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Final Report:

Dried coffee husk for cooking in gasifier stoves, Ethiopia

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Contents

1. Summary

Wood and charcoal are the main cooking fuels in Ethiopia, used by most of the rural population. Women and girls especially are burdened with the collection of wood. Cooking often happens on three-stone fires which generate indoor air pollution and cause adverse health effects. In addition, high CO_2 emissions, deforestation and land degradation result. In Kafa zone in southwest Ethiopia remains a piece of intact mountain rainforest, where the original Arabica coffee is grown. For processing the coffee, sun-drying method is often applied. After peeling the coffee cherries at dehulling stations, dried coffee husk remains as waste. For decreasing the amount of waste, husk is often fired on piles with incomplete combustion and high emissions.

The main objective of the present pilot project was to use sun-dried loose coffee husk as a fuel in energy-efficient low-tech gasifier cookstoves instead of traditional 3-stone fires. The resulting biochar from the gasifying process shall additionally be used in charcoal stoves as replacement of wood charcoal or as soil amendment together with compost or dung for soil improvement, thus dual CO_2 emission reduction. The pilot project was carried out in Kafa zone, Ethiopia.

Within this pilot project, a gasifier stove has been developed for the use of loose sun-dried coffee husk as fuel and for baking injera, the staple food of Ethiopians. Injera is a sort of a sourdough pancake, which is baked on a plate of about 60 cm diameter. Together with the input of local experts and users, the stove has been adapted to the local conditions and requirements (e.g. specific local needs/habits for baking injera, handling, safety) and for being manufactured and assembled locally.

The injera gasifier stove for loose coffee husk is technically feasible and first stoves have been produced, assembled, tested and introduced in Ethiopia. However, loose coffee husk turned out to be very variable depending on the climate and the time of the year. So, a fan for forced draft is necessary. Furthermore, technology adaptation remained challenging und could not completely fulfil all the expected requirements of the stove in an acceptable time frame. User acceptance is challenging, e.g. due to complicated handling or shorter burning duration. Additionally, a viable business model for injera gasifier stoves could not be assured, due to different reasons such as difficulties for local manufacturing, the need for sieving coffee husk for proper functionality of the stove or the amount of coffee husk.

Nevertheless, for institutional injera bakers in urban areas, the main target group, injera gasifier stoves using loose coffee husk are economically viable, compared to the 3-stone fire and compared to an improved cookstove (MIRT stove) using coffee husk for co-firing. Economic viability is given if the resulting biochar from the gasification process is reused as briquettes in charcoal stoves or improved cookstoves. Biggest hurdles are the high investment costs for the gasifier stove.

For these reasons, a business model overview with a more holistic approach including different cookstoves for different target groups and different ways of using coffee husk has been elaborated. Injera gasifier stove is one viable option for institutional injera bakers, and business opportunities with coffee husk and carbonized coffee husk briquettes are included. Biochar out of the gasifier stove has good quality and can be brought into the cycle of briquetting carbonized coffee husk.

For achieving the goal of using the coffee husk waste as fuel, direct carbonization of coffee husk can be a solution, if technology is efficient and emissions low and even better if energy from the gasification/carbonization process can be used. Pelleting the coffee husk for co-firing in MIRT stoves with higher efficiency through higher caloric value is another solution. Gasifier stoves using coffee husk pellets can be added in a second step, having better economic viability and easier handling, thus better user acceptance.

Additionally, deeper knowledge about the local user acceptance of the developed injera gasifier stove model need to be gained in a user field test of larger scale. Only this gives better understanding if slight adaptations can lead to better user acceptance, thus, to better marketing possibilities.

Last but not least, the know-how, findings and experiences gained in this pilot project with technology development and adaptation of injera gasifier stoves shall be shared with local actors and stakeholders who deal with gasifiers.

2. Starting Point

Forests
End of 1960, 40% of Ethiopia were still covered by forest. Meanwhile, the percentage has shrunk to 2.7%. In the province of Kafa in southwest Ethiopia, the original home of Arabica coffee, remain nowadays only 200,000 hectares of intact mountain rainforest, since 2010 a UNESCO biosphere reserve.

In many places of the country, this advanced deforestation results that wood can be collected only after travelling large distances or is bought at high and constantly rising prices. Women and girls especially are burdened with collection of wood.

Stoves and cooking energy
A big number of people in Ethiopia, especially the rural population and the peri-urban to partly urban population, use wood or charcoal for cooking. Traditionally they usually cook on an open fire with three stones. But the incomplete combustion of biomass inside the home generates indoor air pollution which causes adverse health effects, mostly women and girls are intensively exposed. In addition, wood consumption is very high, which increases the pressure on the remaining forests – along with the increasing demand for farmland and pastures.

The staple food of Ethiopians – the injera, a sort of sourdough pancake – is traditionally baked on a wood fire. An extra clay-plate is used, called “Mitad”, which is placed on the fire. Injera is baked in households, but also for sale in hotels and restaurants. Other dishes such as sauces (“wots”), meat and vegetables are also cooked on an open fire. Cooking energy is an important daily need of the local population.


Wood bundle in front of Kafa house


3-stone fireplace inside Kafa house


Injera-baking on 3-stone fire

Coffee production and coffee waste
Ethiopia is Africa's largest producer and exporter of coffee. In about 40% of the whole coffee production the traditional sun-drying method is used, especially in small-scale production. This in contrast to industrial wet processing (washed-processing). With the sun-dried method, picked coffee cherries are dried in the sun and then peeled. After processing/peeling at dehulling stations, dried coffee husk remains, mostly around the processing stations on large piles. Coffee husk consists of coffee pulp and coffee parchment, in a ratio of 1 to 2.5 (coffee cherry = 55% coffee bean, 28% pulp, 12% parchment, 5% pectin, Braham and Bressani, 1972). In many places, these coffee husk piles are set to fire, although the coffee pulp is hardly combustible. Continuous fire with incomplete combustion during several months with high emissions results. This kind of waste treatment is chosen to decrease the quantity of waste.

A REPIC-supported project about development of a technology for combustion of coffee pulp from the Swiss Center of Appropriate Technology and Social Ecology CATSE (Ökozentrum Langenbruck) had shown in 2010, that combustion of dried coffee pulp cannot be completed successfully in practice, excessive smoke development and early extinction of the fuel result (Sattler et al, 2010). However, combustion is only feasible under special laboratory conditions. Depending on the amount of coffee pulp in the husk, this leads to the mentioned uncomplete combustion of coffee husk when the waste piles are set to fire.

From the mountain rainforest of Kafa region originates the fair-trade and organic certified Kafa wild coffee, sold in Switzerland and Germany. In the Kafa Forest Coffee Farmers' Cooperative Union, 26 cooperatives are affiliated with approximately 6,000 small farmers. They process and market mainly sun dried coffee from Kafa Forest. By collecting and selling wild coffee, coffee farmers of Kafa achieve a long-term income from the rainforest. But so far, the residues from the sun-dried coffee production has not been used but is burned in piles in order to get rid of coffee husk waste. Massive air pollution results.

Women with backload bundles of wood

Burning coffee husk pile in Kafa

Dried coffee husk

Gasifier stove, fuel and biochar

Gasifier stoves are an existing, known technology in several places of the world. They can be used in developing countries as low-tech gasifiers. Additionally, biochar is produced as a product of pyrolysis and can be used as soil amendment together with compost or dung or as charcoal for additional cooking purpose reducing the use of charcoal out of wood.

The topic of successful gasification of dried coffee pulp had already been discussed in a REPIC-supported workshop about "*Energetic Use of Residues from Coffee Production*" in 2011, following the results of the REPIC-supported project from CATSE. Furthermore, the Swiss gasifier stove "Pyro-Cook" has been developed by Kaskad-E, which had also tested the use of dried coffee pulp in gasification as discussed in the mentioned workshop. REPIC had supported additionally a project with low-tech gasifiers in Haiti, the P.R.E.B. gasifier, using different fuels and with completely different framework conditions, especially other local cooking habits.

Improved cookstoves and gasifier in Ethiopia

There are several programs for the introduction of improved cookstoves (ICS) in Ethiopia, among others with GIZ as implementer of the Energising Development program (EnDev). Most of the ICS widely spread have been MIRT stoves for baking injera and to a lesser extent Tekikil stoves for normal household cooking (e.g. wats, coffee, water), both of them using mostly wood as fuel. The MIRT-stove is made out of mortar (sand/cement mixture) and comprises six parts. Four of these make a cylindrically shaped enclosure, where the firewood is burned under the injera baking plate. The remaining two parts sit behind the cylindrical enclosure and facilitate smoke removal and cooking on a pot. Tekikil stove is a portable stove with an inner clay liner as combustion chamber covered with galvanized sheet metal on the outside.

Gasifier stoves have only been used in few pilot projects and have not been implemented wider in Ethiopia. Some research has been done and is ongoing in universities about different gasifier stoves. Gasifier for injera baking and for the use of loose coffee husk have not been developed so far. There is no known and tested gasifier stove for coffee husk in Ethiopia.

3. Objectives

The original objectives, overall goal and intended impacts of the project are:

Objectives

- **Use of energy efficient gasifier stoves**
  Low-tech gasifier cookstoves shall be used instead of the traditional 3-stone cooking method on open fire, since gasifier cookstoves are more energy efficient and lower in emissions. The so far unused **coffee husk** from the production of sun-dried coffee shall be **used as fuel** in these cookstoves and replace the wood, thus saving CO_2.

- **Use of resulting biochar**
  The **resulting biochar** from the pyrolysis process shall be promoted for use **as soil amendment** together with compost or dung (for water and nutritient retention, recycling of potassium, increase of pH-value). Applied as a soil amendment with compost/animal manure it increases the soil fertility and thus closes the nutrient cycle.
  Additionally, the biochar can be promoted **as a direct replacement of the charcoal** used additionally in charcoal stoves and in the traditional coffee ceremony.

- **Economic and social benefits**
  The economic and health situation of the population shall have improved through the use of gasifier cookstoves and through the business opportunities with production and sale of injera.

- **Reduction of waste**
  The piles of waste of sundried coffee husk shall be eliminated by the use as fuel in the gasifier stoves. Thus, the high emissions from burning coffee husk piles will be eliminated too.

- **Development, adaptation and implementation in pilot project**
  Based on the Swiss gasifier "PyroCook" and the REPIC-supported low-tech-gasifier P.R.E.B. in Haiti, a suitable low-tech gasifier using coffee husk as fuel and adjusted to the local conditions in Kafa, shall be **developed, adapted and implemented in a pilot project** in Kafa area, Ethiopia, with a market approach.

Overall long term goal of the project

By use of energy efficient low-tech gasifier cookstoves and existing coffee waste (sundried coffee husk) as fuel, life conditions and health situation of the local population are improved and further deforestation and CO_2 emissions reduced.

Intended long term impacts

- Creation of local jobs
- Formation and education of local craftsmen
- Encouraging small entrepreneurs, also female entrepreneurs
- Creation of income opportunities for women, e.g. with production and sale of Injera
- Reduction of indoor air pollution
- Improvement of health situation, especially for women and children (more vulnerable population)
- Strengthening women
- Reduction of deforestation
- Protection of the climate
- Improvement of soil fertility

These objectives shall be achieved with the **following approach:**

→ Loose sun-dried coffee husk will be used as a fuel in the low-tech gasifier cookstoves, the mix of pulp and parchment as remained after the dehulling process.

- → In a first step, a gasifier cookstove shall be developed for the production of injera, the national dish, staple food of Ethiopians.
- → In a second step, a low-tech gasifier stove for domestic use for the preparation of wats and additional dishes shall be developed and adapted.
- → The gasifier stoves shall be produced in Ethiopia through local manufacturers and marketed through local entrepreneurs what shall generate additional income and create business and job opportunities
- → For manufacturing and use of the gasifiers trainings and workshops will be organised.
- → Marketing activities shall be organised, and multipliers demonstrate and spread the gasifier stoves. Restaurants and small injera producing businesses in particular will serve as multipliers. These will also serve as demonstration and model projects for the use of injera-cookstoves and the household cookstoves for domestic purposes. The dissemination is based on the slogan "Train the trainer" and the users of the cookstoves who have been trained at the respective user group trainings will mobilize for the acceptance of the first pilot cookstove series. Campaigns are used to further spread and mobilize for the project.
- → Target group: Primarily urban and semiurban population in Kafa zone. For injera gasifier stove target groups are institutional users and injera bakers for business (better affordability and better acceptance of the new technology expected).
- → Resulting biochar shall be used additionally – as soil amendment with compost or dung or charcoal-replacement in charcoal-stoves. Through the double benefit, interest of users and economic viability is expected to be higher.
- → Efficiency: Compared to the traditional 3-stone fire, a gasifier stove saves in general around 55-75% of primary energy (wood). Even compared to already improved cookstoves as MIRT-stoves, a gasifier is expected to save additionally until 15% of primary energy. If the produced biochar is used again for cooking, another around 30% of primary energy can be saved.

4. Project Review

4.1 Project Implementation

Following the description how the project was carried out.

4.1.1 Project Approach

Originally from piloting to implementation in two phases

The project originally consisted of two phases, from piloting of the technology in the first phase to start implementation in the second phase.

In the **first phase**, development of the injera gasifier stove with the necessary adaptations of the technology to the fuel (loose sun-dried coffee husk) in combination to the local cooking habits (local habits of injera baking and others) and to local manufacturing possibilities had to be carried out. While adapting the stove, simplifications and optimizations were integrated. In the piloting stage, testing and adapting and local manufacturing were the mainly important approaches. After all, development and verification of the business model was the next important step which had to be done. Additionally, possibilities of general finance mechanism for stove producers or byers were checked.

- → Technology adaptation remained challenging und could not meet all the expected requirements in an acceptable time frame. Thus, and additionally, economic viability of the stove with a working business approach and affordability of the injera gasifier stove remained too challenging and not feasible at the present time. Therefore, project had to be **stopped after the first phase**.
- → Nevertheless, looking at the intended objectives in a more holistic way, including different possibilities for using coffee husk and different stove types depending on the target groups, injera gasifier stove can be one additional solution for a specific target group, for institutional injera bakers, as part of the holistic concept. Within this, the intended overall objectives can be achieved (see chapter 4.2 for more details).

In the **originally foreseen second phase**, the start of implementation, focus was foreseen on pilot series production of the first 100 injera gasifier stoves with manufacturing and installation trainings and user trainings with the specific manuals, marketing and communication. Adaptation of a household gasifier stove was foreseen also in phase 2. And especially the whole preparation of further implementation and multiplication, additionally first trainings for the use of biochar as fuel and as soil amendment and a built logistics hub of the fuel with a viable business model.

Requirements for adaptation of the stove technology
The following requirements were identified during the project time, which have to be fulfilled by the injera gasifier stove:

Technically
- Efficiency of the combustion process
- Good quality of emissions → For reduction of indoor air pollution
- Stability of the combustion process with the fuel coffee husk → All type of dried coffee husk as fuel must always be stable ignitable and work the same way. For different altitude and climate.
- Simple and stable starting process of the pyrolysis/gasification → All type of coffee husk as fuel must always be stable ignitable.
- Simple and quick stopping procedure after combustion and for removing the biochar

User requirements for baking injera
- Heat distribution evenly → for approx. 60 cm diameter plate
- Enough heat – enough power (min. 4 kW on the plate)
- Burning time → As the gasifier is working batch-loaded, one batch has to be enough for baking minimum 30-40 injera, thus 90 min.
- Injera from gasifier stoves need to have the same consistency and aroma as “normal” injera
- Nice to have: Additional use for other baking as for “Kotcho” (bread made out of Enset (called “false banana”) → for smaller diameter of clay plate, around 50 cm
- Nice to have: Additional use for cooking side-dishes (wats, water-boiling etc.)

User friendliness
- Safety: Protection from burning (for baker and surroundings, especially for kids)
- Weight (of the parts which have to be carried or moved)
- Simple operation:
    - Simple handling for filling in the coffee husk
    - Simple operation for lightening
    - Simple operation with injera plate → for putting injera plate
    - Simple operation for putting the burner unit
    - Simple handling for removing the biochar
- Comfortable height for cooking/baking
- Regulation of primary and secondary air must be as simple as possible to operate.

→ The operation of the stove must be easy and not more complicated than what local people/the target group are used to.
→ The stove must be safer than a three-stone fire, as better safety in MIRT-stoves had been reported as one of the well appreciated improvements.

Production and installation
- Manufacturing feasible with locally available tools in metal workshops in Ethiopia, minimum in Addis Abeba, best option in Bonga, Kafa
- Minimum assembling of stoves feasible in Bonga, Kafa
- Manufacturing feasible with locally available material
- Installation easy for trained manufacturers or craftsmen/-women
- Locally available metal and quality as good as possible → affects price and life expectancy

→ The production of the stove and the installation through trained local manufacturers and installing people need to be easy and tolerant for slight errors.
→ The manufacturing or assembling needs to be feasible with the limited available metal working tools.
→ The quality and the prices of the used materials need to be taken into account. Quality as good as possible and as little material used as possible. Locally available material is often of minor quality and expensive.

The best balance is necessary between all these requirements, the needs of the targeted customers, the needs of the producers, and the frame conditions of the production chain.

4.1.2 Partners

Following the involved partners:

- The Consortium Kafa gasifier stove, responsible for the project, consists of the companies **bonnepomme Ltd** and **Kaskad-E Ltd**.:
  - **bonnepomme Ltd**: A Swiss consultancy with expertise in the field of renewable energy, energy efficiency and development cooperation; Main project coordination, including with local partners on the ground.
  - **Kaskad-E Ltd**: A Swiss company with expertise in energy and gasification; Technical project leader.
- **Original Food Ltd Switzerland** and **Original Food Germany**: A Swiss and a German company marketing certified organic and fair produced certified wild coffee from Kafa. Collaboration formerly in a Public Private Partnership (PPP) with GIZ and *GEO Rainforest Conservation* with the coffee cooperatives and ***Kafa Forest Coffee Farmers Cooperative Union*** (KFCFCU). Nowadays strategic Alliance with GIZ in the Kafa area.
- **KFCFCU (Kafa Forest Coffee Farmers Cooperative Union)** in Bonga, Ethiopia: Union of 26 coffee cooperatives in Kafa. Formerly, coffee was dehulled in a private dehulling station, where the coffee husk remained in burning piles. Nowadays KFCFCU owns a newly built dehulling station, where coffee husk should be collected instead of being burned.
- **NABU (Nature and Biodiversity Conservation Union)**: A German NGO working in the Ethiopian Kafa area with a local project office in Bonga, Kafa and responsible for the UNESCO-Biosphere Reserve in Kafa. In a former NABU-project about 11'000 MIRT stoves have been disseminated in the Kafa area (Kafa zone/NABU, 2013), mostly in rural households and mostly for free, partly with a contribution for the transportation costs through the users. Nevertheless, these stoves didn't show all the intended improvements, for technical reasons, incomplete installations and minor quality and carelessness due to the mostly free distribution. Thus, further improvements were foreseen. NABU has a current project within the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) for protection of Kafa forest with an included energy component for alternative sources of household energy in Kafa. Their respective Ethiopian energy consultants (a team of GM Clean Energy and Fuel-Efficient Technology Developer and Disseminator Plc. and RK Renew Energy Plc. with a local energy advisor from Kafa) strongly collaborated with the Consortium Kafa gasifier stove team for elaboration and adaptation of the best cooking and coffee husk solutions for the Kafa area.
- Local collaborators: in specific Mussie Tesfay, local gasifier expert who had developed formerly a household and institutional gasifier, mostly working with wood and some other biomass residuals such as coffee parchment and sawdust briquettes, even though no coffee husk.
- **GEO Rainforest Conservation**: A German NGO collaborating with KFCFCU and Original Food and GIZ in the protection of wild coffee forests in Kafa. Had foreseen to support the gasifier stove project in Kafa in the originally intended second phase.

4.1.3 Main Project steps

Following the main project steps with the most important findings are described:

Development first prototype

A first gasifier cookstove prototype for coffee husk and injera was predeveloped in Switzerland after additional tests of coffee husk carbonization. It was adapted from the "PyroCook" gasifier for working with loose coffee husk and further refined for baking injera. For injera baking, which is done on a clay-plate of about 60cm diameter, heat distribution needs to be completely different than in a normal household gasifier stove for cooking.
The prototype was constructed, successfully tested and transported to Ethiopia.

Tests in Switzerland with prototype 1

Successfully carbonized coffee husk

Burning prototype 1 in Bonga, Kafa

Compared to other low-cost gasifiers in the world, the injera gasifier prototype 1 has the following additional features due to its unique combination of specification (baking injera with sundried loose coffee husk):

- Bigger fuel chamber (→ loose husk has a low bulk density and therefore a low energy density)
- Continuously variable inlet for the primary air (→ loose coffee husk has a variable bulk density and therefore a variable air flow resistance)
- Burner unit with a chimney (→ on average, loose coffee husk has a high air flow resistance so that natural draft is not sufficient → process more stable and with less emissions with chimney)
- Burner unit with several metal baffles (→ for an evenly heat distribution)

This prototype 1 is completely made out of metal parts.

Interviews with target groups

Interviews were hold with the possible target group in Bonga town and surroundings, injera-producing women and small restaurants and few semi-urban families. The use of stoves, fuel, prices and fuel consumption and the local requirements were checked and crosschecked. The interviews were also held for possible evaluation which test-users could be interested. An indirect willingness-to-pay could be determined and estimated through the information about current fuel prices. It was not possible to identify a direct willingness-to-pay for an improved cookstove or injera gasifier stove.

→ Injera baking women including small restaurants bake between fifty to several hundred injera/day for sale, depending on their market possibilities. Thus, variety between willingness-to-pay depends a lot on the size and the already used stoves.
→ Electrical stoves for injera baking sometimes exist in households in Bonga and at restaurants/injera-sellers. Nevertheless, even though an electrical stove is available, injera baking for commercial purpose is mostly still done on 3-stones fires. Power supply during the day is considered to be not enough for baking and the heating power of the stove is insufficient. Electrical stoves come only in use in addition during rainy season when the wood price is higher.
→ MIRT stoves in rural and urban area are sometimes not in use anymore or used beside another stove, such as the 3-stone fire. They are sometimes broken or improperly installed and people claim that there is no repairing possibility. (Additional detailed results also available in GM Clean Energy and RK Renew Energy, 2016, and Dresen et al, 2014)
→ Households in urban area use beside wood often charcoal for cooking wats, coffee etc.

Field tests of the first prototype of injera gasifier cookstove
Tests in places with different altitude and climate were carried out: In the capital Addis Abeba (around 2400 m a.s.l)., in Kafa (Bonga town at around 1800 m a.s.l.) and a third place with lower altitude (Gamo Gofa zone at around 1400 m a.s.l.).

→ In Kafa and at a lower altitude tests were carried out successfully, coffee husk was burned and perfect biochar resulted. Challenges remained: Most of the time coffee husk was all burned, but few times the coffee husk was burned only partly and the pyrolysis process stopped before the end. Additionally, burning time, heat distribution and handling of the stove needed to be adapted according to the feedback of local users.
→ In Addis Abeba, tests with the gasifier did not work, thus coffee husk did not burn in the stove, even with a chimney of more than 1 m. The altitude affected functionality of the gasifier (the higher above sea level the less the natural draft), what was confirmed through a local gasifier expert, who carried out tests in Addis Abeba and had made similar experiences with other gasifiers.


Test in Kafa: Burning prototype 1


Successfully produced biochar


Injera-baking test with prototype 1

First production of the stove in Ethiopia
With this experience, a first stove was produced in Ethiopia, mostly a copy of the first prototype with first adaptations on the design for better burning duration and different heat distribution.

→ Metal work was challenging, but a carefully chosen metal worker finally successfully built the stove, with limited tools. A problem was the quality and the thickness of the locally available metal. Thicker metal is pricier and longer lasting, but would especially have been too thick to be worked with the limited metal working tools. Holes were very difficult to produce in the metal and cut parts remained very sharp.
→ Tests of this new stove showed that heat distribution was better, but still needed to be adapted. Rigidity and pyrolysis process stability of the stove were minor.


Prototype 1 made in Switzerland


Prototype 1, production in Ethiopia


Prototype 1, two versions in comparison

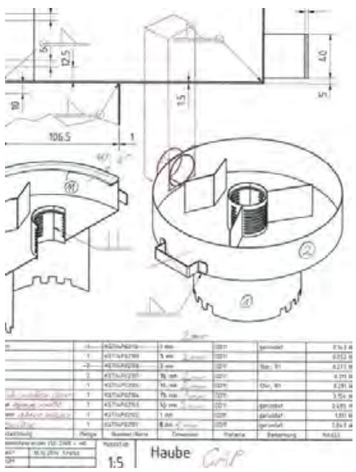
Further adaptations and second production in Ethiopia with new design
Due to the findings after the first round of tests, feedback of users and first production of the stove in Ethiopia, adaptations to the stove design were prepared. A second stove with a new design for different handling for putting the burner unit and removing biochar was afterwards produced in a well-equipped metal workshop in Addis Abeba with experience in more complex metal work. Nevertheless, production was incomplete and didn’t meet all the expected criteria. Adaptations for completing

the stove in the intended way had to be carried out directly through Kaskad-E at the metal workshop in Addis Abeba.

New features of the injera gasifier prototype 1.2:

- New static construction: burner and chimney fix, supported by a metal frame (→ better stability, less burning risk, less weight to move during loading the husk and unloading the biochar)
- Removable fuel container (→ easier handling, possibility to heat continuously with a second swap container)
- Less preheating of the secondary air, means no outer cylinder around the fuel container (→ saving metal and vertical space)
- Better sealing between injera plate and burner unit (→ higher temperature on the plate, more energy saved)

This prototype 1.2 is completely made out of metal parts.



Prototype 1.2: Sketches based on Prototype 1

Prototype 1.2 in Addis: Finishing parts


Prototype 1.2: Test with Injera baking

Tests and on-site adjustments in Kafa of second stove-design

Both stove models, injera gasifier prototype 1 and injera gasifier prototype 1.2, were tested and checked again in the project area in Kafa. Several on-site adjustments have been carried out directly on the ground after tests on one hand with the fuel only and on the other hand with injera baking. For metal work, the local Bonga TVET college (technical vocational education training college, further referred to as "*Bonga technical school")* was involved, as they are equipped with a huge metal workshop and metalworking machines, several of them not working anymore though, and with low power supply. The workshop had formerly been installed by foreign aid together with capacity building of craftsmen in the technical school. Few trained staff was available though, apparently, the knowledge had partly been lost with trained people having left the school. Collaboration with the technical school was suggested through the local collaboration partner NABU.

→ Unhappily most of the tests with both stove models didn't bring the expected results: Gasifying process didn't work properly; combustion was incomplete and no biochar resulted. Surprisingly enough, injera gasifier prototype 1, which had worked properly before, didn't work anymore with coffee husk from the same dehulling station, just some weeks later.

→ User friendliness and heat distribution was better with injera gasifier prototype 1.2, but power not enough (mostly due to the incomplete gasifying process).

→ But handling of injera gasifier prototype 1.2 remained more difficult than expected, as the fuel container was heavy and it was tricky to hang it up from the bottom to the burner unit. Whereas protection from burning from the fuel container was improved.

→ Loose coffee husk turned out to be too variable depending on the climate and the time of the year, even from the same dehulling stations at different times of the year. Coffee husk had sometimes higher moisture content, and was sometimes containing a higher ratio of smaller particles.

→ With co-firing wood chips in a special test design with an inner cylinder with holes, coffee husk was carbonized completely.

→ The technical school turned out to be the best alternative for manufacturing, adapting, assembling the stoves because the investigations had shown that local metal workshops in Bonga were not willing to produce or adapt the stove and denied due to missing tools and missing experience and know-how, especially in bending.

→ The quality of injera gasifier stove adaptation remained difficult even in the technical school with the metal work tools, though better than in normal metal workshops.

→ As local metal workshops were not able to produce the stoves, model with local metal workshops as stove entrepreneurs had to be rethought again. Collaboration with the technical school could be seen as good alternative for building manufacturing and selling possibilities.

Special test with Prototype 1 in Bonga: inner cylinder with holes around is filled with wood chips, the space around is filled up with coffee husk.

Test result: with support of one third of wood chips / wood sticks the coffee husk is carbonized easily and with a hot flame.

Test result: nice biochar out of coffee husk and some wood chips.

Tests with briquettes and pellets

Due to the above findings, additional tests with coffee husk briquettes and with coffee husk pellets took place. The coffee husk briquettes had first been organized from Dilla, a town about 2-3 days away from Bonga. Dilla is the only factory in Ethiopia producing coffee husk briquettes. They are produced out of coffee husk with a mixture of sawdust and under high pressure with a huge briquetting press. Those briquettes originally should have been used in small household gasifiers with electricity production in a project of HOAREC (Horn of Africa Regional Environment Centre). Due to unknown reasons for our project team, this project could not be implemented and those briquettes are apparently fired in a close textile factory.

→ Tests with briquettes from Dilla didn't work: briquettes are too big and too compact for working properly in small cookstoves (inhibited air passage and thermal conduction).

→ Tests with coffee husk pellets out of coffee husk from Kafa (produced for testing purpose in a small quantity in Switzerland) and a very small amount of cooking oil as lubricant, showed very good results: perfect gasifying process and nice biochar pellets resulted.

Additional literature studies, expert interviews and clarifications worldwide about briquettes, pellets and coffee husk took place.

→ Briquettes out of coffee husk are in general not suitable in gasifier stove, for the experienced reason in the tests.

→ Briquette production for briquettes out of coffee husk requires high-pressure equipment and some additional material as binder (often sawdust) (GIZ, 2014). These industrialised briquetting machines need an investment of several thousand USD for the smallest versions. Coffee husk is not suitable for producing briquettes out of hand presses, power is insufficient as also previous tests through NABU have shown.

→ Pellets work very well. In addition, pellets are a compact, in the characteristic stable and reliable fuel. But the production is often more expensive due to high investment and maintenance costs for the imported electrical pelleting machines. In addition, the power demand of one machine normally exceeds the locally available power supply.

→ Very few experiences with dried coffee husk and gasifier worldwide is available.

→ Due to these findings and the high investment costs and the requirement of a reasonable electricity supply for pelleting (and briquetting) presses, decision for working with loose coffee husk was confirmed.

Test with coffee husk briquettes

Process stopped uncontrolled …

… briquettes are too big and too compact (inhibited air passage)

Test with pellets made out of coffee husk

Burning in PyroCook (not enough pellets available for injera gasifier stove)

Nice biochar out of the 1.5 litres of coffee husk pellets

Redesign and adjustments of the stove in Switzerland

Due to these findings, the tests and adjustments on the ground and on the basis of the interviews, a redesign of the stove had to be done with several adjustments and tests in Switzerland and Germany with an expert support from Christa Roth from GIZ (author of "Micro-gasification: cooking with gas from dry biomass", 2014) and Fosera Solarsystems Ltd (developer of a ventilator prototype).

This redesigned injera gasifier prototype 2 was produced in Germany (by Gregor Kraft) and tested in Switzerland with a very new design as follows:

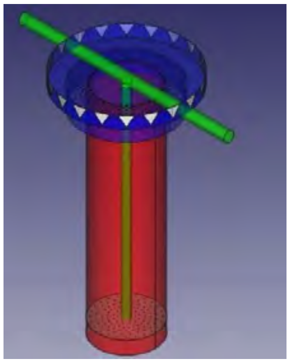
- Continuously variable ventilator to blow in the primary air (→ always controllable flow rate of primary air through any kind of coffee husk)
- Top blow ventilation down to the rust (→ preheated primary air enhances the pyrolysis process)
- No chimney, ventilator instead (→ less material, more evenly heat distribution, closer to the habitus of 3-stone-fire)

This prototype 2 is completely made out of metal parts, again.

→ Unhappily the tests didn't bring the expected results: In fact, gasifying process did work properly but the combustion was incomplete (disturbed/cooled by the upper primary air tube) so that the emissions were unsatisfying.

→ Heat distribution was not bad (mainly the power was enough), however, around the upper two primary air tubes it was less hot.

→ Handling remained more difficult than expected, as the fuel container was heavy and it was tricky to turn it over to unload the biochar.



3d-sketch: Injera gasifier prototype 2

Test with prototype 2 with top blow ventilation

Upper part of injera gasifier prototype 2

Additional redesign and final stove design

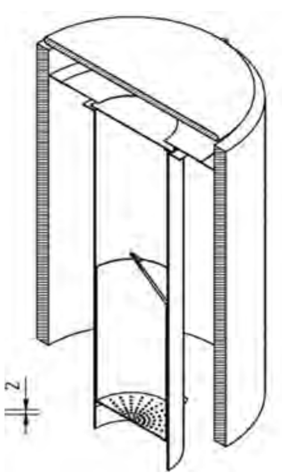
After all these experiences, another redesign was required and injera gasifier prototype 3 was developed.

Its new features are the followings:

- New static construction: outer cylinder in cement and locally available materials like sand/soil, not movable (→ better stability, less burning risk, more local material used instead of expensive metal sheets). The diameter of this cylinder is identical to that of the existing MIRT stove. So, 4 MIRT stoves can be used to achieve the required total height of 880mm
- No chimney, ventilator instead, bottom blow (→ less material, more evenly heat distribution, closer to the habitus of 3-stone-fire)
- Biochar gate at the bottom to remove the biochar (→ easier handling, no turning of a heavy and hot fuel container required, but: difficult to construct it air tight)
- Fuel container with more height of 950mm in total (→ longer burning time, 90 minutes). To assure a comfortable baking height the fuel container is installed 300mm into the ground (→ additional advantage of insulation and therefore less burning risk)

This injera gasifier prototype 3 is partly made out of metal parts (fuel container, burner unit), partly constructed with 4 MIRT stoves one upon the other (outer cylinder). A full clay solution would be very difficult due to the need for certain accuracy in production of a gasifier stove.

One stove of injera gasifier prototype 3 was produced and tested in Switzerland (outer cylinder made out of a concrete tube instead of MIRT stove elements). Thereupon, parts for additional stoves were pre-cut in Switzerland (only metal parts) for finishing production and assembling in Ethiopia.



3d-sketch of injera gasifier prototype 3

Test with bottom blow ventilation (pre-design of prototype 3).

Test prototype 3: with outer cylinder made out of a concrete tube. The fan connector tube is the handle of the bio-char gate as well.

Further intensive round of stove tests and adjustments on site in Kafa
With the new stove design, injera gasifier prototype 3, intensive tests and adaptations have been carried out on site together with feedback from the local population. Luckily the German stove expert Christoph Ruopp, who is consultant for GIZ EnDev program (ENergizing DEVelopment) in Ethiopia for the development of improved cookstoves, accompanied the first round of intensive tests and adaptations with expert know-how. Part of the energy consultant team of NABU for the “alternative sources for household energies in Kafa” project component accompanied the activities.

For the outer cylinder, MIRT stoves had been organized from one of the few remaining and working MIRT producers who had been trained during the former NABU-project. 4 of these MIRT stoves, consisting each of 4 components for the injera-part only, had to be added one on top of another and the existing openings were closed with a mixture of clay-soil, teff-straw and sand. Normally, a MIRT stove consists of 6 components, 4 components for the injera baking part and 2 components for the chimney outlet/pot holder. The inner cylinder (the fuel container) was a rectangular shaped sub-model.

Results of the tests:
- → Sieving of the coffee husk is necessary for getting reliable and low-emission gasifying process: the smallest particles which can make the process to be stocked (uneven air flow through the husk), are removed.
- → For the outer cylinder, installers need proper training to install the MIRT stoves and close the gaps.
- → Simple moulds are necessary for the openings of the MIRT stove, so that the openings for putting the ventilator and removing the biochar are adequate in size.
- → Heat loss through the bigger surface of the fuel container and the longer heating up time at the ratio of injera baking time due to the low energy density of coffee husk was much higher than expected.


Burning injera gasifier stove prototype 3 with fan, test in Kafa


Test with injera baking – for test reasons outside


Perfectly resulted biochar out of the coffee husk

Sieving of the loose coffee husk with a mesh size of 6mm

Coffee husk loaded in injera gasifier prototype 3 (rectangular shape submodel), with the MIRT outer cylinder

Lightening the loose coffee husk in the stove

Production and adaptation of further stoves

With the preproduced parts, further stoves of injera gasifier prototype 3 were produced and assembled in Bonga in the Bonga technical school. Two submodels were produced:

- Round shaped fuel container with gate
- Rectangular fuel container with gate (submodel which had been tested)

These different submodels were produced and tested to check whether the round shaping or the rectangular bending can easier be processed in the workshop of the technical school, and to check which submodel is better functioning.

Several challenges and difficulties remained in production:

→ In fact, round shaping the fuel container is easier than rectangular bending, but to fabricate the associated round shaped (and air tight) gate is much more difficult than a plain gate fitting the rectangular fuel container.

→ The required precision in production for a reliable operation of the stove (concerning the burner unit especially) is feasible but a challenge.

→ The thickness of the rust and the gate metal sheet should be 4mm to achieve a good thermal resistant stability. The processing (bending, cutting, drilling) and even the availability of such thick metal sheets is quite difficult (higher costs).

Assembling at technical school in Bonga

New built burner unit in workshop in Addis

Other adapted part for fixing injera plate and burner unit with fixed gap

New built submodel 3 in workshop in Addis Abeba: round shaped fuel container with ventilator holder on the bottom.

An additional third submodel (round shaped fuel container with a removable biochar container without gate) was produced afterwards, including some adjustments for the burner unit part of the stove. Production happened in Addis Abeba in a metal workshop, which is used to work with cookstoves and international partners. This stove model was produced only from detailed drawings and additional detailed explanations. Usually, in metal workshops – especially in the rural areas – the normal way of production is by copying existing stoves.

- → The third submodel was successfully constructed with fair quality. Round shaping, round cutting, production of the rust with symmetrical holes was much better feasible.
- → Summarized there are 3 submodels with 2 options for removing the biochar:
  - → Biochar gate at the bottom (→ easier handling, no turning of a heavy and hot fuel container required, but: difficult to construct it air tight)
    - Submodel 1: Rectangular shaped fuel container
    - Submodel 2: Round shaped fuel container
  - → Removable biochar container (→ fuel container with perfect air tightness, easier and therefore cheaper construction, but: handling more difficult). → Submodel 3: Round shaped fuel container

Installation and preparation of manuals
Further checks of performance and installation of the third submodel of injera gasifier prototype 3 and other submodels took place in the field, through partners from NABU energy consultant team and through independent user. A standardized Clean Cooking Test (CCT) has not been carried out so far in the field. According to the experts of the NABU team, CCT is expected to take place after a longer user field test with the newest stove prototype. For introducing new stoves in Ethiopia – when development is finished – standardised CCT's have to be carried out and results have to be accepted officially by the responsible government office.

Draft manuals for installation and use have been produced for these installations and user checks. They can be adapted, translated and added with proper pictures/pictograms for trainings of installers and users, in line with the manuals for MIRT and Tekikil stoves from NABU project.

- → Installation of the burner unit and the metal inner cylinder inside the MIRT ring needs to be accurate, even with a tolerance of some mm, to perform properly. This is too accurate for many local people installing the stove.
- → Installation with dwelling or fixing of top ring can be complicated.
- → Burner unit from installer and user were installed the wrong way → performance of the stove was not adequate. Due to common understanding and not proper understanding of gasifying process, people tend to install as they know normal fires. Therefore, trainings and manuals need to take this into account and explain process and installation properly.
- → Handling with injera plate better.
- → Putting burner unit after lightening showed few inconvenience for users as fire is on.


Ethiopian expert observing the fire of injera gasifier prototype 3


Putting the removable biochar container into the inner cylinder


Test with baking injera – on injera gasifier prototype 3 installed through users

Supply preparations of dried coffee husk
For all the tests coffee husk had to be provided and preparations had to be done for husk provision, storage and for establishing logistics for the larger user field test and especially for the implementation of the stoves. Coffee husk in Kafa area is usually burned on piles directly after the dehulling process. These piles are continuously smoking and burning during several months and the coffee husk

is turned quickly into ash, thus the space used for the coffee husk “waste” remains smaller for the dehulling stations. This ashy coffee husk cannot be used as fuel anymore. Therefore, husk cannot simply be collected from the piles as soon as the piles are lit once for the dehulling season.

→ For the use of coffee husk as fuel for implementation of the gasifier stove it turned out to be necessary to stop the process of burning and provide storage possibilities for storing the husk at a dry place and making it easily available.

<u>Coffee husk for testing purpose</u>
For the first on-site field tests of the gasifier stove in Ethiopia and Kafa, the coffee husk had to be made available for the testing. It turned out to be difficult to collect the husk in front of the pile directly after being expelled out of the tube after dehulling because of too much power. Especially at the private dehulling station where the KFCFCU was dehulling coffee. Nevertheless, for the first tests, coffee husk could be collected from some other private dehulling station in the area where the coffee husk was not burning at that time. For other test rounds, husk could be organized through the KFCFCU from the private dehulling station by removing parts of the husk outlet tube for collection purpose.

<u>Preparations for a coffee husk storage and logistics center</u>
KFCFCU built a new dehulling/coffee processing station on their own to be independent from private dehulling stations. KFCFCU is strongly willing to keep the husk without firing it at all. Beside this new dehulling station, on the area of the KFCFCU, it was foreseen to build a storage facility and logistics centre. Preparations, calculations of the size and necessary materials and preparations for an agreement have been carried out. The new dehulling station started processing in May/June 2016.

→ However, storage and logistic centre could not be built so far, on one hand due to financial reasons as finance for the storage could not be assured, on the other hand due to the insecurity about the performance of the injera gasifier stove. As soon as the husk is stored, it has to be used for space reasons until the following dehulling season starts. As the injera gasifier stove is not ready for implementation, this use could not be assured.
→ However, after the first dehulling of coffee started without husk storage, odor emissions and possible decomposition of the husk on an unexpected wet ground could arise, which makes a certain husk storage probably necessary anyway.

First test biochar in charcoal cookstoves and as soil amendment
Use of biochar in charcoal cookstoves (for coffee ceremony and cooking of “watts”) was analysed in Kafa.
→ Loose coffee husk biochar needs to be agglomerated in order to be used in charcoal stoves. The holes in the charcoal stoves are too big to allow a use of loose coffee husk biochar.

Additionally, the possibility to use biochar as a soil amendment together with compost or animal manure for improvement of the soil fertility was checked. The coffee farmers from the cooperatives in Kafa area in general do not use any fertilizer or soil improvement (e.g. compost) according to the information from KFCFCU. On one hand, there is wild coffee in the rainforest with good soil, on the other hand, even when garden coffee is planted, no soil improver is added.

→ For the introduction of biochar as a soil improver it is necessary to collaborate with additional partners in agriculture. A possible partner for field tests of biochar in coffee farming in Kafa area as foreseen in phase 2 could be identified.
→ Nevertheless, samples of coffee husk biochar were handed for field tests to the social company GreenPath Food, who is working with farmer cooperatives and promoting permaculture based organic farming practices in Gurage zone, and who is interested in integrating biochar in agricultural techniques. Test results have not been available so far.

Test briquetting of coffee husk biochar for charcoal stoves

The resulting biochar from the gasifying process of the injera gasifier stove was collected and briquetting was arranged. The biochar was briquetted the same way as carbonized coffee husk is briquetted after carbonization in traditional kilns with simple briquetting presses.

→ The quality of the biochar was attested to be good.

Check economic viability

Investment costs for the stove were calculated based on the estimation of the metal stove producer for a series production with a certain minimum number (metal sheets can be fully used). For calculating economic viability and elaborating the business model, further possibilities for using coffee husk and import possibilities have been checked.

<u>Costs of the stove</u>

Estimated production costs for the metal part with series production lie at 1500-1800 ETB according to the stove producer. Added the MIRT stoves (500-600 ETB, as outer cylinder) and the fan (imported e.g. from Vietnam 300-400 ETB), total amount for one stove lies at estimated 2'300-2'800 ETB (= 125 USD in average, without power supply for charging fan).

→ Pure investment costs are very high compared to MIRT-stoves (120-150 ETB in Kafa) and high compared to electrical injera stoves (1500-1600 ETB). For economic viability, savings through wood replacement and less fuel used are crucial.

<u>Use of coffee husk in co-firing</u>

In Addis Abeba and few other main cities, coffee husk is used for co-firing for injera baking in stoves with wood as primary fuel, according to the information from different sides. However, availability of coffee husk in Addis Abeba is low and coffee husk is brought from some other parts of the countries. Coffee husk has a price of around 160 ETB for one bag (1 quintal) in Addis Abeba. In Kafa and its town Bonga, people have never used coffee husk for cooking and baking, in this area it is still considered as waste. Awareness rising is crucial.

→ In combination with a huge awareness rising campaign, co-firing of coffee husk can be promoted in Kafa and is a feasible alternative instead of having polluting coffee husk waste and can be an addition to the use in an injera gasifier stove. Use of coffee husk for co-firing in MIRT stoves is foreseen in the current NABU-project.

→ Nevertheless, price of coffee husk is expected to remain very low (between free and very low) in Kafa compared to big cities.

<u>Coffee husk for carbonization</u>

Coffee husk can be carbonized directly in traditional and modern kilns and afterwards briquetted into coffee husk biochar briquettes. However, technology for carbonization is often not efficient.

→ For additional use of coffee husk, direct carbonization and briquetting can be a solution. If carbonization is done with an efficient technology where the pyrolysis gas is used, even the double benefit of coffee husk used in gasifier stoves con be obtained. These briquettes can be used in charcoal or multifuel stoves, as foreseen in the current NABU-project in Tekikil stoves.

<u>Import possibilities</u>

Import possibilities of the stove or preproduced parts with fan have also been checked within elaborating economic viability. Import taxes in Ethiopia consist out of 5 taxes: Import (customs) duty, Withholding Tax (a fixed rate of 3%), Excise Tax (if applicable), VAT (a fixed rate of 15%) and Surtax (a fixed rate of 10%). Depending on the imported good and if excise tax is applicable, the import taxes can count all together at the end until more than 200-300% of the initial price without shipping. Excise tax is a sort of a "luxury" tax levied on selected goods such as luxury goods and basic goods which are demand inelastic and has bands of rates between 10-100%. However, metal in general is not subject to excise tax. Nevertheless, total taxes with transport get too high for being interesting for a viable business model.

→ Importing preproduced stoves is not advisable, as selling price will get too high which is not economically viable.
→ Fans might be imported through the solar company Fosera, which is active in Ethiopia as Fosera Manufacturing PLC with an assembling line in Bahir Dar, Ethiopia. So far, Fosera makes the fan assembling only in Germany and is only willing to deliver the fan's core unit if they can sell 1'000 pieces per order. Otherwise the price will be too high. Currently, an interesting fan from Thailand/Vietnam is evaluated, which is already in the mass market and is available for less than 10 dollars per piece (following pictures at the right). Respective contacts are through SNV Netherlands Development Organisation.
→ For importing fans, importer, if other than Fosera, must be evaluated well. Import taxes as described raise up to 200-300% of the initial fan price, as tested for importing fans through the stove producer in Addis Abeba. After all, it is advisable to search for a possibility to produce fans in Ethiopia instead of importing from abroad. The stove producer in Addis Abeba, responsible for the last stove produced in Ethiopia, would be interested.

Fan prototype from Europe, too expensive: core unit from Fosera, housing from Kaskad-E

Core unit of the fan from Fosera, Germany

Alternative fan from Thailand, fitting the injera gasifier: cheap mass production for less than 10 dollars per piece

<u>Calculations and sensitivity analysis for economic viability</u>
Calculations for economic viability and sensitivity analysis for economic viability have been carried out. Economics have been calculated with a baseline of a 3-stone fire compared to the injera gasifier stove and compared to another version of injera gasifier using pellets instead of loose coffee husk. Additionally, it is compared to a MIRT stove using 30% of coffee husk for co-firing.

The parameters/factors used for the economics calculations and sensitivity analysis are based on literature, own experiences and checks and assumptions due to local conditions, all on a conservative level to ensure a most real picture. Background of some of the factors:

- Lifetime of an injera gasifier stove is expected to be low due to the low quality of the metal available and used. Lifetime of injera gasifier stove for institutional use has been estimated at one year due to the long runtime per year and the low quality of the metal together with the hot temperatures. In comparison, lifetime of a MIRT stove is estimated at 5 years.
- Depending on the number of injera baked, maintenance and after sales services are very important. Maintenance costs have to be considered too for economic viability.
- Fuel costs: Wood prices: In urban area in Kafa, Bonga town, a bundle of wood ("women-backload", weight 10-15 kg) costs approx. 30-40 ETB, with rising prices in the rainy season. One bundle of wood is enough for one time injera baking with an average of 30-40 injera, depending on the actual amount of wood. In rural areas, fuel wood is often still collected for free in the forest.
- Fuel costs: Coffee husk so far is for free for collection, but will probably have a price, especially for storing and transporting.
- Coffee husk pellets have a much higher price than loose coffee husk as they need to be produced and a pelleting machine is required.
- Interest rates for investments (if any kind of microcredit solutions will be applied) are included as a base for all versions of improved cook stove solutions with a medium low rate.

1) *Economic viability for institutional injera gasifier cookstove with 720 hours runtime per year*

Table 1: Energetic and economic factors for the injera gasifier stove on institutional level (with a higher amount of runtime during the year, in average) in comparison of the baseline with an injera gasifier stove with loose coffee husk (type 1), an injera gasifier stove with coffee husk pellets (type 2) and a MIRT stove using coffee husk for co-firing (type 3).

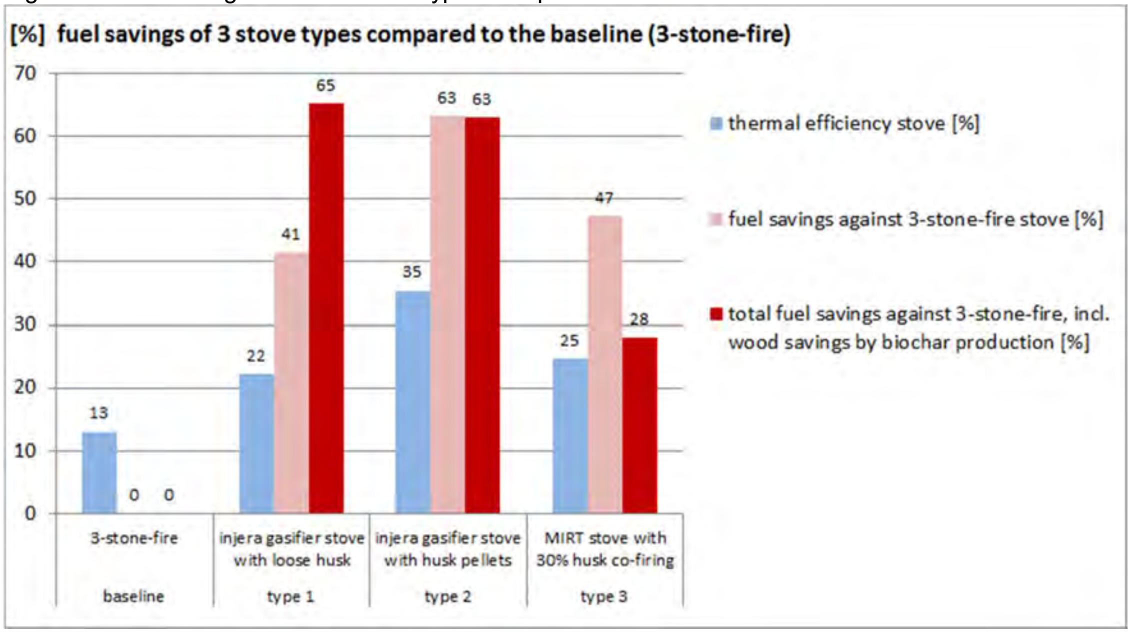
energetic & economic factors	**baseline**	**type 1**	**type 2**	**type 3**	
(estimated middle values)	3-stone-fire	injera gasifier stove with loose husk, without soil amendment, with production of husk biochar briquettes for sale	injera gasifier stove with husk pellets (smaller device with less thermal losses), dito	MIRT stove, co-firing with 30% loose husk and 70% wood	
thermal efficiency	13	22	35	25	%
fuel savings against 3-stone-fire, stove	0	41	63	47	%
additional fuel consumption for equivalent charcoal production (6 kg wood for 1 kg charcoal, biochar output of 1 gasifier stove = 814 kg / year)	4'883	0	1'823	4'883	kg / year
total fuel consumption	11'993	4'163	4'432	8'633	kg / year
total fuel savings against 3-stone-fire	**0**	**65**	**63**	**28**	**%**
investment cost 1 injera gasifier stove **x)**	0	125	60	7.5	USD*
interest rate on investment		5.0	5.0	5.0	%
lifetime of the stove **x)**		1.0	1.0	5.0	years
maintenance costs		25	13	1	USD /year
price for wood **x)**	120			120	USD / ton**
price for coffee husk or husk pellets **x)**		60	160	60	USD / ton
costs for husk briquetting		-30	-30		USD / ton
selling price of husk biochar briquettes **x)**		180	180		USD / ton
wood demand 3-stone-fire	7‘110			2‘540	kg / year
husk demand (85% dm) gasifier stove		4‘160	2‘610	1‘090	kg / year
production of biochar		814	510		kg / year
annual costs of the investment		131	63	2	USD / year
fuel costs of wood for 3-stone-fire	853	0	0	315	USD / year
fuel costs of husk for gasifier stove	0	250	417	67	USD / year
annual costs of mainenance	0	25	13	1	USD / year
revenues out of coffee husk biochar briquettes	0	-122	-77	0	USD / year
net annual costs	**853**	**284**	**416**	**385**	**USD / year**

* Exchange rate USD to ETB: 1 to 20, e.g. price of one injera gasifier cookstove: 125 USD = 2'500 ETB

** Conversion USD / ton to ETB / kg: 100 to 2, e.g. price of one bundle of wood: 120 USD / ton = 2.4 ETB / kg

x) sensitivity analysis relating to these economic factors

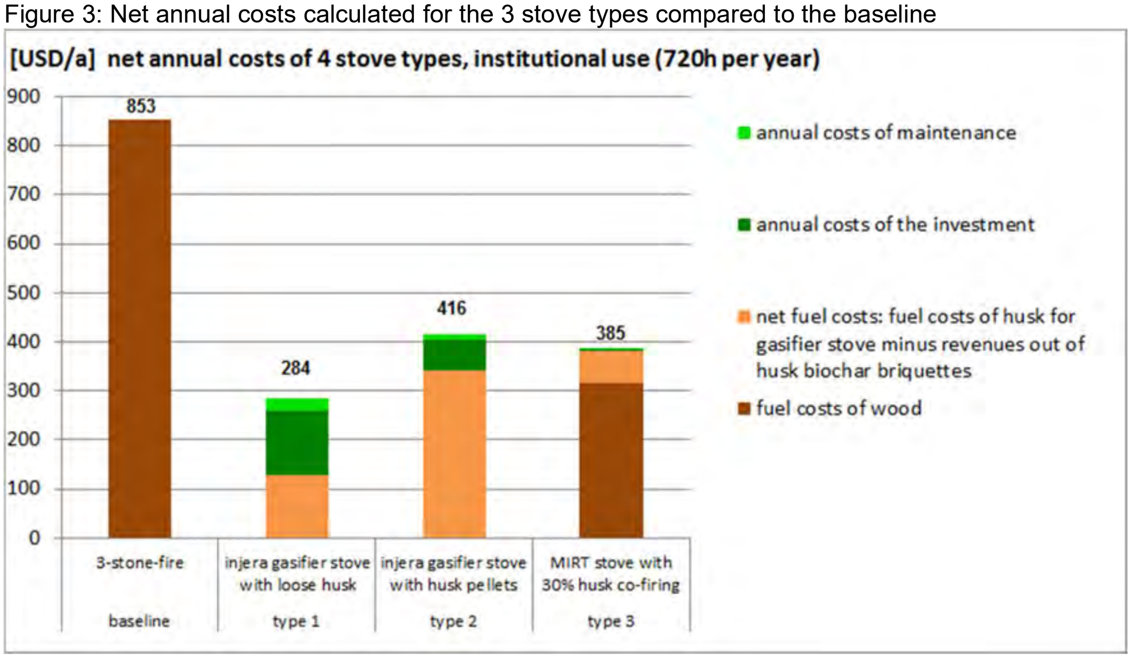
Figure 2: Fuel savings for the 3 stove types compared to the baseline



→ The injera gasifier stove with loose coffee husk and the MIRT stove with using 30% husk for co-firing are similar in fuel savings and thermal efficiency compared to the 3-stone-fire. However, when the biochar production is calculated additionally, total fuel savings of the injera gasifier with loose husk are more than double of the MIRT stove.

→ In thermal efficiency and fuel savings, injera gasifier stove with coffee husk pellets is by far the best option.

Figure 3: Net annual costs calculated for the 3 stove types compared to the baseline

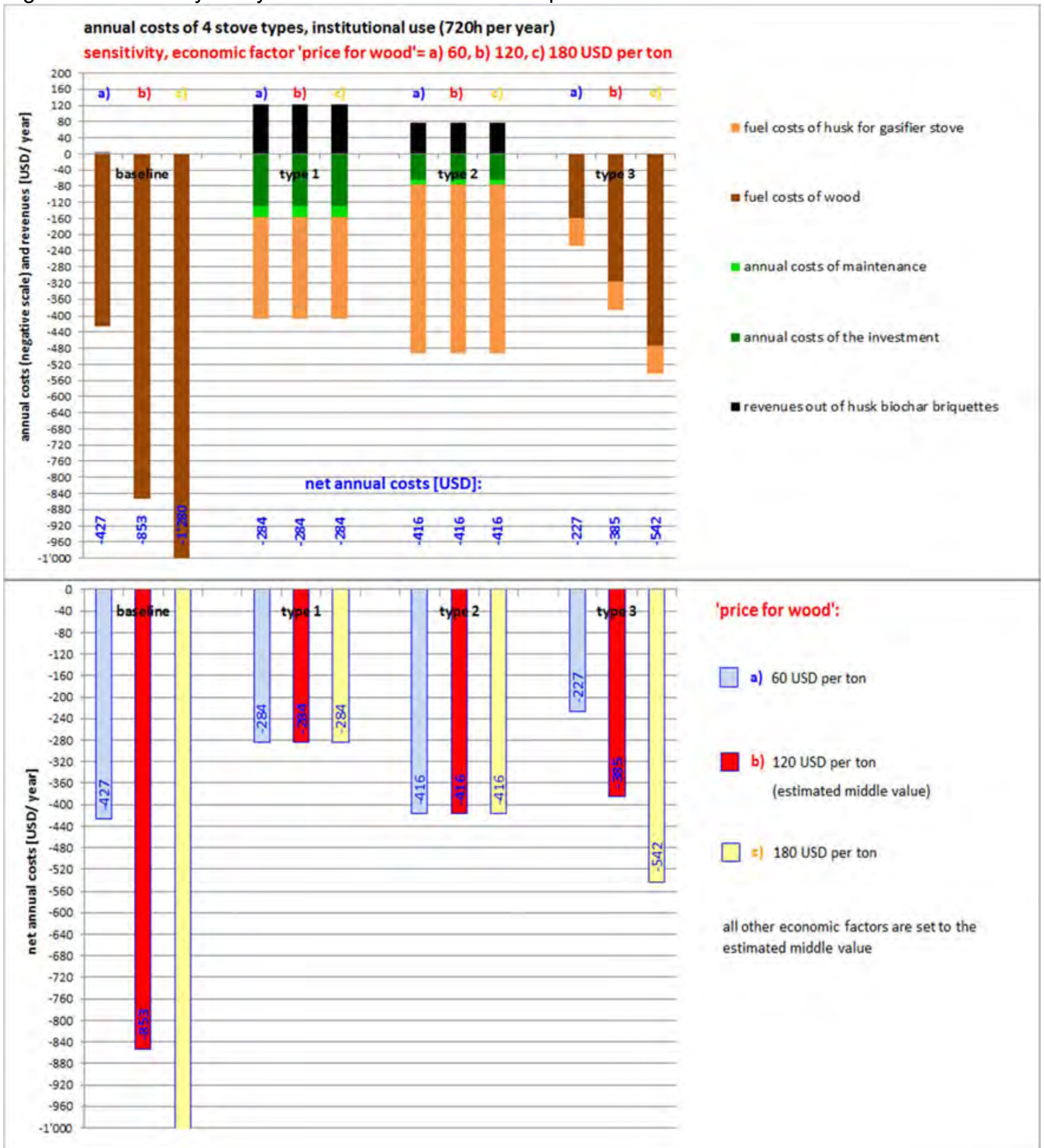


→ Looking at the net annual costs, injera gasifier stove with loose husk is the best option, if revenues of the husk biochar briquettes are included in the calculation.

→ Still, investment costs stay the highest for injera gasifier stove with loose husk.

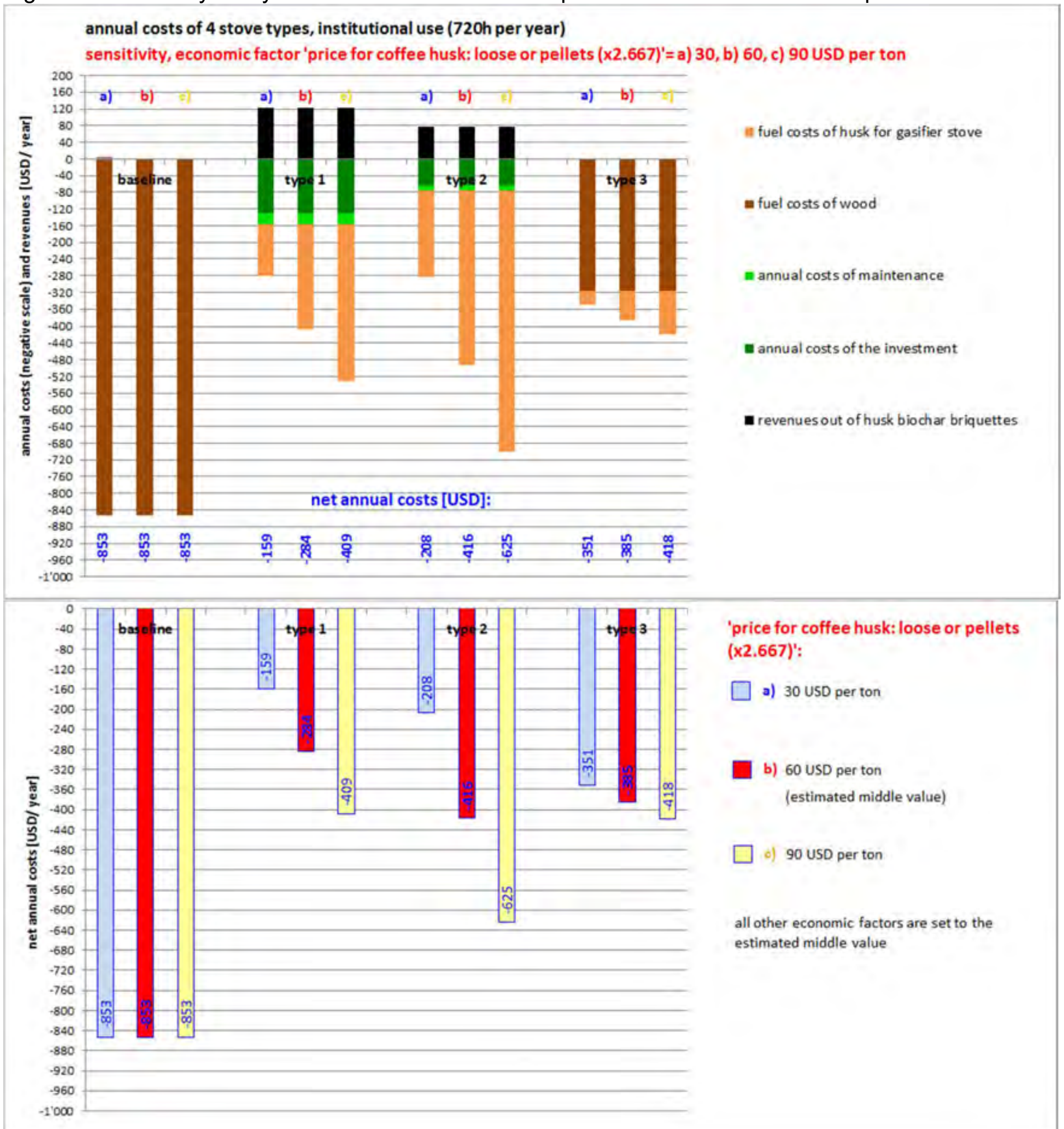
→ Annual fuel costs of the 3-stone-fire are much higher than for any other stove.

Figure 4: Sensitivity analysis for the economic factor ‘price for wood’



→ Changes in the price of wood have the biggest influence on the economic viability of the injera gasifier stove. If wood price is half of the current price, MIRT-stove with co-firing is the best option. With the current price, injera gasifier stove with loose husk (with net annual costs of 284 USD – including the revenues of biochar production and briquettes) is better than the MIRT stove using husk for co-firing (with net annual costs 385 USD). As soon as wood price is rising, injera gasifier stove – with loose husk and with husk pellets get much more economically viable.

Figure 5: Sensitivity analysis for the economic factor 'price for coffee husk or husk pellets'



→ Price of the coffee husk has a big influence on the economic viability. The higher the price of the loose husk or the coffee husk pellets (2.667 times higher than the price of loose husk), the lower the economic viability of the injera gasifier stove. If the husk price is low, at 30 USD per ton husk (= 80 USD per ton for husk pellets), injera gasifier stove is by far the most economically viable option.

More economic sensitivity analysis figures for another three economic factors are found in the annex of the present report.

2) *Economic viability for household injera gasifier cookstove with 120 hours runtime per year*

For crosschecking, the same calculations and sensitivity analysis have been carried out for household use of the same injera gasifier stove. Household injera gasifier stoves have a lower amount of runtime during the year, households bake injera only 2.7 times a week in average.

Table 2: Calculations for the injera gasifier stove on household level (with a lower amount of runtime during the year, in average) in comparison of the baseline with an injera gasifier stove with loose coffee husk (type 1), an injera gasifier stove with coffee husk pellets (type 2) and a MIRT stove using coffee husk for co-firing (type 3).

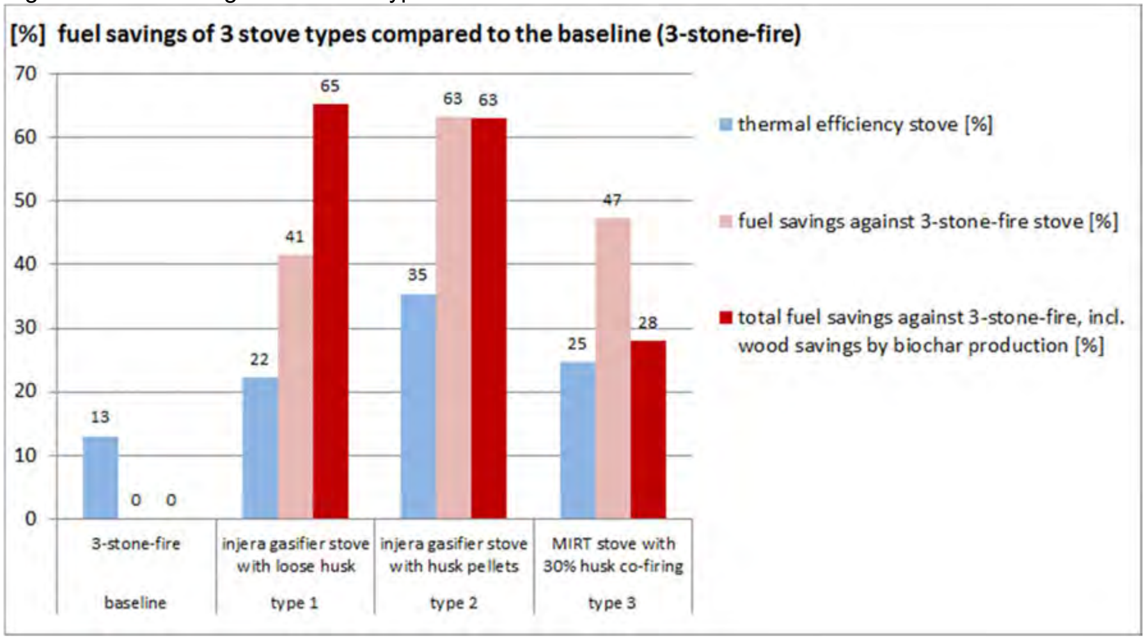
energetic & economic factors	**baseline**	**type 1**	**type 2**	**type 3**	
(estimated middle values)	3-stone-fire	injera gasifier stove with loose husk, without soil amendment, with production of husk biochar briquettes for sale	injera gasifier stove with husk pellets (smaller device with less thermal losses), dito	MIRT stove, co-firing with 30% loose husk and 70% wood	
thermal efficiency	13	22	35	25	%
fuel savings against 3-stone-fire, stove	0	41	63	47	%
additional fuel consumption for aequivalent charcoal production (6 kg wood for 1 kg charcoal, biochar output of 1 gasifier stove = 136 kg / year)	814	0	304	814	kg / year
total fuel consumption	1'999	694	739	1'439	kg / year
total fuel savings against 3-stone-fire	**0**	**65**	**63**	**28**	**%**
investment cost 1 injera gasifier stove **x)**	0	125	60	7.5	USD*
interest rate on investment		5.0	5.0	5.0	%
lifetime of the stove **x)**		3.0	3.0	5.0	years
maintenance costs		10	5	1	USD /year
price for wood **x)**	120			120	USD / ton**
price for coffee husk or husk pellets **x)**		60	160	60	USD / ton
costs for husk briquetting		-30	-30		USD / ton
selling price of husk biochar briquettes **x)**		180	180		USD / ton
wood demand 3-stone-fire	1‘190			420	kg / year
husk demand (85% dm) gasifier stove		690	430	180	kg / year
production of biochar		136	85		kg / year
annual costs of the investment		46	22	2	USD / year
fuel costs of wood for 3-stone-fire	142	0	0	52	USD / year
fuel costs of husk for gasifier stove	0	42	70	11	USD / year
annual costs of maintenance	0	10	5	1	USD / year
revenues out of coffee husk biochar briquettes	0	-20	-13	0	USD / year
total annual costs	**142**	**77**	**84**	**66**	**USD / year**

* Exchange rate USD to ETB : 1 to 20, e.g. price of one injera gasifier cookstove : 125 USD = 2'500 ETB

** Conversion USD / ton to ETB / kg : 100 to 2, e.g. price of one bundle of wood : 120 USD / ton = 2.4 ETB / kg

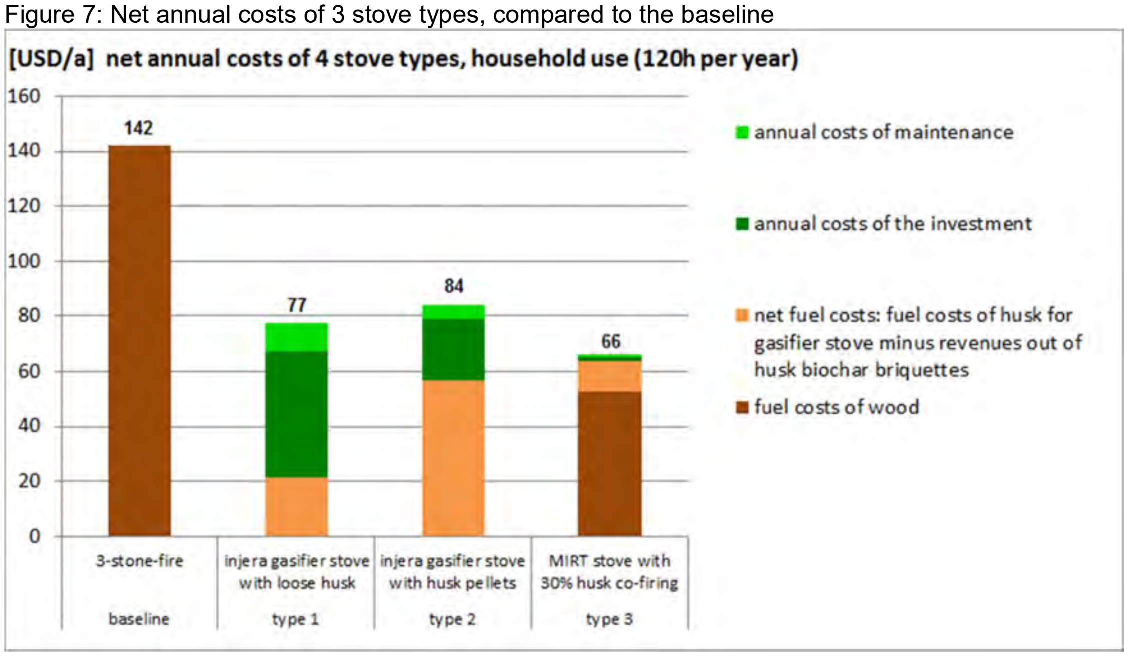
x) sensitivity analysis relating to these economic factors

Figure 6: Fuel savings for 3 stove types and for the baseline



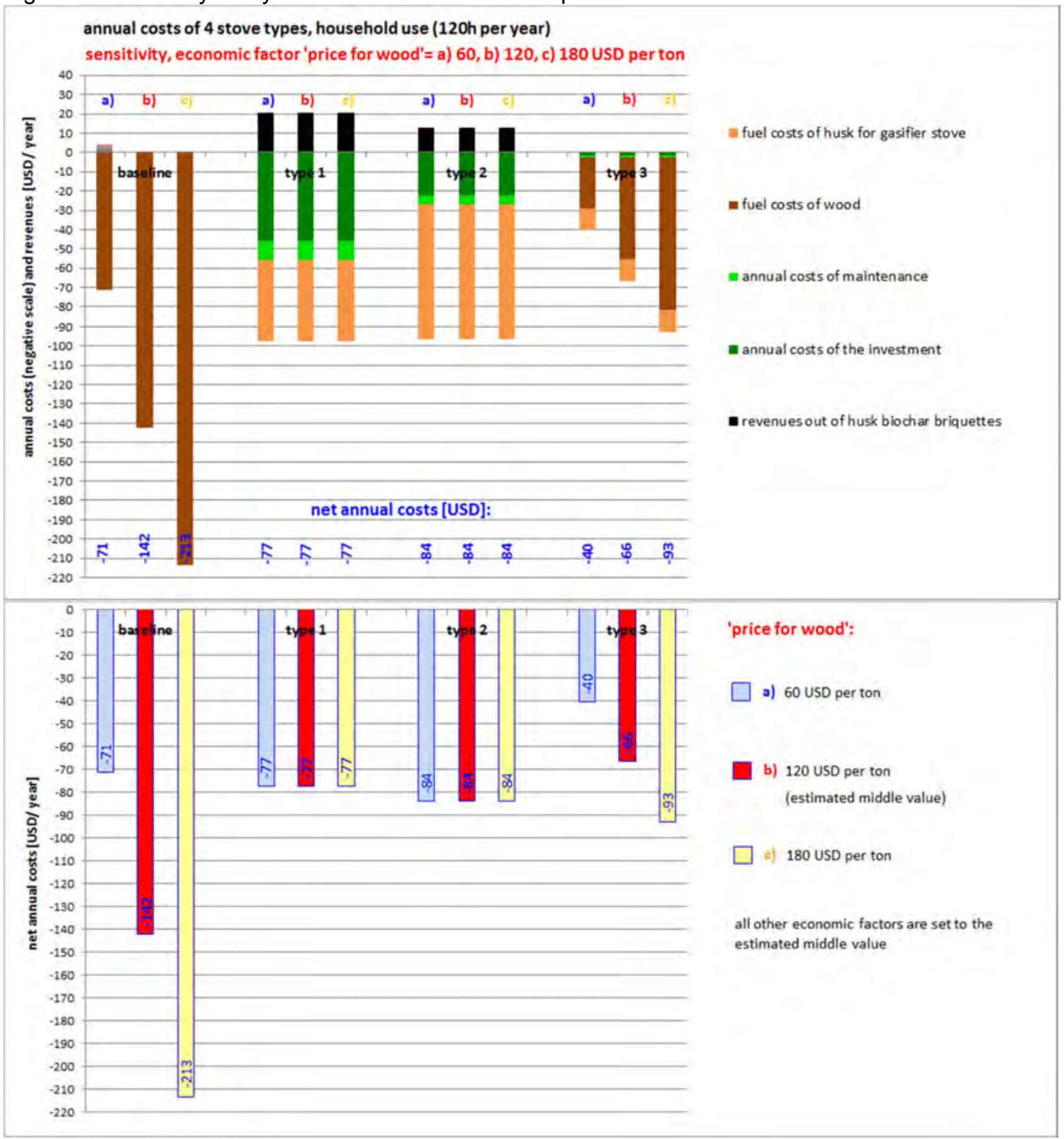
→ Efficiency and fuel savings are comparable in a MIRT stove with 30% husk co-firing and an injera gasifier stove with loose husk, as shown already in figure 1 for institutional injera gasifier stove. Including biochar production as savings, injera gasifier stove is much better.

Figure 7: Net annual costs of 3 stove types, compared to the baseline



→ Looking at the net annual costs including revenues for biochar, injera gasifier stove for household level with loose husk is a bit more expensive than the MIRT stove with husk co-firing.
→ Investment costs are crucial for injera gasifier stove. MIRT stove will be a much more affordable option, and economic viability is slightly better for MIRT stove for household use.

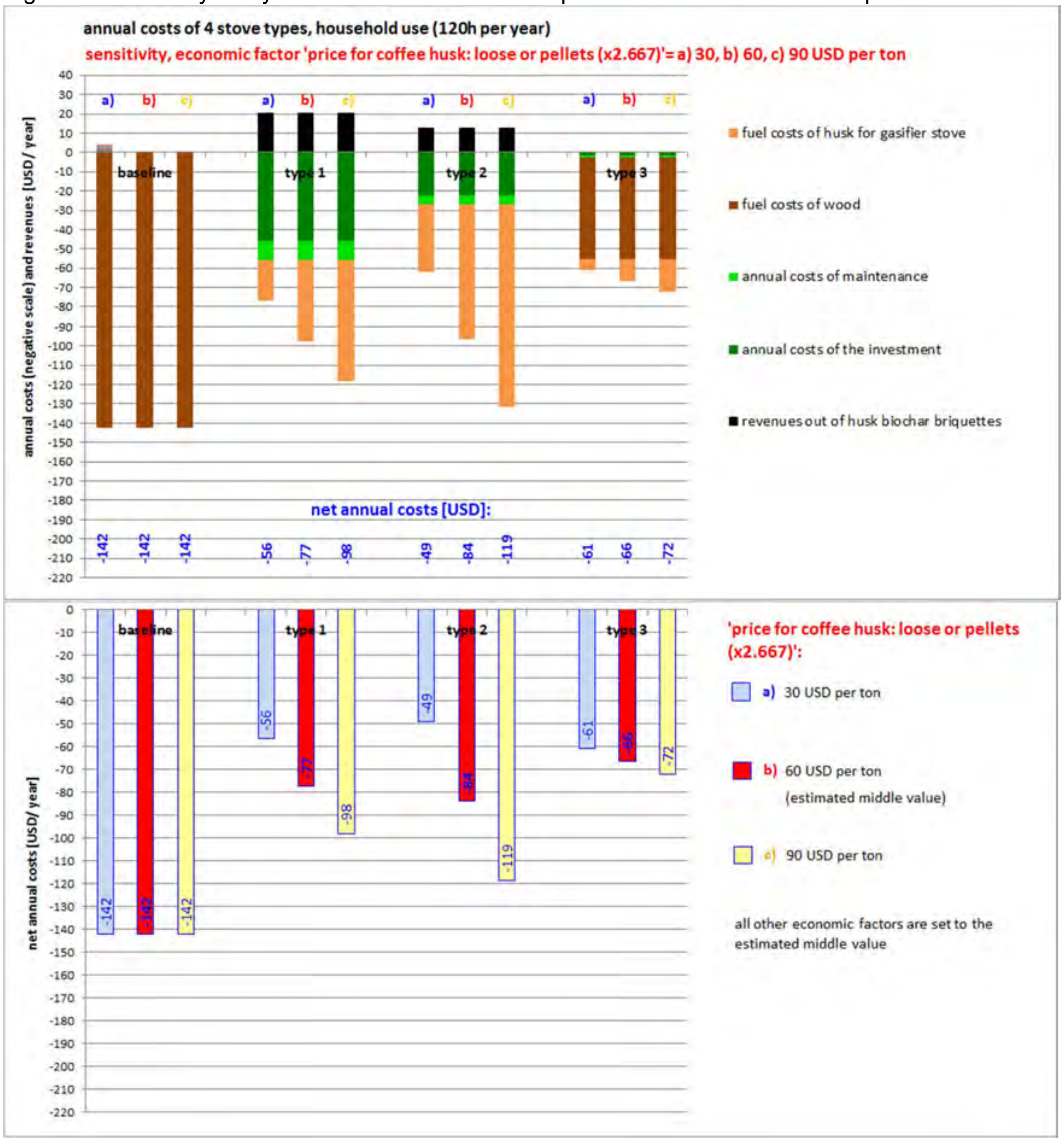
Figure 8: Sensitivity analysis for the economic factor ‘price for wood’



→ Again, wood price has a high effect on the economic viability. If wood price is only half of the current price, annual costs including revenues of biochar are cheapest for MIRT stoves, followed by the 3-stone fire and then slightly later by gasifiers. For household use, wood price therefore has much higher effect than for institutional use. If wood price is double the current price, the injera gasifier stoves are slightly cheaper than the MIRT stove (relating to the net annual costs).

→ Looking at the wood price injera gasifier is not really economically viable compared to a MIRT stove with husk co-firing.

Figure 9: Sensitivity analysis for the economic factor 'price for coffee husk or husk pellets'



→ Looking at the price of coffee husk, loose or pelleted, net annual costs are pretty similar for MIRT stoves with husk co-firing and injera gasifier stove with loose husk, if husk price stays low. With a rising husk price, injera gasifiers stoves are no longer economically viable at all.

More economic sensitivity analysis graphs for another three economic factors are found in the annex of the present report.

Development of business model

For the business model, possible stove producers for metal part and MIRT stove had to be identified. Normal metal workshops in Kafa currently cannot produce the injera gasifier stove on short or middle term and therefore will not act as entrepreneurs like initially intended by the project.

→ For production of the metal parts, metal producer in Addis Abeba, or the mentioned workshop in Mizan Teferi or a collaboration with the Bonga TVET college are all viable options. Thus, they might act as entrepreneurs or in combination with a social enterprise for injera gasifier stove sales.

→ As production/manufacturing of injera gasifier stoves in general meets several difficulties and adaptation to all the required local needs stays very challenging, a viable business model for the injera gasifier stove as standalone is not feasible at the present time.
→ Instead, a business model overview with a more holistic concept including different cookstoves and different ways of using coffee husk has been elaborated (see chapter 4.2.1). This is a possibility to include the injera gasifier stove as one option for a specific target group (institutional bakers) within a variety of adapted cookstoves to be promoted for different target groups. And it is a possibility for using coffee husk with double benefit more efficiently within promotion of coffee husk as fuel in different ways for different stove types.

Clarification of possible microfinance mechanism
Investment costs of the injera gasifier stove are high compared to other stoves, but even with a short lifetime, it is economically viable for urban area and institutional injera bakers where wood price is rising. Sort of a financing solution for investment with credits is necessary.

The microcredit institution based in Bonga is oriented to classical microcredits based on state activities (e.g. seeds, agricultural aid) and not on "newer" technologies like improved cookstoves (ICS) and help to acquire or manufacturing these. Most of the time, micro credits in Ethiopia are given to producers or small business but not end-user.

However, everywhere in Ethiopia, informal savings and loans associations exist, called “EKUB”. EKUB is a rotating fund, an informal savings association of friends or neighbours or people from a community for a limited time. These rotating savings and credit associations consist of a group of individuals who agree to meet for a defined period in order to save and borrow together, as a form of combined peer-to-peer-banking. They exist in different scales, from very small to large scale. Interest rate is often low, but commitment is mostly high due to the good connection between the members and the high transparency. EKUB members contribute to a fixed amount to a fund periodically. These contributions are then allocated to one member at a time in a rotating order.

→ For Kafa area, the EKUB systems can be interesting for buyers of a cookstove when marketing activities also include mentioning about possible saving and loan mechanisms. A good option would be to connect to possible local people building up local saving and loan systems on microscale level and connect those to possible stove target group.

4.1.4 Modification of projects objectives
During the course of the project, main objectives remained the same. With the problems arising due to the high variety of the coffee husk, use of briquetted or pelleted coffee husk instead of the use of loose coffee husk was evaluated. With the solution of including a fan to the injera gasifier stove for forced draft, no changes in the objectives were necessary at that time.

However, with the results of the economic calculations, version with a pelleting option including assumptions for the production costs (including pelleting machine investment and work) is economically interesting again and should be examined deeper.

Additionally, with the results of the present pilot project, main objectives in regard to the use of gasifier stoves need to be modified. Gasifier stoves themselves might only be a solution in combination with other stoves. Therefore, objective of implementation of the gasifier stove could not be achieved (see chapter 4.2.2).

4.2 Achievement of Objectives and Results

4.2.1 Results and discussion

Piloting of the stove – technical feasibility

Piloting of the injera gasifier stove for loose coffee husk has been achieved. Development and several adaptations of the stove design have been carried out and a currently existing stove model of injera gasifier stove with two submodels for the use of loose coffee husk is working. It was successfully tested and continuously adapted to the local conditions, though further small adaptations have to be effected during a larger field test.

→ Despite the encountered challenges with loose coffee husk, **technical feasibility of the injera gasifier stove for loose coffee husk has been shown**. A fan for forced draft is necessary. Using natural draft for gasification of coffee husk is difficult, as coffee husk has a high air flow resistance. Additionally, sieving out the smallest particles of the coffee husk is necessary.

Description of the stove model (technical solution)

The current model of the injera gasifier stove (injera gasifier prototype 3) has the following features:

- Static construction with an outer cylinder in clay and sand/soil, not movable. The diameter of this cylinder is identical to that of the existing MIRT stove. 4 MIRT stoves are used to achieve a total height of 880mm. [1]
- Fix installed inner cylinder made out of metal. [2]
- Bottom blow with a ventilator (fan) [7], therefore no chimney.
- For removing the biochar, 2 versions:
  - Biochar gate at the bottom
  - Removable biochar container [3]
- Fix installed holder [4] to support the burner unit [5] and the injera plate [6]

Figure 10: injera gasifier stove prototype 3, submodel 3 with removable biochar container:

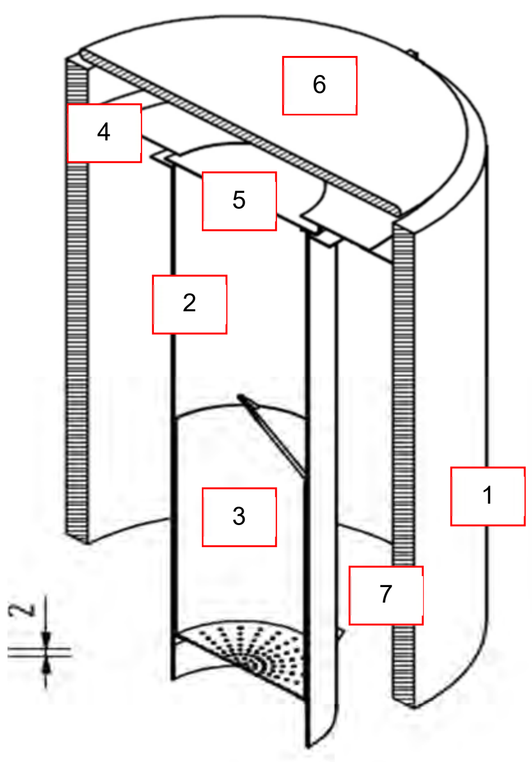


Table 3: Technical details and energy balance of one load (batch with loose husk)

edge length of the rectangular fuel container option	0.25	meters
height	0.85	meters
volume	53	litres
bulk density of the coffee husk unsieved	150	gram/litre
bulk density of the coffee husk sieved	100	gram/litre
filling capacity sieved husk, 85% dry biomass	5.3	kg
filling capacity sieved husk, 100% dry biomass	4.5	kg
heating value, 85% dry biomass	4.0	kWh/kg
energy load in one fuel container	**21.2**	**kWh**
biochar production (23% of husk 100% dm)	1.0	kg
biochar energy content	**9.4**	**kWh**
energy in pyrolysis gas	**11.8**	**kWh**
ratio of energy in pyrolysis gas	56	%
burning time in average	55	minutes
power of the burner total	12.9	kW
therefrom thermal losses (radiation, exhaust gas)	60	%
power of the burner on the injera plate	5.1	kW
thermal efficiency*	22	%

* overall efficiency: heat on injera plate per husk input

Social acceptance and local requirements

Adaptation to user needs and production possibilities have been included to a great extent in the development of the stove. However, required standards of the stove could yet not be fulfilled completely. With improvement of the stove for some criteria, some slight worsening for other criteria resulted. (E.g. optimization for less material used (optimizing costs), leads to more difficult installation, whereas improved burning time increases the metal costs.)

→ Batch-loaded baking: The minimum requirement for one batch was defined as for baking 30-40 injeras (90 minutes). To extend the cooking time several batches in series are required. For technical reasons, a break of minimum 15 minutes between each batch is necessary for cooling down the stove before loading again. Otherwise it could happen that the fresh husk is heated up too much by the hot metal fuel container and pyrolysis starts uncontrolled from the bottom up (high emissions). According to some injera-selling women, who sell between 50-200 injeras/day, breaks between the batches can be organized, e.g. with some other works. Thus, batch-loaded injera baking is feasible, even with some breaks. However, this has to be ensured with a larger field test with injera baker users.

→ Burning time is lower than expected (scarcely 60 instead of 90 minutes), even though maximum height of fuel chamber for longer burning time has been included.

→ Comfortable cooking height of the stove has been assured due to adaptation to the height of electric injera ovens and MIRT stoves on tables in Kafa area.

→ Heat distribution for injera baking is good if stove is properly installed.

→ Technical solutions for assuring the necessary power for baking injera have been integrated, accurate installation is important though. When properly installed, power is mostly enough, few adjustments might be necessary.

→ For an easy and simple handling of the stove, several adaptations have been integrated:

- For removing the biochar two submodels exist (see above): One version with a biochar gate at the bottom to easily remove the biochar. Another version with a removable biochar container, which might be considered as more heavy. For ensuring acceptability of both or one of these removing possibilities, larger field test is necessary too.

- Fire is already on when the burner unit can be placed (and additionally the injera plate as people are used to before). Heat and prevention from burning have to be considered by the injera baker when starting.
- Filling the husk: Coffee husk will be filled into the stove from the top. Coffee husk itself is light, so filling the sieved husk is easy.

→ To ensure social acceptance, a field test with users at larger scale is necessary to get enough feedback from many different users in order to integrate slight modifications in the design of the stove. This includes feedback for heat distribution, power, batch-feeding and breaks and especially handling (starting/putting burner unit and stopping and removing biochar).

→ Most of the local metal stove production possibilities have been considered while developing the stove, however some quality work requirements for production remain. Conflicts between robust and easy construction with easy handling exist (see examples below with current model).

Summary of the advantages and disadvantages of the injera gasifier stove

Table 4: Stove parts of the submodel 3 with removable biochar container (numbers according to figure 10, injera gasifier stove) and its advantages and disadvantages, in comparison with prototype 1

Parts of the stove	*Advantages*	*Disadvantages*
[1] Fix installed outer cylinder made out of clay/sand, e.g. 4 MIRT stoves	Good stability, no burning risk, durability, convenient cooking height, more local material used	Quite expensive construction (4 MIRT stoves necessary), complicated to build up
[2] Fix installed inner cylinder made out of metal with a shorter and moveable charcoal container [3] to unload the produced biochar	Less weight to handle during unloading the biochar, no complicated gate necessary at the bottom to unload	Costs for the charcoal container, handling probably difficult
[4] Fix installed holder to support the burner unit [5] and the injera plate [6]	Accurate gaps between burner and plate, lower emissions	Very complicated to install, accuracy necessary
No chimney, bottom blow fan [7] instead	Less material use, more evenly heat distribution, closer to the habitus of 3-stone-fire. The fan can be completed with a pico solar panel which can recharge also mobile phones or other electronic devices such as lanterns.	Little bit more smoke than the chimney model, quite expensive fan (import taxes). The fan needs to be charged and needs power supply (but not during cooking)
Fuel: loose coffee husk	Waste to fuel, no expensive processing of the husk (pelleting)	Sieving necessary because of husk with variable dust ratio
Fuel container with more height of 950mm in total	Longer burning time (90 minutes expected, only 55 minutes observed)	More thermal losses (bigger surface of the fuel container due to the low energy density of coffee husk)

Production and installation of the first stoves

9 Injera gasifier stoves have been produced and checked in Kafa with different or slightly different designs. Two have been produced in Switzerland, the others have been either produced or partly assembled and adapted in Ethiopia. Whereas, not all the models are yet completely installed and in use at different user places due to problems of assembling and therefore few missing parts.

- → Assembling the stove in Kafa is possible but challenging and needs good training. Whereas complete manufacturing of the whole metal part of the stove in Kafa is currently not feasible, especially not with the limited available tools. With continuous training and know-how transfer and access to finance for additional metal-working tools, it might be built.
- → Production in Addis Abeba is feasible and meets the requirements, will need specific training though.
- → Gasifier-technology seems to be a technology, which cannot be produced locally in Kafa from the beginning, especially not an injera gasifier stove. Requirements for accurate working and specific tools (e.g. bending) are too high.
- → As for installation of the injera gasifier stove, a metal stove (inner part) and an outer cylinder consisting of four MIRT stoves are combined, installation is more challenging than when everything is coming from one producer.

Use of biochar

The resulted biochar from the gasifying process with the injera gasifier stove and coffee husk has good quality.

- → Use of coffee husk biochar in briquette form or another agglomerated form in charcoal stoves or a multifuel Tekikil stove is feasible and can reduce charcoal costs and reduces pressure on the forests. However, ash content in coffee husk is 2-3 times higher than in normal wood charcoal. So, carbonized coffee husk briquettes are slightly lower in quality compared to wood charcoal, no matter whether carbonized in kiln or gasifier.
- → Use as soil amendment together with animal manure or compost has to be considered in collaboration with a larger agricultural training context. Because coffee farmers in Kafa in general don't use any fertilizer nor compost.
- → Interesting might be the possibilities to use coffee husk biochar additionally as amendment for composting wet coffee pulp from the wet-processing of coffee, which is also existing in Kafa. Composting wet coffee pulp from wet processing can otherwise easily lead to groundwater contamination, if composting is not done properly in waterproof containers.

Economic viability

Economic viability has been calculated for injera gasifier stove for two options (loose coffee husk and pelleted coffee husk) and for two user groups (institutional and household) compared to a baseline of the 3-stone fire and compared to the MIRT stove, using 30% coffee husk for co-firing.

- → For **institutional users**, **injera gasifier stoves** with loose coffee husk or pelleted husk are **economically viable**, if the benefit out of the biochar briquette production and sales is included. Injera gasifier stove is economically viable compared to the MIRT stove using coffee husk for co-firing, even with its short lifetime of one year and high maintenance costs. Compared to a MIRT stove using only wood its economic viability is even much better.
- → For household users, injera gasifier stove is not economically viable compared to the MIRT stove using husk for co-firing.
- → From the economic side, biggest hurdles are the **high investment costs**.

<u>Factors influencing the economic viability</u>

- → Pure investment costs for injera gasifier stoves are very high (2300-2800 ETB) compared to MIRT-stoves (120-150 ETB in Kafa) and high compared to electrical injera stoves (1500-1600 ETB). For economic viability, savings through wood replacement and less fuel used are crucial.
- → Economic viability depends heavily on the price of coffee husk and on the price of wood. In general, fuel costs, thus wood prices, coffee husk prices and charcoal/briquette prices are crucial for economic viability.

→ Quality of the metal is another important factor for durability and therefore for economic viability. In general, with locally available metal, the thicker the metal, durability is better for resisting the heat. But the thicker the metal, the higher the price.

→ So, lifetime of the stove is an important factor for economic viability. Lifetime of injera gasifier stove for institutional use has been estimated at one year due to the long runtime per year and the low quality of the metal together with the hot temperatures.

→ Target group of institutional injera bakers and injera baking women is very diverse. Some bake on institutional level and others only bake for the market a much smaller amount of injera/day. Number of baking-hours and injera-sales per week differ. Runtime/year therefore can be quite different between the different institutional uses which influence economic viability.

→ Transport costs for preproduced parts of the stove influences economic viability. Because stoves can be transported with other goods on trucks coming to Kafa which will bring e.g. coffee back to Addis Abeba, transport costs might be hold low.

→ Price of coffee husk depends on the demand for the coffee husk beside storage costs and transporting costs/work of the coffee husk.

Business model

<u>Considerations and challenges for the business model</u>

- Coffee husk needs to be sieved for assuring proper functioning of the Injera gasifier stove, what makes the business case more challenging.
- Challenges in the installation because there are different producers (MIRT and metal part).
- Willingness-to-pay is influenced by the previous NABU-project, where about 11'000 MIRT-stoves have been distributed mainly for free or for transportation costs only. Additionally, it is influenced heavily by the probably highly subsidized adapted MIRT-stoves from the current NABU-intervention, despite the original intention of promoting with a pure market approach. This kind of interventions often reduce the sustainability of clean cookstove interventions.
- Challenges for social acceptance of the injera gasifier, especially for handling and probably because of the shorter burning time than expected and required.
- In Kafa zone alone, target group for the institutional injera gasifier stove is smaller than expected. Thus, the amount of injera gasifier stoves which can be sold is probably lower than expected which influences again the price in a series production and therefore the stove investment costs for user.
- Amount of coffee husk available in Kafa for the different uses and for the injera gasifier stove: Minimum 500t/year, where alone at the new dehulling station of the KFCFCU currently around 300-350t of coffee husk arise per year and it is expected that this amount will raise. The minimum amount (300t) could be used by 120 institutional injera gasifier stoves/year, which makes a stove selling business for injera gasifier stoves economically not very interesting. Business focus should lay on the provision of fuel.
- Coffee husk is only produced for some months during the year. For this reason, storage possibilities are very important which has an influence on the costs.

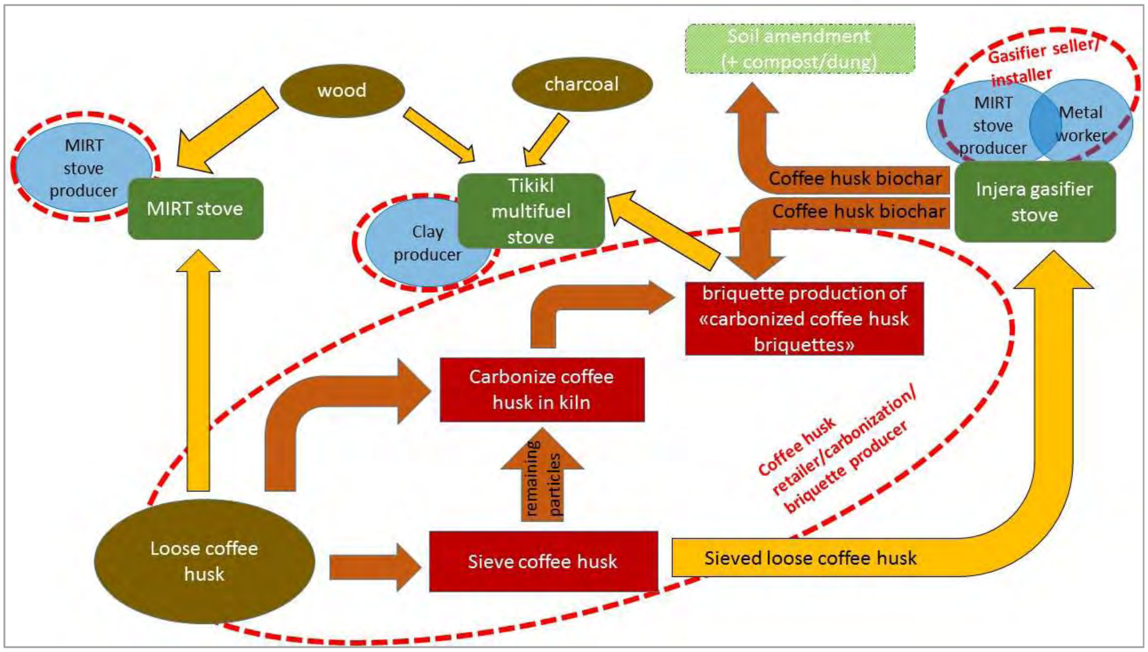
→ Due to all these mentioned reasons, a viable business model for the injera gasifier stove as standalone could not be assured.

<u>Business model and overview with different stoves and coffee husk</u>

Looking at the cooking and coffee husk problem in a broader way, injera gasifier stove can be one solution for a specific target group (institutional injera bakers). So, it shall be included in a more holistic concept with different stove types for different target groups and different possibilities to use coffee husk as a fuel and later as soil amendment.

Table 5: Overview different cookstoves and coffee husk use for Kafa (including energy component of NABU project):

Type of cook-/baking stove	**Fuel**	**Target group stove**	**Stove producer**	**Stove seller and installer**	**Fuel retailer (and producer)**	**Remarks**	**Price stove**
Injera coffee husk gasifier stove → for Injera baking	Loose coffee husk	Institutional injera bakers in urban area	Outer cylinder: MIRT-stove producers Metal parts: in Addis Abeba or Mizan Teferi, Assembling in Bonga possible Fan: purchase through Fosera Manufacturing PLC or manufacturer in Addis Abeba, or from abroad	Outer cylinder: provision through MIRT-stove producer Metal stove parts and fan: entrepreneurs from metal workshops → Due to the complexity, an entrepreneur or wholesaler for the sale of the whole stove "out of one hand" is required → Installation through trained installer (responsible: wholesaler)	Coffee husk retailer is responsible for collection of husk at dehulling station or a coffee husk storage, for sieving the coffee husk and sales/provision of coffee husk → storage for coffee husk necessary, central or decentral → MIRT-stove-producer can be coffee husk retailer and provide stove and fuel → Former fuel wood carriers can make a business as coffee husk provider	Final product: Biochar out of coffee husk → as payment possibility, back to briquette producer →Double benefit and double use of energy → Or use as soil amendment with compost/dung	2'300 - 2'800 ETB estimated (including MIRT and fan)
MIRT-stove → for Injera baking with additional pot holder on chimney-outlet for additional household cooking (wats, boiling water etc.)	Wood and new: Promotion of co-firing of loose coffee husk (into burning fire)	Household level in rural and urban areas	Trained MIRT-stove producer (formerly trained and newly trained through NABU project)	MIRT-stove producers sell the stoves directly → Installation in general through user (training required)	Coffee husk retailer as described above.	Awareness-rising necessary Emissions probably higher than with gasifier (indoor air pollution)	120 - 150 ETB in Kafa zone
Tekikil multi-fuel clay-stove: low-cost variety out of clay → for household cooking (boiling water, wats, coffee etc.)	Briquettes from carbonized coffee husk, normal charcoal and wood possible	Household level in rural and urban areas	Specially trained clay stove producers (e.g. members from Menjda community (local minority) who have been previously trained in clay production), trained through NABU project	Tekikil stove producers are stove sellers	Coffee husk retailer as described above: Coffee husk briquette production out of carbonized husk (in 2 ways: from carbonizing at kiln and from Injera-gasifier stove)	Trainings for carbonization and for briquetting necessary, partly made and covered by NABU-project	60-75 ETB estimated (= 3-4US $)



Explanations according to table 5. Additional explanations of the business model overview:

- Stoves: The three different stoves shall be promoted for different target groups in Kafa.
- Three ways of using coffee husk:
    - Loose, unsieved coffee husk directly for co-firing in MIRT stoves
    - Sieved loose coffee husk for the use in injera gasifier stoves
    - Loose, unsieved coffee husk together with the remaining particles after sieving the coffee husk for carbonizing coffee husk in kilns
- Carbonized coffee husk briquettes: Coffee husk briquettes are produced out of the carbonized coffee husk from kilns and out of the coffee husk biochar from the injera gasifier stove. The briquettes can be used in the clay Tekikil stove and in charcoal stoves. Disadvantage of carbonizing coffee husk directly: the energy used for carbonization is not used and therefore lost. In case of cooking/baking in a gasifier stove, carbonization energy is used and double energy benefit results.
- Coffee husk biochar after the gasification process in the injera gasifier stove can be used in two ways: For briquetting and as soil amendment with compost or dung.
- The same marketing/distribution channels for loose coffee husk for the use in injera gasifier stoves and for the use in MIRT-stoves and for the production and use of briquettes shall be used.
    - Coffee husk retailer is responsible for:
        - collection of husk at dehulling station or a coffee husk storage
        - sieving the coffee husk
        - sales/provision of coffee husk
    - Briquette producer is responsible for:
        - recollection of biochar
        - carbonization of coffee husk in kilns
        - production and sales of carbonized coffee husk briquettes
- Trained MIRT-stove-producer can also be coffee husk retailer and briquette producer to provide stoves and fuel. Former fuel wood carriers (often women) can be integrated to this business as coffee husk provider or briquette producer/seller. In both cases, storage for coffee husk is necessary.
- Coffee husk briquettes: The produced biochar in the injera gasifier stoves is integrated in the coffee husk briquette chain. Biochar coffee husk briquettes can be produced at the same place where other carbonized coffee husk briquettes are being produced.

- For a working business model, coffee husk retailer and briquette producers and sellers should be linked with stove sales. E.g. briquettes can be provided with the respective stove.

Marketing for the stoves and coffee husk as fuel
Communication and marketing activities as foreseen and started through NABU energy consultant team is necessary. E.g. demonstration at market days, radio, involvement of different stakeholders who are present in Kafa such as health department, energy department, women children and youth affairs department, by linking to other main topics of those stakeholders.

Some arguments for the injera gasifier stove:

- Constant burning during one batch, no need for putting wood continuously
- Indoor air quality (coughing, eyes…) → no smoke
- Comfortable height for baking
- Less burning risks (similar to MIRT)
- Show how much wood they save/ which they don't need to buy compared to husk and their normal fuel needs.
- Double benefit of the by-product biochar

Additional considerations about use of gasifier stoves
It is not advisable to go for micro-gasifier stoves on household level. Prices in general are high for a gasifier stove, even though for household level cooking it will be much lower than for an injera gasifier stove. Acceptance probably is more difficult too, due to the handling which is more complicated with gasifiers. Nevertheless, additional research and prototype development would be required.

4.2.2 Achievements of objectives

Use of gasifier stoves and use of biochar
As described in chapter 4.1.1, the objectives concerning use of gasifier stoves with the use of biochar could not be achieved so far.

Development, adaptation and implementation in pilot project
Implementation of the gasifier was not feasible under the arising frame conditions. Development and adaptation of a functioning injera gasifier stove was achieved.

Reduction of waste – Use of coffee husk – Improved cooking – Social and economic benefits
For achieving the intended objectives concerning use of coffee husk, improved cooking and health situation, a much broader approach is necessary. Focus should lie on a holistic concept with different models of improved cookstoves, including injera gasifier stove, and different ways of using dried coffee husk and different target groups.

Looking at different possibilities for using coffee husk in Kafa (gasifier stoves, charcoal-production and briquettes for use in Tekikil-multifuel-stoves or charcoal stoves, co-firing in the newly promoted improved MIRT stoves), this objective can be reached. First possibilities which might be easier to achieve:

- Carbonizing coffee husk and briquetting through trained entrepreneurs through the NABU project component on one hand and on the other hand accompanied with huge awareness-rising through the NABU-project component the use of coffee husk for co-firing. However, carbonizing husk means energy-loss during carbonization which otherwise could be used. Emissions might be high during carbonizing process.
- Pelleting coffee husk and using them for co-firing in MIRT stoves.

In both cases a type of injera gasifier stove could be included in the concept.

Overall long term goal
Accordingly, achievements of the overall goal through only gasifier stoves is not feasible, the overall goal in general however can be achieved through a broader approach as mentioned above.

4.3 Multiplication / Replication Preparation

A lot of networking activities have been carried out to link with different stakeholders working with gasifiers or coffee husk. With these stakeholders, preparations for further use of the findings and implementation of an injera gasifier for later multiplication can be feasible.

GIZ BioDiv (Biodiversity program of GIZ in Ethiopia) is interested to work with coffee husk, possibly in Kafa Biosphere reserve or one of the neighbouring two biosphere reserves, Sheka and Yayu. They are interested to include the findings of the present pilot project with technology development and build up on the results.

For possible implementation and replication of the injera gasifier stove, a first stove of injera gasifier prototype 3 has also been installed and tested through users in another area of Ethiopia in Gamo Gofa zone where sundried coffee husk is available at local dehulling station.

4.4 Impact / Sustainability

The present project was stopped after developing a functioning prototype for injera gasifier stove with the feedback of local users and experts. Therefore, no impacts could be noticed during the pilot project before implementing the stove and before conducting trainings and doing any marketing activities.

5. Outlook / Further Actions

5.1 Next possible steps

Experience sharing and distribution of findings in workshop with actors
A lot of know-how and experiences with gasifier technology combined with coffee husk and Injera baking with gasifier technology have been gathered. To further share these findings, a workshop with relevant experts, different stakeholders and actors working with gasifiers, with injera and even with coffee husk, is necessary. Participants from the following sectors should be included: Stakeholders interested in biochar, the National improved cookstove program, actors from GIZ EnDEV, actors from Ethiopian universities like Addis Abeba University, Bahir Dar University, Jimma University or Mekelle University who have been working with gasifier technology.

Larger user field test of current gasifier model with slight adaptations
For having deeper knowledge about acceptance of the current injera gasifier stove model and the existing submodels, a larger user field test is recommended and shall be carried out. Only this gives the chance to know if slight adaptations can be integrated for having a good acceptance through users. However, it it is important to keep in mind that a too early release to the public bears the risk of public failure and therefore an image problem. Proper communication to test users is required.

Clean Cooking Test CCT
Parallel to the larger user field test, standardized Clean Cooking Test CCT for comparison with other stove types need to be carried out. Emissions shall be compared to have accurate data.

Check fuel type – pellets
It is advisable to check the possibility with coffee husk in pellet form again. Advantages are: technically a simpler model with lower height (less metal, cost optimization), a model without fan as initially intended a TLUD (Top Lift Up Draft) without forced draft (cost optimization, user friendliness), less husk storage needs. Challenges are finding lower cost pelleting possibilities with machines and good quality. Low investment costs for pelleting machines are crucial for economic viability. With conservative assumptions of the price, injera gasifier stove using pellets can be economically viable as shown in the calculations for economic viability above. Additionally, coffee husk pellets might be used for co-firing in MIRT stoves too and be therefore another advantage for using coffee husk in

densified form (caloric value). Transportation possibilities and user acceptance might be better than for loose coffee husk.

5.2 Multiplication / Replication

As the present project was stopped after developing a functioning prototype for injera gasifier stove and before implementation, multiplication and replication could not be prepared so far. Nevertheless, some preparatory and networking activities and have been done.

Biochar

The German Federal Institute for Geosciences and Natural Resources, in cooperation with Professor Bruno Glaser and Cornell University is probably planning a biochar project in Ethiopia in cooperation with the Ethiopian Ministry of Agriculture and Natural Resources MoANR. Connect the findings and results from the gasifier coffee husk project to these activities and to other gasifier/biochar initiatives is foreseen for bringing forward to multiplication the topic gasifier and biochar.

Promotion for other areas

These solutions with different cookstoves (MIRT, clay Tekikil-multifuel and in specific cases gasifier) and the use of coffee husk – loose, pelleted or in carbonized form – can also be considered as possible solutions for protected forest areas (e.g. National parks) in Ethiopia, where:

- alternative fuels like coffee husk or other agricultural waste is available
- pressure on the remaining forests is too high even though there are forest protection regulations
- additional alternative income-generating possibilities for fuel-wood collectors and sellers need to be created

For a quick impact, carbonization of the fuel like coffee husk and briquetting to coffee husk charcoal briquettes afterwards is a feasible alternative. However, if energy during the carbonization step is not used, this energy is lost and high emissions can result too.

For a higher long term impact with double use of the energy, energy from carbonization can already be pre-used, thus through use of the gasification process, e.g. for cooking/baking.

For another quick and longer term impact, pelleting of the coffee husk can be considered. For co-firing in MIRT stoves with higher efficiency through higher caloric value of densified material, easier transportation and less storage space and additionally through gasification with pellets and therefore better economic viability and easier handling. Only if costs for pelleting machine can be amortised within an acceptable time frame.

Willingness to pay for improved cookstoves

Willingness to pay for improved cookstoves from user side is important and is different from place to place, especially where people are used to receive things for free or strongly subsidized. Strong awareness rising and marketing activities have to be carried out to overcome this hurdle. In Kafa, after having received 11’000 MIRT stoves for free or only by paying for transport within the former NABU project in the Kafa zone, local willingness to pay is reduced and awareness rising for any improved cookstove which shall be paid for, is crucial. Nevertheless, in the current NABU project several activities are undertaken through the local energy consultants to raise awareness and increase willingness to pay.

5.3 Impact / Sustainability

A number of sustainable effects of the project was expected, which shall be met through the holistic concept where a gasifier injera stove might be one possibility for a specific target group (institutional and business Injera bakers), in combination with other cooking/baking and coffee husk solutions as described in the business model overview in chapter 4.2.1.

Environmental and CO_2 relevance:

- Protection of the forest and the trees (prevention of erosion, shadow from trees for the protection of coffee trees)
- Reduction of organic waste through recycling waste
- Doubled reduction of CO_2: Substitution of firewood by waste biomass as well as substitution of charcoal by biochar.
- Alternative use of the biochar with compost or manure as a soil improver
  → enhancement of soil fertility and completion of the nutrient cycle. → additional reduction of CO_2

Economic:

- Additional generation of income for local entrepreneurs: for the producers of the cookstoves
- Supplementary income and partially new business opportunities for local producers of Injera and restaurants
- Cost savings for users

Social:

- Improved health situation, especially for women and children:
  - Reduction of indoor air pollution
  - No carrying of heavy bundles of wood
- Time saving, for women and girls especially: Less collecting and carrying of wood, which allows more time for education and income-generating activities.

6. Lessons Learned / Conclusions

One of the main challenges was, that adaptation of a technology to local requirements, especially the combination of a gasifier with injera-baking and with coffee husk, takes a lot of time and continuous work with the local population on the ground. Gasifier themselves are not an easy technology, coffee husk is a difficult fuel and adapting stoves for injera-baking is challenging anyway regarding to local experts. Thus, combination of gasifier, coffee husk and injera is very challenging.

The variability of loose coffee husk is much higher than expected, depending on the climate and the time of the year. Quality of loose coffee husk can even differ from the same dehulling stations at different times of the year. Moisture content and ratio of smaller and bigger particles can vary. For this reason, stable pyrolysis process was challenging to achieve.

Technologically, a gasifier stove using loose coffee husk as fuel is feasible, with forced draft. Technology of injera gasifier stove has been shown to be technically feasible. Nevertheless, a main challenge remained that it had to be adapted for injera-baking.

Looking at the local acceptance in combination with a viable business model and economic mass production with a market, challenges are high again. However, the injera gasifier stove on institutional level is economically viable. It is necessary to look at other options additionally instead of focusing on a single solution. A holistic approach is possible.

Co-firing of coffee husk, carbonization of coffee husk and briquetting, pelleting of loose coffee husk are all options for using the coffee husk in a feasible way for cooking purpose.

Additionally, the intended collaboration with partners, especially for technology development and preparation of implementation, was more difficult than expected due to different reasons and frame conditions. Even though the good will for collaboration of all partners is existing. These hurdles influence the project implementation. Clarifying open questions from the beginning is advisable, e.g. with clear contracts and assignments for the working tasks of the involved parties.

7. References

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8. Annex

8.1 Sensitivity analysis for economic viability

a) <u>Institutional injera gasifier stove with 720 hours runtime per year</u>

Figure A1:
Sensitivity analysis for the economic factor 'lifetime'

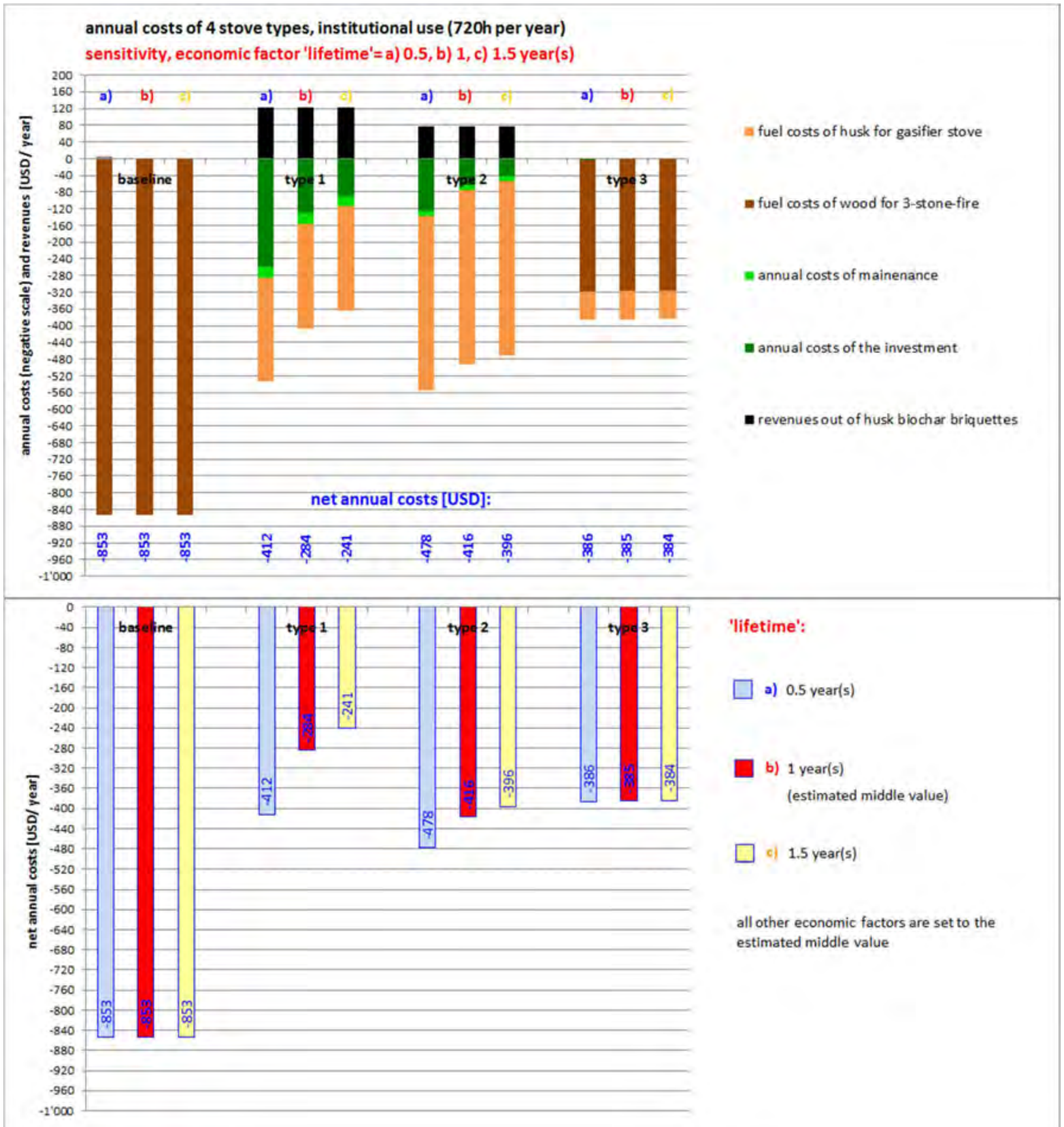


Figure A2:
Sensitivity analysis for the economic factor 'investment cost'

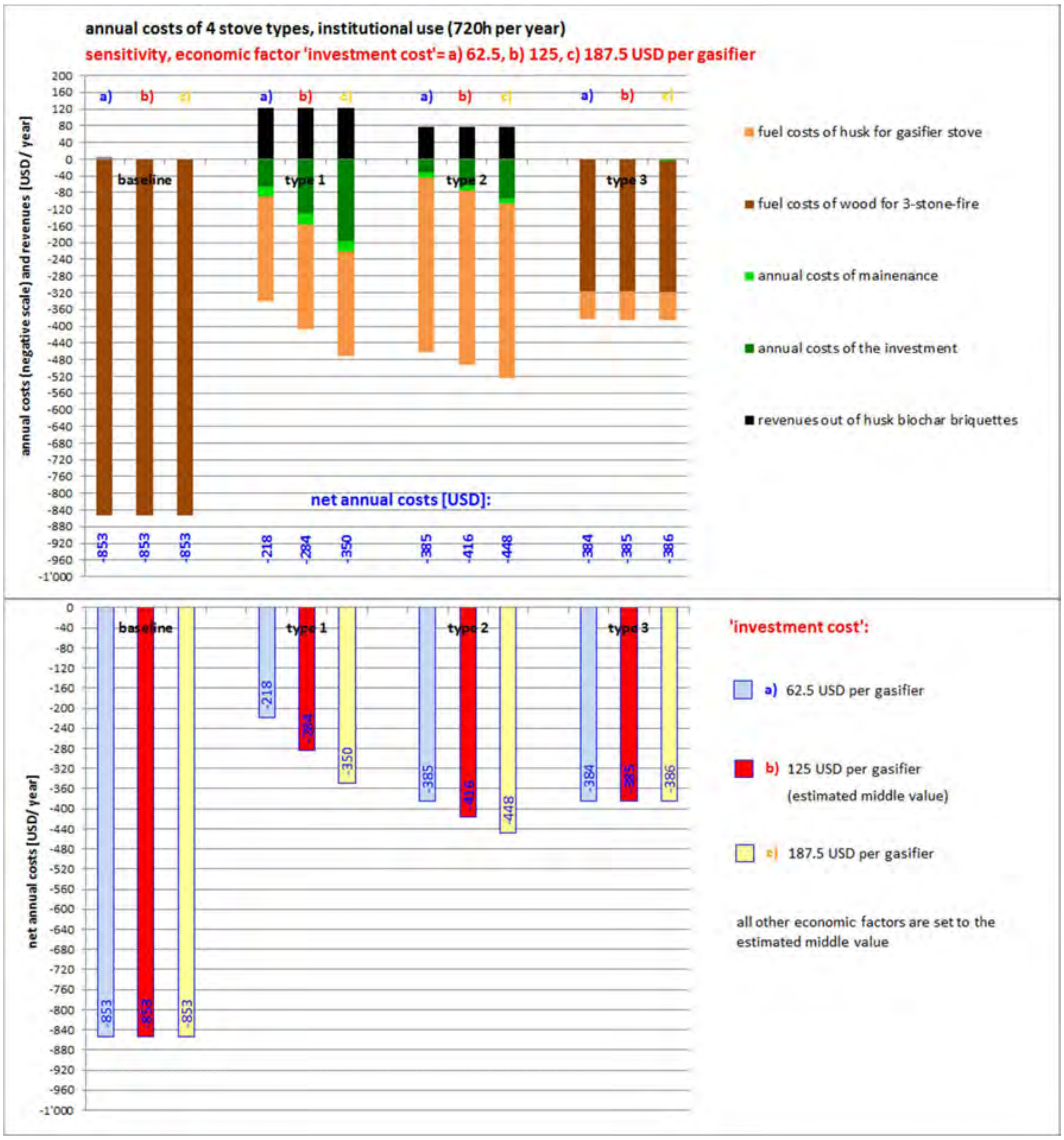
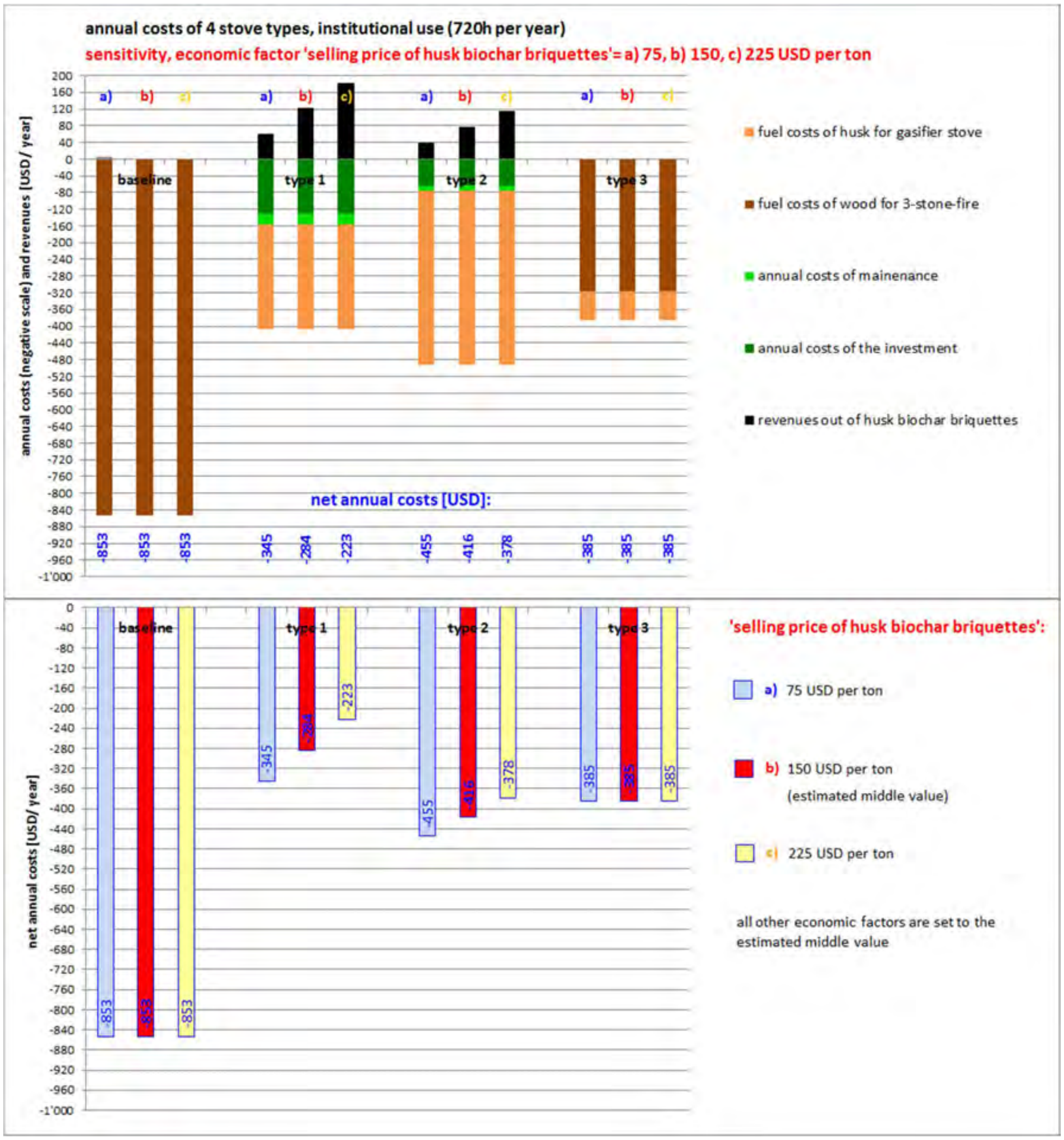


Figure A3:
Sensitivity analysis for the economic factor ‘selling price of husk biochar briquettes’



a) Household injera gasifier stove with 120 hours runtime per year

Figure A4:
Sensitivity analysis for the economic factor 'lifetime'

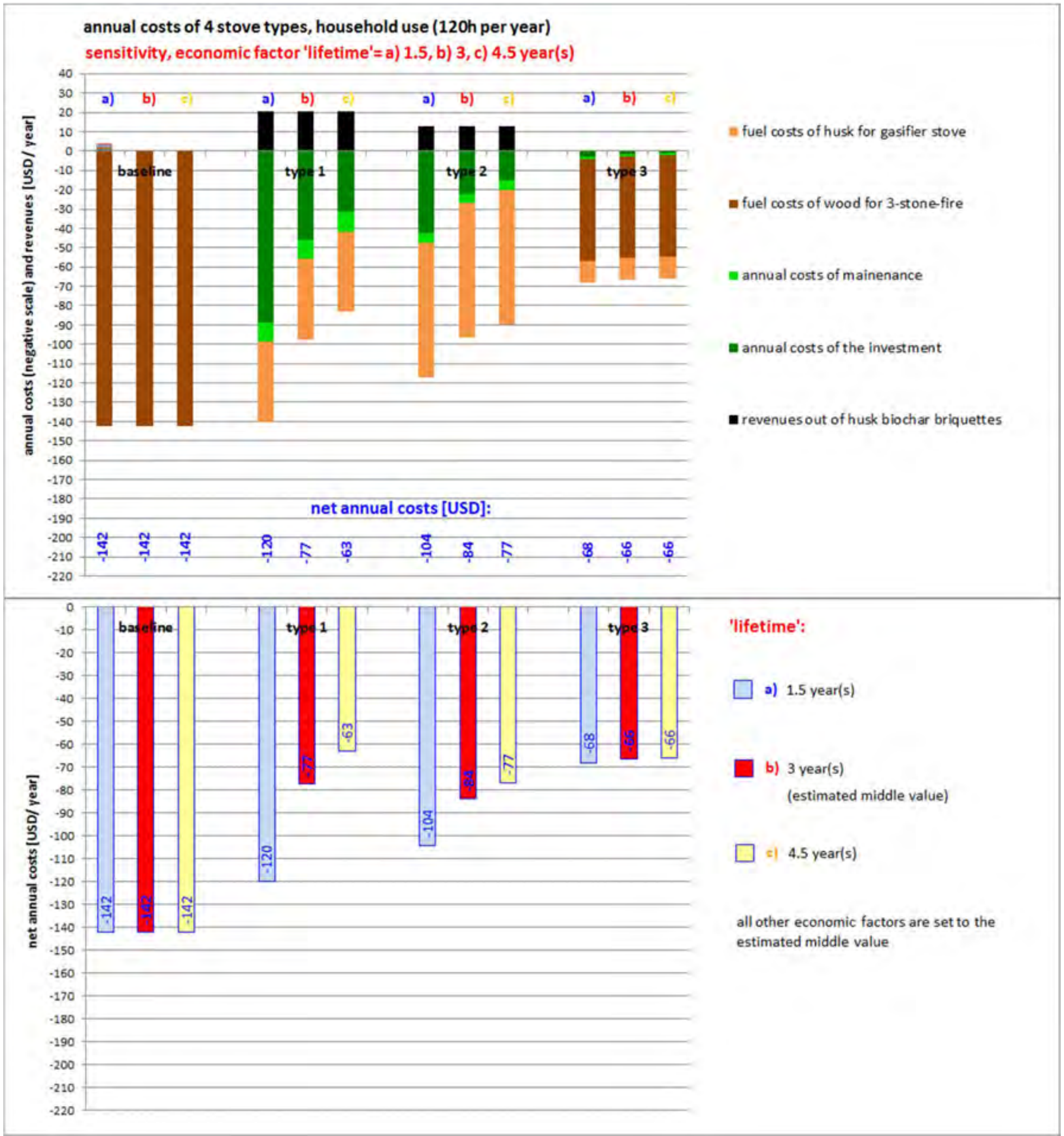


Figure A5:
Sensitivity analysis for the economic factor ‘investment cost’

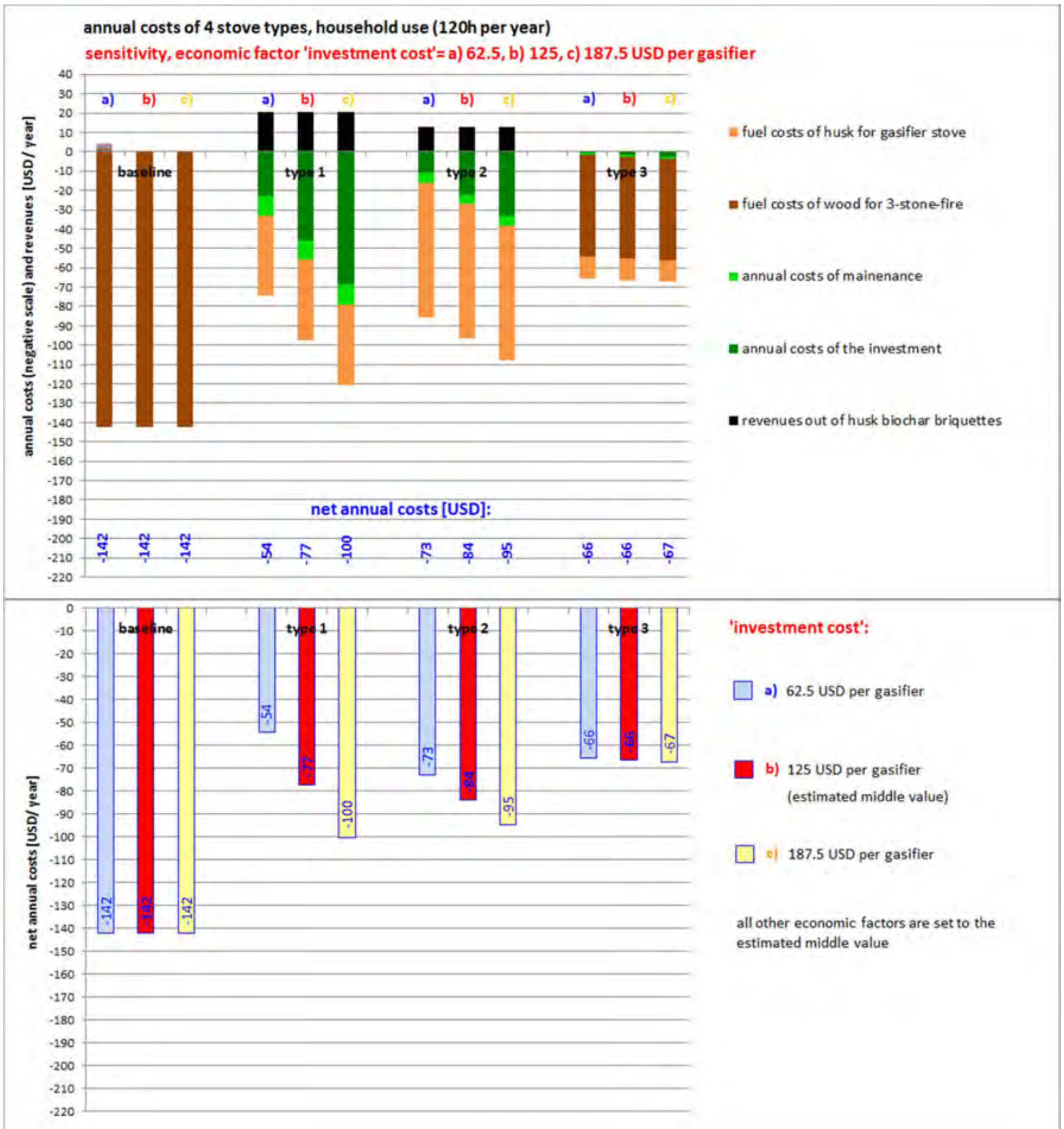


Figure A6: Sensitivity analysis for the economic factor ‘selling price of husk biochar briquettes’