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Four years of sustainability impact assessments accompanying the implementation of improved cooking stoves in Tanzania

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ABSTRACT

Development projects and innovations are often implemented based on scientific recommendations and do not incorporate local knowledge and demand for interventions. In this paper, we demonstrate the successful engagement of local stakeholders in the implementation and evaluation process of *improved cooking stoves;* a technology that improves food security in two climatically contrasting regions in Tanzania.

The *Framework for Participatory Impact Assessment* tool was used to conduct impact assessments on firewood-based *improved cooking stoves* to evaluate their contribution to food security at local stakeholder level. Between 2014 and 2017, four annual impact assessments were conducted with local stakeholders in four villages in the semi-arid Dodoma and the sub-humid Morogoro regions to assess the impact of *improved cooking stoves* on locally defined nine food security criteria. The *Framework for Participatory Impact Assessment* was used to (i) *ex-ante* identify the expected impact, and (ii) to *ex-post* assess the experienced impact of *improved cooking stoves* on the nine food security criteria. The impact assessments showed that the perceived contribution of *improved cooking stoves* towards the food security criteria was positive throughout all assessments. In particular, improved cooking stoves addressed relevant food security criteria such as *social relations, food availability,* and *market participation.* The *Framework for Participatory Impact Assessment* tool supported continuous knowledge exchange between scientists and local stakeholders, thus improving communication and co-learning; while identifying merits and demerits of the *improved cooking stoves* that could be addressed during the project lifetime.

1. Introduction

Food security is one of the most pressing issues for humankind. Especially in developing countries, people in rural areas struggle to secure and maintain food availability throughout the year. In 2015, about 795 million people worldwide (nearly 11% of the total population) were undernourished, with the highest share – 23% – living in Sub-Saharan Africa (FAO, 2016). Food security includes the three physical elements food availability, food accessibility, and food utilization. These elements are complemented by the temporal dimension stability, which refers to the availability of the physical elements of food security at all time (Gross et al., 2000; Weingärtner, 2009).

Around 66% of the Tanzanian population works in the agricultural sector (Diao et al., 2018). Nevertheless, a substantial number of people remain food insecure and vulnerable to external shocks. The agricultural sector presents low productivity growth (2.3% between 2010 and 2015) (Kuzilwa et al., 2017). Inefficient food value chains impair local communities, threatening rural livelihoods and contributing to food insecurity (Graef et al., 2014). Agricultural food value chains comprise production, processing, consumption, and marketing (Gómez et al., 2011). Interventions strengthening food security are required, but their effects differ across innovation types and implementation processes, which are all associated with different risks, potentials, and intended impacts (Breeman et al., 2015; Laurie et al., 2015; Notenbaert et al., 2017; Sieber et al., 2018). Stakeholder dialogue is a prerequisite for effectively addressing complex issues of food security. The introduction, implementation, and dissemination of development projects strengthening food security may require high resource input. By

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assessing local needs, potentially successful strategies can be discussed and identified prior to implementation, thus increasing the likelihood of success (Stringer and Reed, 2007). Reducing the amount of poorly used financial resources and number of unintended consequences is critical. However, decades of international development cooperation show that innovations are not always adopted and sustainably integrated at the local level, leading to development projects achieving poor success rates (Yalegama et al., 2016). One major reason for this is the non-involvement of local stakeholders in the decision and evaluation of a new technology (Khang and Moe, 2008).

Since the 1990s, development projects are increasingly involving local stakeholders in the selection of interventions and decision processes when preparing development projects (Böhnke et al., 2013; Cornwall, 2006; Curtis et al., 2013). Participatory impact assessments follow an integrated approach of combining researcher and local knowledge, integrating local populations in the decision making process regarding the introduction and evaluation of new technologies. Such approaches follow the assumption that local stakeholders know best about the most pressing problems in their communities and how to solve them (Reed et al., 2006; van Asselt Marjolein and Rijkens-Klomp, 2002). Often multiple stakeholder groups are included in the development of innovation, thus accounting for the complexity of innovation (Triomphe et al., 2015; World Bank, 2012).

There are a variety of participatory impact assessments for different scientific disciplines using IT based tools, consensus conferences, repertory grid techniques, as well as focus groups that steer decision making (Bond et al., 2012; de Ridder et al., 2010). The ImpresS (Impact of Research in the South) *ex-post* impact evaluation method is a participatory method that focuses on quantitative and qualitative impact evaluation in developing countries, which is based on an impact pathway concept (Faure et al., 2018). Data collection methods in ImpresS include interviews, focus group discussions, workshops, and surveys. The dialogue with actors focuses on identifying cause and effect relationships for innovation (Barret et al., 2018), as well as learning and management of innovations (Toillier et al., 2018). Another structured participatory impact assessment tool is the Participatory Impact Pathways Analysis (PIPA) tool. Participatory workshops are used to gather *ex-ante* assumptions of the impact of an innovation and to receive *ex-post* information during the implementation of a technology (Alvarez et al., 2010). There is no standardized method to conduct participatory impact assessments. The challenge of tailoring an assessment method to the situated, local, contextual, and technical requirements persist (Catley et al., 2007). After selecting a participatory assessment protocol, it should be used in a standardized way to avoid data bias across different assessments over time.

We used the *Framework for Participatory Impact Assessment* (FoPIA) tool to conduct quantitative and qualitative impact assessments at four case study sites in order to assess positive and negative impacts of improved cooking stoves (ICS) on food security, as perceived by local stakeholders (Partidario and Sheate, 2013), and to monitor perceptions of ICS over time (Schwilch et al., 2011). Initially, the FoPIA tool was developed to involve national, regional, and local stakeholders in order to assess possible implications of a policy decision as well as to identify potential challenges and existing shortcomings of interventions (Helming et al., 2011; Morris et al., 2011). The multidimensional view of FoPIA adds value for planning, implementation, and monitoring of newly implemented technologies (König et al., 2017, 2010; Schindler et al., 2016a,b).

We conducted impact assessments during both the selection and implementation processes of ICS to determine the *ex-ante* and *ex-post* impact of the technology (König et al., 2012). Researchers and local stakeholders decided jointly to introduce ICS at the case study sites because of its potential to enhance food security. Sufficient cooking energy is an important prerequisite for food security as it is directly connected to the amount and quality of food cooked (Scheid et al., 2018). The contribution of ICS towards food security was assessed using nine food security criteria (FSC) that covered the entire food-value chain (Schindler et al., 2016a, 2017). We focused on analyzing the impact of ICS technology on the early users, who are the main drivers of technology adoption. We expanded the existing FoPIA method, developed by Schindler et al. (2016b), analyzing whether ICS addressed critical FSC in the case study sites. We adjusted the FoPIA tool to (i) facilitate bottom-up engagement of local stakeholders into the assessment and implementation process of ICS; and to (ii) derive local knowledge to critically evaluate and improve the acceptance and adoption of ICS throughout the four year project duration.

The objective of this paper is to answer the question of whether ICS contribute to food security and evaluate its (positive or negative) contribution across four case study sites in the semi-arid Dodoma and sub-humid Morogoro regions of Tanzania. The findings are unique, as a systematic and iterative impact assessment of ICS and its perceived impact on food security in Tanzania does not exist.

2. Materials und methods

2.1. Case study sites

The four case study sites are located in the semi-arid Dodoma (Idifu and Ilolo villages) and the sub-humid Morogoro (Ilakala and Changarawe villages) regions of Tanzania. Most of the population is engaged in small scale farming, often with less than 5 acres of arable land. Although cash crops provide produce for markets, the primary focus is on subsistence farming, including livestock. Agricultural production primarily uses human and animal power. Most farmers at the case study sites use firewood with three-stone fire stoves to prepare meals. Firewood is mostly collected by foot (often several times per week); each trip to collect firewood can, depending on household location, take several hours.

In Dodoma region, located at the central plateau of Tanzania, the unimodal rainy season (250 mm – 570 mm) lasts from early December to April (Kahimba et al., 2014; Mnenwa and Maliti, 2010). Unpredictable and unstable rainfall patterns lead to high variability in yields, which directly affects food security (Kahimba et al., 2015). Staple crops are sorghum and millet; cash crops are sunflower and sesame (Graef and Sieber, 2018). Both villages have a long tradition of livestock husbandry (Mnenwa and Maliti, 2010). In terms of market access, Ilolo is advantaged with the nearest market within walking distance; unlike Idifu where the market is 20 min away using a motorcycle.

In Morogoro region, the annual rainfall typically ranges between 600 mm and 800 mm with a bimodal rainfall pattern between October to December and March to May (Graef et al., 2014; Mutabazi et al., 2015). Most of the population depends on subsistence agriculture combined with livestock keeping. Crop production is more diverse than in Dodoma region. The main cultivated crops are maize, sorghum, rice, legumes, and horticultural crops; sesame and sunflower are major cash crops (Mnenwa and Maliti, 2010). The village of Changarawe has relatively good market access and high food availability. Ilakala has relatively poor market access and exceedingly severe food security problems (Höhne, 2015; Röschel et al., 2016).

2.2. Improved cooking stoves

The ICS type in this study follows a rocket-stove model using firewood as fuel to operate. ICS are energy-efficient built-in stoves, constructed inside the homes of residents in the project villages (Hafner et al., 2018). The ICS has a two-pot design with one firewood slot that allows for cooking two pots simultaneously compared to the traditional three-stone fire stoves that can only accommodate one pot at a time (Fig. 1). Due to better insulation, ICS reduce the smoke burden during cooking and are energy-efficient compared to three-stone fire stoves (Garland et al., 2015; Jetter and Kariher, 2009). However, ICS types

Fig. 1. Improved cooking stove (ICS) with a two-pot design and one fire chamber (left), three-stone fire stove with insulation sheet (right).

and fuels used differ among different locations, thus resulting in different firewood consumption patterns during cooking (Grimsby et al., 2016). To construct this type of ICS, local materials such as clay, loam, ground nut husks, sand, and water are used. The ICS were introduced at the case study sites in 2014 as part of a development project. Initially, one ICS group per village was formed, comprising about 20 farmers per village. Together with experts, ICS group members constructed an ICS at their homes and received training on constructing stoves for other villagers. This training of trainers approach focused on enhancing local knowledge about constructing ICS. Trained farmers disseminated ICS, bottom-up, to other villagers.

2.3. *Ex-ante* and *ex-post* impact assessments of improved cooking stoves

Nine FSC were developed in a joint process together with scientists and local stakeholders in three steps: 1) literature review; 2) a researcher workshop; and 3) farmer focus group discussions. The nine FSC were used to evaluate the impact of ICS on food security. Developing bottom-up FSC instead of using pre-defined criteria from the literature ensured that the FSC were tailored to the local condition. The nine FSC were clustered into three sustainability dimensions (Table 1) (Schindler et al., 2016a, 2017):

- Social dimension (SOC)
- Economic dimension (ECO)
- Environmental dimension (ENV)

The quantitative and qualitative data of four impact assessments per village, with one *ex-ante* and three *ex-post* assessments of ICS (one assessment per year) between 2014 and 2017, were analyzed. Participation in FoPIA was voluntary: however, villagers could only participate if they were users of ICS and could construct stoves for other villagers. We selected new participants for each FoPIA session and ensured that each focus group assessment was gender-balanced consisting of 6 to 12 participants. The FoPIA followed a standardized procedure to maintain comparable settings across different focus group assessments.

Step 1 - Quantitative assessment

During this step, participants rated the positive and negative impacts of ICS on the FSC. In the first round, farmers evaluated the perceived positive effects on a four-point Likert scale from 0 (no impact) to 3 (very positive impact). During the second round, the perceived negative effects were evaluated on a four-point Likert scale from 0 (no impact) to -3 (very negative impact). For each village, we accumulated the positive and negative scorings per FSC and displayed the arithmetic mean value of the ratings across all nine FSC. We defined the following thresholds to categorize the cumulated mean scorings:

($-$) 3.0 to ($-$) 2.1: Very positive (negative) impact on FSC.
($-$) 2.0 to ($-$) 1.1: Moderate positive (negative) impact on FSC.
($-$) 1.0 to ($-$) 0.1: Marginal positive (negative) impact on FSC.
0: Neutral/no impact on FSC.

As Likert scale data is ordinal scaled, we opted to use non-parametric tests such as the Kruskal-Wallis test, to account for the non-normal distribution of samples (Sullivan and Artino Jr, 2013). The non-parametric Mann-Whitney *U* test was used to compare the ratings of the FSC across the impact assessments. The comparison is based on the rank given to each item by order of size. Therefore, the absolute differences are not taken into account (Mann and Whitney, 1947; Nachar, 2008; Sawilowsky, 2005). The Kruskal-Wallis test was used to compare the ratings of the four case study sites. The required data characteristics are the same as for the Mann-Whitney U test as well as the calculation principle, with the difference that more than two groups can be compared (McKight and Najab, 2010).

Step 2 - Qualitative assessment

Within focus group discussions, stakeholders explained the ratings

Table 1
Food security criteria (FSC), sustainability dimensions and corresponding definition.

Food security criteria	Sustainability dimension	Definition and regional relevance
Food availability	SOC	Sufficient number of meals (three) per day offering a diversified, balanced diet
Social relation	SOC	Community support during family need (i.e. drought, family incidences, such as illness, death) and share of workload (i.e. field ploughing), family support, and understanding of decision-making about household resources
Working conditions	SOC	Access to appropriate technology/equipment and agricultural practices, reducing working hours and workload
Production	ECO	Amount of food produced and available for family consumption and for selling
Income	ECO	Family financial resources earned from agricultural production and off-farm activities
Market participation	ECO	Selling and buying agricultural products and other needs; knowledge of market prices for improved negotiation power for farmers versus buyers
Soil fertility	ENV	Quality of soil for agricultural production
Soil water availability	ENV	Soil water availability for agricultural production
Agrodiversity	ENV	Cultivated crop variety for family consumption and selling: risk management in case of crop failure

they had given with arguments and discussed the results of the quantitative assessment. In order to avoid data bias, it was critical that the moderator of the impact assessments was able to speak the mother tongue of the stakeholders, preferably being capable of using local dialect to reduce communication problems (Purushothaman et al., 2013). We reduced interpretation bias by using local translators in order to improve the quality of the transcribed data and, hence, decision making. In addition, we ensured that the enumerator team consisted of experts with a regional background of the area to reduce not only language, but also cultural barriers.

Step 3 - Weighting of food security criteria

During the second *ex-post* assessment, the FoPIA method was extended. At the end of the focus group discussions, participants were individually asked to indicate the perceived three most important FSC in order to evaluate whether ICS addressed the most critical out of the nine FSC.

3. Results

3.1. Quantitative impact assessment results in Dodoma and Morogoro regions

Across all four impact assessments, we found a positive impact of ICS on the FSC criteria in the semi-arid region of Dodoma and in the sub-humid region of Morogoro (Tables 2 & 3).

In both regions, the overall impact of ICS was moderately positive. The overall contribution of ICS to the social dimension was very positive (Dodoma: 2.22; Morogoro: 2.29), followed by a moderate positive contribution (Dodoma: 1.75; Morogoro: 1.59) for the economic dimension and a marginally positive contribution (Dodoma: 0.64; Morogoro: 0.72) for the environmental dimension.

In Idifu village, participants of the impact assessments perceived a growing contribution of ICS towards the FSC between the *ex-ante* and the third *ex-post* impact assessment, indicating that the positive impacts of ICS were underestimated during the first assessment. In Ilolo village, the *ex-post* assessments were all moderately positive. During the second and third *ex-post* assessments, the contribution of ICS towards FSC stabilized and was perceived similarly by both focus groups (Fig. 2).

In Changarawe village, the impact assessment showed that the perceived contributions of ICS towards the FSC rose between the *ex-ante* and the final *ex-post* assessment, with a peak during the first *ex-post* assessment, from a marginal positive to a very positive impact. The experienced benefits of ICS during the first year of operation affected the FSC positively, reflecting the *ex-ante* underestimation of the benefits of ICS on food security, similar to Idifu village in Dodoma region. The quantitative ratings of the FSC were stable in Ilakala village throughout the impact assessments. The perceived contribution of ICS towards the FSC developed positively up to the third *ex-post* assessment (Fig. 3).

3.2. Qualitative impact assessment results in Idifu and Ilolo villages

In Idifu, the qualitative assessment showed that all three criteria of the social dimension had a very positive impact on food security. The positive contribution to *food availability* was connected to the technological improvements of cooking two pots at the same time which led to reduced need to purchase firewood, and reduced firewood collection time. The time saved was used to engage in activities related to food production. *Ex-ante*, the villagers anticipated that neighbours without ICS could be jealous because they did not receive ICS training. However, the technology raised the interest of neighbours and improved the communication between ICS and non-ICS users resulting in very positive ratings of the criterion *social relations* during the *ex-post* assessments. The high rating of the criterion *working conditions* was related to the fact that ICS did not need to be attended to during cooking; in addition the stove technology was perceived to be very secure for children and protected them from being burned. Other positive aspects included the low indoor smoke burden, which allowed other indoor activities during cooking. In addition, the firewood and time consumption for conducting a cooking task was reduced compared to three-stone fire stoves.

Within the economic dimension, the criteria *production* and *income* had a very positive impact on the FSC. Enhanced food production was connected to time savings induced by ICS with regard to firewood collection. In addition, the ash produced from ICS was used to fertilize soils, thus enhancing the criterion *production*. As three-stone fire stoves are normally placed outside, its resulting ash is blown away by the wind. This is not the case with ICS, which are operated indoors. The criterion *income* was rated very positively because of the income generation for stove constructors, resulting from stove construction for customers and the reduced need to purchase firewood to meet the domestic firewood demand when using ICS. During the *ex-ante* assessment, farmers did not expect that ICS could highly improve the criterion *market participation*. However, during the *ex-post* assessments, the impact of ICS on the criterion *market participation* was rated very positively. After the introduction of ICS, a stove market evolved with continued demand from other villagers to install an ICS. In addition, a market for firewood evolved to provide resized firewood for usage with ICS.

The environmental dimension was largely not affected by ICS. The marginal positive contribution of ICS towards the criteria *soil fertility*

Table 2
Ex-ante and *ex-post* participatory impact assessment results of improved cooking stoves (ICS) in Idifu and Ilolo villages.

Criterion	Dimension	Idifu								Ilolo[a]					
		Ex-ante		Ex-post 1		Ex-post 2		Ex-post 3		Ex-post 1		Ex-post 2		Ex-post 3	
		n = 10		n = 12		n = 9		n = 12		n = 11		n = 10		n = 10	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Food availability		2.00	1.41	1.91	1.36	2.11	1.27	1.75	1.14	1.09	1.51	2.50	0.53	1.70	0.82
Social relations	SOC	2.10	1.29	2.75	0.87	2.67	0.71	2.42	0.67	1.82	1.47	2.70	0.68	2.50	0.71
Working conditions		2.20	1.23	2.33	1.07	3.00	0.00	1.33	0.98	2.36	0.92	2.40	1.27	3.00	0.00
Production		1.40	1.43	2.17	1.12	2.00	1.00	2.75	0.45	1.18	1.17	1.60	1.17	1.10	1.29
Income	ECO	2.30	1.16	2.00	1.35	2.00	1.00	2.92	0.29	1.00	1.48	2.20	1.03	1.80	0.79
Market participation		0.30	0.95	1.50	1.24	1.78	0.97	2.92	0.29	0.64	1.63	1.90	1.20	2.00	0.67
Soil fertility		0.00	0.00	0.92	1.44	0.67	0.87	0.67	1.07	1.00	1.18	0.90	0.99	1.30	0.82
Available soil water	ENV	0.00	0.00	0.08	1.17	0.00	0.00	0.00	0.00	0.82	1.08	0.30	0.68	0.20	0.42
Agrodiversity		0.50	1.08	1.17	1.64	0.78	1.09	0.58	1.08	1.27	1.68	0.80	1.14	0.90	1.10

[a] In Ilolo, no *ex-ante* impact assessment was carried out.

Table 3
Ex-ante and *ex-post* participatory impact assessment results of improved cooking stoves (ICS) in Changarawe and Ilakala villages.

Criterion	Dimension	Changarawe								Ilakala[a]					
		Ex-ante		Ex-post 1		Ex-post 2		Ex-post 3		Ex-post 1		Ex-post 2		Ex-post 3	
		n = 13		n = 7		n = 12		n = 9		n = 11		n = 11		n = 9	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Food availability	SOC	0.15	0.55	2.29	0.76	2.08	1.17	2.38	0.96	2.45	1.04	2.64	0.67	2.22	0.83
Social relations		0.38	0.96	2.71	0.49	2.42	0.90	2.62	0.51	2.64	0.51	2.82	0.41	2.67	0.50
Working conditions		2.00	1.08	2.71	0.49	2.83	0.39	2.62	0.65	2.91	0.30	2.55	1.04	2.78	0.67
Production	ECO	0.31	0.75	2.71	0.49	1.83	1.19	2.00	0.91	1.55	1.29	1.55	1.37	1.89	1.05
Income		0.38	0.96	2.43	1.13	2.08	1.00	2.15	0.55	1.64	1.29	2.55	0.69	1.89	0.93
Market participation		0.23	0.83	2.00	1.41	0.75	1.06	1.62	0.65	1.27	1.27	1.18	1.33	2.44	0.73
Soil fertility	ENV	0.00	0.00	1.71	1.38	0.83	1.12	1.38	1.39	0.27	0.91	0.00	0.00	0.00	0.00
Available soil water		0.00	0.00	2.29	1.11	0.42	1.00	0.00	0.00	0.36	0.81	0.00	0.00	0.11	0.33
Agrodiversity		0.08	0.28	2.57	0.54	0.33	0.78	1.38	1.04	1.18	1.25	1.45	1.37	1.44	0.88

[a] In Ilakala, no *ex-ante* impact assessment was carried out.

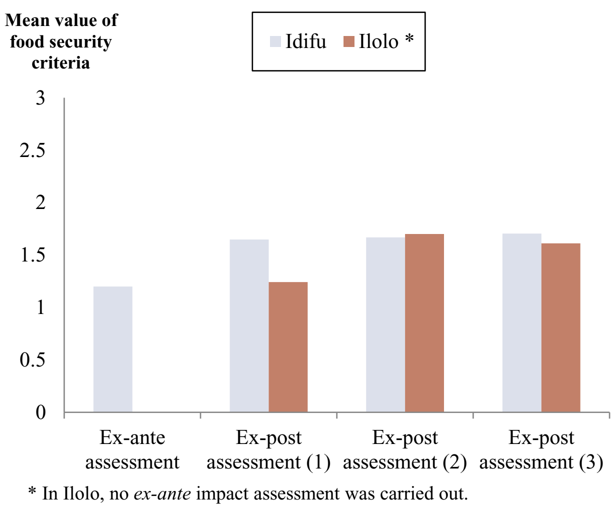

Fig. 2. Mean value of perceived impact of improved cooking stoves (ICS) on the nine food security criteria (FSC) at Idifu and Ilolo villages.

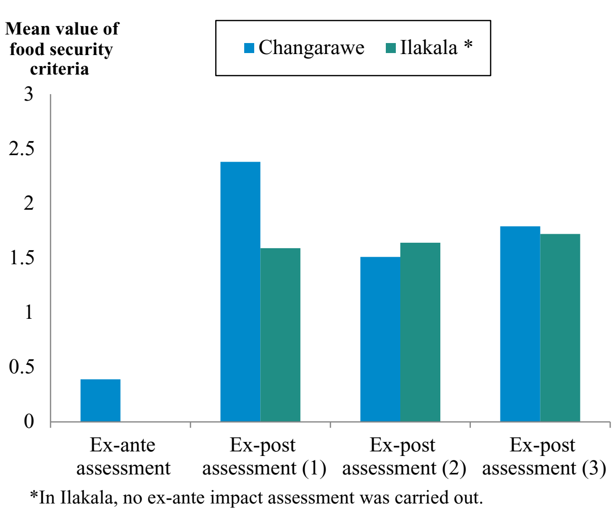

Fig. 3. Mean value of perceived impact of improved cooking stoves (ICS) on the nine food security criteria (FSC) at Changarawe and Ilakala villages.

and *agrodiversity* was connected to the ash produced during the usage of ICS, which was used to fertilize soils. Time savings induced by ICS resulted in enhanced agricultural and pastoral diversified production. *Soil fertility* was also indirectly improved as green matter from trees that were not pruned, due to reduced firewood demand, contributed soil organic matter. The criterion *available soil water* was not influenced by ICS.

In Ilolo, the qualitative ratings underlined that ICS were similarly perceived as in Idifu. Within the social dimension, *social relations* and *working conditions* were rated very positively. Reasons for the positive evaluation of *social relations* were enhanced social exchange between neighbours and within the family. ICS were perceived to be safer for children and the reduced indoor smoke allowed the family to sit together during cooking.

The criterion *working condition* was positively rated due to the two-pot design of ICS and reduced smoke development during cooking. Negative evaluations of the criterion *working conditions* were connected to the fact that some ICS were not properly constructed, with the wrong ratio of input materials used for stove construction, resulting in poorly functioning stoves. This argument was no longer mentioned during the last *ex-post* impact assessment, thus indicating that local stove constructors learned how to construct high-quality ICS with experience.

The criterion *food availability* was rated moderately positive. Using unsuitable firewood, such as oversized firewood, led to reduced heat development during cooking, leaving the food partially uncooked and resulting in negative ratings. In addition, during the introduction of ICS, there was a misunderstanding between researchers and villagers about the required humidity level of firewood, which resulted in operating ICS with insufficiently dried firewood, which led to a negative rating.

The contribution of ICS to the economic dimension was moderately positive. The positive rating of the criterion *production* was due to the safe and efficient usability of ICS, which left more time for alternative activities. The criterion *income* was rated moderately positive during the first *ex-post* assessment. Negative income related aspects were connected to unsuitable firewood that did not burn properly and went out during cooking. The evaluation of the FSC *market participation* was marginally positive during the first *ex-post* assessment. Negative aspects were caused by the fact that the commonly sold firewood did not fit into the ICS fire chamber; therefore reducing the market interaction of ICS users buying firewood. In addition, the local market of clay pots was disturbed due to the fact that clay pots could not be used with ICS, resulting in a less market demand for clay pots. Positive aspects of *market participation* were connected to the creation of a market for input materials needed for stove construction. During the second and third *ex-*

post assessment, cumulative scorings of the criteria *market participation* and *income* were far more positive compared to the first *ex-post* assessment, indicating that sellers adjusted to the changed market conditions and the new requirements of the ICS technology. Because of reduced indoor smoke, households' health expenditures were less compared to those using three-stone fire stoves. Reduced need to purchase firewood saved money, which was invested to enhance food production. The hot leftover charcoal was used for hatching chickens, thus diversifying food production and improving *income*. ICS made it more profitable for food vendors to sell cooked food, which enhanced the criterion *market participation.*

ICS had a marginal to moderate positive impact on the environmental dimension. While a moderate positive impact was accounted to *soil fertility* due to usage of the by-product ash as fertilizer, others claimed not to benefit from a fertilizing effect caused by applying ash. Due to the reduced need of firewood, the cut-down rate of trees was reduced, which enhanced the criterion *available soil water*. In addition, farmers cited that soil moisture in the fields was enhanced due to increased mulching. As crop residuals cannot be used with ICS, the farmers left them on the farm instead of collecting them to be used as fuel. The impact on *agrodiversity* was rated marginally positive and rather indirect, as saved money from using ICS was used to broaden agro-pastoral activities.

3.3. Qualitative impact assessment results in Changarawe and Ilakala villages

During the qualitative assessment in Changarawe, the evaluation of the criterion *food availability* rose from marginally positive during the *ex-ante* assessment to very positive during the third *ex-post* assessment. Savings from reduced firewood consumption resulted in enhanced food purchases. The construction of stoves enhanced household income and, indirectly, food availability. The impact from ICS on the criterion *social relations* rose from marginal to very positive from the *ex-ante* assessment to the *ex-post* assessments. Due to enhanced communication resulting from ICS usage, the relationship between neighbours and within the family improved. Some villagers perceived the prices for hiring a stove constructor as too high, which led to tensions within the village and affected *social relations* negatively. The criterion *working conditions* was rated very positively. The workload to collect firewood was reduced, which especially benefited minors and female household members who often carry the burden of supplying the family with firewood. In addition, safety aspects connected to ICS as well as reduced smoke burden during cooking, which reduced the need to frequently change clothes, were cited as important drivers for the positive evaluation of *working conditions.*

The contribution of ICS towards the economic dimension was rated, *ex-post,* moderately positive compared to the marginal positive impact during the *ex-ante* assessment. During the *ex-post* assessment, an increase in the rating of *production* was recorded due to greater time availability resulting from the usage of ICS. Enhanced income was used to hire farm labor. In addition, *income* increased due to the commercial production of ICS for other users, which also contributed positively to *market participation.* On the other hand, *market participation* also received negative ratings due to the reduced turnover of sold firewood. During the *ex-ante* assessment, the villagers did not expect ICS to contribute to the environmental dimension. However, the *ex-post* assessments showed that ICS had a moderate positive impact on *soil fertility* and *agrodiversity. Soil fertility* was indirectly enhanced by reducing the number of trees cut as well as due to increased fertilizer purchases made with the savings from using ICS. Due to increased income, not only new types of crops were planted, but also different types of animals bred, improving the criterion *agrodiversity.*

In Ilakala, the qualitative ratings underlined the very positive impact of ICS towards the social food security dimension. The criterion *food availability* was supported by ICS because of the two-pot design, which allowed to cook with two pots simultaneously. In addition, the heat released during cooking was perceived to be balanced, which increased the quality of the food cooked. Saved time due to reduced firewood collection and reduced costs to purchase firewood resulted in enhanced and improved food production activities. *Social relations* improved due to better interaction within the families and with neighbours who came to learn about ICS technology. Due to its safe operation, it allowed mothers to keep their children next to the stove during cooking instead of leaving them outside the kitchen. The relationship between ICS users improved due to the exchange of ideas on how to operate the stove best. Nevertheless, *social relations* within families was also rated negatively, especially in the early operation stage of ICS when improper firewood led to poor ignition and poor function of the stove as well as when stoves were constructed with inferior input materials. *Working conditions* improved due to the safe and quick operation of stoves as well as reduced need to collect firewood. Reduced indoor smoke made cooking more comfortable. However, negative impacts on the rating were connected to the firewood preparation steps before cooking: firewood had to be resized and dried properly before usage with ICS to avoid improper ignition and functioning of the stove.

The contribution of ICS towards the economic dimension was moderate to very positive. The criterion *income* was very positively affected by ICS due to income generation from construction of ICS and reduced spending due to lower operational costs for cooking. Saved time from using ICS was spent to conduct other income generating activities like selling fruits. ICS showed a marginal positive impact on the criterion *production*. The saved time from using ICS with regard to cooking time and time needed to collect firewood was used for agricultural activities. During the rainy season, the production of stoves was reduced, which lowered the rating of the criterion *market participation* during the first and second *ex-post* impact assessment. The environmental dimension was mainly not affected by ICS. ICS contributed marginally positive to the criteria *soil fertility, available soil water,* and *agrodiversity*. Applied by-products, such as ash on farms and reduced number of trees cut contributed positively to the criteria.

3.4. Evaluation of food security criteria in Dodoma and Morogoro regions

During the second *ex-post* assessment, local stakeholders indicated the three most important – as they perceived it – FSC. We found that the ICS addressed most important FSC. In Table 4, the three most often cited FSC are listed together with the average rating of the criteria

Table 4
The locally perceived three most important food security criteria (FSC) per village.

	Idifu		Ilolo		Ilakala		Changarawe	
1	Social relations	2.49	Social relations	2.34	Food availability	2.44	Food availability	1.73
2	Working conditions	2.22	Market participation	1.51	Production	1.66	Market participation	1.15
3	Market participation	1.63	Production	1.29	Market participation	1.63	Agrodiversity	1.09
Ø 3 FSC		2.11		1.72		1.91		1.32
Ø 9 FSC		1.55		1.51		1.65		1.52

Table 5
Analysis of variance of improved cooking stoves (ICS) contribution towards the food security criteria (FSC) per impact assessment across the four case study sites.

Criteria	*Ex-ante** assessment	*Ex-post* (1) assessment	*Ex-post* (2) assessment	*Ex-post* (3) assessment
Food availability	0.001	0.100	0.630	0.175
Social relations	0.002	0.115	0.573	0.829
Working conditions	0.462	0.294	0.567	0.000
Production	0.023	0.021	0.851	0.009
Income	0.001	0.150	0.537	0.002
Market participation	0.849	0.279	0.076	0.000
Soil fertility	1.000	0.113	0.066	0.007
Available soil water	1.000	0.003	0.268	0.194
Agrodiversity	0.340	0.144	0.127	0.154

* Idifu and Changarawe village
Significant differences at a level of significance of 0.05

during the four impact assessments. Depending on local context and individual preferences, some FSC are more important to villagers than others. In Dodoma region, the important FSC, *social relations* and *market participation,* were addressed by ICS above average; in Morogoro region, the criterion *food availability*.

Although the strategies were implemented uniformly at all sites, we found that the contribution of ICS towards the FSC differed significantly. We analyzed the ratings of one year of impact assessment across the four villages. Table 5 shows the *p*-values of the analysis of variance between the four case study sites per FSC and impact assessments, demonstrating whether the perceptions of ICS regarding the FSC were significantly different (highlighted in grey) or not.

4. Discussion

4.1. General implications of the impact assessment results

In this study, the integrative approach of FoPIA was used to evaluate the contribution of ICS to relevant FSC in four project villages in the semi-arid Dodoma and sub-humid Morogoro regions of Tanzania. With one *ex-ante* and three *ex-post* impact assessments, local stakeholders identified perceived bottlenecks and challenges throughout the introduction and implementation process of ICS (König et al., 2017). Our analysis provided a holistic analysis of local perceptions of ICS, which was important for identifying the merits and demerits of ICS at the case study sites (Schindler, 2017).

Overall, the quantitative ratings of FoPIA showed that ICS positively impacted FSC across all villages. The social food security dimension (*food availability, social relations,* and *working conditions*) benefited most from ICS in all villages. In particular, the fact that people must walk considerable distances to collect firewood in Idifu and Ilolo contributed to the positive rating of *working conditions.* Each firewood collection trip takes (return trip and collecting firewood at site) 287 min in Idifu and 197 min in Ilolo (Hafner, 2016), which is more than in Morogoro region (45–75 min) (Yustas et al., 2014). Although the economic criteria *production, income* and *market participation* improved due to the use of ICS, the actual contribution of ICS towards these criteria was moderately positive. Due to the very positive qualitative assessment with regard to enhanced household income and the creation of a stove market in some of the villages, a higher rating of these FSC could have been expected. The low marginal positive rating of environmental dimension might be connected to the fact that environmental impacts were not yet visible during the assessment time.

Low expectations concerning the benefits of ICS led to *ex-ante* moderate positive ratings in Idifu and marginally positive ratings in Changarawe. In Idifu and Changarawe, the ratings of the *ex-post* assessments surpassed the *ex-ante* ratings, indicating that *ex-ante* assessments might be misleading when quantifying the potential benefits of a new technology. The *ex-ante* assessments showed that the proposed type of ICS was a new technology for most participants. There were uncertainties about the construction and the utilization of the stove (e.g. firewood size and optimal firewood moisture content, among others) using two-pots at the same time. These uncertainties were reflected in the lower *ex-ante,* compared to the higher *ex-post,* ratings.

The evolving ratings across the four FoPIA demonstrated that the perception of ICS was not linear but rather highly spatial and temporal specific (Douthwaite et al., 2003; Faure et al., 2018; Harkema, 2003). Our findings indicated that ratings of FSC deviated from the *ex-ante* evaluations displaying the learning effect of local stakeholders (Bond et al., 2012; Gibson, 2006). This became evident among stove builders, as the constructed stoves became more durable and included added functionality over time. The learning effects were also evident among the users of stoves, who learned what size and type of firewood was optimal to operate the ICS more efficiently. Learning effects resulted in changes of FSC ratings. In Idifu, for example, the criterion *production* increased between the *ex-ante* and the first *ex-post* assessment, indicating that the benefits of ICS with regard to time saved during cooking was realized during the first year of ICS utilization resulting in a very positive evaluation. During the first year of usage, users realized that they could use the ashes produced in the ICS to fertilize their home garden to enhance horticultural production which potentially diversifies households' diets. Similar developments were observed for the criterion *market participation,* where markets for adequate firewood and cooking equipment had to be adjusted to the new ICS technology, which resulted in a growing positive contribution towards the criterion.

As the implementation of ICS within the case study sites was not done simultaneously, the positive and negative experiences related to ICS occurred at different points in times, thus leading to variations in the ratings across the *ex-post* assessments. The ups and downs in the ratings across time were connected to perceived benefits and challenges during different impact assessments. In Changarawe, the criterion *market participation* dropped during the second *ex-post* assessment due to the fact that the new ICS required less firewood, thus reducing the total turn-over of firewood sold. However, after discussing the benefits of reduced firewood consumption on the environment and on the criterion *working conditions*, local ownership of the production process improved as well as the rating of the criterion during the subsequent assessment. Participatory monitoring, evaluation, and learning mechanisms are critical for ensuring behavioural change (Lennie et al., 2011).

4.2. Site-specific implications of the impact assessment results

Local context influenced the responses and development of FSC, limiting the transferability of the developed indicators to other sites, which might be tempting to reduce the resource input for impact assessments before and during a project. We found that using the results to predict the perception of ICS in other villages might be limited and depend on the socio-economic context in each respective village. However, also different socio-economic contexts can lead to similar developments or ratings during a project, which makes it difficult to draw causal conclusions. In Changarawe, the villagers stated that a market for stoves evolved, which might be explained by its proximity to the nearest market. However, in Idifu, a village with limited market access, a market for stoves evolved as well.

The results indicate that the perceived impact of ICS towards the FSC differed significantly across the villages, especially during the *ex-ante* and the third *ex-post* assessments. The high variance of ratings during the *ex-ante* assessment can be explained by the novelty of ICS in the villages and the contrasting expectations of the technology in each village. The first and second *ex-post* assessments showed that, after implementation, the ratings of ICS were quite homogeneous, indicating a uniform perception of ICS during the first two years of implementation. The diverging ratings during the third *ex-post* assessment might be explained by the different uses and individual developments of the ICS technology at each site. However, when spatial and socio-economic information are available and food-value chains as well as connected risks are comparable, the FoPIA results may be transferable to other sites (Müller, 2011; Riisgaard et al., 2010). This statement is underlined by our findings, which show that the perception of ICS and its contribution to the three food security dimensions were similar across the two contrasting regions of Dodoma and Morogoro.

Throughout the project, multiple hundreds of ICS were constructed per village, whereby more stoves were constructed in the Dodoma than in the Morogoro region. Forest degradation and walking distances to collect firewood is a more severe problem in Dodoma region, thus supporting the assumption that perceived scarcities led to a higher adoption of ICS in the region. This rationale indicates that introducing ICS in a severely degraded context might result in higher adoption rates than if firewood scarcity is not perceived to be a pressing problem.

Addressing locally perceived challenges along the implementation process might be another factor for successful implementation. The challenge connected to badly constructed stoves was addressed; stove builders received regular training on stove construction, which was initiated after early users complained about the low durability of their stoves. In addition, available labor at the household level might promote the usage and uptake of ICS. In particular, households that set aside labor for other economic activities, such as animal husbandry, may not have sufficient labor available to collect firewood and, therefore, opt to adopt the ICS technology. Technology adoption is frequently S-shaped with invention, innovation, and adoption phases (Hagedoorn, 1996). Long-term adoption of ICS is influenced by individual socio-economic situations and challenges throughout the implementation and dissemination process (Troncoso et al., 2007). However, the results of the impact assessments cannot predict the long-term success of ICS at the case study sites. Further *ex-post* assessments over a larger time horizon are recommended to determine the long-term implementation of ICS at the sites. Uckert et al. (2017) note that the successful implementation of ICS during the project was a result of addressing perceived challenges on the ground, including firewood scarcity, high smoke burden, as well as enhanced security during cooking. Further factors for adoption might be user applicability of the technology as well as effective financing of the stoves (Rehfuess et al., 2014). A holistic impact assessment throughout the project duration is recommended to account for challenges occurring during the project. This reduces the risk of drawing incorrect site-specific conclusions from the observations made during the *ex-ante* impact assessments.

4.3. Merits and demerits of the FoPIA tool

The results of the impact assessments provided a detailed picture of the perception of the ICS, which was an important prerequisite for providing feedback to the villagers as well as to address challenges connected to the technology in order to enhance local ownership of ICS and to support its implementation. The FoPIA tool was used to inform and gain information from local stakeholders and scientists (Ridder and Pahl-Wostl, 2005). The application of the tool follows an inclusive bottom-up approach and provides a structured framework for the local population to *ex-ante* and *ex-post* assess the impact of a new technology on their livelihoods (König et al., 2012; Schindler et al., 2015; Singh et al., 2009). It is a flexible and interdisciplinary tool that can be adjusted to different socio-economic environments and includes local stakeholders in the selection process of a new technology. There is no *ex-ante* impact assessment method that gathers all information from a complex system (de Ridder et al., 2010); therefore the final decision to select a new technology should be made jointly between local stakeholders and researchers. The *ex-ante* assessment showed that it is challenging for farmers to anticipate a priori impacts of a new technology.

The nine FSC were selected to reflect relevant dimensions of food security and in order to keep the FoPIA tool operational (König et al., 2010, 2013). Additional FSC might have led to confusion during the assessment and to additional complications in differentiating the criteria. Studies reveal that it is particularly difficult for participants to aggregate complex reality into indicators (König et al., 2013), which impairs the quality of the results and makes the subsequent qualitative focus group discussion essential (Morris et al., 2011). This project benefited from a site-specific definition of FSC, as the definition of food security might vary across sites and local contexts; thus, the participatory definition process is vital.

Impact assessments are time-consuming for researchers and participants (König et al., 2010). Time limitations during the focus group discussions can impair the quality of the discussion, as not all comments can be sufficiently discussed. In our assessment, we focused on providing sufficient room for participants to verbalize their experiences with ICS. We followed a predefined time schedule that determined the available time per FoPIA and, therefore, limited the overall duration of the qualitative assessment part. The feedback provided by the villagers indicated that the time used during impact assessments was sufficient to discuss relevant contributions during the qualitative assessment. However, for other assessments, we recommend that researchers include buffer time in order to encourage additional discussions when needed. Further, rather simple aspects can lead to delays during the FoPIA assessments; e.g. participants arriving late, which reduces the available time for the impact assessment. During the first impact assessment, it was a challenge to keep to the timetable; after multiple impact assessments, both the involved researchers and the participating villagers got used to the procedure, which resulted in an improved efficiency of the process over time.

A benefit of the applied impact assessment method was its clear structure and coherence. We used the same impact assessment method across all villages and provided feedback to the villagers about the outcome of each impact assessment, thus achieving a high level of transparency (König et al., 2010). Although FoPIA follows a structured approach, it provides the flexibility for participants to share experiences. However, any method measuring impact assessments must find a balance between the complexity of the system and the simplification required to make an investigation possible (McIntosh et al., 2008). This became visible during the quantitative assessment, when a different scale to rate FSC could have been used and when villagers provided oversimplified answers during the qualitative assessment to explain their ratings (König et al., 2010, 2013; Schindler et al., 2015).

The impact assessments were done annually, which required the participants to make an assessment over a time period of one year. In order to avoid seasonal data bias due to external factors such as extensive rainfalls and droughts, FoPIA was done at the same time of the year throughout the project. This guaranteed a balanced picture of the perception of ICS. However, the rather long period under review includes the risk that villagers did not provide a full account of their experiences but rather rated ICS based on individual (positive or negative) experiences that they could remember at the point of assessment. Therefore, we emphasized at the beginning of each FoPIA that participants should try to provide a full and balanced account of their experiences with ICS in order to avoid data distortion due to incomplete ratings.

Impact assessment is challenging with regard not just to logistics but also to introducing the concept and method. A positive aspect of our assessment was that it was easy to follow-up and intuitive for researchers and local stakeholders. During each FoPIA, we invited different participants from the villages, thus preventing the process from being perceived as boring and repetitive by the participants. Each year, it was necessary to explain the FoPIA procedure in detail and, at the same time, maintain stakeholder motivation to make the workshop more effective and interesting (König et al., 2010; Ridder and Pahl-Wostl, 2005). In order to maintain manageability of the focus groups throughout the FoPIA process, a group size of 6 to 12 participants was selected (Morgan, 1996). The assessment of a relatively small sample size resulted in high standard deviations indicating that the perception of ICS in the villages was heterogeneous. Although the ICS users per village were considered as a homogeneous group, changing participants during FoPIA assessments across the years contributed to varying ratings of ICS. Due to the small sample size, conclusions must be assessed carefully, including the potential that extreme scorings by participants affect overall ratings. Nevertheless, a larger number of FoPIA participants would have impaired the practicability of the impact assessments. An increased group size might be suitable for other technologies where a more diverse qualitative assessment is necessary. Based on our findings, we do not recommend expanding the group size during the impact assessments; in particular, the quality of responses during the qualitative assessment might not be enhanced by a larger number of participants. We selected an equal number of male and female participants during FoPIA to enhance the objectiveness of the scores and responses, addressing the issue that gender biased responses neglect one gender (Graef et al., 2018). While men often make investment decisions in the case study sites (such as purchasing an ICS or not), women are traditionally responsible for cooking and perceiving the benefits and challenges of the technology directly.

Further advantages of the FoPIA tool are that it is inclusive and provides direct solutions to problems encountered with ICS. The impact assessments benefited from the active participation of stakeholders (Bond et al., 2012; Schindler et al., 2017). Active participation throughout the impact assessments was self-enforced as ICS users were interested in participating in FoPIA, providing insights into their experiences when using ICS. After participating in FoPIA, villagers received feedback on the assessment. This included hands-on recommendations connected to their responses during the qualitative assessment, which also boosted farmers' motivation; there were no monetary incentives provided to participate in FoPIA. The willingness of participants to share their experiences with ICS differed during the assessments. This dependency on participant contributions bears the risk of not receiving quality answers when the participants are neither motivated nor willing to share their experiences.

The information exchange between researchers and local stakeholders is often limited due to socio-cultural differences. Scientists overestimate their ability to properly identify needs and expectations of local stakeholders, leading to the introduction of inappropriate technologies (Hoffmann et al., 2007). While researchers are able to determine the environmental, social, and economic situations of a case study site based on secondary data, individual needs and requirements at the local level need to be considered (König et al., 2010). The exchange of ideas between researchers and local stakeholders resulted in an adapted ICS design incorporating both local preferences and scientific requirements. Lessons learned during the impact assessments were transferred among ICS users during local meetings of the ICS user groups where key outcomes of FoPIA were discussed. However, FoPIA cannot completely solve the challenges of a scientist-local stakeholder dialogue. We found that perceptions on gender roles in focus group discussions as well as unpredictable group dynamics during the impact assessments can lead to limited contributions of individuals, thus potentially impairing the quality of the results.

5. Conclusion

This study presents four *ex-ante* and *ex-post* impact assessments of ICS on food security at four case study sites using the participatory FoPIA tool. The FoPIA tool helps to understand the impact of a new technology at local level and quantifies the perceived impact after its introduction. The results show that ICS contribute to food security in the case study sites, which is a key finding as cooking stoves are often not directly associated with food security. A detailed analysis demonstrates that ICS positively affect, firstly, the social dimension; this is followed by the economic and environmental food security dimensions. While the *ex-ante* impact assessments show that stakeholders expected a marginal to moderate positive contribution of ICS towards the FSC, the three *ex-post* assessments indicate that the experienced contributions of ICS towards the FSC were higher throughout. Information exchange by local stakeholders and researchers was important to address perceived challenges of ICS. During the impact assessments, bottlenecks, like poorly constructed stoves as well as the usage of unsuitable firewood, were identified and directly solved. While the FoPIA tool can be applied to different socio-economic environments, our findings demonstrate that site-specific contexts influence the results, limit the transferability of results to other socio-economic and geographic contexts. FoPIA is a generic tool to conduct *ex-ante* and *ex-post* impact assessments of a new technology to strengthen rural development; the method can be applied for different type of projects, assessing local expectations and the experienced impacts of a technology. However, it is vital that local stakeholders and researchers jointly develop evaluation criteria to improve the efficacy of the impact assessment mechanism.

Declarations of competing interest

None.

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