresponding target market or target market segment to create suitable policies and incentives.

5.2 Key findings of the SWOT analysis

The utilization of biogas backpacks has various strengths and several opportunities exist that could provide impetus to their usage. Nevertheless, the existing weaknesses as well as the

[26] Grope et al. 2018.
[27] Polarstern 2018.

threats reveal that an increased use of biogas backpacks requires considerable planning and structured action. Concluding from the previous chapter, the key findings of the SWOT analysis of biogas backpacks hence are:

- The described strengths make it easy to implement a general increased use of biogas backpacks. Many of the characteristics associated with biogas backpacks facilitate an introduction of business models involving biogas backpacks as a means of distribution of biogas.
- Several opportunities could also give additional impetus and provide the right setting for the usage of biogas backpacks in combination with biogas plants on small farms (see e.g. *Business Model 2* on p. 15).
- In contrast, the weaknesses and threats create a considerable need for a well-planned implementation concept defining for example a clear target group for the usage of biogas backpacks and identifying related contexts of application. It is also necessary to incentivize the implementation of biogas plants to facilitate their spread and hence the usage of biogas backpacks. A suitable possibility is adopting supportive policies to promote biogas plants of sizes larger than domestic small-scale plants, such as farm-based biogas plants. Additionally, possible facilitators such as NGOs can help remedying the weaknesses and threats as well.

6. Concluding Recommendations

In order to implement an increased use of biogas backpacks, a very simple and easy-to-use technology, it is necessary to be aware of its advantages and disadvantages.

To benefit from the given strengths and opportunities, controlling the weaknesses and threats is substantial. The market and involved stakeholders, however, are unlikely to do that independently or, to put it differently, the challenge is considerable to do so, as this study has shown. Thus, an external influence is needed. So far, the promotion of biogas in Cambodia has concentrated on domestic small-scale biogas plants. Considering that the market for domestic solutions is well covered, it appears logical to advocate business models revolving around the usage of biogas backpacks in combination with biogas retrieved from small farms as central locations – and thereby go beyond domestic solutions. The corresponding biogas plants should, however, be technically advanced in order to provide sufficient amounts of biogas not only for the purposes of the farm but also for the users of the biogas backpacks. This could be implemented through incentives by the government and with the help of NGOs as facilitators for logistics. Additionally, a bartering system with the users of biogas backpacks in the surrounding area such as individual households and neighbouring farmers seems helpful to ensure not only the availability of sufficient feedstock for biogas production but also to lower the costs and thus make it more feasible for the involved stakeholders. In this regard, a combination of two of the presented business models could provide the desired solution:

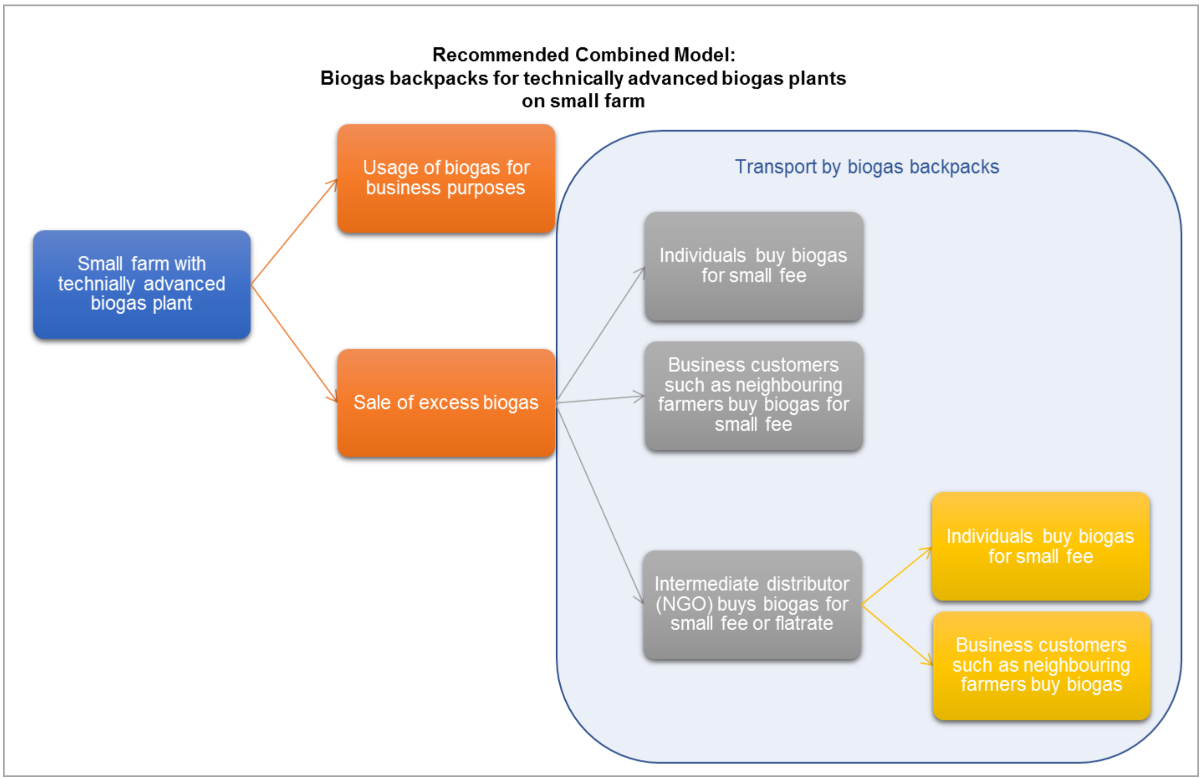

Figure 4: Structure of Recommended Combined Business Model

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