ACCESS TO (GREEN) ENERGY IN RURAL AFRICA

Online Appendix

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ABBREVIATIONS AND ACRONYMS

ATT	Average Treatment Effect on the Treated
BMZ	Federal Ministry for Economic Cooperation and Development
C	Control group
CRS	Creditor Reporting System
DAC	Development Assistance Committee
DC	Development cooperation
DEval	German Institute for Development Evaluation
DiD	Difference-in-differences
EEBC	Energy-efficient biomass cookstove
EnDev	Energising Development
ESMAP	Energy Sector Management Assistance Program
FE	Fixed effects
FOKG	Focus group discussion
GBE	Green People's Energy for Africa
GG	Gender equality marker
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
IQR	Interquartile range
IV	Instrumental Variables
KfW	KfW Development Bank
KLA	Rio marker for climate change adaptation
KLM	Rio marker for climate change mitigation
LPG	Liquefied petroleum gas
MeMFIS	Management, finance and information system of the BMZ
MSME	Micro, small and medium-sized enterprise
MTF	Multi-Tier Framework
O&M	Operation and maintenance
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary least squares
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PSM	Propensity Score Matching
PuE	Productive use of energy
PV	Photovoltaic
RD	Regression Discontinuity
SDG	Sustainable Development Goal
SHS	Solar Home System
SSA	Sub-Saharan Africa
T	Treatment group
UN	United Nations

1. LITERATURE REVIEWS

1.1 Are rural energy access programmes pro-poor interventions?[1]

Abstract

This paper discusses whether energy access programmes in rural Sub-Saharan Africa (SSA) actually reach the poor. We examine on and off-grid electrification as well as improved cooking. Pro-poor development requires that the programmes enable the poor to unlock their productive potential. We therefore focus on the productive use potentials triggered by energy access programmes such as irrigation.

Our review of the recent evaluation literature informed by our sector and evaluation experience on the topic also comprehensively covers other potential channels, including education and health. In doing so, we consider both direct economic benefits to the poor as well as whether indirect effects accrue to the unconnected via spillovers from among the connected.

We conclude by emphasising that energy access is beneficial for the poor if connections are made affordable through subsidisation, but indirect effects from productive use and income generation are largely absent. From a pro-poor perspective, energy efficient biomass cookstoves offer the greatest potential.

Introduction

It is the general consensus that access to electricity is a prerequisite to the provision of basic services and economic growth. Access to affordable and clean energy, which also includes access to improved cooking technologies, is therefore envisioned by the Sustainable Development Goals (SDGs) to improve livelihoods in low-income countries, not least in rural areas of SSA where energy access deficits are most pronounced. But what does the recent experience tell us about whether energy access programmes lead to pro-poor development?

In this perspectives article, we discuss the latest evidence from the energy access literature on whether rural energy access programmes typically reach the poor. This discussion is crucially informed by our experience working in the energy sectors of different SSA countries and several impact evaluations we have conducted. We use our sector expertise to critically review the most relevant literature.

We focus this analysis on the question of whether energy access provides the poor with the opportunities to release their productive potential. Productive use potential to promote capabilities are a key concern of the different understandings of "pro-poorness" (Kakwani and Pernia 2000; Ravallion and Chen 2003; Day et al. 2016), contributing to the distributional dimension of energy justice (Sovacool and Dworkin 2014; Jenkins et al. 2016; Munro et al. 2017).

Pro-poor development effects can unfold by providing direct benefits to those gaining access to affordable and clean energy, who may still be poor despite typically being among the better-off in their communities. Alternatively, the pro-poor effects can unfold via indirect spillover effects from those who have received access to those who still lack energy access. For example, small enterprises or health centres that are newly

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connected to the electricity grid can generate externalities leading to higher income or improved health even among poor and non-connected households.

We therefore first examine a key factor that determines which socio-economic strata of the population obtain access in energy access programmes: the typical cost burden of different energy access options. We then turn to our core discussion of the productive use of energy among enterprises and households in access programmes with no particular targeting, followed by a discussion of targeted productive use programmes and their impact potentials.

Productive potentials among the poor can also be enhanced through educational and health impacts, through direct access or otherwise indirectly through schools and health infrastructure. Lastly, we describe the impact dimensions for which there is the most evidence regarding their pro-poor impact, namely savings in terms of money and time.

In discussing these points, we distinguish between improved cooking technologies, more specifically energy-efficient biomass cookstoves (EEBCs) and clean fuels[2], as well as electrification in the form of the centralised grid, mini-grids and stand-alone solar.

The cost burden of different energy access options

Two features of energy access programmes determine the extent to which poorer strata of the population are reached: a) the costs of the provided technology and b) the cost-sharing ambition of the programme, that is, how much the end users must contribute to acquisition costs via fees and prices.

For on-grid electrification programmes, the cost-sharing ambition is generally low but fees are nevertheless often too high for considerable portions of the target population because of the extremely high costs.

Therefore, only the relatively better-off households get connected. Connection rates "under the grid" across various countries are typically way below 100 % (Golumbeanu and Barnes, 2013). The impact evaluations document connection rates in recently-connected areas of 60 % in Rwanda (Lenz et al., 2017), 39 % in Ethiopia (Bernard and Torero, 2009), less than 30 % in Tanzania (Chaplin et al., 2017) and below 10 % in Kenya (Lee et al., 2020a) and Burkina Faso (Schmidt and Moradi, 2023).

To assess how responsive households are to connection fees, Lee et al. (2020a) randomised transformers across 150 communities in Kenya and, subsequently, randomised different subsidy levels for connection fees. They diagnose a sharp decrease in connection rates as fees increase: while almost all households connected if connection was free of charge, a subsidy equivalent to 57 % or 29 % increased connection rates by only 23 and 6 percentage points respectively. Therefore, considerable parts of the target population – not least the poorer sections – do not directly benefit from grid extension programmes.

Programmes promoting stand-alone solar face lower technology costs than grid extension, yet most programmes follow a market-based paradigm requiring end users to pay cost-covering prices. Programmes often only subsidise the marketing and perhaps also the market expansion and after-sales infrastructure of a solar company.

Since the demand for stand-alone solar is very sensitive to the price (see Grimm et al., 2020 and Meriggi et al., 2021), customers of such programmes are usually from wealthier backgrounds (see Barry and Creti, 2020, Bensch et al. 2018, and Mukoro et al., 2022).

Improved cookstove promotion programmes are also mostly implemented under the market-based paradigm but the costs of the technology are much lower, especially for EEBCs. At the same time, the price-responsiveness of improved cookstove demand is well established – including the diagnosis that many

[2] In rural SSA, providing access to improved cooking technologies usually implies the dissemination of low-cost EEBCs. Liquefied Petroleum Gas (LPG) is barely available in rural SSA and establishing supply chains is prohibitively expensive. Pilot interventions for other clean stoves like gasifier stoves or biogas have largely failed (Carrión et al., 2021; Puzzolo et al., 2016; Rupf et al., 2015).

households in rural areas cannot afford the investment (Bensch and Peters, 2020; Beltramo et al., 2015; Munyehirwe et al., 2022; Pattanayak et al., 2019).

Therefore, the cost-sharing approach screens out poorer households, especially in rural areas where the woodfuel is collected and not purchased, meaning that no monetary savings can occur.

Productive use in energy access interventions

Technically, the grid and sufficiently-sized mini-grids provide powerful electricity that can be used for energy-intensive machinery and three-phase current. Productive use potentials for grid electrification therefore constitute the upper bound of productive use potentials related to energy access. If productive use does not emerge in the wake of grid connection, it is unlikely to emerge when lower-powered stand-alone solar systems or smaller-scaled mini-grids are promoted.

Overall, recent impact evaluations suggest that the productive use of electricity in newly connected regions is very limited. Technical potentials are not exploited and consumption remains on a very basic level. What is more, most enterprises in grid-covered rural areas are shops, bars, tailors and hairdressers, and home enterprises in households are rare.

They use electricity for lighting and small appliances like electric shavers, entertainment devices and fridges, sometimes complemented by offering phone charging. The use of grid electricity for irrigation is rare, since pumps are mostly needed in plots that are too far away from the grid.

Only few enterprises are typically found in rural areas that use powerful electric machinery (in most cases welders, carpenters and mills). What these enterprises have in common is that they mostly serve local demand. Products are very rarely sold to regional or urban markets.

These patterns have been observed in several impact evaluations covering both enterprises and households in different countries. Chaplin et al. (2017) use a difference-in-differences (DiD) design to evaluate a large-scale grid extension programme in Tanzania, and observe very little productive take-up in enterprises or through home enterprises.

In a different part of Tanzania but also using a DiD design, Bensch et al. (2019) confirm these findings. Lenz et al. (2017) evaluate a country-wide grid roll-out programme in Rwanda, using a mixed-methods DiD identification strategy. They also observe very low consumption levels among enterprises and households, mostly for lighting, which is generally in line with literature reviews on commercial and domestic productive use potentials (see, for example, Terrapon-Pfaff et al., 2018, Kizilcec and Parikh, 2020 or Radley and Lehmann-Grube, 2022). Lee et al.'s (2020a) study also does not find a productive take-up among households in their sample in Kenya.

Again in Kenya, Taneja (2018) documents another remarkable pattern: even when accounting for the time since grid connection, electricity consumption levels in areas which have been newly connected to the grid are drastically lower for households and also notably lower for small enterprises. This underpins the idea that with progressive electrification, poorer and more remote and poorer regions are gaining access to the centralised grid.

One valid concern about all these studies is the short-term evaluation horizon: they examine adoption and impacts two to five years after connection. Masselus et al. (2024) therefore provide a 10-year long-term evaluation of the Lenz et al. (2017) sample, and find that the consumption and take-up patterns have not changed. A very modest productive take-up among enterprises was also documented in Benin seven years after the grid connection (Peters et al., 2011).

Contrary to these studies which use primary, self-collected data, the literature based on secondary data diagnoses positive impacts of grid-extension electrification (see Lee et al., 2020b for a review). Ankel-Peters and Schmidt (2023) argue that the key difference is that secondary-data studies cannot use well-specified interventions but instead have to rely on proxy interventions to identify where electrification happened; they also note a higher risk of publication bias in secondary-data studies due to there being less incentive to publish with a null result than with primary-data studies given the high costs of data collection.

Moreover, only few secondary-data studies examine countries or regions in SSA (Hamburger et al., 2019; Peters and Sievert, 2016). Regardless of the deeper reasons for the divide in findings between these two types of studies, we argue that the impact evaluation literature referred to above is more relevant for programme evaluation purposes and intervention specific cost-benefit analysis in rural SSA.

The literature on stand-alone solar and micro-grids confirms our prior of modest productive use and the impacts of programmes promoting these technologies (see Grimm et al., 2017, Bensch et al., 2018, Kizilec and Parikh, 2020, and Radley and Lehmann-Grube, 2022 for stand-alone solar and Aklin et al., 2017 for micro-grids).

Most improved cooking programmes target households, not enterprises (see Grimm and Peters, 2015 for an efficient cookstove intervention targeting local beer breweries in urban Burkina Faso). One widespread productive application of improved cookstoves is in restaurants. Here they likely lead to higher productivity, but probably not in a transformative way – also since, as discussed above, these enterprises mainly cater to local demand.

Targeted productive use interventions

The previous section showed that programmes providing energy access to the broader population of households and enterprises in SSA yield no significant impacts on productive uses. We now turn to energy access interventions that specifically target certain users with high productive potential (see Lukuyu and Taneja, 2023). For example, a mini-grid intervention could select only villages that host a so-called anchor customer.

In practice, however, this proves difficult, as such anchor customers in remote areas are rare and can often not be identified (see Duthie et al., 2023 for a large programme pursuing this approach in Indonesia; see also Peters et al., 2019). Mini-grid placement according to irrigation potentials is another option (Wamalwa et al., 2023). Lukuyu et al. (2022) propose a technique to detect such potentials based on existing diesel-fed irrigation pumps using remote sensing data.

Another approach is to target potential productive users with stand-alone solar-powered machinery. Their portability makes solar-powered water pumps particularly interesting. Increasing agricultural productivity via irrigation additionally circumvents the barrier to many other productive uses in rural areas, which is a lack of market access.

Most parts of rural SSA are well integrated into markets for agricultural products, which means that expanding agricultural production is more straightforward than for artisanal or manufactured products (Peters and Sievert, 2016).

While proof-of-concept evidence for solar-powered irrigation does exist (Burney et al., 2010), a broader view of the thin literature available suggests that promotion at scale is faced with various problems: groundwater depletion, operational problems ranging from maintenance problems to lack of power on cloudy days (see Closas and Rap, 2017) and unresolved regulatory questions such as land tenure (Chokkakula and Giordano, 2013).

Solar-powered water pumps also compete with diesel, which under many circumstances is the more economically viable energy source from the farmers' perspective (see Smith and Urpelainen, 2016 and Xie et al., 2021).

In general, diesel is the most important hazard to the impact potentials of this targeting approach, because potentials for standard productive uses such as milling and pumping are typically already exploited in regions which are not covered by the grid by using diesel-powered generators, pumps or mills. Less obvious productive potentials are much harder to identify.

As a result, targeting programmes must either increase the risk they take and aim at not-so-obvious productive potential which has previously been untapped by diesel-driven appliances. If the programme otherwise supports the conversion of existing productive uses from diesel to solar or other sources of electricity, impact potentials are limited to potential reductions in fuel costs (if the electricity is cheaper than diesel) and environmental benefits.

In sum, reliable evidence on targeted energy access programmes is very scarce. Development practitioners' priors on such programmes are often shaped by experience and anecdotes from small-scale pilot interventions. Tacit knowledge like this is not irrelevant, but it needs to be considered that small-scale pilot interventions are often successful because they are small-scale and pilot. That is, the level of care the intervention receives from implementers typically cannot be replicated at scale, and once at scale, the increased supply of the supported production (e.g. irrigated vegetables) may find it harder to find sufficient demand.

Nevertheless, productive use impact prospects for a programme featuring a well-crafted targeting are certainly higher than for the typical non-targeted electrification programme. In case they prove successful, a pro-poor effect is also plausible via external effects on local employment and income. In any case, targeted approaches will also require subsidies to overcome the limited purchasing power and liquidity constraints in the high-risk investment setting that rural entrepreneurs typically face.

Health and education

Energy access may not only reach the poor through economic development in the narrow sense, but also by improving their health and educational status. This might happen through immediate impacts on households with energy access or indirectly via improved educational and health services in public institutions.

Positive health effects at the household level are possible if dirty kerosene lamps are replaced by electric lighting (Barron and Torero, 2017). However, the LED lighting transition that rural SSA has experienced over the past 15 years has changed the baseline situation. That is, kerosene is rarely used any more in rural SSA and has been replaced by LED torches and small solar lamps (Bensch et al., 2017).

Household-level health effects are most widely discussed for improved cooking technologies. Simple EEBCs do not reduce smoke emissions to a level that is sufficient to prevent significant health hazards according to the guidelines of the World Health Organisation.

While there is some suggestive evidence that positive health effects might nevertheless materialise (La Fave et al., 2021), for example because of a reduced cooking time and hence less exposure to smoke (see Bensch and Peters, 2015), it seems more prudent not to expect substantive positive health effects in EEBC dissemination interventions (Bensch et al., 2023).

The alternative option of disseminating clean stoves like LPG or gasifier stoves has proven to be very difficult in rural SSA. Even in efficacy studies where the clean stoves (or fuels) were delivered free of charge to households, no health improvements could be observed because many households continued to use dirty fuels for at least part of their food preparation (Jack et al., 2021; Mortimer et al., 2017).

Educational effects at the household level are most likely to materialise because of improved lighting conditions for studying at home. This has indeed been observed in Rwanda (Grimm et al., 2017), for example, but could not be confirmed in Malawi (Stojanowski et al., 2021). In sum, while positive educational and health effects might materialise at the household level under certain circumstances, it is unlikely that they will be very pronounced among the poorer strata of the population – also because adoption rates are low.

At the institutional level, it has often been claimed that the lack of electricity in rural health facilities and schools is a barrier for service provision (see for example Moner-Girona et al., 2021; IEG, 2008). In our experience (see Lenz et al., 2017, for example), however, even grid-connected schools barely use electricity for educational purposes.

Schools only operate during daytime hours and computers are not used in class. Teachers – often civil servants from urban areas – benefit, and anecdotes suggest they tend to stay longer in a village, if connection to the grid is available. Rural health centres in regions beyond the reach of the grid mostly use solar panels to fuel basic appliances like a fridge, a steriliser and lighting. Fridges are otherwise also run on kerosene or gas.

Electricity therefore facilitates services (and lowers costs), but it is not key. Both health services and education are incredibly important for empowering the poor to develop out of poverty. However, both services are mainly hampered by the combination of other bottlenecks instead of the lack of access to electricity alone, including limited budgets and the lack of skilled staff and equipment.

Main impacts on the poor: savings of time and money

We have outlined in the previous sections that in most programmes the poorer households in the respective target population do not obtain the relevant access, largely for reasons of affordability, and that the main transformative development effects on income, health and education are limited. We now intend to discuss the other pro-poor effects which can be identified, at least for those with direct access to energy.

For electricity, most important direct effects are on quality of life and convenience rather than dimensions with transformative potential. Electricity access can lead to monetary savings if electricity is cheaper per kWh than what was used at the baseline. Even then, the net savings effect on the household budget is either negligible or even negative, since new and often consumptive (not productive) energy services are used such as television.

Savings potentials are also limited for households who only consume lighting, because people use cheap LED torches or non-branded solar products to meet their basic lighting needs in the absence of access to electricity (Bensch et al., 2017; Grimm and Peters, 2016; Groenewoudt et al., 2020).

The most accentuated impacts with some transformative potential occur for households which gain access to an EEBC. Here, the ratio between what can be expected in terms of monetary or time savings and the costs of an EEBC is clearly higher than for electrification. Firewood savings in rural areas for appropriate EEBCs which are also regularly used are between 15 and 40 % (see Bensch and Peters, 2015; Munyehirwe et al., 2022, Mekonnen et al., 2022, and Usmani et al., 2017).

Since the amount of time spent collecting firewood is often in the ballpark of 8 to 12 hours per week, especially in biomass-scarce regions, it is easy to see that such savings have a noteworthy impact on people's time constraints (see for example Krishnapriya et al., 2021). Purchasing firewood is much rarer in rural SSA, but for those who purchase firewood the time savings are considerable and in the order of the savings mentioned above.

Conclusion

Energy access is important for a decent living, and providing everybody with electricity and proper cooking opportunities is a first-order policy priority as reflected in the Sustainable Development Goals (SDG 7). However, rural energy access alone does probably not lead to transformative impacts in terms of economic development – even if the non-renewable wisdom also holds true in that electricity is required to enable endogenous growth.

Most programmes also require the target group to share parts of the costs through connection fees or even cost-covering market prices, which excludes significant shares of the population from the service. Even for EEBC programmes, where the disseminated technology comes at much lower costs than for stand-alone solar or grid extension programmes, the poorer strata of the population mostly abstain from making the investment.

If these groups at the bottom of the pyramid can be reached, significant subsidies are necessary to bring down end user prices to affordable levels. The interest of poorer households in improved energy services has been widely documented. It is affordability that hampers them from adopting these services. Subsidies targeted at potential productive users are probably also required if productive take-up is to reach levels that might trigger transformational economic impacts.

Simply replacing existing diesel applications (for example for irrigation pumps) may be a worthwhile undertaking for grid planning and environmental reasons, but also to develop the market for such solar appliances. However, in order to have a noticeable impact, targeting procedures need to identify productive potentials that had not been profitable enough with diesel machinery. The extent to which such income generation activities then reach the poor or otherwise spill over to poorer sections of the population is another open question. In fact, from a pro-poor perspective, affordable and therefore subsidised EEBCs offer the greatest potential.

1.2 Rural energy access and women's empowerment[3]

Abstract

In this note, we discuss the link between energy access and women empowerment. The focus is on access to electricity and improved cooking technologies in rural Sub-Saharan Africa (SSA), where access rates are low. The discussion is informed by our experience working in the energy sectors of different sub-Sahara African (SSA) countries, several impact evaluations we have conducted and a critical reading of the literature. We examine impact dimensions that are not necessarily women empowerment indicators in the narrow sense, but that are plausibly related to the degrees of freedom of women in SSA societies – and hence changes on these levels would plausibly empower women within and beyond the household, and to aspire for more agency in society (see as well Das et al., 2023).

Electrification

It is common sense that electrification of household tasks in today's industrialized countries contributed to women empowerment by freeing up time that could be used for other purposes including labor market participation (Greenwood et al., 2005; Lewis, 2018). Similar effects are generally plausible for contemporary electrification interventions in the Global South. Several policy reviews and systematic reviews summarize the academic literature on gender and rural electrification (Das et al., 2020, 2023; Grantham, 2022; Pueyo and Maestre, 2019; Rewald, 2017; Wilhite, 2017). According to these reviews, three categories of potential impacts have emerged in the literature: labor market participation and non-agricultural employment, gender norms, and fertility.

First and foremost, the most influential and most cited studies find considerable effects of rural electrification on female employment. The seminal paper by Dinkelman (2011) finds an increase of 9 percentage points in female labor market participation in rural South Africa, relative to a very low baseline of 6 percent (see Figure 1, Panel A). Another study from rural Nicaragua finds positive statistically significant results on paid employment of over 20 percentage points (Grogan and Sadanand, 2013; see Figure 1, Panel B). The broader picture that emerges from the literature is less clear. The two panels in Figure 1 compile all impact estimates from published work using at least some form of quasi-experimental method, retrieved from the abovementioned reviews, additional systematic reviews that generally assess electrification impacts (Ayana et al., 2022; Raitzer et al., 2019), and an additional search among the most recent research. Regarding female labor market participation presented in Panel A, the remaining literature finds lower and often insignificant effects (note also that the right-hand scales for studies using Instrumental Variables (IV) are double the left-hand scales for other studies). Interestingly, even zooming into more specific types of employment, such as paid and off-farm employment, does not yield the strong and significant effects as found in the flagship reference, Grogan and Sadanand (2013). All these studies assess rather short to medium term effects, with few exceptions covering impacts accruing more than 6 years after electrification.

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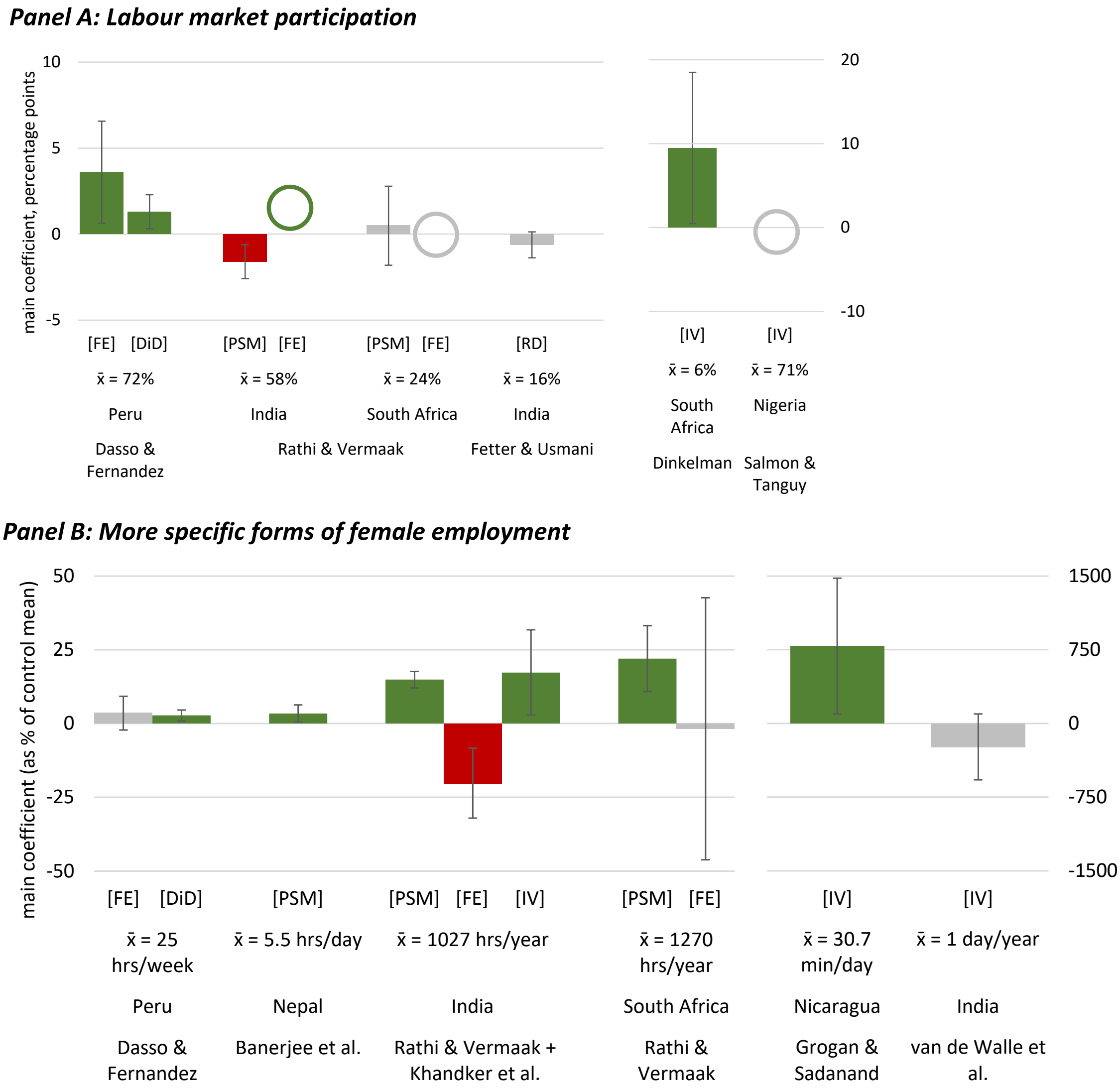
Figure 1 Female employment effects



Source: DEval, own figure

*Note: The charts differentiate between Instrumental Variables (IV) studies on the right-hand scales and studies using other methods of causal identification on the left-hand scales. Point estimates (bars) and the 90 % confidence intervals (whiskers) indicate the margins of error. Circles imply that no point estimate and confidence interval can be derived for the respective study. x̄ refers to the baseline or control group mean. Additional information provided below each bar include the authors, the study country, and the employed technique for data analysis, ranging from [weighted] Propensity Score Matching (PSM[-w]) over Difference-in-Differences (DiD), Regression Discontinuity (RD) and Fixed effects (FE) to Instrumental Variables (IV) estimations (see, for example, Gertler et al., 2016). Panel B additionally mentions the type of female employment assessed. * refers to studies with both rural and urban populations – all other studies include only rural households*

It is also important to make two qualifications about the IV approach used in the two highlighted studies with the most pronounced effect estimates. First, these estimates are not readily comparable to estimates derived from other methods and harder to interpret, because they refer to specific sub-populations that usually cannot be readily characterized (the so-called local average treatment effect [LATE] issue, see Marbach and Hangartner 2020, for example). Second, this method has recently been subject to substantive methodological criticism, also with regards to electrification (see Bensch et al., 2020 and Lee et al., 2020). One might furthermore be concerned about publication bias, since the incentives to pursue towards publication with a null result in this type of work are low (see Brodeur et al., 2020). In sum, we argue that for program evaluation purposes it is very hard to make project-specific claims based on this evidence.

Evidence on gender norms and fertility is much scarcer, with the dominating studies being Jensen and Oster (2009) and La Ferrara et al. (2012), examining the effect of television on women's status and fertility in India and Brazil. Both studies rely on context-specific events for identification of causal effects, namely the arrival of cable TV in rural India and the surge in soap operas at a Brazilian TV channel around the 1990's and 2000's. La Ferrara et al. (2012) find significant reductions in fertility, especially among women with lower socio-economic status. In numbers, they are on average 0.5 percentage points less likely to give birth in any given year. Jensen and Oster (2009) find reductions in women's tolerance of spousal violence and increases in women's autonomy, but their results only hold true for educated women (see also Iversen and Palmer-Jones, 2019). Fertility and contraceptive usage have furthermore been investigated in Grimm et al. (2015), Peters and Vance (2011) and Peters et al. (2014), with mixed results.

Beyond methodological concerns, it should be stressed that virtually all these studies look at countries outside of Africa, with South Africa as an exception, arguably a very particular country in SSA. There are important reasons to question the transferability of these findings to rural SSA. The underlying mechanism in many labor market studies is that appliance ownership and usage in newly electrified communities liberates women's time that was absorbed by household chores before. In rural Africa, though, there is a growing consensus that uptake of time-saving appliances (in particular electric stoves, washing machines and fridges) in newly connected rural areas is virtually zero (Bensch et al., 2019; Chaplin et al., 2017; Lee et al. 2016, 2020b; Lenz et al. 2017; Taneja, 2018). Rural dwellers do not have the financial means to make such investments and electrification does not lead to meaningful economic development (see Ankel-Peters et al., 2024a). Labor market effects that materialize through time savings are hence unlikely. Regarding the likelihood of effects on gender norms and fertility, transferability is also questionable. TV usage once households are connected is much lower in SSA than in Asia and Latin America. Moreover, the full coverage of mobile communication in rural Africa also prior to electrification leads to a different baseline situation in terms of access to information, making significant impacts in these regards much less likely.

Our focus in this note is on on-grid electrification, which is also what the literature studying the gender-related effects of electricity access is mostly looking at. Our verdict that relevant effects from a project evaluation perspective are unlikely to materialize in rural SSA, also holds for stand-alone solar and certainly for Pico-PV (see Grimm et al., 2017). While women also benefit from these technologies, the resulting effects are not transformative.

Improved cookstoves

Potential impacts of improved cookstoves in rural areas inherently accrue to women because cooking related chores – the cooking process itself as well as the fuel provision – are borne by women in SSA. Virtually all household in rural SSA use biomass for cooking, mostly firewood. The firewood is collected and depending on biomass availability in the region this can entail collection work of 10 or more hours per week (Krishnapriya et al., 2021). The firewood is used in open fires or very simple metal stoves with the emitted smoke being extremely harmful for people's health (WHO 2016). Hence, improved or clean cooking solutions can affect women's health and workload. These are important dimensions affecting women's capacities and degrees of freedom.

We distinguish between low-cost energy-efficient biomass cookstoves (EEBC) and clean fuels and clean stoves (LPG and gasifier stoves). EEBC are low-cost technologies, between 10 and 50 EUR, for which well-adapted versions exist for many regions in rural SSA that have also proven to be intensely used (see Jeuland et al., 2020). Such well-adapted EEBC have found to reduce firewood consumption considerably, depending on the baseline cooking situation and the specific EEBC type between 10 and 50 %. This, in turn leads to a significant workload reduction for firewood collection (see Bensch and Peters, 2015; Krishnapriya et al., 2021; Munyehirwe et al., 2022). Many EEBC types are also more convenient to use and reduce cooking duration (see Bensch and Peters, 2015; Krishnapriya et al., 2021). In terms of health, EEBC do not meet air pollution standards of the World Health Organization and are generally not considered clean. While there is some suggestive evidence that even EEBC lead to improved health status (Bensch and Peters, 2015;

LaFave et al., 2021), for example due to cooking in better ventilated places (Lenz et al., 2023), it is more advisable not to expect positive health effects of EEBC via a reduction of air pollution.

To effectively address the detrimental exposure to cooking related air pollution, clean stoves or fuels are required. Hitherto, however, there is no proof-of-concept evidence that LPG or gasifier stoves lead to a measurable improvement of people's health status. Even in efficacy studies where the clean stoves (or fuels) were delivered free of charge to households, no health improvements could be observed (Jack et al., 2021; Mortimer et al., 2017). This is mainly due to the so-called stacking of different stoves, including the traditional ones, and due to inappropriate applications, but perhaps also because of ambient air pollution.

Conclusion

Rural energy access improves the quality of life considerably and it particularly affects the lives of women in rural areas. The much deeper improvements, though, come from improving cooking technologies as compared to rural electrification. From a project evaluation perspective, effects of electrification in SSA on female labor market participation and gender norms through information and media exposure are possible, but probably much less pronounced than what a project can measure and what a project would consider relevant. The reason is that electric appliance uptake is substantially lower in SSA than Asia and Latin America and the baseline situation in terms of access to information thanks to mobile phone coverage is better today in SSA than it used to be when countries in Asia and Latin America were electrified, making significant impacts in this regard much less likely. The labor market effects observed in some studies mostly materialize through time saving effects of electrification – something which cannot be expected in rural SSA.

If anything, such effects might unfold for improved cooking interventions, because here, also simple EEBC can lead to considerable effects on women's time use. These diagnosed improvements for the livelihoods of women in SSA related to EEBC dissemination are noteworthy and while not of immediate relevance for women empowerment, they create the freedom to exploit other opportunities, employment-related or beyond.

1.3 Cost-effectiveness of rural energy access strategies[4]

Abstract

Quantitative benchmarks for cost-effective provision of rural energy access are difficult to obtain because deployment costs vary across technologies, contexts, and technical assistance approaches – but crucially also across sustainability assumptions. As an alternative, this policy perspective provides a qualitative cost-effectiveness assessment of different energy access strategies.

That is, we discuss the different cost factors and additionally account for differences in impact potentials across rural energy access options. We include on-grid and off-grid electrification and improved cooking technologies. The focus is on rural sub-Saharan Africa (SSA), where energy access rates are low.

We diagnose largely disappointing impacts of high-power electrification technologies, turning stand-alone solar into the more cost-effective electrification strategy in that setting. We conclude by emphasising the high impact-cost ratio for energy-efficient biomass cookstoves.

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Introduction

Investment requirements to reach Sustainable Development Goal 7 – universal access to electricity and modern cooking energy – are high. The level of investment needs to grow by at least 35 percent to reach the goal by 2030 or even more than 100 percent if climate goals are also to be met (IEA and IFC, 2023).

While public investment flows are scarcer due to the multiple crises around the world, more public funds are pledged to climate mitigation and adaptation agreements, such as the Loss and Damage Fund established at the UN Climate Change Conference in 2022, COP27.

This paper reviews costs and benefits of rural energy access options to improve the effectiveness of public resources in achieving the universal energy access goal and subsequent poverty impacts. We consider on- and off-grid electrification and improved cooking technologies. The regional focus of our analysis is on Sub-Saharan Africa (SSA).

Quantitative benchmarking is difficult and hence we provide a qualitative cost-effectiveness assessment, taking into account capital costs and technical assistance costs as well as impact potentials. This assessment, therefore, borrows from cost-benefit analysis. The discussion is informed by our experience working in various SSA energy sectors and several impact evaluations we have conducted. It is hence a perspective paper, supported by substantive evidence.

The different technologies under scrutiny serve different purposes. Most notably, electricity is rarely used for cooking in SSA, even in areas where the grid is available. Households traditionally use firewood and charcoal as cooking fuels and improved or clean cooking solutions are based on more efficient biomass combustion technologies or Liquefied Petroleum Gas (LPG).

Intervention assessments therefore rarely compare the cost-effectiveness of electrification and improved cooking to justify the investment. This comparison is nevertheless important since donor investments into these two policies often come from the same portfolios.

Qualitative cost-effectiveness assessment

In Table 1 we provide an overview of costs and benefit potentials for the different energy access technologies. First, we compile indicative figures for capital costs of different energy access technologies (see column 1). Note that while these numbers cannot be taken at face value in any specific context, they broadly reflect the incurred acquisition costs regardless of who pays.

Depending on the cost-sharing model, the national government, donor agencies and end users may contribute in varying proportions. For example, the lion's share of grid connection costs is typically borne by the government and its utility, often supported by an international donor, while the end users contribute a smaller share through the connection fee. In many improved stove and off-grid solar programmes, in contrast, it is the end user who bears the entire capital costs by purchasing the appliance at a cost-covering price.

Here, a donor agency's contribution typically is to provide technical assistance, for example to support institutionalising market structures. Such technical assistance costs come on top of the numbers in column (1). This is an important caveat for the interpretation of Table 1 because technical assistance requirements vary considerably between the different technologies as indicated in column (2), from fairly low for grid extension to very high for the mostly nascent mini-grid sector.

Table 1 **Cost-effectiveness appraisal for rural energy access technologies**

	(1) Cost per connection, in US$	(2) Technical assistance requirement	(3) Energy service potential, by MTF tier*	(4) Impact evidence	(5) Technical lifetime; operation & maintenance (O&M) intensity
Electricity					
Pico-PV	20-50	Medium	Tier 1	convenience and improving daily routines, minor monetary or time savings	2-5 years
		mainly to establish market structures	one spotlight and one charging slot	impact potential constrained by baseline technology, typically dry-cell battery driven LED	low O&M intensity
Stand-alone Solar Home System (SHS)	100-700	Medium	Tier 1-2	convenience and improving daily routines, minor time saving impacts	5+ years
	e.g. depending on capacity	mainly to establish market structures	multiple light points, phone charging, radio and potentially TV or fan	productive use impacts restricted to small shops and extended working hours, mainly by limited power	medium O&M intensity
Mini-Grid	750-2,000	High	Tier 3-5	few impacts beyond convenience and time saving impacts	10-20 years
	e.g. depending on connection rates and anchor customers	because most countries lack enabling regulatory framework	Tier 2 + any medium-power appliances such as refrigerators; partly also high-power appliances, such as mills	impacts constrained by low electricity consumption due to limited affordability (to buy electric appliances), lacking market access for enterprises, and if mini-grids do not operate all day	high O&M intensity
On-Grid	500-1,500	rather low	Tier 4-5	few impacts beyond convenience and time saving impacts	20+ years
		due to long-standing local know-how	Tier 3 and high-power appliances, such as mills	impacts constrained mainly by low electricity consumption due to limited affordability (to buy electric appliances) and lacking market access for enterprises	low to medium O&M intensity

	(1) Cost per connection, in US$	(2) Technical assistance requirement	(3) Energy service potential, by MTF tier*	(4) Impact evidence	(5) Technical lifetime; operation & maintenance (O&M) intensity
Cooking					
Energy-efficient biomass cookstoves	5-30	medium to high (low in urban areas) to establish market structures	Tier 0-2	reduced woodfuel consumption and subsequent impact on monetary and time savings	2-5 years
		low to medium if provided for free	higher energy efficiency; no reduction in air pollution		low to medium O&M intensity
Advanced biomass cookstove	75-100	very high to establish market structures	Tier 2-3	even stronger reduced fuel consumption and thus on time savings but mixed results regarding air pollution	2-5 years
		medium if provided for free (to train users)	higher fuel efficiency and lower emissions	impacts constrained mainly by continued use of traditional stoves ('stove stacking'), inappropriate use, and limited availability/high cost of processed woodfuels (pellets)	medium O&M intensity
Liquefied Petroleum Gas (LPG)	20-100	very high to establish market structures, particularly LPG supply chain in rural areas	Tier 4-5	strong reduction of traditional fuel use and thus on time savings, but so far no evidence for reducing health risks (mainly due to continued use of solid fuels and ambient air pollution)	5+ years
	plus fuel costs	high if provided for free	high fuel efficiency and low to zero emissions	adoption typically constrained due to high costs of fuel supply (e.g. to rural areas) and need of bulk cylinder purchase	low O&M intensity

	(1) Cost per connection, in US$	(2) Technical assistance requirement	(3) Energy service potential, by MTF tier*	(4) Impact evidence	(5) Technical lifetime; operation & maintenance (O&M) intensity
Biogas digester	500-1,500	very high	Tier 4-5	similar to LPG, in addition co-benefits for agricultural households (fertiliser) and zero monetary fuel costs	10-20 years
	e.g. depending on capacity	due to need to change behaviour, including keeping cattle in stable	high fuel efficiency and low emissions, lighting as co-benefit	virtually all programmes in Africa have low adoption rates or have failed due to high up-front and maintenance costs, and not enough cow dung and water	high O&M intensity

Source: DEval, own table, Sources on costs: Lighting Global et al. 2022 (SHS); AMDA 2022, BloombergNEF 2020, ESMAP 2022 (Mini-grids); Lee et al. 2020b, BloombergNEF 2020 (on-grid), ESMAP 2020, Jeuland et al. 2018 (cooking)
*Note: *The tiers of energy access are described in the Multi-Tier Framework (MTF), developed by ESMAP. Energy access is measured on a tiered spectrum, from tier 0 (no access) to tier 5 (the highest level of access), differentiated by household electricity and domestic cooking energy*

Table 1 also features the technologies' energy service potential (column 3) and a qualitative assessment of impacts effectively observed in programmes across SSA (column 4). Broadly speaking, energy-efficient biomass cookstoves have proven to deliver in terms of their expected impacts, that is, a reduction of fuelwood consumption and hence, of monetary expenditures or firewood collection time, depending on whether the woodfuel is purchased or collected (Jeuland et al., 2020).

These are noteworthy impacts in most settings in rural SSA, especially since the reduced workload for firewood collection mainly accrues to women (Bensch and Peters, 2020; Berkouwer and Dean, 2022; Das et al., 2023; Jeuland et al., 2021). The evidence on reducing household air pollution induced by woodfuel usage, however, is more pessimistic, not only for efficient biomass cookstoves but also for LPG and clean gasifier stoves.

While it remains true that only exclusive use of clean stoves has the potential to fully eliminate household air pollution, clean stoves today usually fail to fully displace all dirty stoves in a household (Pope et al., 2021). Nevertheless, the impact potentials of improved cooking are impressive relative to the low costs, in particular for efficient biomass cookstoves. Among energy access technologies, improved cooking therefore clearly has the best cost-benefit ratio, even under very conservative assumptions.

For electrification, the case is much more complex. Different technologies have, in theory, different impact potentials, but empirically impacts do not differ in most cases. For higher-power technologies, technically possible demand potentials are not exploited, and consumption remains on a very low level.

In other words, impacts of on-grid electrification and mini-grids on the household level in most of rural SSA are not very different from most solar home systems. Some small enterprises in newly grid-connected areas do use electric machinery (typically shops, tailors, hairdressers, welders and carpenters), but the restricting factor for economic development is market access – which is very limited in most villages in SSA.

New and larger enterprises rarely emerge as a result of the village's connection to the grid. The major difference between the technologies is that grid access would allow demand growth to give way to endogenous local growth. In contrast, solar home systems lack this possibility due to the absence of high-power electricity. It is also important to note that if there is productive use potential in a not-yet-connected village, electricity is already there, by means of diesel generators in most cases. It is rare that demand potentials are not exploited and only emerge once the grid is available.

These patterns have been observed in well-crafted impact evaluations in several SSA countries (Bensch et al., 2019, 2022; Chaplin et al., 2017; Lee et al., 2020b; Masselus et al., 2024; Lenz et al., 2017; Peters et al., 2011; Schmidt and Moradi, 2023; Taneja, 2018). The absence of considerable economic impacts in electrification programmes is also documented in literature reviews (Bos et al., 2018; Lee et al., 2020a; Peters and Sievert, 2016).

The effects of small-scale solar are mostly at the level of convenience and improving daily routines like studying at home and housework (Grimm et al., 2017, 2020; Stojanowski et al., 2021). There are only minor impacts on time savings and monetary expenses (while amortisation is not always a given), and no discernable positive effects on productive and commercial uses.

Women certainly also benefit from the convenience and housework chore effects of small-scale solar, but this is hardly transformative and certainly much less pronounced than the considerable time savings and workload reductions that have been diagnosed for energy-efficient biomass cookstoves.

It is also worth emphasising that some of the positive evidence on small-scale solar stems from a baseline situation in which costly and dirty kerosene lamps have been replaced. This, however, is no longer the baseline situation in most settings in SSA because LED torches and non-branded solar has replaced kerosene virtually everywhere (Bensch et al., 2017), reducing impact potentials for small-scale solar considerably.

When scaled from small-scale solar to larger solar home systems, effects change with regards to a few appliance types that are additionally used, mostly TV sets and fans. Productive and commercial use is still very limited (Aklin et al., 2017; Bensch et al., 2018; Kizilcec and Parikh, 2020; Lee et al., 2016; Radley and Lehmann-Grube, 2022), for the same reasons as outlined for grid electrification above.

Beyond the classical impact categories typically scrutinised in impact evaluations, we stress that large infrastructure like the power grid also has more subtle but potentially important effects, which are under the radar of such impact evaluations.

For example, the availability of the grid might provide a sense of social inclusion. It might affect participation in elections, and via television also lead to modernisation, not least with respect to gender norms (Tanner and Johnston, 2017). Such effects are much likelier (although largely unknown) for on-grid electrification and perhaps functioning mini-grids than for stand-alone solar and improved cookstoves.

Yet, while these are noteworthy effects, and perhaps detectable on the country level, they are probably too subtle to decisively affect the cost-benefit analysis on the intervention level, given the high investment costs of grid extension.

Two important additional considerations need to be taken into account when interpreting the indicative cost numbers in Table 1: sustainability and low connection rates. Sustainability of on-grid electrification could indeed alter the cost-benefit analysis. When looking at a very long-term perspective, say, 15 or 20 years, the power grid is much more likely to provide sustainable electricity access than decentralised electricity sources, which need to be maintained and replaced.

The maintenance of the grid is a decades-old fair for utilities, and they make sure the grid operates, in the long run – on behalf of and financially supported by the government. Organising maintenance for mini-grids and, even more so, for stand-alone solar, is a much more difficult task (Duthie et al., 2023; Peters et al., 2019; Tenenbaum et al., 2014; Zigah et al., 2023).

In other words, the costs of sustainable provision to the services in Table 1 might well alter the relationship between the different technologies, in favor of grid extension. Nonetheless, this will probably not change the qualitative verdict that grid extension into rural areas is very expensive given the low demand and impact expectations.

This verdict is further substantiated by the importance of connection rates for costs per connection: costs per connection easily run into thousands of EUR if only a fraction of households in a village in fact connect, as it was observed, for example, in recent impact evaluations with connection rates below 30 % in Tanzania (Chaplin et al., 2017) and below 10 % in Kenya (Lee et al., 2020b) and Burkina Faso (Schmidt and Moradi, 2023).

Conclusion and policy implications

All things considered, from a cost-effectiveness perspective it is hard to make a case for grid extension. The same arguments however also apply for mini-grids, especially when sustainability considerations are taken into account (unless mini-grids are targeted at areas far away from the grid with a high-demand anchor customer).

It is therefore likely that the most cost-effective electricity access solution in most rural areas will be stand-alone solar. However, broadening the scope beyond electrification, energy-efficient biomass cookstoves stand out in terms of cost-effectiveness since they clearly deliver important impacts – especially for women – at very low costs.

Also from a sustainability standpoint, low-maintenance models of energy-efficient biomass cookstoves exist that do not require major investments until they need to be replaced.

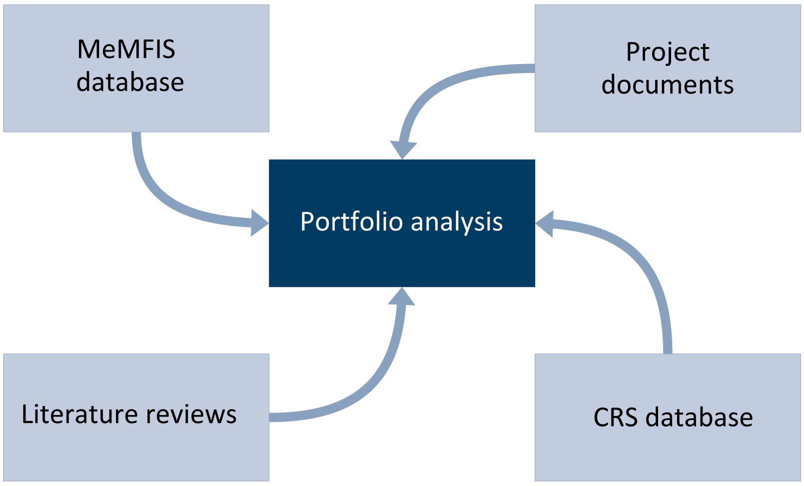
2. PORTFOLIO ANALYSIS[5]

2.1 Introduction

The portfolio analysis, conducted as part of the evaluation "Access to (Green) Energy in Rural Africa" gives an overview of the German-funded energy portfolio in Africa, including its development over time. It focuses on off-grid energy access and cooking energy in rural Africa.

It is intended to supplement the portfolio (Chapter 5) in the evaluation report. The portfolio analysis is based on various data sources, as illustrated in Figure 2.

Figure 2 Data sources used in the portfolio analysis



Source DEval, own figure

2.2 Evaluation subject

The focus of the portfolio analysis is on German Official Development Assistance (ODA) interventions as mandated by the Federal Ministry for Economic Cooperation and Development (BMZ) within the energy sector (Organisation for Economic Co-operation and Development (OECD) Development Assistance Committee (DAC) Creditor Reporting System (CRS) purpose codes 23x), as well as within the funding area of cooking energy implemented in Africa between 2000 and 2022, in which off-grid technologies were also implemented (see also Chapter 4.2.2 in the evaluation report).[6] German ODA mandated by the BMZ is also referred to as German Development Cooperation (DC).

The interventions identified were mostly aimed at providing first access to energy and improving access to modern energy for rural populations in Africa using off-grid approaches or a combination of off-grid and on-grid approaches. The nature of the interventions varied, but they frequently included elements such as consultations with stakeholders, support for the enabling and framework conditions, financing, subsidies and the provision of technologies, incentive and support mechanisms for households and Micro, Small and Medium-Sized Enterprises (MSMEs) to acquire and use the technologies, the removal of market barriers, the creation of technical and quality standards, advice and subsidies for operators, the creation of monitoring systems and training.

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[6] 2000 was chosen as the start date because there was a steady increase in the financial volume in the energy sector in the German portfolio from 2000 onwards. The most recent data available at the time of analysis is for 2022. Furthermore, the data in the MeMFIS database starts from 2000.

2.3 Reconstruction of the portfolio

In the sampling frame of the evaluation, we included all German ODA-eligible interventions commissioned by the BMZ in the energy and cooking energy sector between 2000 and 2022 in rural Africa. An additional inclusion criterion was that the interventions supported off-grid technologies, though not exclusively so, since some of these interventions were integrated with those that also targeted on-grid access.

Retrieving the relevant interventions for the sampling frame was challenging. The management, finance and information system (MeMFIS) database of the BMZ, which is at the core of the analyses, does not provide information on whether an intervention is conducted in rural areas or whether it is an off-grid intervention. It was also challenging to determine whether an intervention was relevant for the African context due to the existence of global and sectoral interventions that include Africa but also implement beyond it. Therefore, we applied several strategies to approximate the energy and cooking energy portfolio for rural Africa.

In a first step, we used the OECD DAC CRS purpose codes as identifiers wherever possible. Then, we requested documents for the relevant interventions from the implementing organisations Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and KfW Development Bank (KfW) based on the definition of the evaluation subject. This was an iterative process, where we discussed the interventions belonging to the evaluation subject with the implementing organisations based on MeMFIS intervention lists that were prefiltered by DEval.

Afterwards, we conducted a qualitative document analysis based on the documents that we received. Lastly, we conducted manual keyword searches in the MeMFIS database to identify cooking energy interventions as well as off-grid interventions. The reconstruction of the portfolio relied on the data sources listed in Table 2.

Table 2 Data sources

Data source	Description
BMZ MeMFIS	• The BMZ MeMFIS database serves as a data source of ODA-eligible bilateral development interventions under the responsibility of the BMZ. • This includes bilateral development cooperation. • This includes the time period 2000-2022.
OECD DAC CRS[7]	• The Creditor Reporting System (CRS) to OECD DAC on ODA of all DAC member countries. • This includes bilateral and multilateral development assistance, including core contributions to multilateral organisations. • This includes contributions from other ministries besides the BMZ.
KfW and GIZ project documents	• The implementing organisations KfW and GIZ have documentation of the interventions implemented. • 68 interventions could be linked to the MeMFIS dataset. Of these, 40 could be identified as off-grid interventions for which detailed information on the technical approaches implemented was available.
Literature reviews	• Three literature reviews to assess the state of the evidence on: the cost-effectiveness of rural energy access strategies, whether rural energy access programmes are pro-poor interventions, and rural energy access and women's empowerment.

Source: DEval, own table

7 The CRS data was used for the portfolio (Chapter 5) of the evaluation report, not for the supplementary information in this online appendix.

We operationalised the key variables using the identification strategies described above to approximate the sampling frame and identify the relevant interventions. Table 3 gives an overview of the key variables.

Table 3 Operationalisation of key variables

Variable	Definition and computation
Africa	• All interventions in the funding region Africa ("Förderregion Afrika").
Africa plus (default)	• All interventions in the funding region Africa. • + interventions that were not assigned to a funding region such as global or sector interventions, providing they were relevant for energy access in Africa. On the one hand, some of the interventions were already included in the data request to the implementing agencies. On the other hand, we performed a manual extraction of relevant interventions in the MeMFIS database, since not all relevant interventions had the (German) keyword "Afrika" in the database descriptions.
Energy interventions	• All interventions with purpose code 23x (1st, 2nd, 3rd or 4th purpose code).
Cooking energy	• Interventions with the purpose code 32174 ("Clean cooking appliances manufacturing"). There were 0 interventions coded as 1st purpose code and 2 interventions coded as 2nd purpose code. • + Keyword search in the MeMFIS database in German and English (29 keywords in different spellings, e.g. "Koch", "stove", "energy-efficient", "EEBC", etc.), followed by a manual exclusion of non-applicable hits. • + Interventions in the document analysis that were coded as cooking energy interventions.
Sampling frame "energy and cooking energy"	• All interventions in the variables "Energy interventions"+ "Cooking energy".
Off-grid interventions	• Interventions in the document analysis that were coded as off-grid or off-grid/on-grid interventions. • + Keyword search in the MeMFIS data base in German and English (38 keywords in different spellings, e.g. "off-grid", "netzunabhängig", "Solarpumpe", "PuE stand-alone" etc.), followed by a manual exclusion of non-applicable hits. • + Interventions with the purpose codes 23631 ("Electric power transmission and distribution (isolated mini-grids)") and 23231 ("Solar energy for isolated grids and standalone systems").
Rural development	• Dummy variable based on cross-sectoral identifier "Rural development" ("Ländliche Entwicklung").
Rural interventions	• Keyword search in MeMFIS database. • Manual extraction of rural interventions.

Source: DEval, own table

2.3.1 Intervention identification process

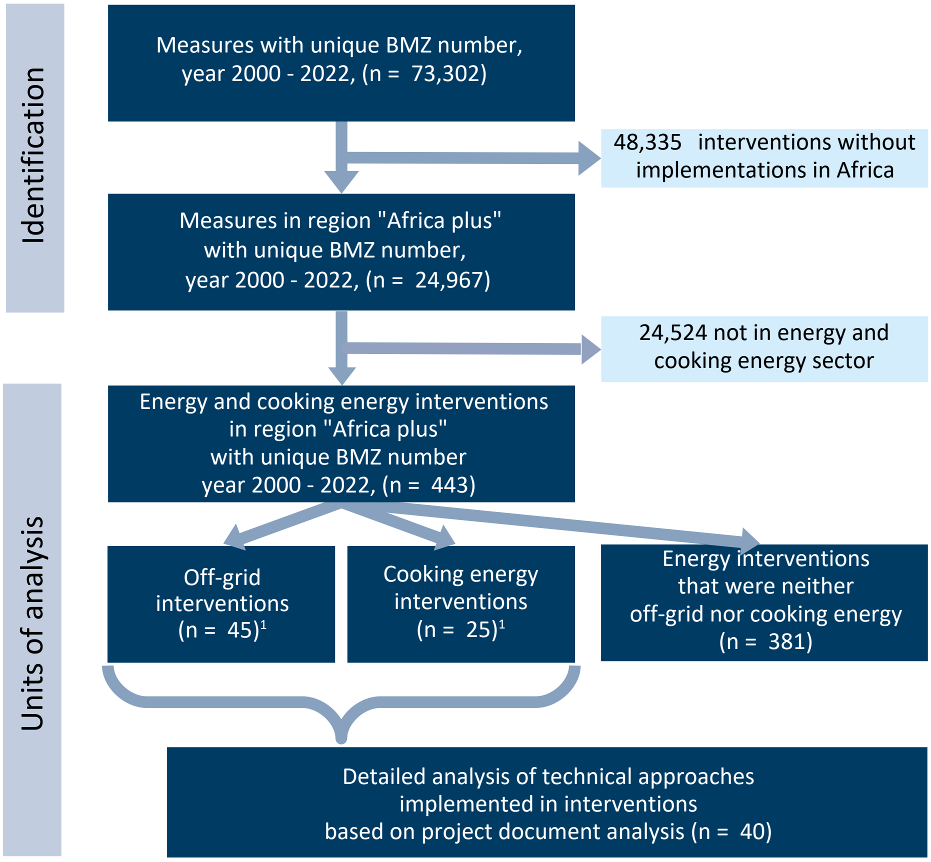
The identification process of the interventions relevant for the evaluation subject was based on the operationalisation of key variables as outlined in Table 3. Firstly, interventions in the region "Africa plus" were selected and then narrowed down to interventions in the sampling frame "Energy and cooking energy interventions".

In subsequent steps, we identified "off-grid" and "cooking energy" interventions and the relevant technical approaches of off-grid interventions. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram in Figure 3 summarises the selection process for determining the energy and cooking energy portfolio for rural Africa.

We analyse all energy interventions implemented by the German DC in the period under review. However, a large proportion of these interventions can be attributed to the energy access portfolio.

In operationalising energy access interventions, we rely on the CRS purpose codes that can be attributed to energy access according to Bazilian et al. (2011). In addition, we used the purpose codes that the interventions have been assigned to in the GIZ and KfW documentation that was provided to us.[8]

Figure 3 PRISMA diagram of case selection for portfolio analysis



Source: DEval, own figure

Note: These categories include eight interventions that contained both off-grid and cooking energy interventions

2.3.2 Limitations

Since the MeMFIS and CRS data frequently lacked detailed information on the characteristics of implementation and technical approaches, we had to rely on identifiers and markers such as purpose codes, the Rio marker for climate change mitigation (KLM) and the marker (GG) for gender equality.

[8] When operationalising energy access interventions, the evaluation is based on the purpose codes that can be attributed to energy access according to Bazilian et al (2011). However, their publication was based on the old CRS purpose codes. The updated list of purpose codes according to their definition include 23110 ("Energy policy and administrative management"), 23181 ("Energy education/training"), 23182 ("Energy research"), 232* ("Energy generation, renewable sources"), 233* ("Energy generation, non-renewable sources"), 23630 ("Electric power transmission and distribution (centralised grids)") and 23631 ("Electric power transmission and distribution (isolated mini-grids)"), 23640 ("Retail gas distribution"). We also added the newer code 23642 ("Electric mobility infrastructures"). Compared to the paper by Bazilian et al. (2011), which focused exclusively on electricity production and gas distribution, this evaluation also acknowledges other sources of energy such as fuels, including 23641 ("Retail distribution of liquid or solid fossil fuels"). In addition, the purpose code 23183 ("Energy conservation and demand-side efficiency") was also included, as this was present in interventions sent by the implementing organisations for off-grid interventions in rural Africa. This purpose code comprises two interventions in the document analysis and a total of 28 interventions in the sampling frame.

One challenge with this is that even though an intervention may be assigned up to four different purpose codes, most interventions only have one (89.2 % for the subject of this evaluation) or even none (about 1.0 %). Furthermore, we were limited by the fact that there is no identifier in MeMFIS for interventions that were conducted in rural areas and there is no reliable identifier or purpose code delineating off-grid interventions.

Adding to this challenge, full-text information, including data for the variable "objectives" ("Zielsetzung") of the interventions, was often not available. Given the challenges in identifying the interventions that ought to be included in the portfolio analysis we partly relied on the documentation from the relevant implementing organisations. However, this data was incomplete, since some of the interventions were still being implemented.

The reliance on the established markers or purpose codes may lead to results that are imprecise. Purpose codes create a clear delineation of interventions which may not correspond to reality. For instance, energy-relevant interventions with similar approaches are also implemented in energy-adjacent sectors such as agricultural interventions that promote energy access through solar irrigation pumps, as is confirmed by the evaluation's reference group. These interventions may not be labelled with a 23x purpose code despite their energy-related nature.

Nonetheless, the evaluation relies on purpose codes for several reasons. First, it is important to apply the benchmarks to test the evaluation questions for the sector they were intended for, namely the energy sector and the area of cooking energy. Second, using purpose codes ensures that the analysis and methods are transparent and replicable.

2.4 Additional findings[9]

2.4.1 Descriptive overview of the portfolio

As already described in the evaluation report, German DC implemented a total of 443 interventions in the energy sector, including cooking energy, in Africa between 2000 and 2022 (see Figure 3). These figures include interventions that were in the funding region Africa and those that were relevant for Africa (e.g. global and sector interventions that were also implemented in Africa). Only 45 interventions (10.2 %) could be identified as off-grid and 25 (5.6 %) as cooking energy.

Financially, the commitments have been growing for the entirety of the energy and cooking energy sector since 2000 as well as for off-grid interventions. While the financial commitments for the whole sector were 60.2 million euros in 2002, they increased to 649.7 million euros in 2022. Commitments for off-grid interventions exhibited more fluctuations. For example, they added up to 12.4 million euros in 2000, 3.5 million euros in 2001, increased to 103,7 million euros in 2021 and fell back to 59.2 million euros in 2022.[10] Additionally, the share of commitments for off-grid interventions increased from 10.6 % in the period 2000-2002 to 13.5 % in the period 2019-2022.

2.4.2 Overview of technical off-grid approaches

There are numerous technical approaches implemented in off-grid interventions (see Table 3 in the evaluation report), which serve different purposes and provide different tier levels of energy access.

[9] All findings on the productive use of energy for the evaluation criterion relevance can be found in the evaluation report

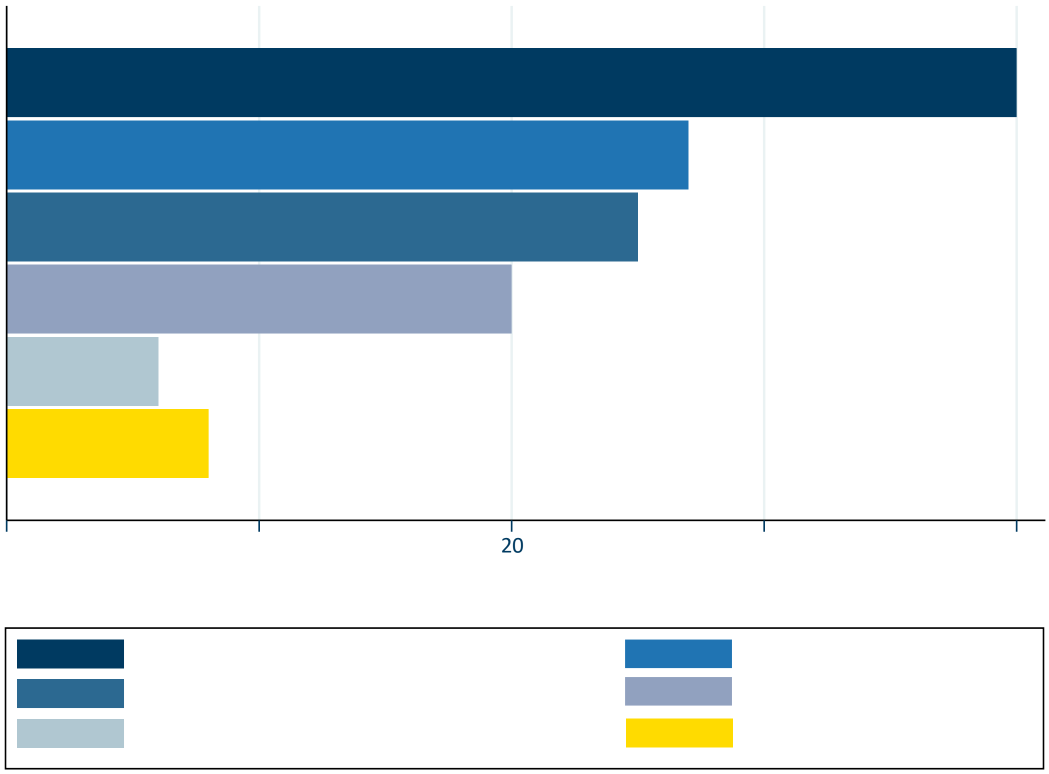
[10] If a category (e.g. off-grid interventions) only includes a few interventions, fluctuations can be expected because the commitments are associated with the financial year of the intervention. Large, multi-annual interventions may produce a spike in the associated financial year. In this regard, it is important to note that interventions (by unique BMZ number) may comprise several entries in the MeMFIS database, which frequently have separate values for the commitments and financial years.

During the detailed qualitative content analyses of intervention documents the following technical approaches were assessed: mini-grids, stand-alone systems, Pico-PV systems, cooking energy, and on-grid approaches that were embedded in off-grid interventions. We excluded interventions that only focused on improving on-grid access.

Figure 4 shows the number of technical approaches implemented in off-grid interventions. The analysis was based on 68 interventions in the document analysis, out of which 40 interventions were identified as off-grid interventions that provided sufficient information on the technical approaches implemented. 14 interventions (35.0 %) of the off-grid interventions sought to implement only one technical approach, 13 (32.5 %) implemented two technical approaches and 13 (32.5 %) aimed for three to five approaches.

Mini-grids were implemented most frequently, namely 27 times (67.5 % of off-grid interventions assessed in detail in the document analysis), followed by 25 on-grid implementations that were embedded in off-grid interventions (62.5 %). 16 of the mini-grid interventions also implemented on-grid interventions. Stand-alone systems were implemented 20 times (50.0 %). Cooking energy interventions were implemented eight times (20.0 %). Pico-PV systems were implemented only six times (15.0 %).

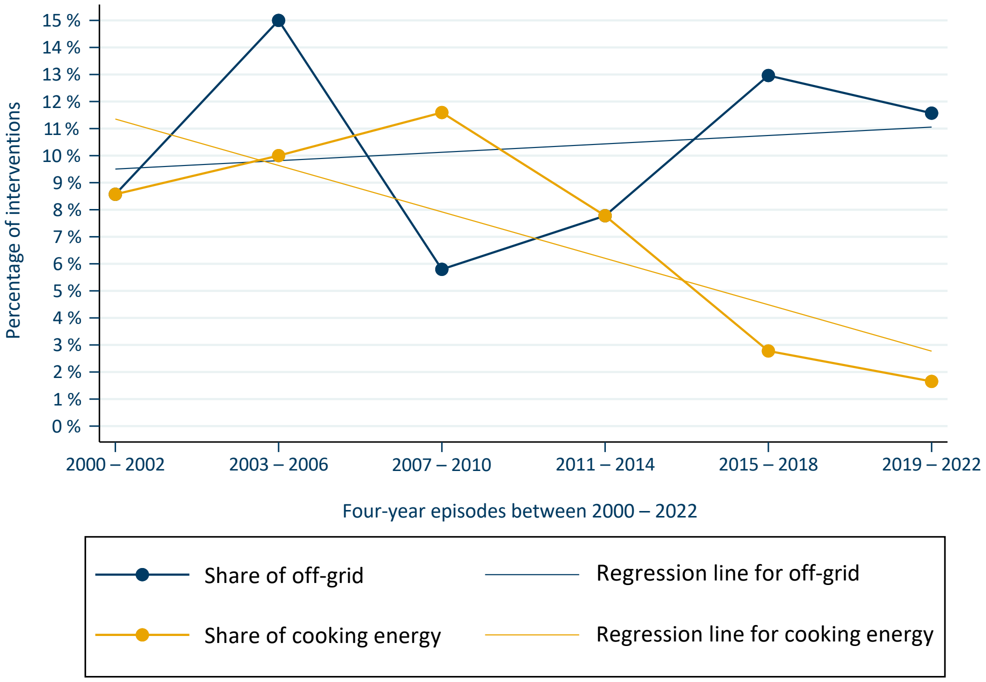
Figure 4 Implemented technical approaches in off-grid interventions



Source: DEval, own figure. Document analysis, region Africa plus, n = 68. Interventions may implement multiple technical approaches.

Figure 5 shows the share of cooking and off-grid interventions in the overall energy portfolio over time.

Figure 5 **Share of off-grid and cooking energy interventions in overall energy portfolio in the years 2000-2022**



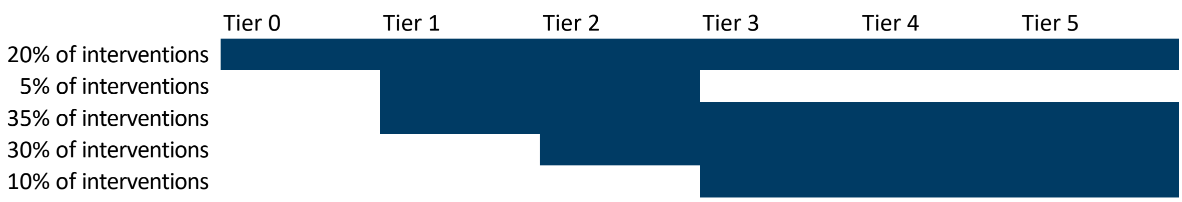
Source: DEval, own figure, MeMFIS 2000-2022, region Africa plus, n = 443 Energy and cooking energy interventions, 8 interventions are double-counted as they included off-grid and cooking energy implementations

2.4.3 Initial access to modern energy in rural areas

Concerning the relevance of the targeted tier level of a development intervention for SDG 7, in theory, initial access could be achieved at the highest tier level of 5. Realistically, initial access to modern energy in rural areas in Africa is more likely to be situated at a lower tier level. For that reason, the portfolio analysis assesses the lowest-implemented tier level over time as an indicator for the first access.

Since most interventions implement more than one technology, the range of likely targeted tier levels can be broad. Figure 6 gives an overview of the tier level targeted by the technical approaches implemented in off-grid interventions. 20 % of interventions implement approaches that start at tier level 0, 40 % of interventions start at tier 1, 30 % at tier 2 and 10 % at tier 3. None of the interventions sought to exclusively implement technical approaches at tier 4 or 5.

Figure 6 **Tier level targeted by off-grid interventions**

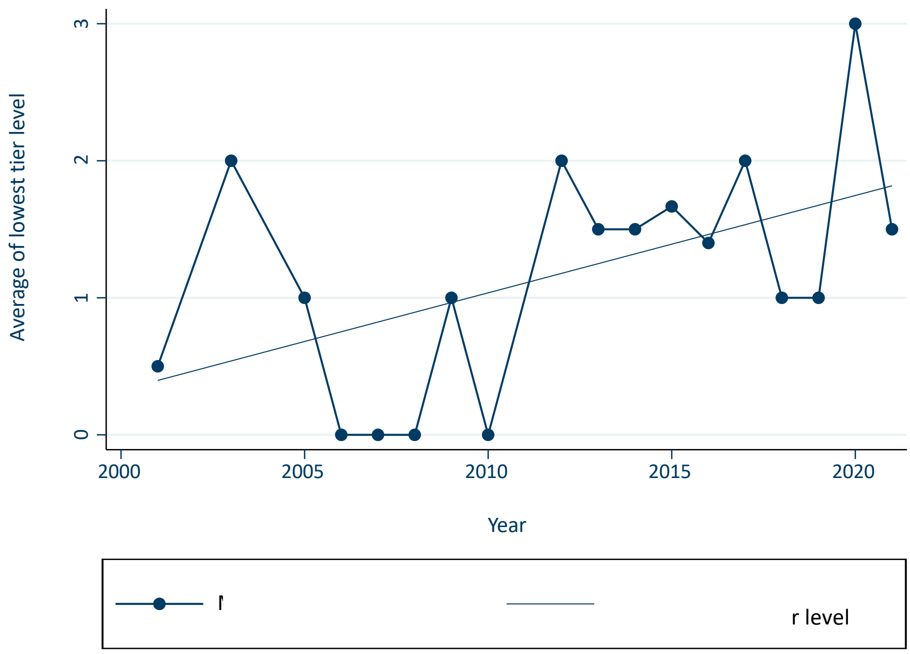


Source: DEval, own figure, Off-grid interventions in document analysis, literature review, region Africa plus, n = 40
Note: The range of tier levels depends on the technical approaches implemented.

An important finding is the trend of initial access over the past few years. Figure 7 shows the trend over time regarding initial access based on the results of the literature reviews and the summary of approaches suitable for initial access (according to Table 3 in the evaluation report).

As can be seen, the average lowest tier level targeted by the interventions in a given year has substantially increased since 2001. This is because the number of implemented technical approaches which are unsuitable for initial access are able to provide a higher minimum tier level, e.g. mini-grids. These have been growing faster than approaches like Pico-PV, cooking energy and stand-alone systems.

Figure 7 Lowest targeted tier level of off-grid interventions between the years 2000-2022



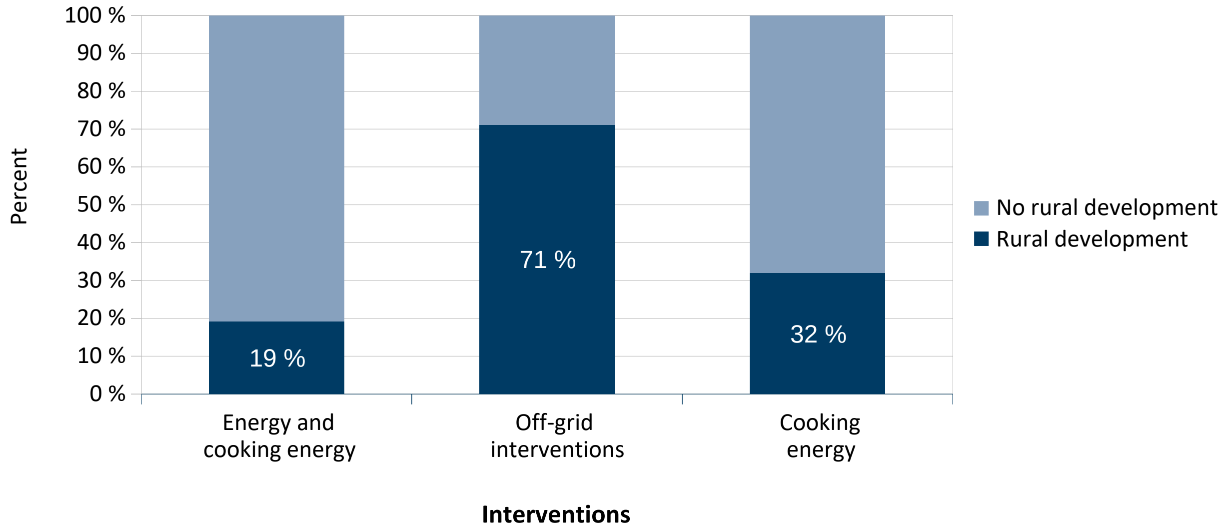
Source: DEval, own figure. Document analysis, off-grid interventions, region Africa plus, n = 40. Interventions may implement multiple technical approaches. The figure represents the mean of the lowest targeted tier level of off-grid interventions.

The availability of modern energy in rural areas plays an important role in achieving first access to modern energy. Rural development is a cross-sectoral indicator in MeMFIS. This indicates whether an intervention is geared towards rural development and/or food security (BMZ, 2010).

According to the guidelines of the BMZ, the rural development label for energy can be awarded for interventions that improve the political and institutional framework conditions in the energy sector, as well as for the provision of energy infrastructure. We use the variable “rural development” to determine whether an intervention contributes to rural development or not. We apply it as a proxy to assess how well rural areas are catered for regarding energy access.

As Figure 8 demonstrates, only 19.2 % of the energy and cooking energy interventions aim to contribute to rural development, while 71.1 % of off-grid interventions and 32.0 % of cooking energy interventions aim to contribute to rural development. However, these results are tentative, since the cross-sectoral indicator for rural development was not specifically designed for rural energy access.

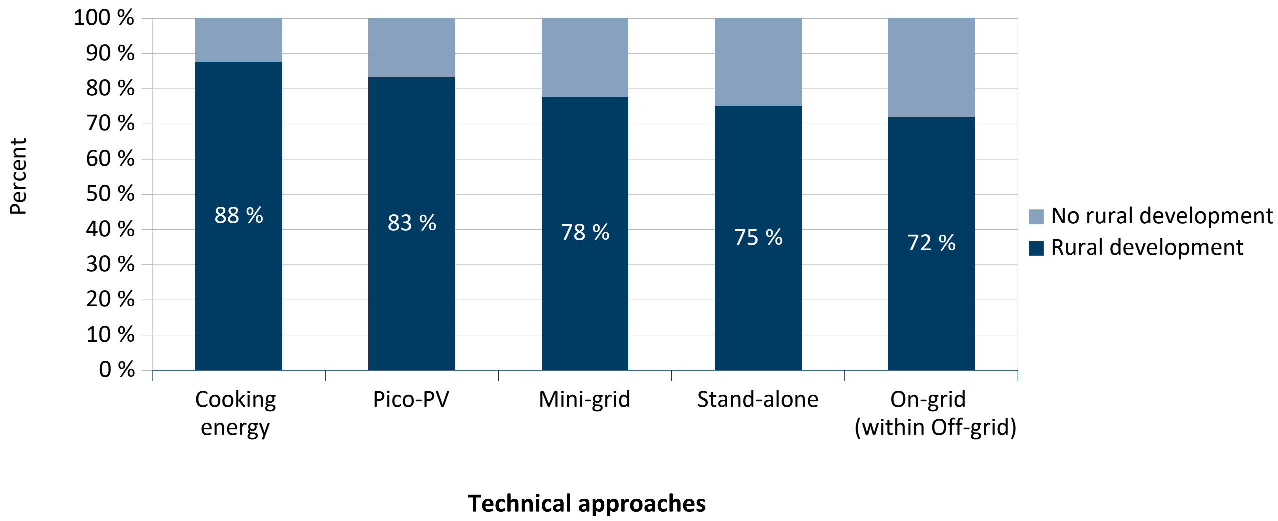
Figure 8 **Share of rural development in energy and cooking energy interventions in the years 2000-2022**



Source: DEval, own figure, MeMFIS 2000 - 2022, region Africa plus, n = 443 Energy and cooking energy interventions. 8 interventions are double-counted as they included off-grid and cooking energy implementations.

Figure 9 is based on the technical approaches in off-grid interventions which were reported on in more detail in the document analysis. According to the documents, interventions of cooking energy (87.5 %) and Pico-PV (83.3 %) are most often marked as contributing to rural development. However, also according to the documents analysed, over 70 % of the other technical approaches in off-grid interventions also contribute to rural development.

Figure 9 **Share of technical approaches with the marker ´rural development´ within the off-grid portfolio in the years 2000-2022**



Source: DEval, own figure, Document analysis 2000 - 2022, region Africa plus, n = 40 off-grid and cooking energy interventions. Interventions may implement multiple technical approaches.

2.4.4 Gender equality and women's empowerment

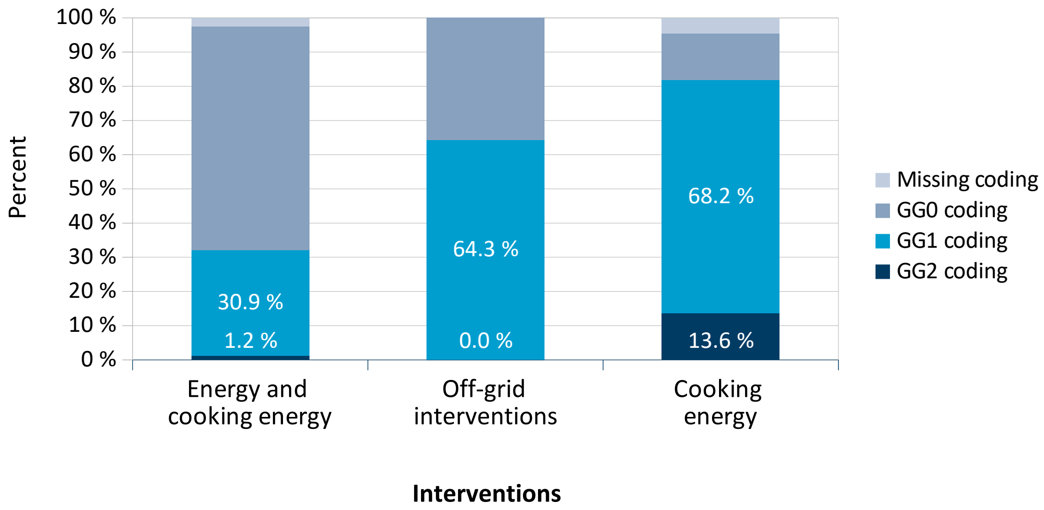
An important criterion in achieving gender equality and improving the livelihoods of women and girls is whether the needs of women and girls are considered in the objectives, conception and implementation of interventions in the energy and cooking energy sector.

This was analysed by using the cross-sectoral marker of gender equality (GG) ("Gleichberechtigung der Geschlechter") in the MeMFIS database. GG2 represents gender equality as the primary (main) objective of the development intervention, and GG1 represents a secondary objective. Gender equality has been coded reliably since 2003.[11] For this reason, our analyses cover the period from 2003-2022.

Throughout the entire energy and cooking energy sector only 32.1 % of interventions target gender equality, with only 1.2 % marking it as a main objective and 30.9 % as a secondary objective.

As Figure 10 shows, off-grid interventions exhibit a comparatively high percentage of interventions promoting gender equality at 64.3 %, though only as a secondary objective. The share of interventions promoting gender equality was highest among cooking energy interventions at 81.8 %, with 13.6 % as a main objective and 68.2 % as a secondary objective.

Figure 10 Gender equality (GG) as an objective in energy and cooking energy interventions

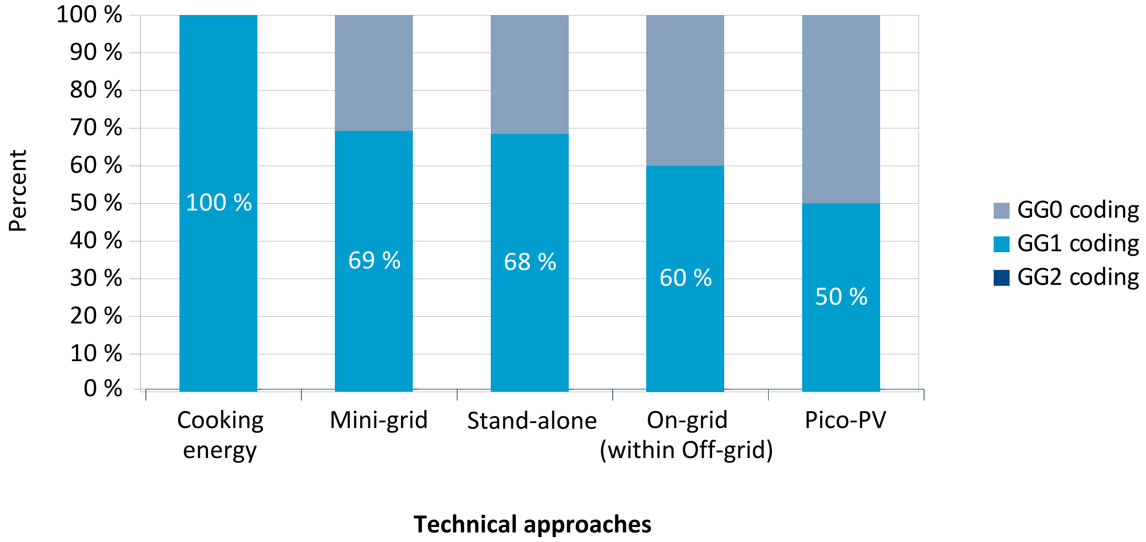


Source: DEval, own figure, MeMFIS 2003-2022, region Africa plus, n=408. 8 interventions were double-counted as they included both off-grid and cooking energy implementations

None of the 72 off-grid interventions analysed in the document analysis in detail state gender equality as their main objective. The percentage of gender equality as a secondary objective varied substantially between the technical approaches as illustrated in Figure 11. While all cooking energy interventions (100 %) promoted gender equality, only 69.2 % of mini-grid and 68.4 % of stand-alone systems interventions stated gender equality as an objective. Among the off-grid interventions studied, the technical approach with the lowest share of gender equality was Pico-PV (50.0 %).

[11] The years 2000 – 2002 still contain a substantially higher number of missing values in the GG coding compared to later periods.

Figure 11 Gender equality (GG) objectives in off-grid interventions in the years 2011-2022



Source: DEval, own figure, MeMFIS, Document analysis 2011-2022, region Africa plus, n=35 off-grid and cooking energy interventions. Interventions may implement multiple technical approaches

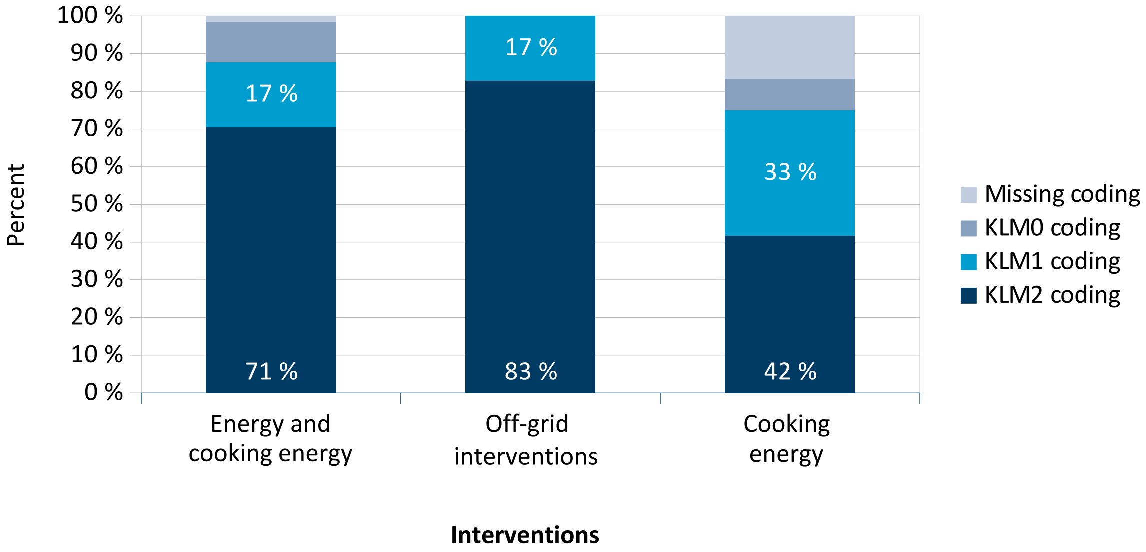
2.4.5 Climate change mitigation

The energy and cooking energy sector is relevant for achieving climate change mitigation goals. Furthermore, no interventions which are reliant on fossil fuels are expected to have been implemented as a result of the Paris Agreement in 2015.

Figure 12 shows that most interventions in the energy sector contribute to climate change mitigation. The Rio marker for climate change mitigation (KLM) indicates whether climate change mitigation is a principal objective (KLM2) or a significant objective (KLM1) of the intervention.

As shown in the evaluation report, 87.8 % of energy interventions have climate change mitigation as an objective, with most interventions (70.5 %) having mitigation as the principal objective. All off-grid interventions (100 %) contribute to climate change mitigation, with 82.9 % having it as a principal objective. Among the interventions concerning cooking energy, the share contributing to mitigation is 75 %, with 41.7 % having it as the principal objective.

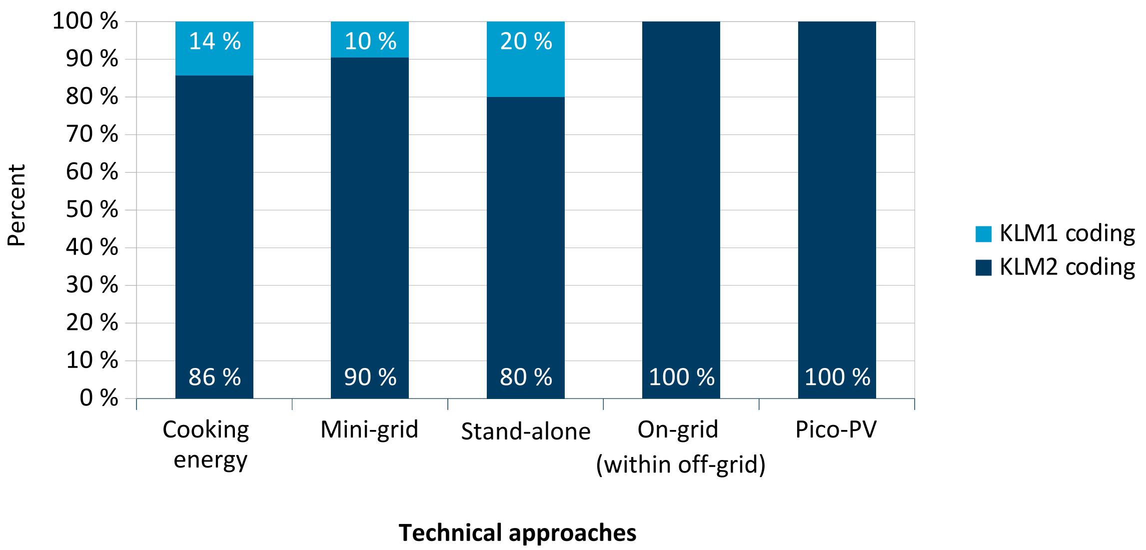
Figure 12 Share of interventions contributing to climate change mitigation in the years 2011-2022



Source: DEval, own figure, MeMFIS 2011-2022, region Africa plus, n=319 Energy and cooking energy interventions. 8 interventions are double-counted as they included off-grid and cooking energy implementations

The more detailed analyses of technical approaches within off-grid interventions (see Figure 13) shows that 100 % of the interventions were marked as being relevant for climate change mitigation (KLM1 and KLM2). Among these, all on-grid interventions (within off-grid interventions) and interventions that implemented Pico-PV systems were labelled as having climate change mitigation as their principal objective as well as 90.5 % of the interventions implementing mini-grids. Among stand-alone systems and cooking energy, over 80 % were labelled as having mitigation as their principal objective.

Figure 13 Share of technical approaches in off-grid interventions contributing to climate change mitigation in the years 2011-2022



Source: DEval, own figure. MeMFIS, Document analysis 2011-2022, region Africa plus, n=35 off-grid and cooking energy interventions. Interventions may implement multiple technical approaches. One figure does not add up to 100 % due to rounding.

In response to the Paris Agreement in 2015, German DC has been expected to halt its support for interventions that include non-renewable (fossil) energy. Table 4 shows that this has been achieved. Since 2003, only 8 interventions implemented non-renewable (fossil) energy and only one after 2018.

A closer look at this sole intervention after 2018, which is called "Crowdfunding for Energy Inclusion", reveals that it was misclassified in MeMFIS, and is in fact coded as KLM2 (climate mitigation as a principal objective) and supports renewable energies.

Table 4 Non-renewable (fossil) energy interventions by financial year

Financial year	Number of interventions supporting non-renewable (fossil) energy
2003	1
2008	2
2009	1
2010	1
2013	1
2015	1
2019	1
Total	**8**

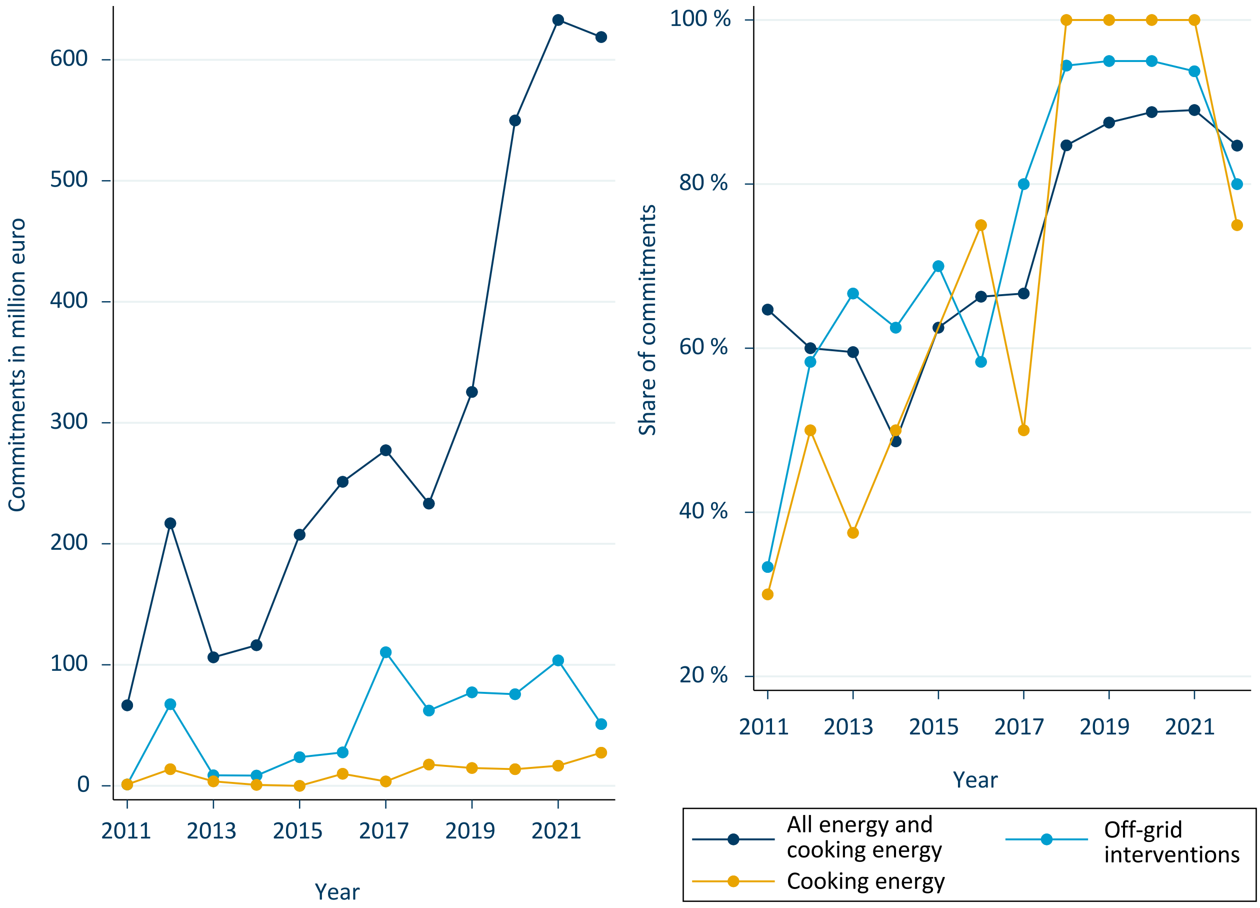
Source: DEval, own table, MeMFIS 2000-2022, region Africa plus, n=443 energy and cooking energy interventions
Note: Non-renewable (fossil) energy was defined as purpose code 233 "Energy generation, non-renewable sources" with all sub-codes, purpose code 23640 "Gas distribution to the customer (retail)" and 23541 "Distribution of liquid or solid fossil fuels to the customer (retail)"

Figure 14 illustrates the financial commitments for climate change mitigation over time. The commitments for climate change mitigation for the entire energy and cooking energy sector have increased substantially.

While they amounted to 66,5 million euros in 2011, they increased to 618,8 million euros in 2022. The contributions for climate change mitigation for off-grid interventions and cooking energy interventions have also increased, but at a lower level.

The commitments for off-grid interventions have fluctuated significantly, and were 1,1 million euros in 2011, jumped to 67,4 million euros in 2012, and then reached 103,7 million euros in 2021 and 51,0 million euros in 2022. The commitments to climate change mitigation through cooking energy interventions increased from 1,2 million euros in 2011 and 13,8 million euros in 2012 to 27,4 million euros in 2022.

Figure 14 Financial commitments for climate change mitigation (KLM-coded) in the years 2011-2022



Source: DEval, own figure. MeMFIS 2011-2022, region Africa plus, n=319 Energy and cooking energy interventions. 8 interventions are double-counted as they included off-grid and cooking energy implementations. Commitments include reprogramming and approved amounts. KLM2 contributions were applied 100 %, KLM1 were 50 % discounted. Euro values represent fixed amounts in euros at the base value 2015

Note: Left panel: KLM commitments in million euros; Right panel: Share of KLM commitments in overall commitments

Considering the entirety of the financial commitments to energy, the aggregate share of KLM commitments constitutes 73.6 % for the whole sector of energy and cooking energy for the entire period 2011-2022. Among these interventions, off-grid interventions have a slightly higher share of 79.7 % while cooking energy interventions have a substantially lower share of 62.5 % (over the entire period 2011-2022).

Like the absolute financial commitment, the share of objectives towards climate mitigation (KLM) for energy and cooking energy interventions has increased since 2011, when KLM markers were properly coded for the first time, from 64.7 % in 2011 to 84.7 % in 2022 (see Figure 14). Unlike the development of commitments in absolute figures over time, the various subsectors of energy show similar shares of climate-related commitments (see Figure 14).

2.5 Conclusion

The portfolio analysis provides several insights into the state of and the trends visible in the energy and cooking energy portfolio in Africa, in which off-grid technologies were also implemented. A main finding of the analysis is that the share of off-grid interventions in the energy sector is comparatively low and has only slightly increased over the last twenty years, though the share of financial commitments for off-grid interventions increased.

Regarding cooking energy interventions, which indicate particularly positive effects on women, they have rarely been implemented since 2014. Overall, the share of cooking energy interventions has decreased substantially over time while the share of commitments has slightly increased.

Within the off-grid portfolio, mini-grids and on-grid interventions (within off-grid interventions) were implemented most frequently, while stand-alone systems, and particularly Pico-PV and cooking energy, were implemented the least. Only 35 % of interventions sought to implement only one technology, while most interventions (65 %) included at least two technical approaches.

Over the years, the mini-grid and on-grid approaches (within off-grid interventions) had the strongest growth, surpassing stand-alone systems since the mid-2000s. The number of implementations of Pico-PV grew at a low level and cooking energy stagnated at a low level.

Achieving access to modern energy by 2030 (SDG 7.1) is one of the goals of the German DC. However, the share of interventions providing initial access to modern energy has been decreasing and the lowest tier level implemented in interventions has been increasing over the years. This trend makes it very unlikely that the German DC is on track towards achieving SDG 7.1.

In relation to the entirety of the energy and cooking energy sector, off-grid interventions were more than three times more likely to contribute to access to energy in rural areas, while cooking energy interventions were more likely to promote rural development than the average of the energy sector, but much less often than off-grid interventions.

However, among off-grid interventions, cooking energy interventions were the most likely to promote rural development, followed by Pico-PV systems. Moreover, about two thirds of mini-grids, stand-alone systems and on-grid (within off-grid interventions) implementations promoted rural development.

Evidence from the literature reviews shows that the impact of modern energy access on productive use is very limited. Technical approaches that may possibly lead to productive use were stand-alone systems (particularly if enterprises are targeted).

However, the results of the portfolio analysis show that the German DC does not focus on either of these approaches. The implementation levels of both approaches are low for stand-alone systems and very low for cooking energy respectively. Furthermore, the trend over time of the share of both approaches is strongly negative. Targets regarding the productive use of modern energy are unlikely to be reached given these trends and the low implementation levels.

The share of interventions promoting climate change mitigation was already high in 2019-2022. It has been steadily increasing over the years. Along with this, the financial commitments for climate change mitigation have also been increasing among all types of interventions, as has the share of commitments for mitigation in relation to overall commitments.

In addition, our findings confirm that there was no promotion of interventions in the German DC portfolio that relied on fossil fuel energy after the Paris Agreement in 2015.

The share of interventions promoting gender equality has decreased substantially for the energy and cooking energy sector and for off-grid interventions. It increased for the few cooking energy interventions. Overall, very few interventions marked gender equality as their main objective.

In summary, the trend of the German DC's portfolio regarding initial access to modern energy (SDG 7.1) and gender equality (GG) does not yet point towards Germany achieving its goals by 2025 (GG) and 2030 (SDG 7.1). The promotion of climate change mitigation has increased. No fossil fuels were supported after the Paris Agreement in 2015, and the energy and cooking energy sector exhibit high levels of financial commitment to climate change mitigation.

3. DATA COLLECTION OF FOCUS GROUPS

3.1 Benin

A total of 10 focus groups were held in Benin. They took place in June and July 2023 in the departments of Alibori, Borgou, Couffo, Mono and Ouémé, and were meant to capture different contexts across agricultural zones. Five focus groups were mixed-gender while five were exclusively female. The participants were a mixture of beneficiaries of the EnDev and GBE interventions and non-beneficiaries.

Further, the groups were conducted with groups of farmers, animal breeders and shop owners. Within each group, at least one participant was a beneficiary of the productive use components of EnDev or GBE which provided access to solar appliances. The female focus groups took place in cooperation with the local women's association in the same localities.

3.2 Senegal

A total of 20 focus groups were held in Senegal. They took place in August and September 2023 across the departments of Guinguinéo, Kébémer, Thiès and Tivaouane in the regions of Louga, Kaolack and Thiès. They took place in August and September 2023 across the departments of Guinguinéo, Fatick, Kébémer, Thiès and Tivaouane in the regions of Foundiougne, Louga, Kaolack and Thiès. Like in Benin, these were intended to cover different contexts across agricultural zones via a broad selection. For the ten focus groups on solar stand-alone appliances, the recruitment process for participants was identical to the one in Benin.

Apart from that, the team also conducted ten focus groups with entrepreneurs in villages where EnDev had facilitated the installation of mini-grids through the components of ERSEN1 and ERSEN2. Additionally, these components also provided access to productive-use appliances such as fridges to be used in conjunction with the mini-grids. These focus groups were conducted in the regions of Fatick and Thiès in the departments of Foundiougne and Tivaouane. Again, mirroring Benin, five groups were mixed-gender and five consisted exclusively of women, which was enabled through the cooperation with local women's organisations.

3.3 Uganda

A total of ten focus groups were held in Uganda in August 2023. Specifically, six focus groups were held in the districts of Gulu, Kitgum and Lamwo in northern Uganda, addressing the target groups and technical approaches of the GBE. Four focus groups were conducted in the districts of Buikwe and Wakiso in central Uganda to encompass the target groups and technical approaches of EnDev. Overall, seven focus groups were mixed-gender while three focus groups were exclusively female. All target groups included a mixture of beneficiaries of the interventions and non-beneficiaries.

4. SURVEYS ON STAND-ALONE SOLAR PUE APPLIANCES[12]

The data collection is described in detail in Chapter 4 of the evaluation report.

4.1 Identification strategy

To assess the effects in terms of outcomes and impacts of the use of the stand-alone appliances for productive use of energy, we use three types of estimates: 1) before-after comparisons within the treatment group, 2) cross-sectional analyses between treatment and control groups at the time of the survey and, 3) difference-in-differences (DiD) analyses.

Since there is no baseline data on either GIZ beneficiaries or the control groups (non-beneficiaries), the status quo from before the intervention had to be reconstructed. This was done using recall questions about the past for both the beneficiaries and the control groups. The reference year is the year before the intervention began, namely 2015 in Benin and 2019 in Senegal.[13]

4.1.1 Before-after comparisons

The before-after comparison is performed within the treatment group through a paired Student's t-test. Since the same units are compared to each other, there are no time-invariant factors at individual or village level that could confound the relationship between the treatment and control groups. A potential source of bias, however, is a secular trend that would have improved the 'after' even in the absence of an intervention. This is addressed by complementing the simple before-after comparison with a DiD model that is more immune to time trends.

The before-after comparison compares the potential outcome of the individuals and MSMEs in the treatment group before they received the treatment to their outcome after the treatment. This comparison serves to verify the plausibility of the results from the more complex causal analyses. It does this by testing whether the treatment group improved over time.

The simple comparison also allows us to explore the short-term effects of the interventions, since the before-after comparison compares individuals a year after the individual installation date of the solar appliances to a year before the installation date.[14] This is in most cases a much shorter timespan than between the time of the survey (2023) and the reference year before any individual or MSME received the treatment (2015) in Benin.

In Benin, the intervention was implemented from 2015 to 2022. Here, individual dates for the pre- and post-treatment periods are used in the before-after comparison. The period before the treatment is one year prior to the individual installation date of the solar appliance. The period after the treatment is one year after the individual installation date of the solar appliance. According to the key assumption of this strategy, the

[12] Contributors: As'Ad Assani, Fredo Bankole, Gerald Leppert, Mame Mor Anta Syll, Whitney Edwards, Yannick Gunia.

[13] Many MSMEs in the study are farms. The relevant period for them is the agricultural campaign, which does not entirely overlap with the calendar year. When the surveys were tried and piloted, it turned out that MSMEs in Benin were better able to report outcomes with respect to the agricultural campaign, while those in Senegal were able to report on the calendar year. This is why when we refer to the reference year and the outcome year in Benin, the questionnaire asked about the agricultural campaigns for the periods 2015-2016 and 2022-2023 respectively.

[14] The installation date is the date when the appliance was received by the beneficiary according to the monitoring data by the interventions studied. This date is used in the analyses, since it is the first possible date where the appliance could potentially have been used by the beneficiary and the treatment could have begun to unfold.

intervention should be the only element impacting changes in our results over time. If the intervention did not exist, the results would have been the same for both before and after the study period.

As the intervention duration was much shorter in Senegal – from 2021 to 2023 – outcomes at individual points in time were not collected and no before-after-comparison was performed.

4.1.2 Constructing and sampling a control group and an alternative treatment group

We construct a control group for the cross-sectional and DiD analyses. This control group is made up of MSMEs (many of which are farms) that share important characteristics with the beneficiaries in the respective municipality:

- they were engaged in the same activity as the beneficiaries in the reference year (2015 in Benin, 2019 in Senegal);
- had a level of activity comparable to that of the beneficiary in the reference year;
- did not have access in any form to an appliance supplied to the beneficiary.

The control group is divided into two sub-types: a group that does not use modern energy (C1) and a group that uses modern, non-solar energy (C2). This is necessary, because past research suggests different effects for these two types of controls (see Chapter 3 in the evaluation report for a review).

While enterprises that use modern energy for the first time in an economic activity have a high potential of seeing a substantial increase in productivity and sales, enterprises that switch from fossil to solar energy in their economic activity are more likely to experience changes in their energy expenses and more moderate changes in other outcomes.

The main comparison is between GIZ beneficiaries of solar stand-alone appliances and a control group that is similar in several factors, with the main difference being the use of conventional, non-renewable energy for their economic activity (C2).

We made this decision because according to our quantitative data and information from focus group discussions, solar appliances were mainly acquired by entrepreneurs who had previously been using fossil energy for the same activity. On the contrary, only few MSMEs that did not use modern energy for their activity benefitted from the intervention.

The protocol for recruiting the control groups was as follows: the enumerator asked the beneficiary interviewed to name a fixed number of other entrepreneurs in the same municipality who the beneficiary thought would be interested in using solar appliances for their activity.

Another prerequisite was that the interviewee and the suggested respondent were similar to each other in terms of activity in 2019 in Senegal (the year before the COVID-19 pandemic started and used as the reference year) and in 2015 in Benin, respectively.[15] The entrepreneur to be recruited for the control group ought to have been involved in the same activity as the beneficiary in the reference year and on a similar scale.[16]

[15] In Senegal 2019 was used as the pre-treatment period and 2023 as the post-treatment period in all analyses. The year 2019 was used instead of 2020, as 2020 was exceptional due to the outbreak of the COVID-19 pandemic. Using 2020 as a reference year could have led to an overestimation of positive effects as enterprises were recovering from the pandemic.

[16] Original wording in French: « niveau d'activité comparable au bénéficiaire »

Moreover, the potential control respondent should not have profited directly or indirectly from the solar appliance of the beneficiary. Those individuals suggested were then divided by the enumerator into the two different types of control groups (C1 or C2) or the alternative treatment group.[17]

The alternative treatment group (T2) consisted of MSMEs which were similar to the beneficiary with regard to the above-mentioned criteria and which also use a solar appliance for their economic activity. The difference between the main treatment group – the GIZ beneficiaries (T1) – was that T2 had not aquired their solar appliance through the GIZ interventions under study. There are two reasons why this alternative treatment group was recruited.

First, the GIZ beneficiaries' contact data was not always up to date, meaning that there was a risk of not being able to sample enough respondents from T1 to be able to run statistical analyses (more so in Benin than in Senegal). Secondly, recruiting T2 (called "GIZ and non-GIZ treated" in the regression tables) allowed analyzing whether the effects were specific to the GIZ interventions or instead resulted from using solar appliances as compared to fossil-fuel-powered appliances or no modern energy source at all.

4.1.3 Cross-sectional analyses

To verify the robustness of the results of the before-after comparison, cross-sectional analyses between the treatment groups and the control groups were applied. The cross-sectional analyses compare the outcomes for treatment and control MSMEs in the post-treatment period.

The assumption underlying this approach is that the enterprises who received the treatment do not differ systematically from those who did not receive it. This was attempted through the recruitment protocol described. The credibility of this assumption was enhanced by applying a propensity score matching (PSM) technique.

This means that treatment and control units were matched based on observable variables (matching variables). Matching variables were selected that are not influenced by the treatment itself but that could plausibly confound the relationship between the treatment and outcomes under study (for details, see Chapter 4.3).

Cross-sectional analyses can account for differences between the treatment and control groups prior to treatment to a certain extent thanks to the inclusion of controls that were intervened prior to treatment.

The econometric specification to be used in the cross-sectional comparison is:

$$Y_i = \alpha + \beta * Treat_i + \gamma 1Cov_i + \gamma 2Cov_v + \gamma 3Cov_z + \varepsilon_i$$

Y_i is the outcome variable of interest.

$Treat_i$ is the treatment variable, which takes the value 0 for the control group and the value 1 for MSMEs and their owners who have bought and installed the appliance.

Cov_i, Cov_v and Cov_z represent the vectors of the baseline (2015 in Benin; 2019 in Senegal) characteristic of the MSMEs used for calculating the propensity score and the related weight in the PSM approach (age of enterprise, size of enterprise at baseline, high-quality flooring yes/no).

The index *i* includes baseline characteristics of the interviewed owner of the MSME (age, at least primary education yes/no). The index *v* represents a baseline characteristic at the community level (rural/urban) and the index *z* represents the location of the MSME in a certain agricultural zone.

[17] The conclusions of the evaluation focus mainly on the comparison between GIZ beneficiaries and the control group which uses fossil energy for the same activity as the one carried out by the beneficiary. This is the most important comparison, as most beneficiaries themselves used fossil energy for their economic activity prior to treatment. This is also in line with an argument in the literature that the main competitor to solar pumps is diesel pumps (Ankel-Peters et al., 2024a; Smith & Urpelainen, 2016). The evaluation contextualises these findings wherever suitable with reference to those from the other comparisons.

β captures the treatment effect on the treated (ATT), i.e. the use of stand-alone PuE appliances, as a coefficient of the treatment $Treat_i$.

4.1.4 Difference-in-differences (DiD) analyses

We complement the before-after comparisons and the cross-sectional analyses with DiD analyses. The assumption underlying this approach is that there are no unobservable differences between treatment and control that affect the changes over time.

To reduce selection bias and control for confounding factors, we apply the same PSM matching procedure as described above for the cross-sectional comparison (for details on the PSM procedure and matching variables, see Chapter 4.3).

The econometric specification in the DiD estimations is:

$$Y_i = \alpha + \beta 1 * T_i + \beta 2 * Treat_i + \beta 3 * T_i * Treat_i + \gamma 1Cov_i + \gamma 2Cov_v + \gamma 3Cov_z + \varepsilon_i$$

Y_i is the outcome variable of interest.

T_i denotes the time period which takes the value 0 for the baseline year (2015 in Benin; 2019 in Senegal) and 1 for the year 2023. The data on the baseline year T_0 was obtained using recall questions in the survey at T_1.

$Treat_i$ is the treatment variable, which takes the value 0 for the control group and the value 1 for individuals/MSMEs who have bought and installed the appliance.

Cov_i, Cov_v and Cov_z represent the vectors of the baseline (2015 in Benin; 2019 in Senegal) characteristic of the MSMEs used for calculating the propensity score and the related weight in the PSM approach (age of enterprise, size of enterprise at baseline, high-quality flooring yes/no).

The index *i* includes baseline characteristics of the owner of the MSME (age, at least primary education yes/no). The index *v* represents a baseline characteristic at the community level (rural/urban) and the index *z* represents the location of the MSME in a certain agricultural zone.

β captures the treatment effect on the treated (ATT), i.e. the use of stand-alone PuE appliances, as a coefficient of the treatment $Treat_i$.[18]

4.2 Outcome variables

We study two main types of outcomes. Firstly, we examine MSME performance, operationalised through production, sales, energy expenses, innovation/value added and the number of employees. According to the theory of change, the outcomes that were investigated are the following: revenue[19], sales[20], processing of products (dummy)[21], energy expenses[22], number of employees, having customers from outside their own municipality (dummy for Benin, numerical as percentage of customers for Senegal)[23], planted area[24], quantity

[18] The study did not intend to capture the intention to treatment effect (ITT), since it is not plausible that MSMEs were offered an appliance, but did not obtain it.

[19] Original wording in French: « Dans quel intervalle se situent les revenus totaux de l'entreprise? »

[20] Original wording in French: « A combien estimez-vous les ventes totales de l'entreprise? »

[21] Original wording in French: « Procédez-vous à la transformation de vos produits avant de les vendre? »

[22] Original wording in French: « Combien dépensez-vous en termes d'énergie (FCFA/Mois) pour votre activité économique principale au cours des différentes périodes suivantes? »

[23] Original wording in French: « Quelle es/était la structure de votre clientèle en termes de localisation géographique? »

[24] Original wording in French: « Quelle est la superficie emblavée pour [culture principale]? »

of product sold[25], quantity of product sold during dry season[26], cultivation during dry season (dummy, variable only used in Senegal sample)[27], food security (dummy)[28] and assets[29].

Secondly, we also study the economic wellbeing of the owner of an enterprise (and their family), operationalised through questions on food security, assets and housing quality. A third category of outcomes concerns the non-material wellbeing of MSME owners and some gender-specific outcomes. These outcomes are assessed in separate descriptive analyses that focus on self-reported effects. These analyses are only performed on the subsample of GIZ beneficiaries.

4.3 Causal pathways and operationalisation

Chapter 3 of the evaluation report identifies the causal pathways from access to solar appliances to the outcomes and impacts including wellbeing of entrepreneurs and their families and economic impacts. However, there are some factors that may lead to a bias in the estimations of the treatment effect on different outcomes and impacts if unaccounted for. These factors are potential confounders, which simultaneously predict the selection into treatment as well as the outcome and impact under study (Rosenbaum and Rubin, 1983). In the absence of a random allocation to the treatment group, we need to correct for this selection bias in the analysis.

One potential confounder between access to a solar appliance and the likelihood of switching to more valuable crops or processing products before selling them is the age of the owner. Akudugu et al. (2012) find a U-shaped relationship between age and adoption of a new technology, with middle-aged entrepreneurs being more likely to adopt a new technology (Akudugu et al., 2012). Interestingly, the results from Benin contradict this finding, and show that older enterprise owners are more likely to acquire a solar appliance but also those whose enterprise is younger. Adding to that, larger firms also appear more likely to purchase a solar appliance (Closas and Rap, 2017) and owners of larger enterprises seem more likely to adopt a new technology (Akudugu et al., 2012).

Another potential group of confounders that we account for are regional factors. First, the agricultural zone in which a respondent is located may be a proxy for regional differences in weather, temperatures and climate in general. This is important, since weather drives both the need for irrigation or the provision of water for animals, and also directly affects the production level and the health of animals (Burney et al., 2010). Secondly, depending on infrastructure and the institutional setting, the degree of urbanisation of an area is generally associated with higher income and productivity, and also with effects on labour markets and knowledge spillovers (Dudwick et al., 2011). These factors may also be correlated with the accessibility of solar appliances and at the same time post-treatment outcomes such as revenues.

The pre-treatment size of an enterprise is also expected to affect its capacity and, consequently, its likelihood of acquiring a costly solar appliance. At the same time, enterprise size may also correlate with indicators of post-treatment enterprise performance.

[25] Original wording in French: « Quelle quantité de votre culture principale vendez-vous pendant la saison des pluies au cours les différentes périodes suivantes? »

[26] Original wording in French: « Quelle quantité de votre culture principale vendez-vous pendant la saison sèche au cours des différentes périodes suivantes? »

[27] Original wording in French: « Cultivez-vous pendant la saison sèche? »

[28] Original wording in French: « Au cours des périodes suivantes, avez-vous jamais été affamé ou n'avoir pas mangé du fait de l'insuffisance de la nourriture ou d'argent? »

[29] Original wording in French: « Quels sont les biens matériels dont dispose le propriétaire/ Président ou les membres de son ménage pendant les périodes? »

Moderating factors are another type of variable which are relevant for the analysis and identification of the causal pathways. As for moderating factors, they influence the strength of the relationship between treatment and outcome.

For example, a MSME that has access to markets outside the community may benefit more from the treatment compared to other MSMEs. Or in other words, their treatment effect may be larger if market access exists. Generally, there may be an overlap between moderating factors and confounders if the moderating factor also influences the selection into the treatment, but a moderating factor can also only influence the relationship between treatment and outcome, or it may influence the relationship of treatment and outcome as well as the outcome itself.

In our study, we assume that the effect of having access to a solar appliance on sales and income is amplified by an enterprise having better access to customers and markets (Ankel-Peters et al., 2024b). This is because local demand typically does not increase economic welfare in the community, since the money spent by a local customer for one product will be a substitute for buying a different local product. Overall, the customer will not spend any more in the municipality. It is assumed that an increase in production will only lead to an increase in sales (and productivity) if the enterprise can expand beyond local markets. Additionally, we also perform subgroup analyses for female entrepreneurs to account for the possibility that effects may differ between men and women.

Selection bias and confounding factors can be addressed through matching on them. A requirement for their selection is that they must remain unaffected by the treatment to avoid the introduction of endogeneity (Angrist and Pischke, 2009, p. 52–59). In order to control for selection bias and potential confounding factors, PSM and specifically kernel matching was applied. See Garrido et al. (2014) for more general information on the kernel method.

As described above, the control group was selected to have similar characteristics to the treatment group. The control group was relatively large. Kernel matching, which uses relatively more information, is expected in such cases to lead to a reasonable estimation, performing better than, for example, the frequently used nearest-neighbour matching (Caliendo and Kopeinig, 2008; Frölich, 2004).

Specifically, kernel matching was applied with replacement using the Gaussian kernel and a bandwidth of 0.05. For the diagnostics of the models, several characteristics were assessed, such as the balancing and reduction of differences after matching, the reduced and remaining bias, the variance ratio, Rubin's B and Rubin's R.

With slight variations between Benin and Senegal, matching variables were applied that fall into three categories: characteristics of the area (agricultural zone, rural environment), characteristics of the MSME (age of enterprise, size of enterprise at baseline, high-quality flooring yes/no), and characteristics of the owner (age, at least primary education yes/no).

Using PSM, treatment and control groups were matched on several characteristics that fulfil these conditions. The matching and subsequent analyses were performed separately for each outcome pair (e.g. revenue 2015 and revenue 2023 for Benin) and for each subgroup on variables from the baseline year. This approach was selected to preserve case numbers, considering the variation in data availability between groups and outcomes. Country-specific differences in the matching procedure are discussed in the respective sections.

Moreover, apart from analyses performed on the full sample, subgroup analyses differentiate further between GIZ beneficiaries only (T1), farmers and women. To minimise data loss, outliers were trimmed using a threshold set at three times the interquartile range (3 IQR), a more lenient approach than the suggested 1.5 IQR by Heumann et al. (2016). This means that outliers are not removed and are instead replaced with the last value in the dataset, still falling into the 3 IQR.

4.4 Results for Benin

4.4.1 Descriptive results

As a first step, outcome variables in 2015/2016 (pre-treatment) and 2022/2023 (post-treatment) were compared using a mean comparison test (Student's t-test) on the unmatched samples. As a general rule, the number of observations in 2015/2016 is somewhat smaller than for 2022/2023 due to missing values, given that recall questions were used. According to the t-tests, GIZ beneficiaries (T1) (see Table 5) only significantly statistically differed from the control group (C2) at baseline (2015) concerning two outcome variables: the number of employees and the servicing of customers from outside their own municipality. On average, enterprises in the treatment group employ more than twice as many employees compared to the control group. Furthermore, enterprises in the GIZ treatment group are significantly more likely to have customers from outside their own municipality. Regarding their performance, GIZ beneficiaries tend to have higher revenues, be more likely to process products and have higher monthly energy expenses but lower sales, though the differences between the means in these outcomes is not statistically significant. GIZ beneficiaries also tend to have fewer personal assets on average and are more food secure, but these findings are also not statistically significant.

Table 6 shows the results for the outcome variables in the post-treatment period in 2022/2023 respectively. The two significant outcomes from the pre-treatment period persist in the post-treatment period in 2022/2023: beneficiaries still employ significantly more staff than the control group, and they are also still more likely to service customers from outside their own municipality. Additionally, they have higher revenues than the control group, are more food secure and farmers cultivate a larger area. It should be noted, however, that the outcome of the area planted was measured only once (in 2022/2023), and it remains unclear whether there was already a significant difference pre-treatment in 2015/2016. The differences in all other outcomes remain insignificant.

The mean comparison of the variables to be matched on is presented in the section on matching for Benin (see Table 8 and Table 9).

Table 5 Mean comparison tests of outcomes in 2015/2016 (pre-treatment), GIZ beneficiaries vs. control group, Benin

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Processing	186	111	0.06	0.09	0.25	0.29	-0.03
Customers from out of municipality	198	114	0.43	0.59	0.50	0.49	-0.16***
Sales	75	20	82,479.96	5,400.45	336,133.52	22,337.96	77,079.51
Assets	198	114	0.19	0.18	0.09	0.07	0.01
Energy expenses	198	114	16,122.47	43,452.50	56,114.00	263,042.67	-27,330.03
Revenue	158	101	315,981.01	3,926,250	1.17e+06	2.99e+07	-3.61e+06
Number of employees	99	64	2.10	5.30	3.26	10.17	-3.20***
Food security	197	112	0.79	0.86	0.41	0.35	-0.07

Source: DEval, own table

*Note: Mean comparison between the GIZ treatment group and control group (T1 vs. C2) in Benin in 2015, equal variances, outliers not trimmed. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 6 **Mean comparison tests of outcomes in 2022/2023 (post-treatment), GIZ beneficiaries vs. control group, Benin**

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Processing	198	114	0.12	0.11	0.33	0.32	0.01
Customers from outside the municipality	198	114	0.47	0.66	0.50	0.48	-0.19***
Assets	198	114	0.44	0.44	0.13	0.17	0.00
Sales	75	20	313,080	65,800.05	1.13e+06	75,674.88	247,279.95
Energy expenses	198	114	60,674.24	55,822.81	357,414.64	255,346.13	4,851.44
Revenue	158	101	689,493.67	6.42e+06	1.02e+06	3.20e+07	-5.73e+06**
Number of employees	192	113	2.05	5.05	3.05	9.17	-3.01***
Food security	197	114	0.81	0.89	0.39	0.31	-0.08*
Cultivation during dry season	77	72	0.97	0.99	0.16	0.12	-0.01
Area planted	77	72	1.95	4.89	2.67	11.95	-2.95**

Source: DEval, own table. Mean comparison between the GIZ treatment group and control group (T1 vs. C2) in Benin in 2023, equal variances, outliers not trimmed

Note: Cultivation during the dry season and area planted were only measured in 2023, not in 2015.

** p < 0.10, ** p < 0.05, *** p < 0.01*

4.4.2 Before-after comparison

Table 7 shows the results of the before-after comparison for the treatment group (GIZ beneficiaries only). The date of treatment (i.e. installation of the appliance) varies between the MSMEs. Therefore, GIZ beneficiaries were asked about their circumstances 12 months prior to installing their appliances and 12 months afterwards. The results show that the MSMEs had more staff and higher revenues a year after the installation of the solar appliance promoted by the GIZ than a year before they bought them, whereas other outcomes did not differ significantly from the baseline period. However, the simple before-after comparison does not allow an interpretation of these as positive short-term consequences of the interventions with certainty. The before-after comparison needs to be triangulated with the more sophisticated cross-sectional and difference-in-difference analyses that follow below.

Table 7 Paired Student's t-test after vs. before within the GIZ treatment group, Benin

	Obs		Mean		Std.dev		t-test
	Before	After	Before	After	Before	After	Before/After
Customers from outside municipality	114	114	0.62	0.66	0.48	0.47	-1.15
Sales	71	71	107.38	149.52	429.1452	447.3894	-0.96
Energy expenses	114	114	32,142.54	37,953.95	187,805.1	192,958.4	-0.66
Revenue	99	99	4,934,205	6,074,551	3.13e+07	3.18e+07	-1.81**
Number of employees	92	92	4.67	5.36	8.54	9.28	-3.01**
Food security	113	113	0.88	0.89	0.32	0.30	-0.08

Source: DEval, own table, Paired t-test with equal variance within the GIZ treatment group (T1), after vs. before installation of the appliance in Benin

Note: Comparison between one year after vs. one year before the individual installation date for each beneficiary. Group, outliers not trimmed. $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

4.4.3 Matching

As mentioned above, the weights that result from the PSM were included in the cross-sectional as well as the DiD analyses. Given the variability in missing values across outcomes and diverse populations within subgroups, separate matchings for each outcome, subgroup and treatment type were conducted. The aim was to conserve as many observations as possible.

Table 8 and Table 9 further illustrate that the amount of available data points differed widely between outcomes and times. In a trade-off between the goodness-of-fit of the matching and comparability across countries, analyses and subgroups, the decision was made to include the same matching variables in every matching, with adjustments only being made in terms of operationalisation (e.g. inclusion of quartiles vs. tertiles) and reference categories within variables. The only exception from this is the inclusion of geographical factors in Benin but not in Senegal, specifically agricultural zone and rural classification. It was determined that the distribution of those variables in Senegal did not allow for a balanced sample, resulting to inferior matching results where they were included. Consequently, it was concluded that while these geographical factors may act as confounding factors in Benin, their influence appears to be less pronounced in Senegal. This circumstance might be related to country-specific differences in geography and established infrastructure.

Table 8 and Table 9 display the matching variables that were used for Benin, including the GIZ sample (T1) (see Table 8), as well as the GIZ and non-GIZ treated (T1 and T2) (see Table 9), respectively, and descriptive information on them. The variable agricultural zone was coded based on Abdul-Jalil et al. (2023), with two comparable zones being combined due to low case numbers and with Atacora Ouest being the reference category. Agricultural zone was included in the tables below for the sake of completeness, despite not displaying any values due to it being a nominal variable. High-quality floor is a dummy variable, which is coded 1 if the flooring was reported to be PVC flooring/asphalt, tiles or cement and 0 if flooring was dirt or cow dung/droppings. This variable was included on the recommendation of local experts. The variable age of the enterprise is coded as tertiles, with the middle category being the reference category, and the age of the owner is a numerical variable. The size of the enterprise is a composite variable that captures differences between enterprises. It has a three-step coding (small, medium and large), and is composed of the size of cultivated land, tertiles of revenue in 2015 and differences in livestock.

Lastly, the primary education variable is a dummy variable that indicates whether the owner of the enterprise has completed primary education or higher; and, in accordance with the World Bank definition, rural is a binary variable that is coded 1 if the density of inhabitants in the respondent's municipality is less than 300 per km^2 and is coded 0 otherwise (World Bank, 2020).

Table 8 Mean comparison tests for the matching variables 2015, GIZ beneficiaries vs. control group, Benin

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Agricultural zone (4 categories)	198	158	-	-	-	-	-
Alibori Sud - Borgou Nord - 2KP - Vallé	198	158	0.20	0.18	0.40	0.38	0.02
Atacora Ouest	198	158	0.04	0.05	0.20	0.22	-0.01
Borgou Sud - Donga - Collines	198	158	0.22	0.34	0.34	0.42	-0.09**
Ouémé - Atlantique - Mono	198	158	0.63	0.55	0.49	0.50	0.08
High-Quality Floor	198	158	0.86	0.87	0.34	0.34	0.00
Age of enterprise (in years)	198	158	10.48	10.49	9.59	10.00	-0.01
Age of owner (in years)	198	158	42.21	45.65	10.96	12.23	-3.44***
Size of enterprise*	198	158	1.83	2.20	0.79	0.76	-0.37***
At least primary education	198	158	0.78	0.81	0.42	0.39	-0.03
Rural	198	158	0.42	0.52	0.50	0.50	-0.09*

*Source: DEval, own table, Equal variances. GIZ treatment group. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

*Note: *Size of enterprise is an ordinal variable with three levels of size: 1 = small, 2 = medium, 3 = large*

Table 9 Mean comparison tests for the matching variables 2015, GIZ and non-GIZ treated vs. control group, Benin

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Agricultural zone (4 categories)	198	158	-	-	-	-	-
Alibori Sud - Borgou Nord – 2KP - Vallé	198	158	0.20	0.18	0.40	0.38	0.02
Atacora Ouest	198	158	0.04	0.05	0.20	0.22	-0.01
Borgou Sud - Donga - Collines	198	158	0.22	0.34	0.34	0.42	-0.09**
Ouémé - Atlantique - Mono	198	158	0.63	0.55	0.49	0.50	0.08
High-quality floor	198	158	0.86	0.87	0.34	0.34	0.00
Age of enterprise (in years)	198	158	10.48	10.49	9.59	10.00	-0.01
Age of owner (in years)	198	158	42.21	45.65	10.96	12.23	-3.44***
Size of enterprise*	198	158	1.83	2.20	0.79	0.76	-0.37***
At least primary education	198	158	0.78	0.81	0.42	0.39	-0.03
Rural	198	158	0.42	0.52	0.50	0.50	-0.09*

*Source: DEval, own table, Equal variances, GIZ treatment group, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

*Note: *Size of enterprise is an ordinal variable with three levels of size: 1 = small, 2 = medium, 3 = large.*

We applied several matching diagnostics to ascertain the quality of the matching results. First, Rubin's B is reported in Table 10 for the matching results for the GIZ sample (T1 vs. control) and in Table 11 for the full sample (GIZ and non-GIZ treated and control group, T1, T2, C2). This statistic measures the balance between the treated and control samples by computing the absolute standardised difference of the means of the linear index of the propensity score in the treated and (matched) non-treated group (Rubin, 2001).

Additionally, we also report Rubin's R, which measures the ratio of treated to (matched) non-treated variances of the propensity scores (Rubin, 2001). Both measures are considered important diagnostic tools for assessing the reduction in bias and the quality of a propensity matching. Rubin (2001) recommends that B should be less than 25 and R remains in a range between 0.5 and 2 as an indication of a sufficient balancing of the samples. As both tables show, the B-values as well as the R-values stay well within the recommended range, which marks the performed matching as successful in the sense of achieving a greater comparability between treatment and control groups.

Figure 15 and Figure 16 illustrate the how the control and treatment groups became more similar in statistical terms after the matching for the outcome variable of energy expenses.

Table 10 Results of the matching per outcome in 2015 and 2023, GIZ beneficiaries vs. control group, Benin

Outcome	Obs				Common Support		Rubin's B	Rubin's R
	2015		2023					
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Matched	Matched
Revenue	78	136	99	157	75	136	13.6	1.14
Processing [30]	109	154	112	155	103	154	20.6	1.15
Energy expenses	112	197	112	197	101	197	11.6	1.33
Number of employees	65	98	111	191	61	98	17.5	1.43
Customers from outside the municipality	112	197	112	197	101	197	11.6	1.33
Assets	112	197	112	197	101	197	11.6	1.33
Food security	110	196	112	196	99	195	12.4	1.31

Source: DEval, own table, Outliers trimmed

It is notable that even though the number of observations for the combined sample of GIZ and non-GIZ treated is higher (Table 11), which is generally associated with an improvement in the balancing of the samples, Rubin's B indicates a better balance for the outcomes of energy expenses, customers from outside the municipality, the assets and food security in the sample where only GIZ beneficiaries are matched with the control group (Table 10). This might be an indication that the GIZ sample is more homogenous or has different baseline characteristics from the sample, including all solar appliance users for these outcomes. Furthermore, regarding the quality of matching of the single matching variables, we tried to ensure that the percentage of bias remained low at well under 10 and that the variance ratio was between 0.5 and 2.

Table 11 Results of the matching per outcome in 2015 and 2023, GIZ and non-GIZ treated vs. control group, Benin

Outcome	Obs				Common Support		Rubin's B	Rubin's R
	2015		2023					
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Matched	Matched
Revenue	104	136	135	157	98	136	9.2	1.28
Processing[31]	144	154	155	155	138	154	24.9	1.19
Energy expenses	155	197	155	197	150	197	10.7	1.16
Number of employees	82	98	154	191	78	98	14.1	1.22

[30] Numbers reported are for the comparison GIZ treatment sample vs. the control group that uses no modern energy, since it will be used in the analyses.

[31] Numbers reported are for the comparison of GIZ and non-GIZ treated vs. the control group that uses no modern energy, since it will be used in the analyses.

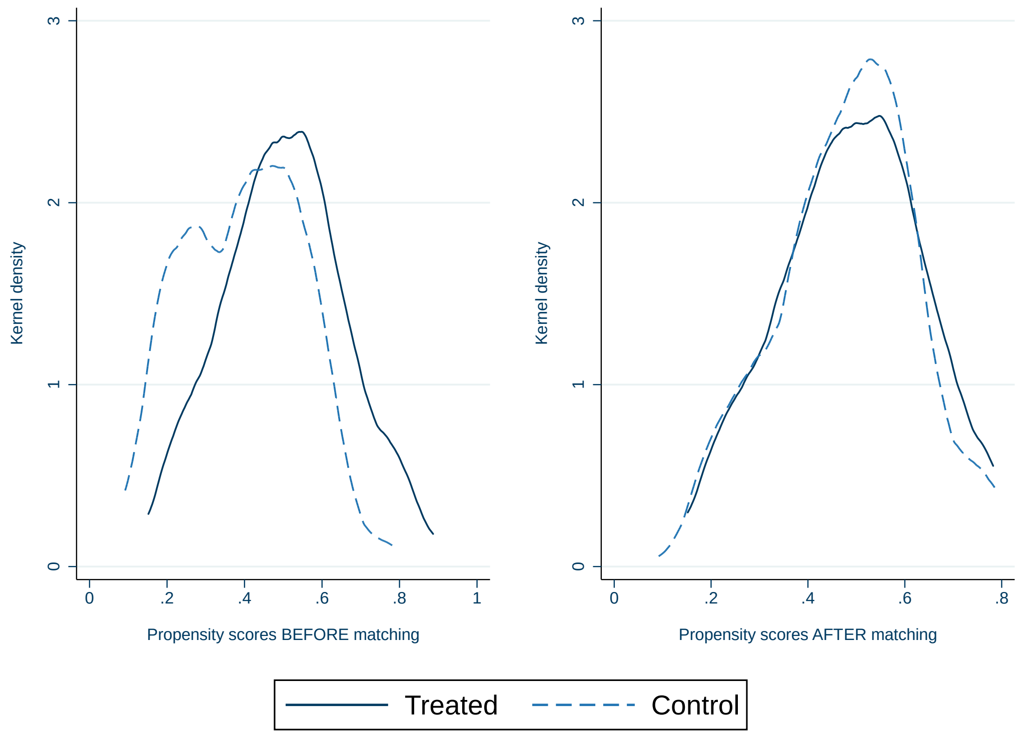
Customers from outside the municipality	156	197	156	197	151	197	10.8	1.16
Asset index	156	197	156	197	151	197	10.8	1.16
Food security	153	196	155	196	147	195	10.4	1.12

Source: DEval, own table. Outliers trimmed

Regarding the matching for the subgroups, there is a stark difference in the overall quality of the matching between farmers and women. The matching performed the same or even better for farmers on some outcomes compared to the sample including GIZ and non-GIZ treated. Despite lower case numbers, farmers appear to be a somewhat homogenous group.

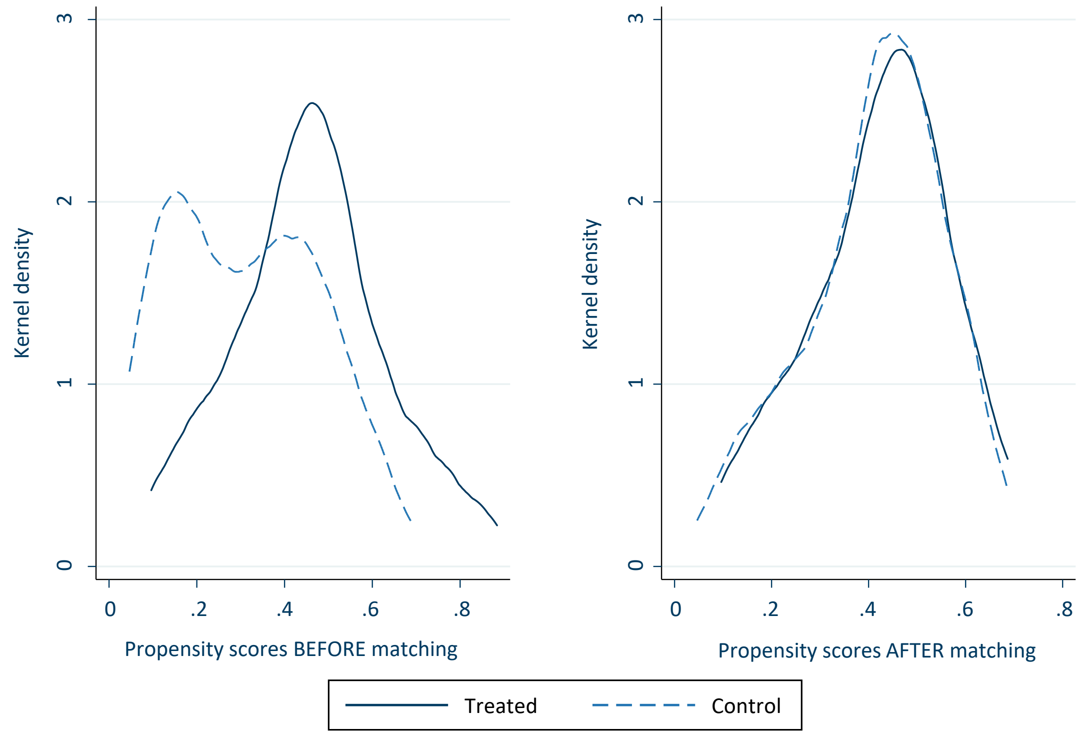
For women on the other hand, the quality of the matching was worse than for the sample of all entrepreneurs and, in some cases, the strict thresholds for Rubin's B and R could not be upheld. The case numbers for women were lower than for farmers, and it can be concluded that the women in the sample are a heterogenous group. However, the matching for the subgroup women still leads to an overall improvement in the balance of the samples when compared to the unmatched sample. Figure 15 and 16 show how the matching helped make control and treatment group statistically more similar to each other, as illustrated for the outcome of energy expenses.

Figure 15 Density plot for pre-treatment outcome energy expenses for before and after matching state, GIZ and non-GIZ treated versus control group, Benin



Source: DEval, own figure

Figure 16 **Density plot for outcome energy expenses for before and after matching state, GIZ treatment sample, Benin**



Source: DEval, own figure

4.4.4 Cross-sectional analysis

Table 12 to Table 14 show the results of the cross-sectional analyses performed on the matched samples. In terms of economic performance, GIZ beneficiaries and non-GIZ treated alike report higher revenues, lower energy expenses and the employment of more staff (see Table 12 and Table 13) than the respondents who use fossil fuels for the same economic activity (control group).Additionally, GIZ beneficiaries (T1) seem more likely to be food secure than the control group (see Table 14), and all treated MSMEs appear more likely to service customers from outside their municipality (see Table 13) than the control group.

Furthermore, the results show that apart from the effects of the treatment mentioned, there are no statistically detectable differences between the treated and the control group regarding their likelihood of processing their products before selling them or their sales, personal assets of the owners of the enterprises (see Table 12, Table 13 and Table 14) or the size of the planted area that farmers work on (see Table 17 and Table 18).

Table 12 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ beneficiaries vs. control group, Benin**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Having customers from outside the municipality
GIZ treatment	301,751.3**		-17,734.2***	0.996*	0.190
	(133,824.9)		(3721.8)	(0.561)	(0.164)
GIZ treatment (vs. no modern energy)		0.152			
		(0.252)			
Constant	742,792.8***	-1.573***	34,614.6***	2.562***	0.135
	(65,770.2)	(0.174)	(2,420.3)	(0.298)	(0.104)
Observations	251	257	299	295	299
R^2	0.026		0.089	0.014	
Pseudo R^2		0.003			0.004

*Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed. All outcome variables measured in 2023. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01*

Table 13 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ and non-GIZ treated vs. control group, Benin**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Having customers from outside the municipality
GIZ and non-GIZ treatment	266,513.8**		-16,532.5***	1.078**	0.275*
	(114,105.5)		(3,555.6)	(0.491)	(0.147)
GIZ and non-GIZ treatment (vs. no modern energy)		0.0788			
		(0.269)			
Constant	721,797.9***	-1.394***	35,239.8***	2.604***	0.0433
	(63005.8)	(0.224)	(2545.6)	(0.305)	(0.104)
Observations	289	292	348	342	349
R^2	0.022		0.072	0.017	
Pseudo R^2		0.001			0.009

Source: DEval, own table, T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R2 and probit regression if pseudo R2 is reported. Outliers trimmed
*Note: All outcome variables measured in 2023. Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.*

Table 14 **Cross-sectional treatment effect on sales, assets and food security, GIZ beneficiaries vs. control group, Benin**

	(1) Sales	(2) Assets	(3) Food security
GIZ treatment	-34,344.2	-0.0108	0.346*
	(38,182.6)	(0.0205)	(0.204)
Constant	117,050.1***	0.427***	0.853***
	(33,291.5)	(0.0117)	(0.125)
Observations	67	299	300
R^2	0.024	0.001	
Pseudo R^2			0.015

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed

Note: All outcome variables measured in 2023. Standard errors in parentheses. p < 0.10, ** p < 0.05, *** p < 0.01*

Cross-sectional subgroup analysis: farmers

We ran the same models on sub-samples of farmers (see Table 15 to Table 18) and female entrepreneurs only (see Table 19 to Table 22). The findings from the sample of GIZ and non-GIZ treated are largely robust in restricting the analysis to farmers. Accordingly, among farmers, the treated have higher revenues, more employees, lower energy expenses and are more likely to be food secure (GIZ beneficiaries only) than the control group.

Table 15 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, GIZ and non-GIZ treated vs. control group, Benin, farmers only**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ and non-GIZ treatment	313,110.1**		-17,429.1***	1.035*
	(136,240.8)		(4,335.3)	(0.606)
GIZ and non-GIZ treatment (vs. no modern energy)		0.251		
		(0.323)		
Constant	791,065.7***	-1.532***	35,494.7***	2.840***
	(75,020.8)	(0.273)	(3258.4)	(0.364)
Observations	170	235	206	205
R^2	0.032		0.086	0.016
Pseudo R^2		0.008		

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 16 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, GIZ beneficiaries vs. control group, Benin, farmers only**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ treatment	341,922.3**		-20,130.4***	1.057
	(155,806.6)		(5,019.4)	(0.705)
GIZ treatment (vs. no modern energy)		0.454		
		(0.310)		
Constant	803,249.0***	-1.689***	37,187.0***	2.891***
	(79,304.3)	(0.250)	(3,860.1)	(0.409)
Observations	149	218	186	185
R^2	0.036		0.106	0.015
Pseudo R^2		0.026		

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed.
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 17 Cross-sectional treatment effect on planted area, assets and food security, GIZ and non-GIZ treated vs. control group, Benin, farmers only

	(1) Planted area	(2) Assets	(3) Food security
GIZ and non-GIZ treatment	0.0891	-0.00139	0.295
	(0.498)	(0.0214)	(0.221)
Constant	2.368***	0.409***	0.806***
	(0.362)	(0.0143)	(0.152)
Observations	145	207	205
R^2	0.000	0.000	
Pseudo R^2			0.011

*Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes. OLS regressions. Outliers trimmed. All outcome variables measured in 2022/2023. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01*

Table 18 Cross-sectional treatment effect on planted area, assets and food security, GIZ beneficiaries vs. control group, Benin, farmers only

	(1) Planted area	(2) Assets	(3) Food security
GIZ treatment	0.0476	-0.0199	0.473*
	(0.492)	(0.0232)	(0.251)
Constant	2.250***	0.410***	0.764***
	(0.342)	(0.0150)	(0.159)
Observations	133	186	183
R^2	0.000	0.005	
Pseudo R^2			0.027

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed.
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01*

Cross-sectional subgroup analysis: women

Among women entrepreneurs, the effect of the treatment on reduced energy expenses remains for GIZ beneficiaries only (see Table 19). However, the effects on higher revenues and the number of employees disappears (the latter only for GIZ beneficiaries versus control group). In addition, the results suggest a negative treatment effect among female entrepreneurs on their food security.

Table 19 Cross-sectional treatment effect on revenue, processing, energy expenses and number of employees, GIZ beneficiaries vs. control group, Benin, women only

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ treatment	108,122.7		-16,325.0**	1.070
	(298,141.0)		(7,118.2)	(0.995)
GIZ treatment (vs. no modern energy)		-0.434		
		(0.507)		
Constant	500,968.2***	-0.926***	28,658.3***	1.055***
	(62,265.0)	(0.341)	(2,829.2)	(0.244)
Observations	61	43	75	74
R^2	0.005		0.125	0.031
Pseudo R^2		0.023		

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed.
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 20 Cross-sectional treatment effect on revenue, processing, energy expenses and number of employees, GIZ and non-GIZ treated vs. control group, Benin, women only

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ and non-GIZ treatment	3,881.1		-8,236.1	1.593*
	(190,906.6)		(6,016.3)	(0.829)
GIZ and non-GIZ treatment (vs. no modern energy)		-0.330		
		(0.463)		
Constant	514,539.9***	-0.839**	24,200.4***	1.074***
	(67,967.9)	(0.365)	(2,460.0)	(0.267)
Observations	69	53	88	85
R^2	0.000		0.030	0.060
Pseudo R^2		0.013		

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed.
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 21 Cross-sectional treatment effect on sales, assets and food security, GIZ beneficiaries vs. control group, Benin, women only

	(1) Sales	(2) Assets	(3) Food security
GIZ treatment	-60,217.0	-0.0616	-0.854**
	(70,055.2)	(0.0461)	(0.423)
Constant	133,359.9**	0.465***	1.285***
	(63,864.5)	(0.0185)	(0.256)
Observations	32	75	75
R^2	0.071	0.043	
Pseudo R^2			0.081

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed
*Note: All outcome variables measured in 2022/2023. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

Table 22 Cross-sectional treatment effect on sales, assets and food security, GIZ and non-GIZ treated vs. control group, Benin, women only

	(1) Sales	(2) Assets	(3) Food security
GIZ and non-GIZ treatment	-38,272.9	-0.00507	-0.887***
	(34,414.3)	(0.0394)	(0.338)
Constant	97,091.1***	0.449***	1.351***
	(28,334.1)	(0.0244)	(0.230)
Observations	51	88	88
R^2	0.045	0.000	
Pseudo R^2			0.086

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes. OLS regressions.
Note: Outliers trimmed. All outcome variables measured in 2022/2023. Standard errors in parentheses.
** $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

4.4.5 Difference-in-differences (DiD) analysis

Table 23 and Table 24 show the results of the DiD analysis for the GIZ beneficiaries and GIZ and non-GIZ treated vs. the control group across different outcomes. They further confirm the treatment effects from the cross-sectional analyses regarding the revenues for the GIZ sample and the energy expenses for all treatment groups. However, the effect on the number of employees disappears.

Table 23 DiD treatment effect on revenue, processing, energy expenses, number of employees, Benin

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
Post	371,718.4***	365,638.3***	-3.07e-16	-1.80e-16	23,717.6***	22,555.8***	0.373	0.334
	(78,337.5)	(81,089.6)	(0.317)	(0.246)	(2,856.5)	(2,729.6)	(0.621)	(0.594)
GIZ and non-GIZ treatment	3,304.8				-3,968.6**		1.294*	
	(52,899.2)				(1,616.9)		(0.708)	
GIZ and non-GIZ DiD	175,389.8				-12,563.8***		0.230	
	(130,566.1)				(3,906.0)		(1.015)	
GIZ treatment		-7,977.0				-4,244.2**		1.640**
		(58,916.7)				(1,689.7)		(0.792)
GIZ DiD		273,962.3*				-13,490.0***		0.634
		(154,495.0)				(4,087.4)		(1.138)
GIZ and non-GIZ treatment (vs. no modern energy)			0.0788					
			(0.269)					
GIZ and non-GIZ DiD (vs. no modern energy)			2.21e-16					
			(0.380)					
GIZ treatment (vs. no modern energy)				0.152				
				(0.251)				

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
GIZ DiD (vs. no modern energy)				8.44e-16				
				(0.355)				
Constant	374,591.8***	414,486.7***	-1.394***	-1.573***	11,522.2***	12,058.8***	2.680***	2.426***
	(38,083.5)	(39,966.6)	(0.224)	(0.174)	(1,296.0)	(1,262.1)	(0.423)	(0.408)
Observations[32]	480	426	584	514	696	598	352	318
R^2	0.121	0.135			0.176	0.176	0.029	0.053
Pseudo R^2			0.001	0.003				
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ beneficiaries sample, C = users of non-renewable energy, except for processing, for this outcome C = no modern energy. Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01. OLS regressions if R^2 is reported, probit regressions otherwise. All outcomes measured in 2015 and 2023. Outliers trimmed*

[32] All DiD tables presented report the total number of statistical observations, wherein two data points are included per respondent: one observation from the baseline and another from the post-treatment period. Therefore, when seeking to retrieve the number of respondents included in the analysis, it is necessary to divide the number of observations from the table by two to account for the number of data points per respondent.

Table 24 DiD treatment effect on sales, assets, customer origin and food security, Benin

	(1) Sales	(2) Sales	(3) Assets	(4) Assets	(5) Having customers from outside the municipality	(6) Having customers from outside the municipality	(7) Food security	(8) Food security
Post	128,375.4***	117,049.4***	0.235***	0.232***	0.0914	0.0909	0.0338	0.0234
	(26,034.1)	(33,291.5)	(0.0130)	(0.0150)	(0.147)	(0.147)	(0.166)	(0.175)
GIZ and non-GIZ treatment	0.598		-0.00993		0.0316		0.0328	
	(0.630)		(0.00986)		(0.146)		(0.166)	
GIZ and non-GIZ DiD	-46,843.4		0.0139		0.244		0.157	
	(31,055.1)		(0.0200)		(0.207)		(0.241)	
GIZ treatment		0.225		-0.0191*		0.129		0.169
		(0.732)		(0.0115)		(0.163)		(0.194)
GIZ DiD		-34,344.5		0.00835		0.0613		0.263
		(38,182.6)		(0.0235)		(0.231)		(0.287)
Constant	0.736**	0.716*	0.193***	0.196***	-0.0481	0.0439	0.848***	0.832***
	(0.307)	(0.365)	(0.00741)	(0.00930)	(0.104)	(0.104)	(0.116)	(0.122)
Observations	202	134	698	598	698	598	686	592
R^2	0.304	0.310	0.490	0.471				
Pseudo R^2					0.009	0.005	0.004	0.015
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regressions if R^2 is reported, probit regressions otherwise. All outcomes measured in 2015 and 2022/2023. Outliers trimmed*

DiD analysis: farmers

Table 25 and Table 26 show the results when the sample is restricted to farmers. The only treatment effect that is robust is the negative impact of solar appliances on energy expenses. Apart from that, none of the treatment effects from prior analyses persists for farmers.

Table 25 DiD treatment effect on revenue, processing, energy expenses, number of employees, Benin, farmers only

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
Post	403762.4***	414904.7***	5.00e-16	-9.93e-17	21609.9***	22412.5***	0.338	0.134
	(91,787.8)	(96,701.9)	(0.388)	(0.323)	(3,462.7)	(3,668.4)	(0.688)	(0.672)
GIZ and non-GIZ treatment	34,198.5				-3,010.0		0.682	
	(62,164.5)				(2,016.0)		(0.751)	
GIZ and non-GIZ DiD	211,812.3				-13,495.4***		0.333	
	(151,382.2)				(4,642.3)		(1.071)	
GIZ treatment		2,956.4				-3,596.5*		0.844
		(65,246.5)				(2,094.1)		(0.868)
GIZ DiD		270,328.9				-14,630.5***		0.786
		(168,291.0)				(5,035.3)		(1.233)
GIZ and non-GIZ treatment (vs. no modern energy)			0.274					
			(0.323)					
GIZ and non-GIZ DiD (vs. no modern energy)			-5.12e-16					
			(0.457)					

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
GIZ treatment (vs. no modern energy)				0.538*				
				(0.294)				
GIZ DiD (vs. no modern energy)				-4.49e-16				
				(0.415)				
Constant	394,389.1***	397,883.8***	-1.555***	-1.766***	12,648.6***	12,714.5***	3.034***	2.916***
	(46,170.9)	(46,005.0)	(0.274)	(0.229)	(1,549.1)	(1,594.1)	(0.480)	(0.488)
Observations	300	268	470	434	416	374	266	232
R^2	0.156	0.172			0.160	0.173	0.015	0.026
Pseudo R^2			0.010	0.036				
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy, except for processing, for this outcome C = no modern energy. Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01. OLS regressions if R^2 is reported, probit regressions otherwise.*
Note: All outcomes measured in 2015 and 2022/2023. Outliers trimmed

Table 26 DiD treatment effect on assets, customer origin and food security, Benin, farmers only

	(1) Assets	(2) Assets	(3) Having customers from outside the municipality	(4) Having customers from outside the municipality	(5) Food security	(6) Food security
Post	0.237***	0.236***	0.175	0.167	0.0880	0.0869
	(0.0160)	(0.0166)	(0.196)	(0.199)	(0.209)	(0.219)
GIZ and non-GIZ treatment	-0.00964		-0.0815		0.111	
	(0.0109)		(0.187)		(0.206)	
GIZ and non-GIZ DiD	0.00868		0.343		0.162	
	(0.0235)		(0.272)		(0.301)	
GIZ treatment		-0.0193*		0.00322		0.227
		(0.0108)		(0.202)		(0.229)
GIZ DiD		0.00142		0.210		0.291
		(0.0252)		(0.293)		(0.343)
Constant	0.187***	0.188***	0.335**	0.346**	0.753***	0.723***
	(0.00704)	(0.00723)	(0.137)	(0.140)	(0.145)	(0.153)
Observations	420	374	420	374	414	370
R^2	0.529	0.530				
Pseudo R^2			0.018	0.011	0.008	0.023
Sample	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy. Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regressions if R^2 is reported, probit regressions otherwise. All outcomes measured in 2015 and 2022/2023. Outliers trimmed*

DiD analysis: women

These results are also further confirmed by the subgroup analysis for female entrepreneurs, reported in Table 27 and Table 28. It should be mentioned that the subgroup analysis for women has a low number of case numbers, resulting in the omission of certain outcomes. As such, the results for this subgroup should ideally be regarded as supplementary for the sake of corroborating the robustness of other analyses.

Table 27 Treatment effect on revenue, processing, energy expenses, number of employees, Benin, women only

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
Post	265,276.2***	261,180.9***	-1.57e-16	-3.79e-16	17,796.8***	21,406.7***	0.221	0.273
	(96,814.6)	(81,694.7)	(0.508)	(0.463)	(2,974.2)	(3,143.7)	(0.510)	(0.530)
GIZ and non-GIZ treatment	43,243.0				1,115.6		1.335	
	(102,227.8)				(2,839.0)		(1.276)	
GIZ and non-GIZ DiD	-29,165.1				-9,368.2		0.000862	
	(228,082.3)				(6,701.6)		(1.552)	
GIZ treatment		62,810.8				2,338.2		-0.815***
		(114,031.8)				(3,655.8)		(0.302)
GIZ DiD		88,819.1				-17,473.4**		1.227
		(320,550.0)				(7,965.5)		(1.218)
GIZ and non-GIZ treatment (vs. no modern energy)			-0.371					
			(0.458)					
GIZ and non-GIZ DiD (vs. no modern energy)			-6.06e-16					
			(0.647)					

	(1) Revenue	(2) Revenue	(3) Processing	(4) Processing	(5) Energy expenses	(6) Energy expenses	(7) Number of employees	(8) Number of employees
GIZ treatment (vs. no modern energy)				-0.459				
				(0.494)				
GIZ DiD (vs. no modern energy)				4.92e-16				
				(0.699)				
Constant	253,979.2***	219,007.3***	-0.798**	-0.924***	6,420.1***	6,061.8***	0.776**	0.815***
	(59,482.5)	(47,656.6)	(0.359)	(0.327)	(1,462.3)	(1,569.3)	(0.362)	(0.302)
Observations	124	110	106	88	176	150	76	62
R^2	0.055	0.076			0.128	0.188	0.067	0.125
Pseudo R^2			0.017	0.026				
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy, except for processing, for this outcome C = no modern energy. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regressions if R^2 is reported, probit regressions otherwise. All outcomes measured in 2015 and 2022/2023. Outliers trimmed*

Table 28 Treatment effect on sales, assets, customer origin and food security, Benin, women only

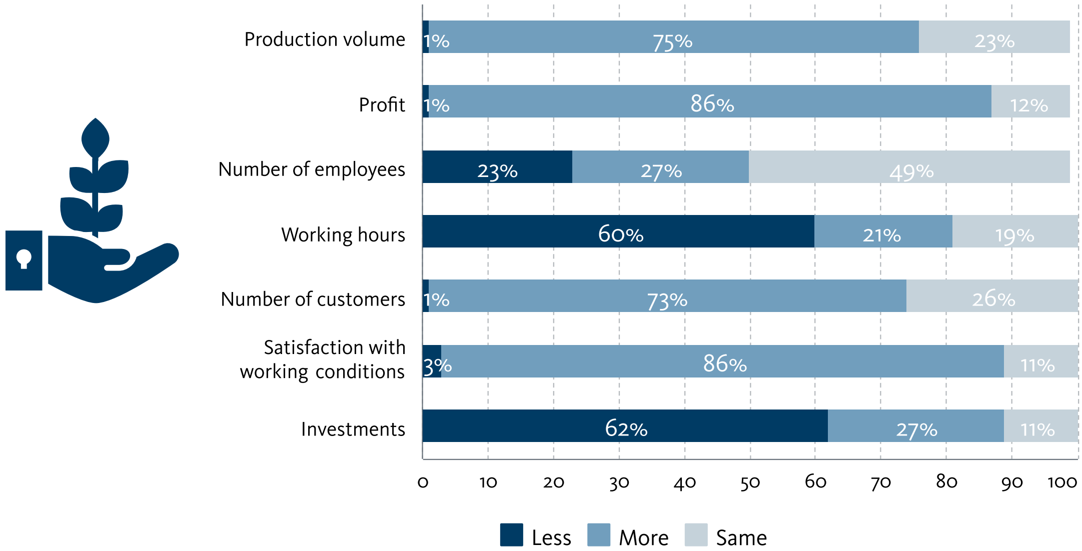
	(1) Sales	(2) Sales	(3) Assets	(4) Assets	(5) Having customers from outside the municipality	(6) Having customers from outside the municipality	(7) Food security	(8) Food security
Post	97,264.9***	138,861.1**	0.272***	0.282***	0.0893	0.0855	0.107	0.140
	(29,161.9)	(68,268.6)	(0.0264)	(0.0226)	(0.291)	(0.304)	(0.338)	(0.350)
GIZ and non-GIZ treatment	-0.462		-0.0103		0.230		-0.977***	
	(1.223)		(0.0185)		(0.319)		(0.332)	
GIZ and non-GIZ DiD	-38,448.2		0.00472		0.00497		0.0852	
	(35,098.9)		(0.0437)		(0.449)		(0.483)	
GIZ treatment		-1.078		-0.0172		0.591		-0.780*
		(1.006)		(0.0209)		(0.389)		(0.404)
GIZ DiD		-65,718.3		-0.0419		-0.255		-0.140
		(74,092.2)		(0.0515)		(0.553)		(0.582)
Constant	1.916**	1.078	0.194***	0.197***	-0.596***	-0.675***	1.249***	1.268***
	(0.772)	(1.006)	(0.00950)	(0.00887)	(0.206)	(0.214)	(0.228)	(0.235)
Observations	102	64	176	150	176	150	174	150
R^2	0.303	0.348	0.562	0.572				
Pseudo R^2					0.007	0.027	0.098	0.080
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regressions if R^2 is reported, probit regressions otherwise. All outcomes measured in 2015 and 2022/2023. Outliers trimmed.*

4.4.6 Perception of outcomes and impacts

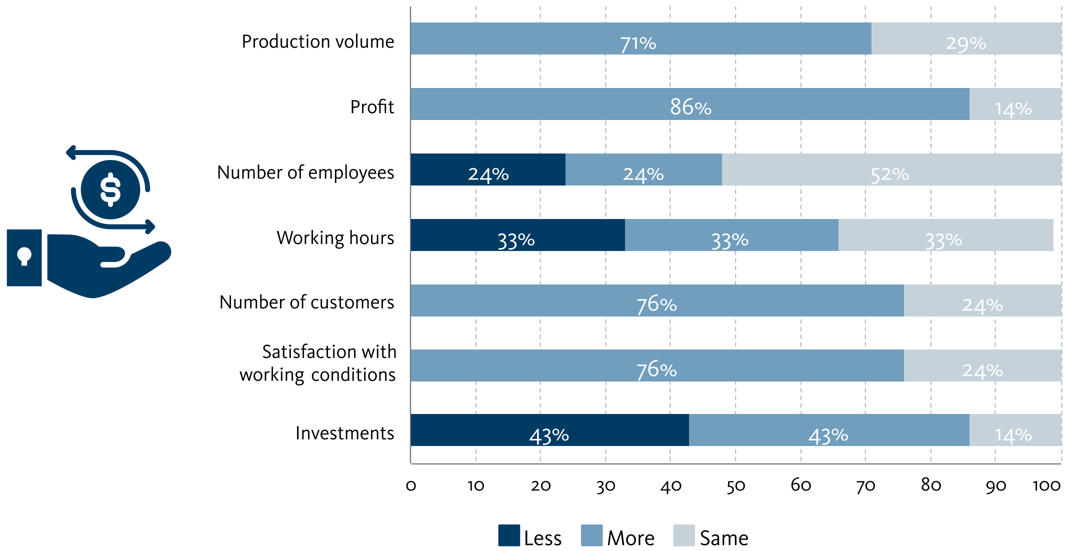
The most common effects of using solar appliances, as self-reported by the respondents in the surveys, are increases in production volume and profits, increases in customer numbers and increased satisfaction with their working conditions (see Figure 17 and Figure 18). The perceived changes of more women-specific effects and impacts, such as those illustrated in Figure 19, are discussed in the evaluation report in Chapter 6.3.

Figure 17 Perceived changes in enterprise-related outcomes for farmers, Benin



Source: DEval, own figure. Some figures do not add up to 100 % due to rounding

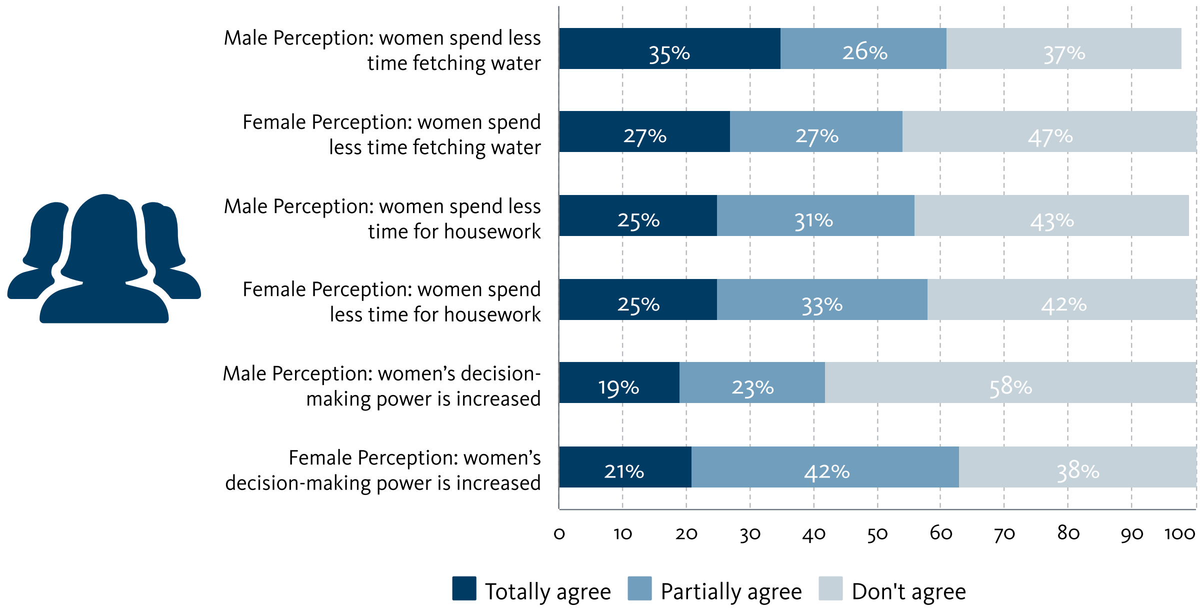
Figure 18 Perceived changes in enterprise-related outcomes for trade and other, Benin



Source: DEval, own figure. Some figures do not add up to 100 % due to rounding

The focus group participants in Benin primarily reported lower energy expenses (FOKG 31-36), accompanied by an increase in turnover (FOKG 39), the ability to grow crops in the dry season (FOKG 34) and a diversification of their production and livestock farming (FOKG 31, 35). Similarly, participants in Senegal reported decreases in energy expenses (FOKG 11-13, 18) and production costs (FOKG 11-12, 20), as well as increased production (FOKG 13, 18). Lastly, participants in the focus groups in Uganda also reported increased crop yields and a boost in income. As a result, they are now able to pay medical bills and school fees, build up assets and secure food for themselves and their families (FOKG 1-10).

Figure 19 Perceived changes in gender-related outcomes and impacts, Benin



Source: DEval, own figure, Some figures do not add up to 100 % due to rounding

4.5 Results for Senegal

The analyses performed on the survey data from Senegal follow the same logic as those performed on the Benin data using the same types of treatment and control groups.

4.5.1 Descriptive results

Table 29 reports descriptive results for the pre-treatment period in 2019 before the matching. The results suggest that even before the matching, the GIZ beneficiaries and the control group are similar pre-treatment on a number of outcomes. Their means are statistically indistinguishable.

Table 29 Mean comparison tests of outcomes in 2019 (pre-treatment), GIZ beneficiaries vs. control group, Senegal

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Quantity sold (dry season)	44	112	14,590.23	6,763.69	75,058.00	35,264.23	7,826.54
Percentage of customers from outside the municipality	19	72	93.26	87.93	22.41	19.81	5.33
Quantity sold	52	153	14,097.65	6,757.10	69,243.24	39,881.31	7,340.55
Energy expenses	45	134	339,444.44	257,242.54	435,760.28	604,298.51	82,201.91

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Revenue	50	138	3.30	3.04	1.57	1.52	0.26
Number of employees	57	168	5.30	4.77	13.41	10.87	0.52
Food security	57	168	0.56	0.47	0.50	0.50	0.09

Source: DEval, own table. Mean comparison between the control (non-renewable energy) and treatment group (GIZ) in Senegal in 2019, outcome processing omitted due to a low number of cases, equal variances, outliers not trimmed.
Note: The variable revenue was used as an ordinal variable with five categories: category 1: 0-100,000, category 2: >100,000 – 200,000, category 3: > 200,000 – 500,000, category 4: > 500,000 – 1,000,000, category 5: > 1,000,000.
** p < 0.10, ** p < 0.05, *** p < 0.01*

Table 30 presents the mean comparison tests for the outcomes of interest post-treatment for GIZ beneficiaries compared to the control group. Overall, there is a positive time trend within the treatment group between 2019 and 2023. The treatment group is better off in 2023 on most outcome indicators (with the exception of percentage of customers serviced outside the municipality and the number of employees) and their energy expenses are substantially lower than in 2019. Energy expenses is the only outcome according to which the treatment group is statistically significantly better off than the control group in 2023.

Table 30 Mean comparison tests of outcomes in 2023 (post-treatment), GIZ beneficiaries vs. control group, Senegal

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
Quantity sold (dry season)	44	112	29,438.16	7,813.49	150,524.97	38,566.65	21,624.67
Processing	57	168	0.09	0.15	0.29	0.36	-0.06
Percentage of customers from outside the municipality	22	106	84.50	82.93	31.68	26.58	1.57
Quantity sold	57	168	24,739.37	7,305.17	132,353.51	41,988.07	17,434.20
Energy expenses	57	168	659,129.82	126,502.98	2.51e+06	313,908.55	532,626.85***
Revenue	55	168	3.51	3.67	1.56	1.27	-0.16
Number of employees	57	168	5.30	4.77	13.41	10.87	0.52
Food security	57	168	0.54	0.48	0.50	0.50	0.07

Source: DEval, own table, Mean comparison between the control (non-renewable energy) and treatment groups (GIZ) in Senegal in 2023, paired, equal variances, outliers not trimmed
Note: The variable revenue was used as an ordinal variable with five categories: category 1: 0 – 100,000, category 2: > 100,000 – 200,000, category 3: > 200,000 – 500,000, category 4: > 500,000 – 1,000,000, category 5: > 1,000,000.
** p < 0.10, ** p < 0.05, *** p < 0.01*

Whether any of these differences pre- and post-treatment can be interpreted as causal will be analysed in more sophisticated analyses on the matched sample and in the triangulation with the findings from the focus groups.

4.5.2 Matching

To establish a foundation for comparing the results, the matching method in Senegal is identical to the one performed in Benin. The only differences are firstly the exclusion of geographical variables, namely agricultural zones and rural, and secondly some slight deviations in the operationalisation of matching variables. The exclusion of agricultural zones and rural is owed to the fact that their inclusion led to a notable decline in matching quality for Senegal. As mentioned above, this is partly due to the distribution of those variables in Senegal and perhaps due to country-specific differences in geography and established infrastructure. Generally, the coding for the matching variables is the same as in Benin.

Concerning the differences in variable operationalisation, quartiles were used for the age of the enterprise owner, and the variable size of enterprise. The computation of quartiles of the age of the owner resulted in the following ranges: quartile 1: 18-32 years, quartile 2: 33-41 years, quartile 3: 42-51 years, and quartile 4: 52-78 years. As in the Benin sample, the size of the enterprise is a composite variable that captures differences between enterprises, which is composed of the size of cultivated land, tertiles of revenue in 2015 and differences in livestock. For the Senegal sample, the variable only distinguishes between small (which includes enterprises coded as medium in Benin) and large, due to it leading to an improvement in matching quality. Table 31 and Table 32 show the matching variables that were used for Senegal and include descriptive information about them.

Table 31 Mean comparison tests for the matching variables 2019, GIZ beneficiaries vs. control group, Senegal

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
High-quality floor	57	168	0.74	0.47	0.44	0.50	0.27***
Age of owner* (ordinal, 4 categories)*	57	168	2.86	2.51	1.08	1.06	0.35**
Age of enterprise (ordinal, 3 categories)*	57	168	2.07	1.76	0.82	0.81	0.31**
Size of enterprise (small/medium v. large)	57	168	0.53	0.40	0.50	0.49	0.12
At least primary education	57	168	0.25	0.32	0.43	0.47	-0.07

Source: DEval, own table. Equal variances. GIZ treatment group and control group that uses non-renewable energy.

*Note: * p < 0.10, ** p < 0.05, *** p < 0.01. As for the ordinal variables, the lowest category (youngest) is 1 and the highest category (oldest) is 4 (age of owner) or 3 (age of enterprise) respectively*

Table 32 Mean comparison tests for matching variables, GIZ and non-GIZ treated vs. control group, Senegal

	Obs		Mean		Std.dev		t-test
	Control	Treatment	Control	Treatment	Control	Treatment	Control/Treatment
High-quality floor	57	262	0.74	0.53	0.44	0.50	0.21***
Age of owner (ordinal, 4 categories)*	57	262	2.86	2.47	1.08	1.09	0.39**
Age of enterprise (ordinal, 3 categories)*	57	262	2.07	1.91	0.82	0.81	0.16
Size of enterprise (D, small/medium v. large)	57	262	0.53	0.45	0.50	0.50	0.07
At least primary education	57	262	0.25	0.29	0.43	0.45	-0.04

*Source: DEval, own table. Equal variances. GIZ and non-GIZ treated (GIZ & non-GIZ) and control group that uses non-renewable energy * p < 0.10, ** p < 0.05, *** p < 0.01.*
Note: As for the ordinal variables, the lowest category (youngest) is 1 and the highest category (oldest) is 4 (age of owner) or 3 (age of enterprise) respectively

Mirroring Benin, Table 33 and Table 34 demonstrate that the number of available cases differs widely between outcomes and time. We once again applied the same matching diagnostics, Rubin's B and R, to estimate the quality of the matching. The results, reported in both tables, confirms that the threshold of 25 for B and the range of 0.5 to 2 for R can be upheld. This marks the performed matching for Senegal as an overall success in terms of achieving a balance between the samples. Due to a comparatively low number of cases for the control group, there are more off-support cases within the treatment group than in Benin. This is simply because there is a smaller pool of respondents to draw from when trying to find a match in terms of characteristics for the treatment group. Figure 20 and Figure 21 show how the matching helped make control and treatment group statistically more similar to each other, as illustrated for the outcome of energy expenses.

Overall, however, the matching for the full sample group performs worse in Senegal than in Benin, which may be an indication that the respondents in Senegal are more heterogenous. However, the opposite trend can be identified for the GIZ sample. While a certain homogeneity can already be identified for GIZ beneficiaries in Benin, this trend is even more pronounced in Senegal. Lastly, it is important to note that the remarks made regarding the matching quality for the subgroups in Benin also apply to Senegal.

Table 33 Results of the matching per outcome in 2019 and 2023, GIZ beneficiaries vs. control group, Senegal

Outcome	Obs				Common Support		Rubin's B	Rubin's R
	2019		2023					
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Matched	Matched
Revenue	119	48	168	55	106	47	12.7	1.40
Energy expenses	134	45	168	57	117	45	11.2	1.19
Number of employees	168	57	168	57	145	57	12.5	1.16
Customers from out of municipality	72	19	106	22	60	18	21.6	1.24
Asset index	168	57	168	57	145	57	12.5	1.16
Food security	168	57	168	57	145	57	12.5	1.16
Quantity sold	153	52	168	57	135	52	12.4	1.12
Quantity sold (dry season)	112	44	112	44	96	44	14.5	1.42

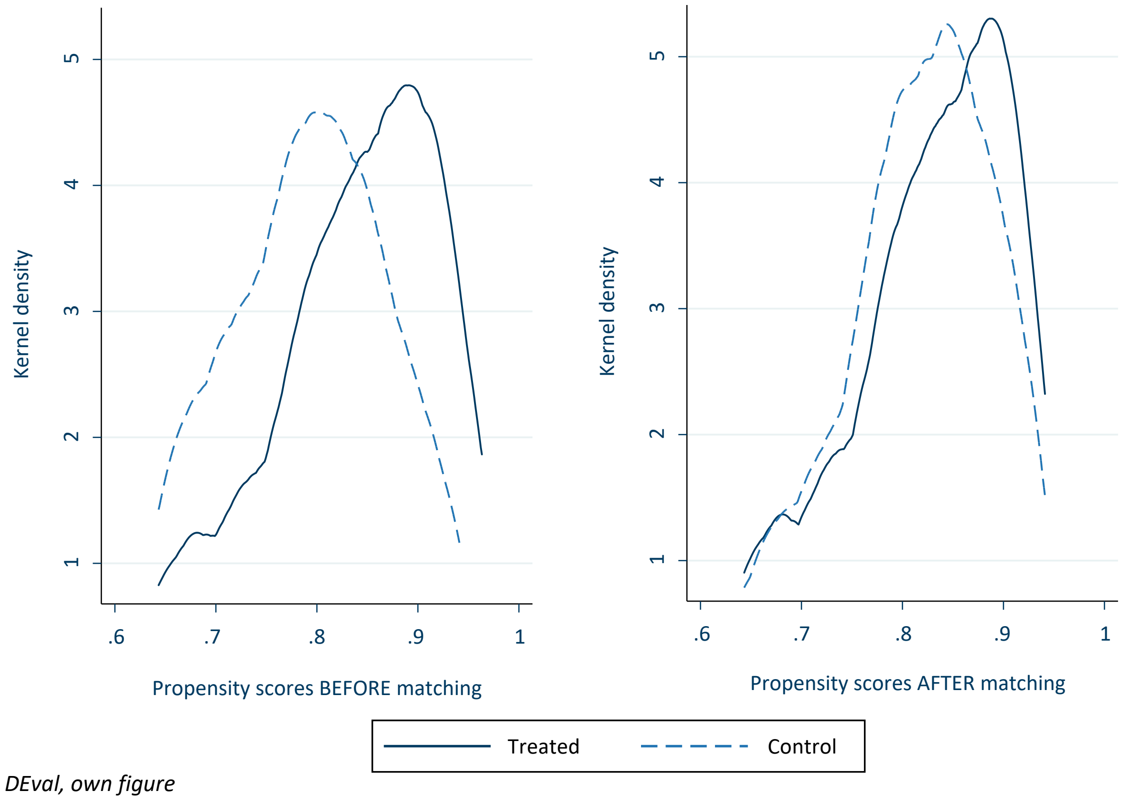
Source: DEval, own table. T = GIZ treatment, C = non-renewable energy
Note: Outcome processing omitted due to the variable having too few cases for 2019. Outliers trimmed

Table 34 Results of the matching per outcome in 2019 and 2023, GIZ and non-GIZ treated vs. control group, Senegal

Outcome	Obs				Common Support		Rubin's B	Rubin's R
	2019		2023					
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Matched	Matched
Revenue	197	48	260	55	182	47	18.0	1.42
Energy expenses	220	45	262	57	201	45	17.8	1.62
Number of employees	262	57	262	57	243	57	22.4	1.51
Customers from out of municipality	105	19	147	22	83	18	13.4	1.17
Asset index	262	57	262	57	243	57	22.4	1.51
Food security	262	57	262	57	243	57	22.4	1.51
Quantity sold	238	52	262	57	221	52	22.5	1.53
Quantity sold (dry season)	195	44	195	44	152	44	8.6	1.34

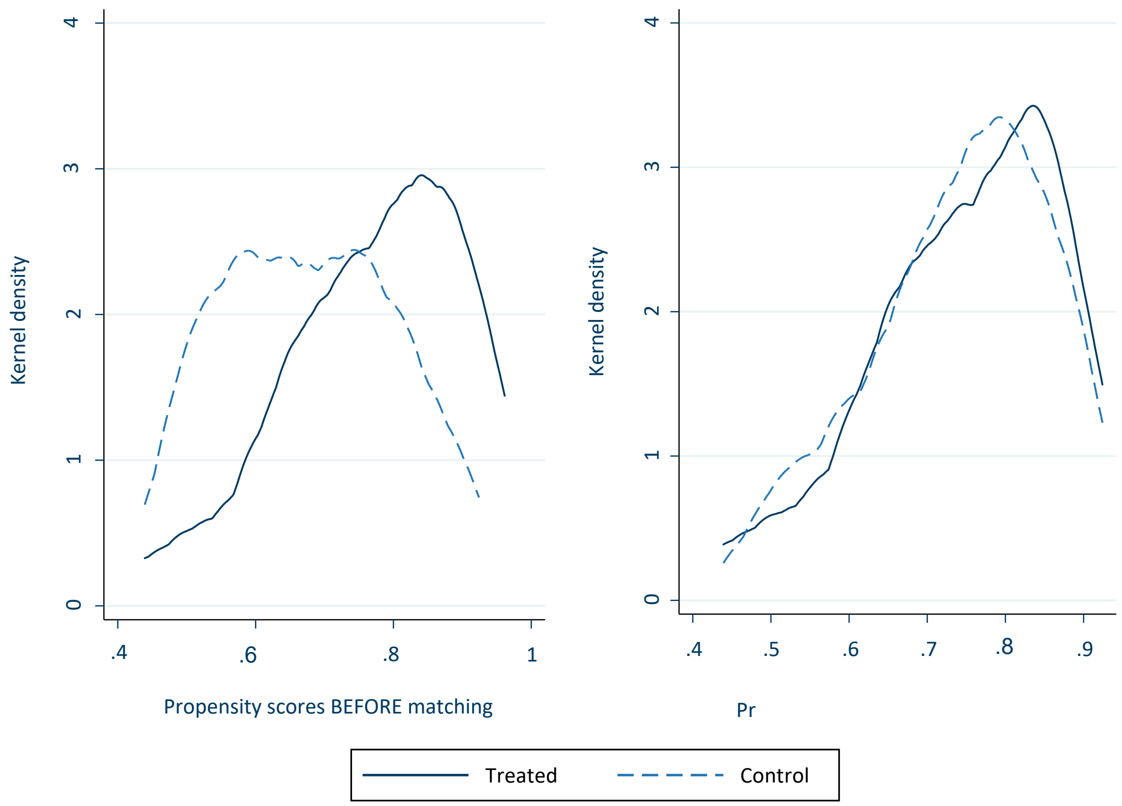
Source: DEval, own table. T = GIZ and non-GIZ treated, C = non-renewable energy
Note: Outcome processing omitted due to the variable having too few cases for 2019. Outliers trimmed

Figure 20 Density plot for outcome energy expenses for before and after matching state, GIZ and non-GIZ treated, Senegal



Source: DEval, own figure

Figure 21 Density plot for outcome energy expenses for before and after matching state, GIZ treatment sample, Senegal



Source: DEval, own figure

4.5.3 Cross-sectional analysis

The results of the cross-sectional analyses performed on the matched sample are largely in line with the simple comparison using t-tests reported in Table 29 and Table 30. The treatment groups have lower energy expenses than the control group (see Table 37 and Table 38). Furthermore, as Table 35 and Table 36 show, farmers among both GIZ beneficiaries and non-GIZ treated are more likely to cultivate during the dry season than those who do not use modern energy.[33] Apart from that, the treatment group appears to have no significant advantage over the control group regarding the size of the personal assets of the owners or the enterprises, their food security, the quantity in tons that they sell during a period (dry season or otherwise), their revenues, their number of employees, the share of customers who they serve from outside their municipality or their likelihood of processing products before selling them.

Table 35 Cross-sectional treatment effect on assets, food security, quantity sold and cultivation during dry season, GIZ beneficiaries vs. control group, Senegal

	(1) Assets	(2) Food security	(3) Quantity sold	(4) Quantity sold (dry season)	(5) Cultivation during dry season
GIZ treatment	-0.176	-0.243	-1,798.1	-1,853.2	
	(0.227)	(0.213)	(1,604.7)	(1,486.8)	
GIZ treatment (vs. no modern energy)					2.464***
					(0.454)
Constant	3.334***	0.165	6,399.1***	6,296.0***	-0.824**
	(0.195)	(0.186)	(1,507.5)	(1,387.2)	(0.402)
Observations	202	202	202	140	113
R^2	0.004		0.011	0.019	
Pseudo R^2		0.007			0.481

*Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for cultivation during dry season, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses, Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 36 Cross-sectional treatment effect on assets, food security, quantity sold and cultivation during dry season, GIZ and non-GIZ treated vs. control group, Senegal

	(1) Assets	(2) Food security	(3) Quantity sold	(4) Quantity sold (dry season)	(5) Cultivation during dry season
GIZ and non-GIZ treatment	-0.222	-0.0221	-941.3	-159.2	
	(0.200)	(0.196)	(1,591.8)	(1,260.3)	

[33] We were unable to run the comparison only between GIZ beneficiaries and those in the control group that use fossil energy, because the sample was too small for the model to converge.

	(1) Assets	(2) Food security	(3) Quantity sold	(4) Quantity sold (dry season)	(5) Cultivation during dry season
GIZ and non-GIZ treatment (vs. no modern energy)					2.665***
					(0.418)
Constant	3.296***	0.151	6,719.9***	5,730.2***	-0.827**
	(0.176)	(0.178)	(1,493.8)	(1,125.1)	(0.377)
Observations	300	300	300	197	196
R^2	0.006		0.003	0.000	
Pseudo R^2		0.000			0.520

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for cultivation during dry season, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses
*Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 37 Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ beneficiaries vs. control group, Senegal

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Share of customers from outside municipality
GIZ treatment	0.145		-157,319.0***	0.0347	4.159
	(0.234)		(35,695.5)	(0.694)	(9.887)
GIZ treatment (vs. no modern energy)		0.285			
		(0.180)			
Constant	3.566***	-1.327***	257,167.3***	3.752***	77.73***
	(0.209)	(0.135)	(32,945.1)	(0.603)	(9.462)
Observations	204	397	202	202	109
R^2	0.003		0.142	0.000	0.005
Pseudo R^2		0.010			

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy
*Note: All outcomes measured in 2023. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS-Regression if R^2 and probit regression if pseudo R^2 is reported. Unlike in Benin, the revenue variable is ordinal (1 to 5) and the share of customers variable is numerical. Outliers trimmed*

Table 38 Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ and non-GIZ treated vs. control group, Senegal

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Share of customers from outside municipality
GIZ and non-GIZ treatment	0.0400		-190,662.5***	-0.0538	1.820
	(0.218)		(33,262.5)	(0.642)	(8.571)
GIZ and non-GIZ treatment (vs. no modern energy)		0.194			
		(0.165)			
Constant	3.607***	-1.349***	271043.2***	3.811***	79.94***
	(0.197)	(0.131)	(31733.9)	(0.583)	(8.232)
Observations	296	487	300	300	141
R^2	0.000		0.203	0.000	0.001
Pseudo R^2		0.005			

*Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Unlike in Benin, the revenue variable is ordinal (1 to 5) and the share of customers variable is numerical. Outliers trimmed*

Cross-sectional subgroup analysis: farmers

Table 39 to Table 42 show the results after restricting the sample to farmers, where the findings are similar to the sample including all MSME types. As Table 39 and Table 40 show, farmers in the treatment group are more likely to cultivate during the dry season than the control group, but the intervention appears to be associated with a smaller planted area for GIZ beneficiaries (see Table 39). Lastly, for farmers the treatment also appears to be associated with a decrease in energy expenses (see Table 41and Table 42).

Table 39 Cross-sectional treatment effect on planted area, food security, quantity sold and cultivation during dry season, GIZ beneficiaries vs. control group, Senegal, farmers only

	(1) Planted area	(2) Assets	(3) Food security	(4) Quantity sold	(5) Quantity sold (dry season)	(6) Cultivation during dry season
GIZ treatment	-0.434*	0.0246	-0.0507	-3,081.1	-2,151.0	
	(0.224)	(0.246)	(0.249)	(2,035.1)	(1,482.0)	
GIZ treatment (vs. no modern energy)						2.463***
						(0.457)
Constant	1.338***	3.104***	0.0879	9147.0***	6390.1***	-0.823**
	(0.190)	(0.200)	(0.215)	(1,926.4)	(1,395.5)	(0.405)
Observations	145	145	145	145	139	113
R^2	0.035	0.000		0.029	0.027	
Pseudo R^2			0.000			0.480

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for cultivation during dry season, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses
*Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 40 **Cross-sectional treatment effect on planted area, food security, quantity sold and cultivation during dry season, GIZ and non-GIZ treated vs. control group, Senegal, farmers only**

	(1) Planted area	(2) Assets	(3) Food security	(4) Quantity sold	(5) Quantity sold (dry season)	(6) Cultivation during dry season
GIZ and non-GIZ treatment	-0.222	-0.00603	0.235	-586.7	-179.6	
	(0.203)	(0.226)	(0.226)	(1,764.9)	(1,276.6)	
GIZ and non-GIZ treatment (vs. no modern energy)						2.679***
						(0.417)
Constant	1.322***	3.133***	0.00548	8,482.7***	5,781.4***	-0.835**
	(0.175)	(0.191)	(0.202)	(1,588.6)	(1,141.8)	(0.377)
Observations	202	202	202	202	196	198
R^2	0.009	0.000		0.001	0.000	
Pseudo R^2			0.006			0.524

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for cultivation during dry season, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses
*Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 41 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ beneficiaries vs. control group, Senegal, farmers only**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Share of customers from outside municipality
GIZ treatment	0.204		-168,434.9***	-1.254	8.284
	(0.255)		(42,662.1)	(0.817)	(10.20)
GIZ treatment (vs. no modern energy)		-0.247			
		(0.300)			
Constant	3.598***	-1.461***	295,029.0***	4.551***	78.99***
	(0.228)	(0.217)	(38,617.4)	(0.748)	(9.829)
Observations	144	259	145	145	78
R^2	0.006		0.150	0.026	0.023
Pseudo R^2		0.008			

*Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses, Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 42 **Cross-sectional treatment effect on revenue, processing, energy expenses, number of employees, customer origin, GIZ and non-GIZ treated vs. control group, Senegal, farmers only**

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees	(5) Share of customers from outside municipality
GIZ and non-GIZ treatment	0.0675		-225,149.2***	-0.949	1.256
	(0.259)		(37,767.3)	(0.754)	(8.359)
GIZ and non-GIZ treatment (vs. no modern energy)		-0.288			
		(0.260)			
Constant	3.550***	-1.463***	307,497.3***	4.480***	83.26***
	(0.232)	(0.204)	(35,807.7)	(0.695)	(7.998)
Observations	200	345	202	202	104
R^2	0.001		0.268	0.014	0.001
Pseudo R^2		0.011			

*Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy. All outcomes measured in 2023. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Cross-sectional subgroup analysis: women

In order to improve the matching quality for the subgroup of women, the reference category was adjusted for the variables of high-quality flooring and age of owner. Moreover, the subgroup of women contained low case numbers for certain outcomes. Therefore, some outcomes had to be omitted since convergence could not be achieved in the regression models.

Table 43 to Table 46 present the results of the subgroup analysis for women. It should be noted that the case numbers for the analyses, especially for the GIZ treatment group, are very low and should therefore be interpreted with caution. Nevertheless, the negative treatment effect for energy expenses persists, though it is only statistically significant when both treatment groups are taken together (including T1 and T2, Table 46), which is likely due to the low number of cases for the GIZ treatment group.

Interestingly, the use of solar appliances appears to be related to additional effects for women. It appears to negatively impact their assets (see Table 43 and Table 44), the number of employees (see Table 45, GIZ beneficiaries only) and the likelihood of processing products before selling them compared to those not using modern energy (see Table 46, when GIZ and non-GIZ treated are taken together).

Table 43 **Cross-sectional treatment effect on planted area, assets, food security and quantity sold, GIZ beneficiaries vs. control group, Senegal, women only**

	(1) Assets	(2) Food security	(3) Quantity sold
GIZ treatment	-1.397***	0.705	973.2**
	(0.353)	(0.599)	(447.4)
Constant	4.818***	0.298	45.79
	(0.146)	(0.484)	(46.54)
Observations	28	28	28
R^2	0.301		0.119
Pseudo R^2		0.056	

*Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy. All outcomes measured in 2023. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 44 **Cross-sectional treatment effect on assets, food security and quantity sold, GIZ and non-GIZ treated vs. control group, Senegal, women only**

	(1) Assets	(2) Food security	(3) Quantity sold
GIZ and non-GIZ treatment	-1.568***	0.269	2,217.2***
	(0.369)	(0.480)	(720.0)
Constant	4.568***	0.128	35.20
	(0.300)	(0.447)	(35.44)
Observations	64	64	64
R^2	0.265		0.082
Pseudo R^2		0.008	

*Source: DEval, own table, T = GIZ and non-GIZ treated vs. C = non-renewable energy. All outcomes measured in 2023. Robust standard errors in parentheses, * $p<0.10$, ** $p<0.05$, *** $p<0.01$. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed. The sample size was too small to estimate effects on the planted area in the subsample of women*

Table 45 Cross-sectional treatment effect on revenues, processing, energy expenses and number of employees, GIZ beneficiaries vs. control group, Senegal, women only

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ treatment	-0.00248		-57,185.8	4.337**
	(0.633)		(41,750.8)	(1.606)
GIZ treatment (vs. no modern energy)		0.464		
		(0.284)		
Constant	3.687***	-0.959***	106,501.6***	1.347*
	(0.557)	(0.225)	(32655.3)	(0.705)
Observations	28	150	28	28
R^2	0.000		0.079	0.169
Pseudo R^2		0.025		

Source: DEval, own table. T = GIZ treatment sample vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy
*Note: All outcomes measured in 2023. Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

Table 46 Cross-sectional treatment effect on revenues, processing, energy expenses and number of employees, GIZ and non-GIZ treated vs. control group, Senegal, women only

	(1) Revenue	(2) Processing	(3) Energy expenses	(4) Number of employees
GIZ and non-GIZ treatment	-0.0737		-70,296.5**	2.621
	(0.611)		(31,606.5)	(1.637)
GIZ and non-GIZ treatment (vs. no modern energy)		0.503**		
		(0.221)		
Constant	3.565***	-1.144***	104987.4***	2.342
	(0.571)	(0.170)	(29,498.6)	(1.420)
Observations	64	184	64	64
R^2	0.001		0.148	0.058
Pseudo R^2		0.030		

Source: DEval, own table. T = GIZ and non-GIZ treated vs. C = non-renewable energy for all outcomes except for processing, C for this outcome = no use of modern energy,
*Note: All outcomes measured in 2023. Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regression if R^2 and probit regression if pseudo R^2 is reported. Outliers trimmed*

4.5.4 Difference-in-differences (DiD) analysis

The DiD analyses on the survey data from Senegal are run on the matched samples, just like with the data from Benin. The results for both types of treatment groups are presented in Table 47and Table 48. Overall, most of the effects observed in the cross-sectional comparison are not robust to using a DiD estimator.

However, there are two interesting effects. The DiD analyses confirm the finding that energy expenses have decreased as a result of the interventions, even though this effect is only statistically significant for the subgroups of farmers (see Table 49) and female entrepreneurs (see Table 51), and not for the sample of all MSME types (see Table 47). In addition, the results suggest a negative effect on the amount of personal assets by the owners of the enterprises, which appears robust across the MSME types (Table 48, Table 50 and Table 52).

Table 47 DiD treatment effect on revenue, energy expenses, number of employees and food security, Senegal

	(1) Revenue	(2) Revenue	(3) Energy expenses	(4) Energy expenses	(5) Number of employees	(6) Number of employees	(7) Food security	(8) Food security
Post	0.292	0.373	1,617.8	4,191.2	1.064	1.022	-0.0321	-0.0218
	(0.320)	(0.338)	(65,215.4)	(72,742.8)	(0.789)	(0.829)	(0.252)	(0.263)
GIZ and non-GIZ treatment	0.0899		-99,762.0*		0.0224		-0.0438	
	(0.260)		(58,291.6)		(0.586)		(0.196)	
GIZ and non-GIZ DiD	0.0976		-109,652.6		-0.0761		0.0217	
	(0.355)		(69,953.0)		(0.869)		(0.277)	
GIZ treatment		0.170		-54,557.0		-0.267		-0.213
		(0.288)		(68,324.9)		(0.639)		(0.214)
GIZ DiD		0.0982		-128,152.8		0.302		-0.0301
		(0.385)		(81,238.8)		(0.944)		(0.302)
Constant	3.333***	3.226***	287,553.0***	275,347.6***	2.747***	2.729***	0.183	0.187
	(0.234)	(0.253)	(53,678.1)	(59,972.5)	(0.532)	(0.569)	(0.178)	(0.186)
Observations[34]	458	306	492	324	600	404	600	404
R^2	0.015	0.028	0.094	0.065	0.016	0.023		
Pseudo R^2							0.000	0.006
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy.

[34] All difference-in-differences tables presented report the total number of statistical observations, wherein two data points are included per respondent: one observation from 2019 and another from 2023 for Senegal. Therefore, when seeking to retrieve the number of respondents included in the analysis, it is necessary to divide the number of observations from the table by two to account for the number of data points per respondent.

*Note: Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regressions if R^2 is reported, probit regressions otherwise. Unlike in Benin, the share of customers from outside the municipality is numerical. All outcomes measured in 2019 and 2023. Outliers trimmed*

Table 48 DiD treatment effect on assets, share of customers from outside the municipality and quantity sold, Senegal

	(1) Assets	(2) Assets	(3) Share of customers from outside municipality	(4) Share of customers from outside municipality	(5) Quantity sold (dry season)	(6) Quantity sold (dry season)	(7) Quantity sold	(8) Quantity sold
Post	0.554**	0.528**	-6.313	-6.942	2,689.6**	3,050.1*	2,170.0	1,932.3
	(0.246)	(0.262)	(15.82)	(17.41)	(1,266.0)	(1,589.6)	(1,822.2)	(1,811.4)
GIZ and non-GIZ treatment	0.476**		-1.603		291.5		-164.0	
	(0.193)		(11.52)		(712.2)		(1,104.8)	
GIZ and non-GIZ DiD	-0.698**		7.145		-212.7		-406.2	
	(0.278)		(16.19)		(1,440.3)		(1,966.1)	
GIZ treatment		0.401*		0.516		-297.6		-391.7
		(0.210)		(12.77)		(879.6)		(1,163.4)
GIZ DiD		-0.576*		6.392		-1,555.5		-979.5
		(0.309)		(17.85)		(1,727.5)		(1,976.6)
Constant	2.742***	2.806***	86.87***	85.72***	2,995.1***	3,245.9***	4,186.5***	3,936.4***
	(0.172)	(0.175)	(11.24)	(12.47)	(611.9)	(776.2)	(1,006.4)	(1,026.9)
Observations	600	404	202	156	392	280	546	374
R^2	0.024	0.021	0.008	0.012	0.047	0.053	0.015	0.014
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

Source: DEval, own table, T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy.
*Note: Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regressions. Unlike in Benin, the share of customers from outside the municipality is numerical. All outcomes measured in 2019 and 2023. Outliers trimmed*

DiD analysis: farmers

Table 49 DiD treatment effect on revenue, energy expenses, number of employees and food security, Senegal, farmers only

	(1) Revenue	(2) Revenue	(3) Energy expenses	(4) Energy expenses	(5) Number of employees	(6) Number of employees	(7) Food security	(8) Food security
Post	0.275	0.449	12,547.2	22,182.1	1.625*	1.542	-0.0459	-0.0291
	(0.373)	(0.382)	(61,813.2)	(66,435.8)	(0.909)	(1.026)	(0.285)	(0.304)
GIZ and non-GIZ treatment	-0.0351		-80,400.2		0.0562		0.205	
	(0.293)		(54,978.5)		(0.648)		(0.226)	
GIZ and non-GIZ DiD	0.244		-147,367.0**		-1.005		0.0295	
	(0.414)		(68,741.5)		(0.994)		(0.319)	
GIZ treatment		0.238		3,408.3		-0.544		-0.00510
		(0.320)		(64,968.2)		(0.763)		(0.249)
GIZ DiD		0.144		-181,810.0**		-0.710		-0.0456
		(0.428)		(80,016.5)		(1.118)		(0.352)
Constant	3.302***	3.111***	294,893.4***	276,940.5***	2.855***	3.009***	0.0513	0.117
	(0.263)	(0.285)	(47,791.3)	(51,138.6)	(0.586)	(0.702)	(0.202)	(0.215)
Observations	334	244	366	244	404	290	404	290
R^2	0.020	0.048	0.112	0.065	0.028	0.041		
Pseudo R^2							0.006	0.000
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy.
*Note: Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regressions. Unlike in Benin, the revenue variable is ordinal (1 to 5). All outcomes measured in 2019 and 2023. Outliers trimmed*

Table 50 DiD treatment effect on assets, customer origin and quantity sold, Senegal, farmers only

	(1) Assets	(2) Assets	(3) Share of customers from outside municipality	(4) Share of customers from outside municipality	(5) Quantity sold (dry season)	(6) Quantity sold (dry season)	(7) Quantity sold	(8) Quantity sold
Post	0.507*	0.429	-8.222	-6.610	2,752.3**	3,122.4*	2,833.3	2,908.4
	(0.283)	(0.288)	(11.86)	(22.78)	(1,292.4)	(1,601.6)	(2,046.7)	(2,419.0)
GIZ and non-GIZ treatment	0.760***		-8.198		174.1		-280.1	
	(0.234)		(8.097)		(719.4)		(1,298.1)	
GIZ and non-GIZ DiD	-0.766**		9.955		-261.7		-180.8	
	(0.325)		(12.58)		(1,460.1)		(2,287.8)	
GIZ treatment		0.542**		5.959		-445.2		-830.6
		(0.248)		(16.94)		(880.9)		(1,528.5)
GIZ DiD		-0.518		6.193		-1,705.8		-1,652.0
		(0.350)		(23.21)		(1,724.0)		(2,612.4)
Constant	2.626***	2.675***	91.56***	80.74***	3,009.6***	3,267.7***	5,538.4***	5,607.6***
	(0.209)	(0.208)	(7.462)	(16.64)	(622.9)	(785.8)	(1,137.4)	(1,355.8)
Observations	404	290	152	104	388	278	362	262
R^2	0.041	0.025	0.018	0.029	0.048	0.060	0.025	0.029
Sample	Full	GIZ	Full	GIZ	Full	GIZ	Full	GIZ

Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy

*Note: Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regressions. Unlike in Benin, the share of customers variable is numerical. All outcomes measured in 2019 and 2023. Outliers trimmed*

DiD analysis: women

Table 51 DiD treatment effect on revenue, energy expenses and number of employees, Senegal, women only

	(1) Revenue	(2) Revenue	(3) Energy expenses	(4) Energy expenses	(5) Number of employees	(6) Number of employees
Post	0.201	0.179	96,852.0**	88,022.8*	1.647	1.320
	(0.920)	(0.588)	(47,307.4)	(48,845.3)	(1.443)	(1.185)
GIZ and non-GIZ treatment	-0.609		-3,505.3		2.305***	
	(0.781)		(16,660.1)		(0.770)	
GIZ and non-GIZ DiD	0.370		-92,076.2*		0.533	
	(1.068)		(49,053.0)		(1.809)	
GIZ treatment		-1.252*		-27,971.8		1.142
		(0.700)		(25,742.4)		(1.023)
GIZ DiD		1.266		-47,772.8		3.055
		(0.886)		(56,929.1)		(2.285)
Constant	3.276***	4.030***	17,315.6	29,721.8	0.555	0.545
	(0.684)	(0.492)	(13,878.0)	(25,682.9)	(0.361)	(0.351)
Observations	56	32	70	24	118	50
R^2	0.031	0.201	0.330	0.308	0.116	0.194
Sample	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy. Robust standard errors in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01. OLS regressions. Unlike in Benin, the revenue variable is ordinal (1 to 5). All outcomes measured in 2019 and 2023. Outliers trimmed*

Table 52 DiD treatment effect on assets, quantity sold and food security, Senegal, women only

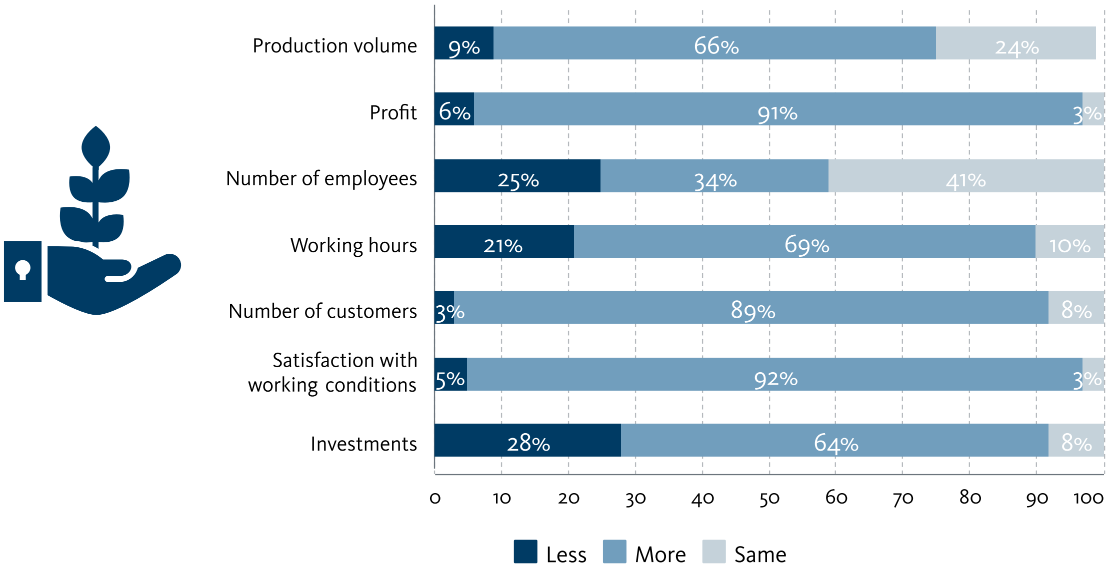
	(1) Assets	(2) Assets	(3) Quantity sold	(4) Quantity sold	(5) Food security	(6) Food security
Post	1.902***	1.999***	26.00	33.45	-1.36e-16	2.71e-16
	(0.365)	(0.362)	(26.81)	(34.84)	(0.646)	(0.726)
GIZ and non-GIZ treatment	0.761**		1,505.5**		0.230	
	(0.293)		(640.4)		(0.493)	
GIZ and non-GIZ DiD	-2.282***		524.2		7.37e-17	
	(0.467)		(1,005.6)		(0.697)	
GIZ treatment		0.854*		280.0*		0.461
		(0.426)		(159.5)		(0.631)
GIZ DiD		-1.812***		496.5		-1.40e-16
		(0.589)		(478.7)		(0.892)
Constant	2.699***	2.709***	1.02e-12	5.68e-14	0.237	0.426
	(0.231)	(0.283)			(0.457)	(0.513)
Observations	118	50	114	48	118	50
R^2	0.265	0.306	0.065	0.118		
Pseudo R^2					0.006	0.025
Sample	Full	GIZ	Full	GIZ	Full	GIZ

*Source: DEval, own table. T = GIZ and non-GIZ treated; GIZ treatment sample, C = users of non-renewable energy. Robust standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS regressions if R^2 is reported, otherwise probit regression. All outcomes measured in 2019 and 2023. Outliers trimmed*

4.5.5 Perception of outcomes and impacts

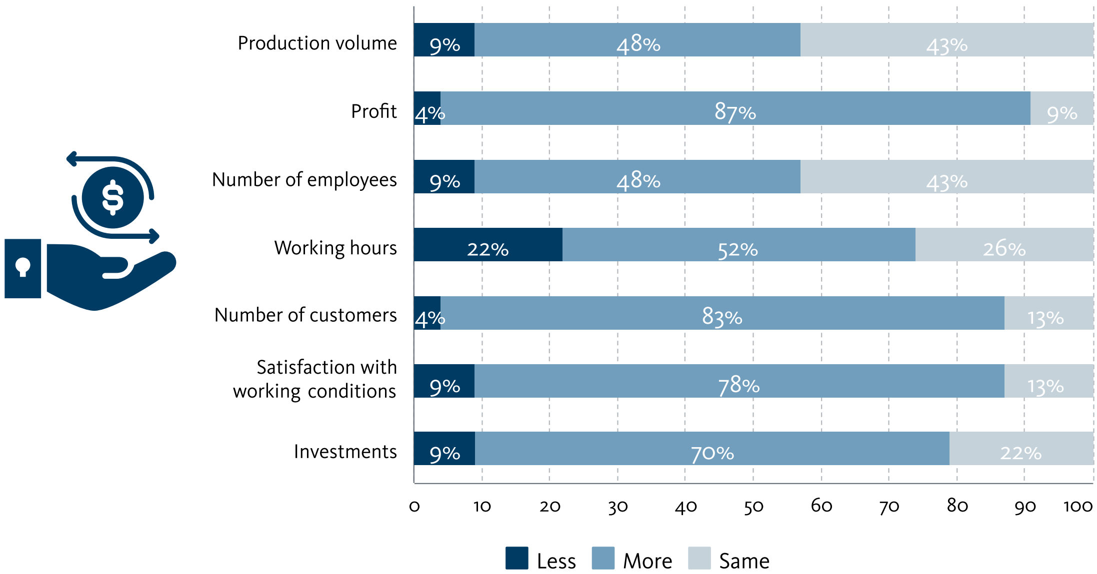
The most common effects of using solar appliances, as self-reported by the respondents in the survey in Senegal, are increases in production volume and profits, increases in customer numbers and increased satisfaction with their working conditions (Figure 22 and Figure 23), and are therefore similar to the findings from Benin. More effects, including the perceived changes on gender-related outcomes and impacts (Figure 24), are discussed in the evaluation report in Chapter 6.3.

Figure 22 Perceived changes in enterprise related outcomes for farmers, Senegal



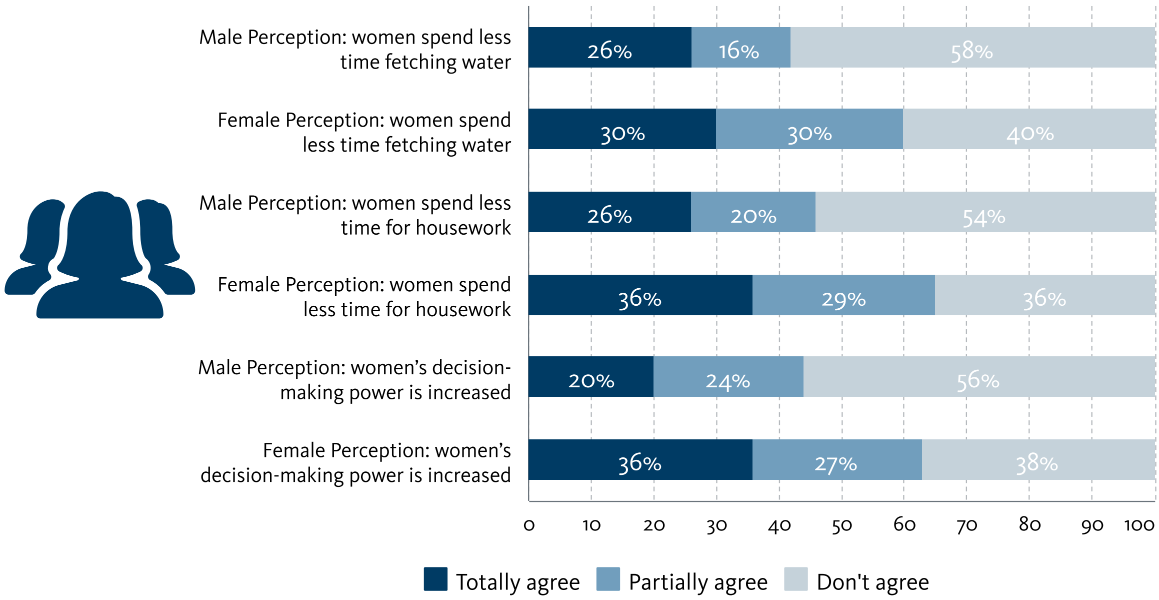
Source: DEval, own figure. Some figures do not add up to 100 % due to rounding

Figure 23 Perceived changes in enterprise related outcomes for trade and other, Senegal



Source: DEval, own figure. Some figures do not add up to 100 % due to rounding

Figure 24 Perceived changes in gender-related outcomes and impacts, Senegal



Source: DEval, own figure. Some figures do not add up to 100 % due to rounding

5. MINI-GRID SURVEY[35]

The ERSEN 1 and ERSEN 2 interventions implemented by EnDev facilitated the installation of mini-grids in 90 villages in Senegal between 2016 and 2021. In addition to providing the mini-grids, EnDev also facilitated access to appliances such as fridges, mills and sewing machines to be used in conjunction with the grids. Moreover, they set up boutiques to aid in the payment system for the tariffs to use the mini-grid's energy. Usually, the same end users who had a boutique also obtained a fridge to facilitate their enterprise. Such appliances were provided in nine municipalities. The aim of this component was to foster the use of energy from the mini-grid for productive purposes.

We interviewed the village head and the person responsible for managing the mini-grid at village level in 82 of those villages. The objective of this descriptive survey was firstly to find out how many mini-grids were functioning up to seven years after their installation, and secondly to assess the potential for the productive use of the energy from those grids within the villages. The survey contained a range of questions addressed to the village head or their deputy and to the local manager of the mini-grid. The design of the questionnaire was closely modelled on a questionnaire administered in the same localities in 2019 by researchers at the RWI – Leibniz-Institut für Wirtschaftsforschung, Essen (RWI Essen), Julian Rose and Jörg Ankel-Peters.

Our survey was carried out by phone in September and October 2023. Out of a list of 90 villages where mini-grids were installed, 82 consented to participate in the survey.

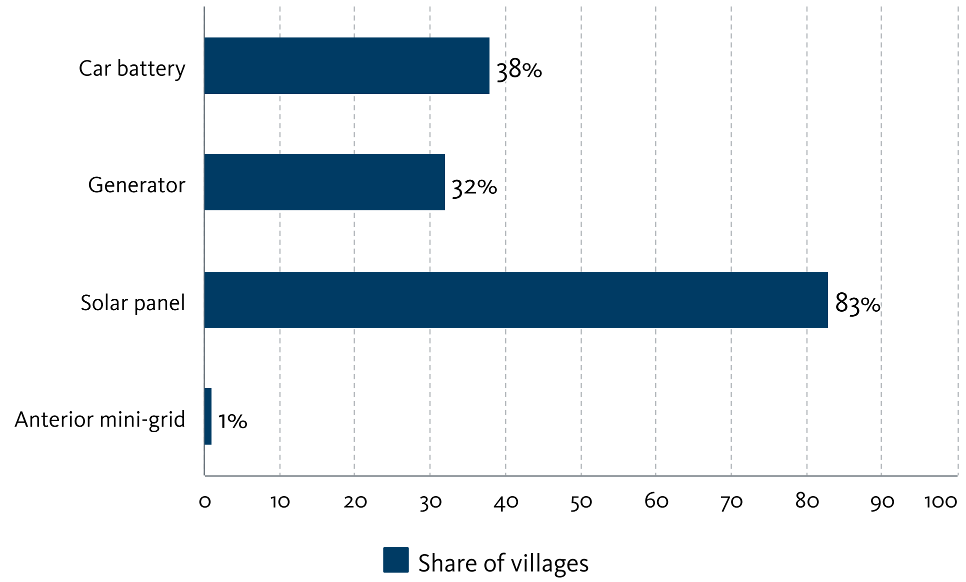
5.1 Relevance for SDG 7.1 – energy for all by 2030

The mini-grids examined in Senegal are not very effective at creating initial access. The survey in the mini-grid villages showed that before the mini-grids were installed, 38 percent of villages (31 villages) used car batteries, 32 percent (26 villages) used generators and 83 percent (68 villages) used solar panels. This means

[35] **Contributors**: Mame Mor Anta Syll, Whitney Edwards.

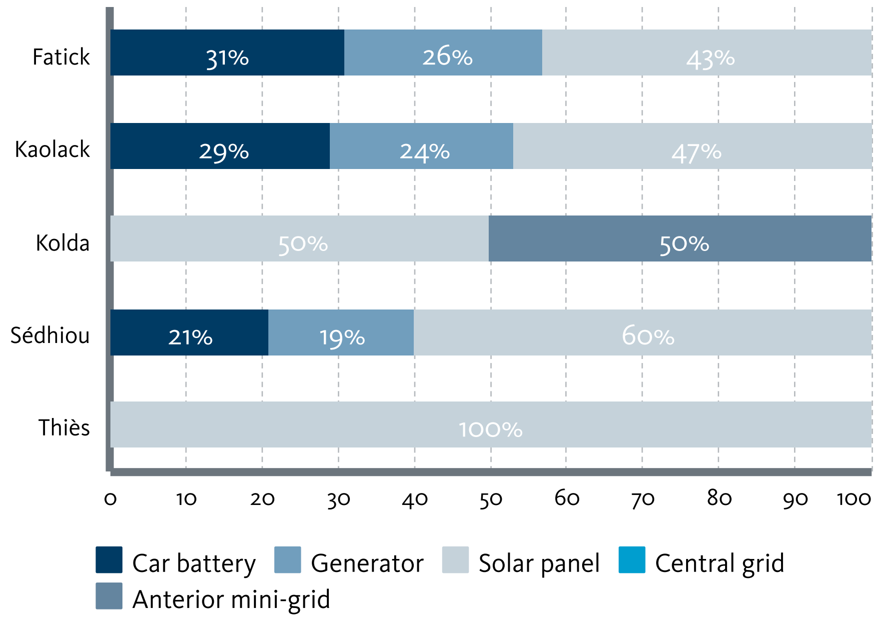
that a large proportion of the villages already had access to modern electricity, even though the mini-grids presumably increased the tier level (Figure 25 and Figure 26).

Figure 25 Share of villages by type of energy source before the mini-grids were installed



Source: DEval, own figure

Figure 26 Energy used before the mini-grids were installed by area



Source: DEval, own figure

5.2 Functionality of the mini-grids

While our data does not allow for a causal estimation of the economic impact of the mini-grids on rural enterprises and populations in these villages, it can be used to assess the potential for economic impacts. The main prerequisite for the productive use of energy from the grids is that the grids are functional and provide sufficient energy at the right times.

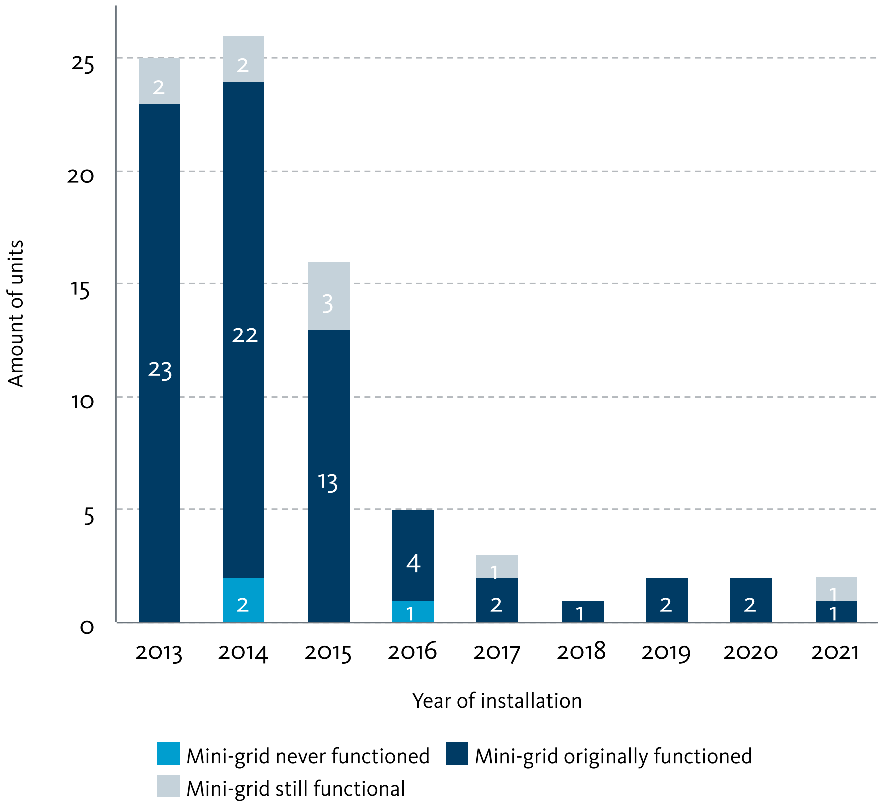
Out of the 82 villages surveyed, only nine reported still having functioning mini-grids. The villages with their mini-grids still working are the following: Yacine Mandina (1), Yacine Tambana (2), Néma Diaour (3) in Sédhiou, Bangalère (4) and Keur Babou Ndity (5) in Foundiougne, Lamel (6) and Sina (7) in Goudomp, Saré

Koubé (8) in Kolda and Souaki (9) in Bounkling. Villages with mini-grids which were reported to have never been functional are Bantanto and Mansang in Bounkiling and Keur Mandiaye Fatim in Foundiougne.

Out of the 82 villages interviewed, 79 of them have at least enjoyed the use of their mini-grids some of the time. The time of operation was 24 hours a day for 39 villages (or 49 % of the sample) and less than 24 hours for 40 villages (or 51 % of the sample) as shown in Figure 30.

Figure 27 demonstrates that even mini-grids which started operating quite recently (2018, 2019 and 2020) already no longer work. Interestingly, some of the mini-grids which were installed comparatively early on (2013, 2014 and 2016) were reported to still be functional at the time of the survey.

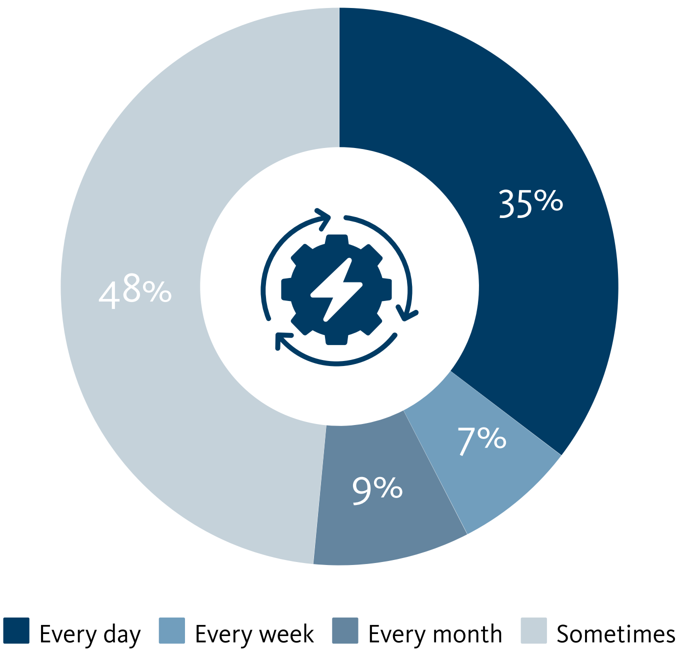
Figure 27 Year of installation and functionality in 2023



Source: DEval, own figure

During the dry season, the mini-grids experience power outages frequently (Figure 28). In 35 % of the villages in the study, the shutdown during the dry season occurs every day. Only few villages had experienced weekly or monthly shutdowns (7 % and 9 % of villages respectively).

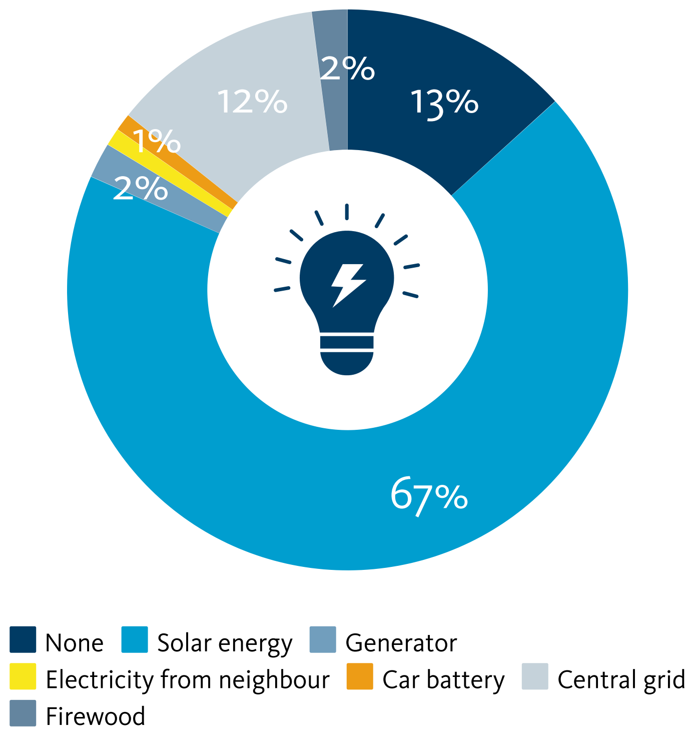
Figure 28 Frequency of power outages of the mini-grids during the dry season



Source: DEval, own figure. Figure does not add up to 100 % due to rounding

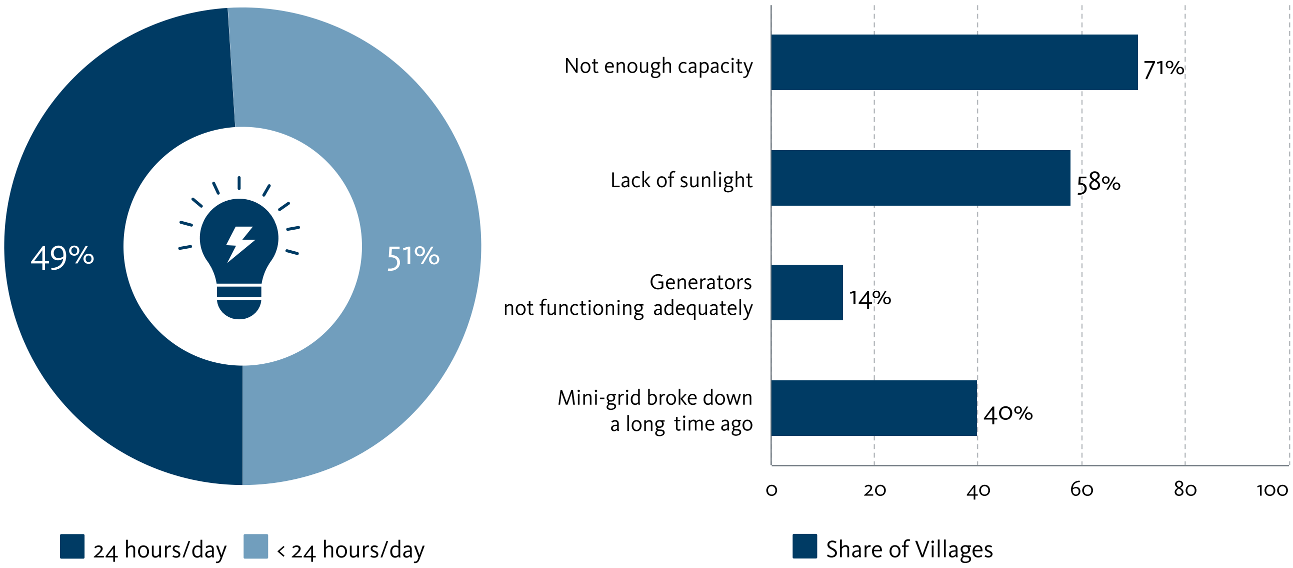
Entrepreneurs who are not using the mini-grids as their main source of energy use different sources of energy for their economic activities. The data shows that they primarily use (other) solar energy in 67 % of the villages. For 12 % of villages, the primary source of energy for income-generating activities which are not connected to the mini-grids is the central electricity grid. However, in 13 % of villages respondents reported that they had no source of electricity for the economic activities within their villages (see Figure 29).

Figure 29 Sources of alternative electrical energy used by enterprises and households (when not connected to mini-grids)



Source: DEval, own figure. Figure does not add up to 100 % due to rounding

Figure 30 **Share of villages by mini-grid operating hours (left) and by reasons for not operating all day (right)**

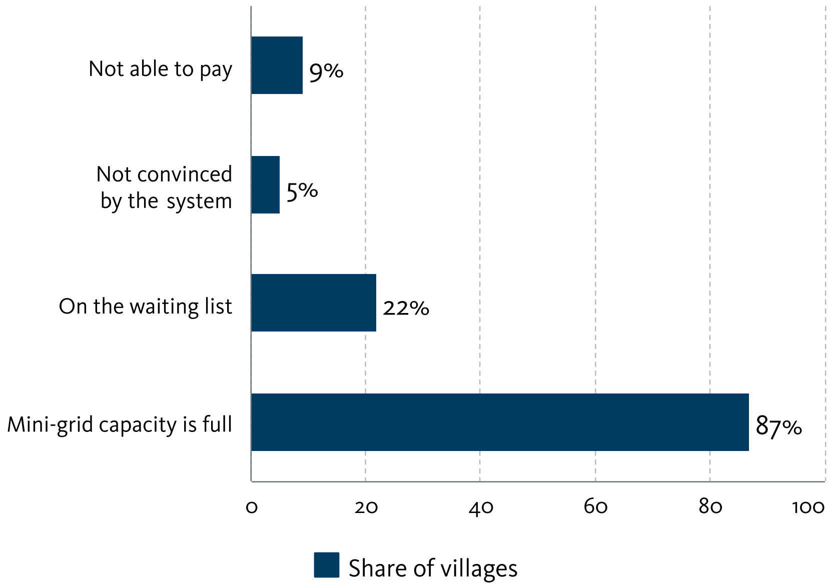


Source: DEval, own figure

Mini-grids have a variety of operational challenges that inhibit their continuous operation (see Figure 30). The analysis of the provided data indicates that, on average, 71 % of villages face issues with round-the-clock operation. In 40 % of the villages the mini-grid had completely broken down and stopped working. In the majority of the remaining villages, the capacity of the mini-grid was not sufficient to operate all day. In 58 % of the villages mini-grids did not operate all day due to the lack of sunlight. Normally, the mini-grids are supposed to be powered by a generator that uses fossil fuel, mostly diesel, in the absence of sunlight. But 14 % of the villages reported that those generators did not work as intended, either because they were not functional and not repaired or simply because the fuel was not available. It is the operator of the mini-grid who would have been responsible to supply the generators with fuel.

Overall, these findings underscore the widespread challenges faced by mini-grids, emphasising the need for addressing technical issues, ensuring operator competency and exploring solutions for consistent energy availability across different locations. The survey data highlights disparities in household connections to the mini-grids across the villages. Figure 31 offers insights into the reasons behind households remaining unconnected. In 22 % percent of the villages, households were on waiting lists, in 13 % of the villages more households could not get connected due to the capacity of the grid already being full. Other reasons were households' inability to afford the connection or trust issues.

Figure 31 Share of villages by reasons for not being connected to the mini-grids



Source: DEval, own figure

5.3 Economic activities in mini-grid villages

Table 53 provides an overview of the different income-generating activities in the villages where mini-grids were installed as part of the GIZ interventions under study. The mean values represent the percentage of villages in which the activities were practiced. The main activity in the mini-grid villages is farming and there are also small enterprises across the board. Related to the predominance of farming, a wide-spread economic activity is processing of agricultural produce. Also sewing is widespread.

Table 53 Share of villages by income-generating activities

	N	Mean	Min	Max	Median	Std. dev.	t-value
Woodwork	82	.378	0.000	1	0	.488	7.017
Hairstyling	82	.195	0.000	1	0	.399	4.431
Sewing	82	.707	0.000	1	1	.458	13.991
Woodwork	82	.512	0.000	1	1	.503	9.222
Small enterprise	82	.841	0.000	1	1	.367	20.735
Catering	82	.378	0.000	1	0	.488	7.017
Bar	82	.012	0.000	1	0	.11	1
Processing (mill)	82	.646	0.000	1	1	.481	12.167
Farming	82	.927	0.000	1	1	.262	32.031
Selling fresh produce	82	.573	0.000	1	1	.498	10.429
Seller	82	.061	0.000	1	0	.241	2.293

Source DEval, own table

Table 54 reports the prevalence of various appliances used in the mini-grid villages, to get an overview over the potential to power appliances with the mini-grid for income generating activities. Like above, the means represent the percentage of villages in which an appliance was used. The most frequently used appliances in the villages are electric ovens, freezers, electric irons, computers, electric mills and black and white TVs. Conversely, fans, oil or fuel mills, and dryers are less commonly used on average. The data, furthermore, suggest only little variability between villages in the patterns in which the appliances are used.

Table 54 Share of villages by appliances used

	N	Mean	Min	Max	Median	Std. dev.	t-value
Charcoal iron	82	.171	0.000	1	0	.379	4.084
Electric iron	82	.305	0.000	1	0	.463	5.96
Generator fridge	82	.037	0.000	1	0	.189	1.754
Electric fridge	82	.012	0.000	1	0	.11	1
Freezer	82	.293	0.000	1	0	.458	5.789
Electric oven	82	.293	0.000	1	0	.458	5.789
Fan	82	0	0.000	0	0	0	.
Black and white TV	82	.244	0.000	1	0	.432	5.112
Color TV	82	.073	0.000	1	0	.262	2.529
Computer	82	.244	0.000	1	0	.432	5.112
Oil/fuel mill	82	.061	0.000	1	0	.241	2.293
Electric mill	82	.28	0.000	1	0	.452	5.619
Mechanical sewing machine	82	.146	0.000	1	0	.356	3.726
Electric sewing machine	82	.146	0.000	1	0	.356	3.726
Grinding wheel	82	.024	0.000	1	0	.155	1.423
Welding machine	82	.049	0.000	1	0	.217	2.038
Dryer	82	.012	0.000	1	0	.11	1
Lighting	82	.317	0.000	1	0	.468	6.132
Other (specify)	82	.012	0.000	1	0	.11	1

Source: DEval, own table

Table 55 shows the income-generating activities for which the mini-grids were used. This overview suggests that on average, a substantial proportion of enterprises that use the electricity of the mini-grid are engaged in small enterprise activities or selling fresh produce. Conversely, there appears to be less usage of the mini-grid energy for woodwork, for running a bar and for farming.

Table 55 Main income-generating activities for enterprises connected to the mini-grids

	N	Mean	Min	Max	Median	Std. dev.	t-value
Woodwork	82	0	0.000	0	0	0	.
Hairstyling	82	.037	0.000	1	0	.189	1.754
Sewing	82	.122	0.000	1	0	.329	3.354
Small enterprise	82	.768	0.000	1	1	.425	16.388
Catering	82	.024	0.000	1	0	.155	1.423
Bar	82	0	0.000	0	0	0	.
Processing (mill)	82	.061	0.000	1	0	.241	2.293
Farming	82	.012	0.000	1	0	.11	1
Selling fresh produce	82	.524	0.000	1	1	.502	9.45
Shop seller	82	.159	0.000	1	0	.367	3.907

Source: DEval, own table

Lamps, freezers and fridges are the main electric appliances used in conjunction with the mini-grids for income-generating activities.

The survey also explored the potential of the mini-grids to foster economic activities in general and among women in particular. There are an average of 20 enterprises per village, nine of which are directed by women. On average, four of these enterprises source energy from the mini-grids. Of these four enterprises that are supplied by the grids, one – i.e. one-quarter – is led by women (Table 56). According to information from the village heads, less than one of these 20 enterprises began its economic activity as a result of the arrival of the mini-grids.

Table 56 Share of villages by number of enterprises

	N	Mean	Min	Max	Median	Std. dev.	t-value
# of enterprises	82	19.683	3.000	70	15	12.954	13.759
# of enterprises led by women	82	8.768	1.000	50	7	8.351	9.508
# of enterprises connected to the mini-grid	82	4.305	0.000	32	3	5.562	7.009
# of enterprises connected to the mini-grid led by women	68	1.088	0.000	7	0	1.751	5.124
# of new enterprises or economic activities in the village thanks to the mini-grid	82	.683	0.000	1	1	.468	13.208

Source: DEval, own table

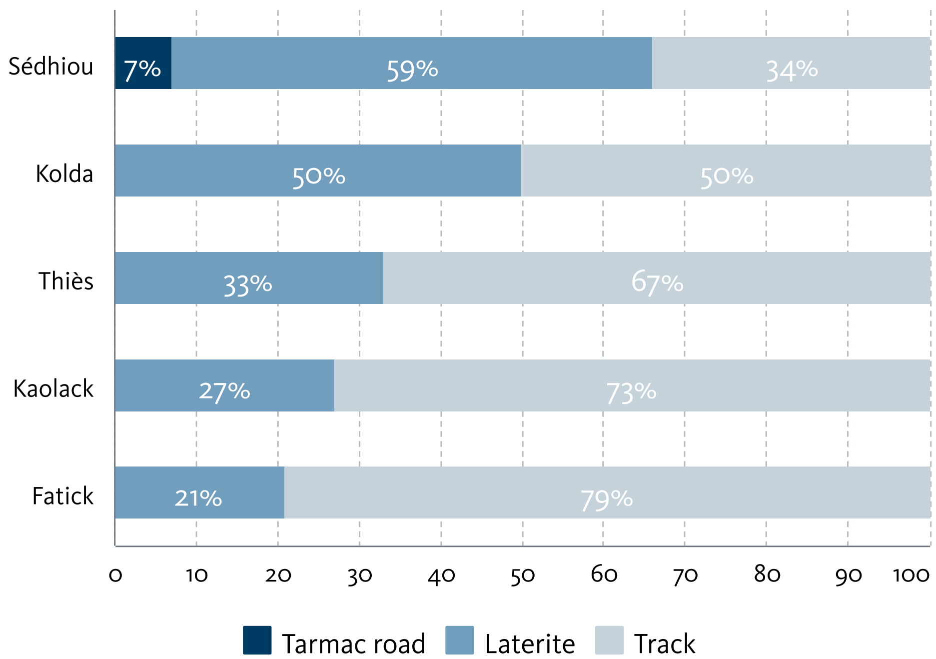
5.4 Productive use potential of mini-grids

However, some of the village heads do report that enterprises were created as a result of the arrival of the mini-grids in their localities. These enterprises include hairdressers, tailors, carpenters, shops, processing units (mills) and enterprises that sell ice cubes and cool drinks (likely users of freezers). Small enterprises in terms of small trade and small kiosks were the most important category of businesses created thanks to the mini-grids.

Assuming that the mini-grids are functional and their energy is being used productively, there is another important prerequisite for the productive use of energy being able to contribute to economic development. Producers and enterprises need to be able to market their produce profitably, which is more likely to be achieved if they export their goods outside their localities.

An important factor in this is the accessibility of villages, which is, among other things, influenced by the type of road leading into it. Most villages can only be reached via laterite and track roads (Figure 32). It is worth noting that tracks can include roads that are just sand tracks but which are supposed to eventually be converted to main roads. Only few villages can be reached via paved roads.

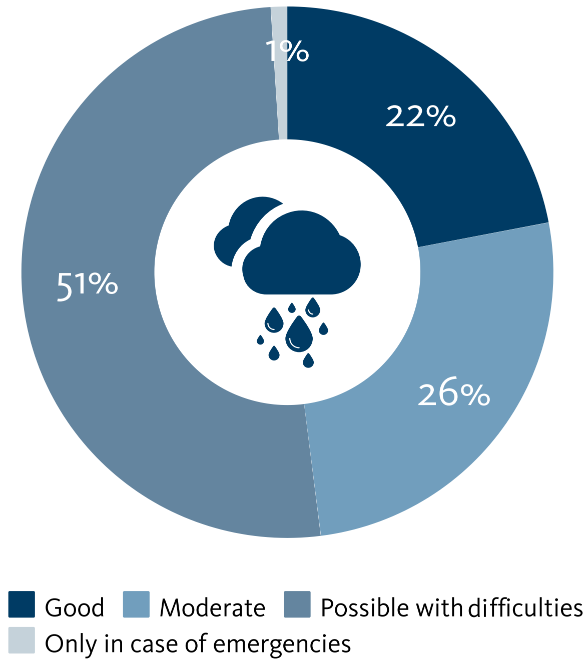
Figure 32 Types of road connecting the villages



Source: DEval, own figure

Another important factor when considering the accessibility of a village are the weather conditions during the rainy season. Figure 33 shows that in 22 % of the villages in the sample, accessibility remains good during the rainy season. Accessibility is moderate in 26 % of villages. However, for the majority of the sample (51 %), accessing the villages during the rainy season is very difficult, though not impossible. One village is only accessible during this period in the event of an emergency.

Figure 33 Share of villages by level of accessibility during the rainy season

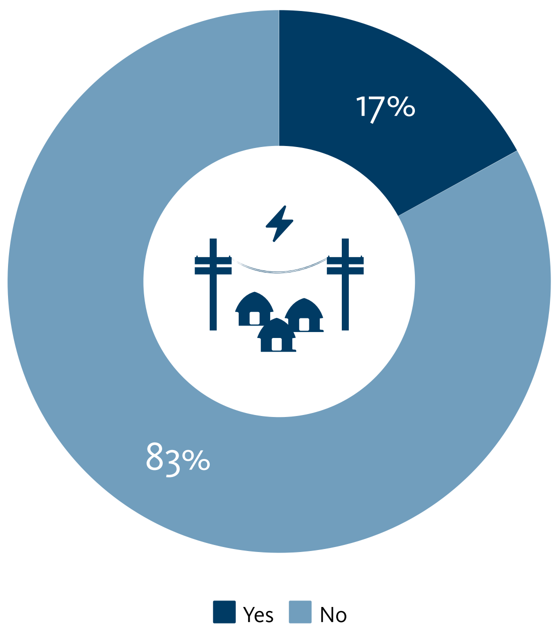


Source: Deval, own figure

5.5 Sustainability and maintenance of the mini-grids

As previously reported in Figure 27, only nine (11 %) of the mini-grids were functional at the time of the survey. The average lifespan of the mini-grids was 4.8 years. As Figure 34 shows, 17 % of these villages have since been electrified by the central grid.

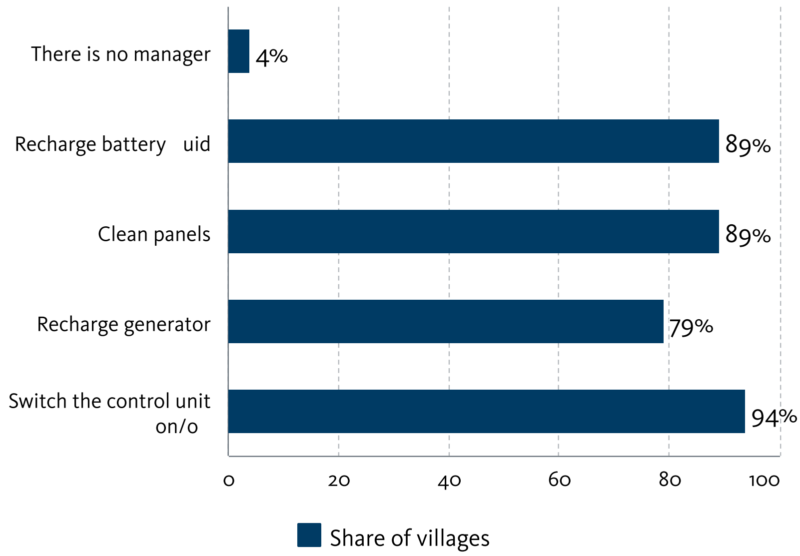
Figure 34 Share of villages entirely or partially electrified by central grid



Source: DEval, own figure

In terms of maintenance, nearly every mini-grid has an assigned manager. Figure 35 shows that only 4 % of the villages, i.e. three villages, reported they do not have a manager for their mini-grid. The tasks of the managers are varied and include recharging the battery fluid (in 89 % of villages), cleaning the panels (in 89 % of villages), recharging the generator (in 79 % of villages) and switching the control unit on and off (in 94 % of villages).

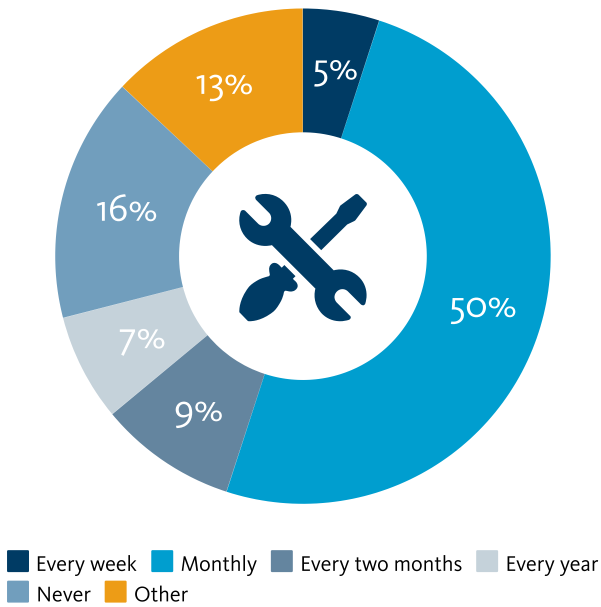
Figure 35 Share of villages by tasks of the mini-grid managers



Source: DEval, own figure

Repairs to the mini-grids are carried out periodically, whereby the frequency can differ, as is shown by Figure 36. In 50 % of villages repairs are carried out every month, in 9 % every two months, in 7 % every year and in 5 % every week. Interestingly, 16 % of villages report that their units have never been repaired.

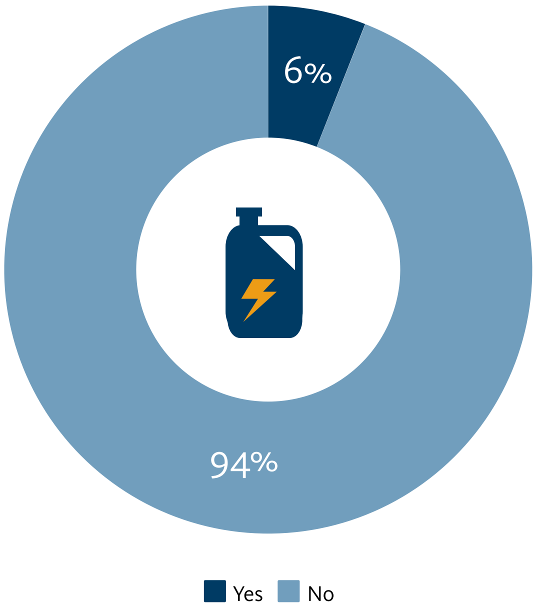
Figure 36 Share of villages by frequency of maintenance of the mini-grid



Source DEval, own figure

Along those lines, the survey data also shows that 94 % of the mini-grids are not supplied with fuel by their operators on a regular basis. These findings are also illustrated in Figure 37.

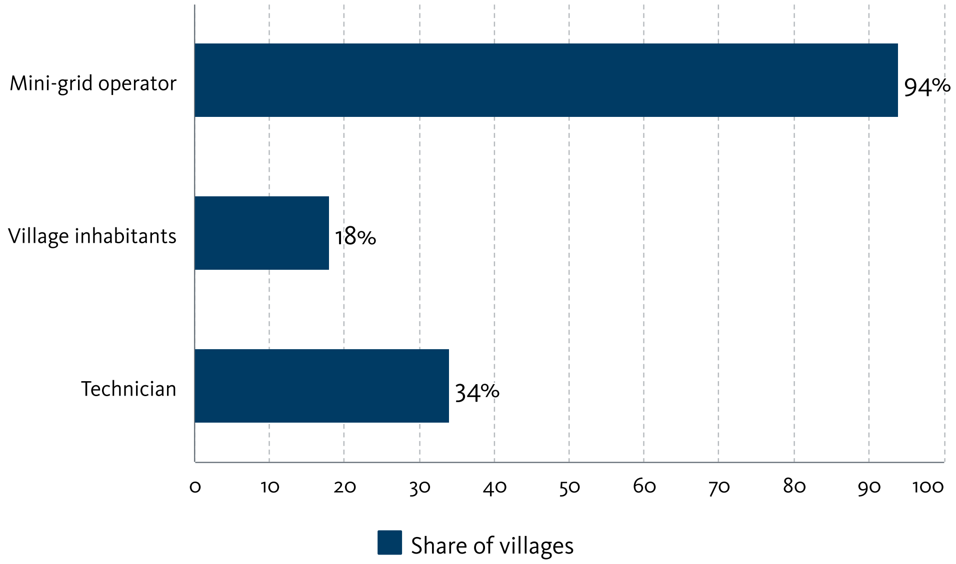
Figure 37 Share of villages supplied with fuel on a regular basis by the mini-grid operator



Source: DEval, own figure

Figure 38 shows that when the unit breaks down, most villages (94 %) call the company responsible for the installation, 18 % repair it themselves and 34 % call someone else to repair it.

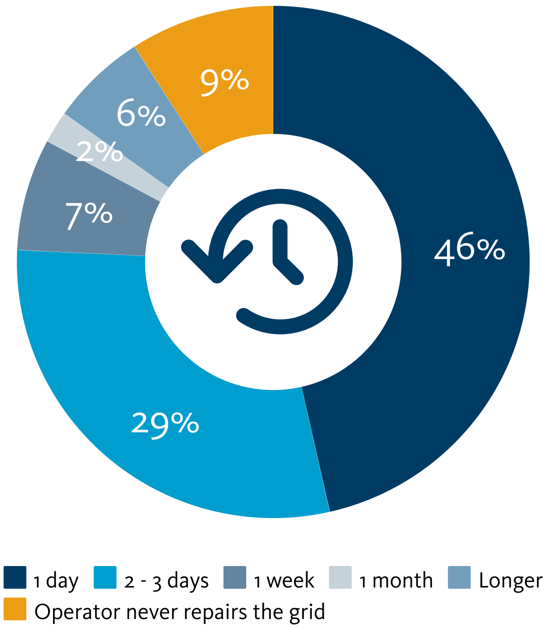
Figure 38 Share of villages by repair entity of the mini-grid



Source: DEval, own figure

In the event of a breakdown, operators are often called to carry out repairs. As Figure 39 shows, for most villages these repairs take an average of one day (as is the case in 46 % of villages). For 29 % of mini-grids, the repairs take two or three days. For 7 % of villages, the repairs take a week. For 2 % of villages, a month was needed to carry out the repairs, and for 6 % it took even longer. However, 9 % of villages also reported that their units were never repaired.

Figure 39 Time it takes the operator to repair the mini-grid



Source: Deval, own figure
Note: Figure does not add up to 100 % due to rounding

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