Chapter 4

Sustainable energy interventions in low-income households in the Anthropocene: Case studies of the uptake of cleaner energy

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Abstract

As global efforts to transition to renewable energy intensify, there is a real risk that households in the Global South, particularly sub-Saharan Africa, will be left behind. The use of dirty fuels can be time-consuming, especially for households that collect wood, and has negative implications for the health and safety of household members. Programmes promoting clean energy use in households typically substitute a dirty fuel or appliance with a cleaner alternative, such as a clean-burning stove. Sustainable energy use can also be approached considering the trade-offs that need to be made between energy security, affordability, and environmental sustainability. However, projects designed using these approaches, such as clean cooking stove roll-outs, have typically achieved poor rates of adoption and sustained use. In this chapter, we argue that sustainable household energy interventions are those based on user requirements, designed to meet energy service needs and impact favourably on a household's ability to meet its fundamental needs. We analyse the approach that the Nova Institute has used to design clean household fuel interventions that have achieved remarkably high success rates in several towns in South Africa. Methods employed in developing interventions for communities in the Platinum Belt in the North West and Limpopo provinces of South Africa are examined. We find that essential elements informing the design of successful interventions are increasing the scale of implementation as knowledge and control increase through a rational project life cycle, a comprehensive understanding of household fuel stacking practices to provide energy applications, and an assessment of the impacts of interventions on the overall quality of life.

Keywords: energy transition, household energy use, in-community testing, rational project life cycle, satisfaction ratings, sustainability

1. Introduction

Energy services are deemed essential to human development and life satisfaction (Brand-Correa & Steinberger, 2017; Max-Neef et al., 1991). A sizeable proportion of the world's population still experiences energy poverty. In sub-Saharan Africa in 2021, almost 600 million people lived without access to electricity and around 900 million without clean cooking fuels (IEA, IRENA, UNSD, World Bank, WHO, 2021). The implications of using inadequate or dirty energy at the household level are vast: indoor air pollution from solid and liquid fuels was responsible for 2.3 million premature deaths globally in 2019 (Murray et al., 2020). More profoundly, energy poverty results in the inability to fulfil essential states and activities required for human dignity, well-being and a flourishing life (Day et al., 2016; Nussbaum, 2000).

Many interventions have been implemented to promote access to sufficient, sustainable energy at the household level. These interventions take many forms and typically aim to change the technology or energy source used by a household; for example by providing a clean cooking stove (Dagnachew et al., 2020; Pailman et al., 2018) or an electricity subsidy (Makonese et al., 2012; Ruiters, 2009), or to influence a change in behaviour such as by teaching household cooks low-emission techniques for making fires (Le Roux et al., 2009; Surridge et al., 2005) or increasing awareness of excessive energy use (Löfström & Palm, 2008).

Despite the good intentions of many of these programmes, they are plagued by low adoption rates and households abandoning them after a short period of use (Gill-Wiehl et al., 2024; Khandelwal et al., 2017; Pope et al., 2017; Quansah et al., 2017). Reasons cited for the poor success of the programmes include inadequate design of the disseminated technologies, lack of training, and cultural and social factors.

In this chapter, we review conceptions of sustainability that are typically assumed in household energy interventions and argue that sustainable household energy practices must be understood as providing household members with essential services that enable them to meet fundamental human needs or capabilities. We report on an approach used by the Nova Institute in South Africa to develop sustainable energy interventions in a phased manner tailored to address the specific household energy service needs in a community. Drawing on case studies in the Platinum Belt region in the North West and Limpopo provinces, we demonstrate the value of in-community testing of proposed interventions[1] and employing a quality-of-life assessment to ensure that interventions are aligned with household requirements and will be permanently adopted.

2. Sustainability in household energy use interventions

The development of household energy interventions is strongly influenced by the understanding of the notion of sustainable energy and the dynamics underlying household energy use, whether explicit or assumed. An overview of the different conceptions of sustainability as applied to household energy use and the processes by which households make energy choices and adopt sustainable interventions is provided here.

Often, interventions to promote sustainable energy at the household level in the Global North focus simply on reducing the carbon footprint of household energy use by improving energy efficiency and energy conservation, and sometimes increasing renewable energy use (Borg & Kelly, 2011; Löfström & Palm, 2008; Naus et al., 2015). In the Global South, where a significant proportion of households still use solid and liquid fuels such as wood, coal or paraffin (IEA, IRENA, UNSD, World Bank, WHO, 2021), sustainable energy is assumed to be fuels or technologies that emit less air pollution, especially particulate matter and its precursor gases (Pope et al., 2017).

1 Editors’ note: The reader may wish to compare this chapter with Chapter 9.

Attention has also been drawn to the safety risks of using solid fuels and paraffin, including fires (which may spread between dwellings), burns, and poisonings from inadvertently drinking paraffin (Kimemia et al., 2014). These are one-dimensional notions of sustainability, only considering a single aspect of the environmental impact of energy use.

The Brundtland Report (Federal Office for Spatial Development, 1987, p. 41) inextricably linked sustainability with the provision of social services when it defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Elkington (1997) acknowledges the inevitable financial trade-offs that need to be made when deploying resources to meet human needs in an environmentally benign way by introducing the triple bottom line – profit, people and the planet – to measure the economic, social and environmental performance of a business or organisation (Alhaddi, 2015). The triple bottom line forms the basis of the *2030 Agenda for Sustainable Development*, "a plan of action for people, planet and prosperity" (UN, 2015, p. 3). The *2030 Agenda* focuses on sustainable development and poverty eradication through the 17 Sustainable Development Goals (SDGs)[2]. SDG 7 is to "ensure access to affordable, reliable, sustainable and modern energy for all" and targets universal access, increased renewable energy, energy efficiency, and the development of associated infrastructure and technology.

However, the relationship between energy and human flourishing and well-being goes deeper than access to adequate energy and the services that energy provides. Max-Neef et al. (1991) reflect on the nature of human needs and identifies nine fundamental needs: subsistence, protection, affection, understanding, participation, idleness, creation, identity, and freedom. He defines 'satisfiers' as the means to fulfil the needs. While human needs are unchanging across time and culture, the satisfiers are culturally, socially, and temporally flexible.

2 Editors' note: As discussed in Chapter 1.

Brand-Correa and Steinberger (2017) argue that energy services satisfy some human needs.

In a similar vein, Day et al. (2016) draw on the work of Amartya Sen and Martha Nussbaum (Nussbaum, 2000; 2011; Nussbaum & Sen, 1993; Sen, 1992; 1999) and conceptualise energy use within a capabilities framework. Capabilities are the opportunities to be able to 'be and do' and include states such as being in good health or activities such as being able to earn a living. Sen and Nussbaum argue that development programmes should aim to increase people's capabilities. Day et al. (2016) argue that a distinction should be made between primary capabilities, such as good health and having social respect, and secondary capabilities, which are precursors to the basic capabilities. Energy services are required to achieve some secondary capabilities. For example, good health (the primary capability) requires space heating or air conditioning and cooking nutritious food (the secondary capabilities), all of which require energy. Basic capabilities (the ultimate objective of development programmes) thus require secondary capabilities, some of which require energy services. Energy services require an energy source (such as biomass or electricity) and a conversion technology (such as a stove). An understanding of the energy services that a household requires, and the energy applications used to fulfil secondary and primary capabilities is needed to inform the development of sustainable household energy interventions.

This understanding of the role of energy services in human development and well-being is a far cry from the notion of sustainable energy as that which minimises the emissions of carbon dioxide or air pollutants. Sustainable energy use, therefore, should be considered to be much more than practices that do not harm the climate, the environment, or the health of the energy users, but rather practices that support the attainment of fundamental human needs and basic capabilities[3].

Our understanding of the dynamics and motives underlying household energy use practices is similarly wide-

3 Editors' note: Chapter 1 again.

ranging. The energy ladder model postulates that households naturally embrace cleaner, more modern and more convenient energy sources as household income increases (Hosier & Dowd, 1987; Leach, 1992). The energy stacking model recognises that the move to clean energy is not linear but that households use multiple fuels concurrently, even for the same utility, to ensure energy security. Multiple fuel use is also driven by the household's diverse energy service needs (Foley, 1995). For example, solid fuels are effective for providing heat but cannot power electronic equipment or household appliances such as refrigerators. Van der Kroon et al. (2014) further propose that household energy choices are affected by factors external to the household in addition to features of the household. He categorises the external factors into the socio-cultural and natural environment (factors such as climate, ecology, and history) and the political, institutional and market environment (such as government policies and consumer markets).

These frameworks assume that households make rational decisions to optimise their resources to meet their requirements for energy services as fully as possible. However, it is well established that there is often a gap between households' knowledge and values, and their behaviour. Frederiks et al. (2015) explain the discrepancy using behavioural economics and psychology. Irrational decisions are made because of cognitive biases, such as the sunk cost effect, when people persist with a course of action even when it is no longer reasonable. Other biases include weighing potential losses more than potential gains and the tendency to be swayed by social norms and the influence of people deemed to be trustworthy. Kowsari and Zerriffi (2011) explain seemingly irrational energy use behaviour by adding habits and experience (for example, cooking method) and attitudes as factors that affect energy choices, in addition to household characteristics and the external environment.

More recently, households have been considered in the literature on transitions to more sustainable socio-technical systems (Raven et al., 2021; Skjølsvold et al., 2018; Yadav et al., 2019). In this context, particularly in the Global North, households are considered sources of environmental pollution and lock-in to high-consumption and high-carbon lifestyles, and they are increasingly becoming generators of renewable energy and drivers of sustainable practices from the consumer side. Raven et al. (2021) identify two broad approaches to households in the sustainability transitions literature. Much more commonly, households are considered to be a fixed unit of analysis with specific attributes, such as income level, that determine how they interact with their external environment (closed-box approach). These interactions determine technology adoption and energy source selection, for example. Occasionally, households are assigned agency and internal dynamics are recognised, such as productive systems, the social and material context, and relations between household members and with other households (open-box approach).

The energy ladder and energy stacking models, Van der Kroon et al.'s (2014) external environments framework, and even the psychological explanations for decision-making biases align with the closed-box approach. Spurling et al. (2013) point out that this thinking leads to three types of policy interventions: innovating technology, shifting consumer choices, and changing behaviour. Two examples of these types of policy interventions, clean cooking stove programmes and awareness programmes, have been widely implemented in the household energy context. These programmes have achieved surprisingly poor results (Gill-Wiehl et al., 2024).

On the other hand, the open-box approach lends itself to a greater understanding of household energy use by considering it to be a manifestation of social practice. Social Practice Theory (Hargreaves, 2011; Shove et al., 2012) identifies the three elements of practices as *materials* such as technologies, *competencies*, which are skills and techniques, and *meanings*, which are the shared meanings, social norms and aspirations of a group of people. Social practice is the manifestation of interdependencies between these elements. Persistent use of coal, for example, is then understood to arise in part because a household has inherited a robust coal stove (material), is skilled in making traditional porridge on a coal fire (competence) and bonds over family meals where the porridge is eaten (meaning).

From this perspective, policy interventions should instead aim to recraft practices by changing the elements that make up the practices, substituting practices with more sustainable alternatives, and changing how practices interlock (Spurling et al., 2013). A successful intervention depends on practitioners being willing to purchase new material, learn new skills and create new meanings for their new practice (Frost et al., 2020).

In summary, the development of sustainable energy interventions needs to understand the full range of energy services required by a household and how fuels and technologies are used to achieve these services and perhaps more importantly, the fundamental human needs and capabilities that these energy services enable. Interventions should not simply focus on changing fuel, technology, or behaviour, but also more holistically on the competencies and meanings of practices.

3. An alternative model for developing sustainable household energy interventions

The Nova Institute has been developing and implementing household interventions for several decades and has incorporated several elements into its approach that have enabled it to achieve remarkable success in permanently shifting household practices to embrace the interventions. The elements are:

1. Following a *rational project life cycle* to increase the scale of implementation as knowledge and control increases, ensuring that community-specific information is available for intervention selection and design, and deliberately planning for the longevity of an intervention after implementation
2. Developing customised interventions that are *community-specific*[4] and based on *user (household) requirements*
3. Evaluating the feasibility of proposed interventions based on the *impact on quality of life*, determined during *in-community testing* in real-life conditions

4 Editors' note: As was said in the Overview of the book, the context can be as important as the intervention.

These features incorporate the critical aspects of sustainability into selecting, designing, and implementing household clean energy interventions. A project's longevity, whether through maintenance plans, ensuring financial viability or partnering with local government authorities, is explicitly planned for. Moreover, the user-centred approach emphasising quality of life (incorporating environmental, economic, and social aspects of development) puts fulfilling fundamental human needs at the core of the development of interventions.

Two notable examples of initiatives of the Nova Institute that have been rolled out using this approach are the improved top-down ignition methods for coal fires[5] (called *Basa Magogo!* or *Basa njengo Magogo*) that were implemented in approximately 80,000 households on the South African Highveld over a number of years (Van Niekerk et al., 2021), and the swopping of a coal stove for an insulated ceiling and liquid petroleum gas (LPG) heater and stove that Sasol implemented in approximately 5,500 households on the Mpumalanga Highveld (Murray et al., 2023; see also Phogole et al., 2022). We outline here the overall programmatic context and the approach to developing sustainable household interventions followed by the Nova Institute, focusing on the particular elements of the strategy that reflect their understanding of sustainability. The approach prioritises achieving fundamental human needs.

The rational life cycle approach is typically executed through three phases:

- Phase 1a: establishing a baseline[6]
- Phase 1b: developing and selecting appropriate interventions[7]
- Phase 2: implementing selected interventions[8]

5 Editors' note: Featuring in various chapters of this book.
6 This phase can overlap with the scoping stage – Stage 1 of intervention development. (These stages are set out below.)
7 This phase usually includes Stages 2–4 of intervention development – pre-feasibility, feasibility, and pilot.
8 This phase typically overlaps with Stages 5 and 6 – launch and scale.

- Phase 3: monitoring and evaluating the impact of programme interventions[9]

A baseline study for a large programme typically includes gathering technical measurements and social indicators through quantitative and qualitative methods. The baseline not only provides pre-intervention indicators essential for impact measurement; it informs the development and selection of appropriate interventions. The baseline information helps to identify the drivers for behaviours or technologies that are currently in use but are sub-optimal.

Intervention development usually aims to provide alternative usage patterns or technologies that are more beneficial to end users and the environment. Households use dirty fuels such as coal, wood, or paraffin for various reasons. On the South African Highveld during the cold winters, people living in thermally inefficient houses, such as those without ceilings or shacks built from corrugated iron, choose coal as the cheapest energy carrier for space heating (Graham & Dutkiewicz, 1999). In addition to the availability and affordability of coal in regions near coal mines, the drivers for coal use are climatic conditions and energy poverty. Nova designed a solution with households[10] and other stakeholders to address both these drivers – the demand for space heating on winter nights was reduced by insulating houses, and stoves and heaters using the cleaner and more convenient LPG were provided. The intervention was remarkably successful, as 97% of dwellings where the intervention was implemented remained coal-free for at least three to five years after installation (Murray et al., 2023). The case study discussed in this chapter is located in the warmer areas of South Africa in the North West and Limpopo provinces. Here, winters are mild and thermal comfort is not the primary driver of solid fuel (wood) use. Households often have access to electricity and prefer electricity for cooking. However, they do not have warm water for bathing, and several

9 This phase typically overlaps with Stages 5 and 6 – launch and scale.

10 Editors' note: Compare chapter 9 where the requirements for co-creation are discussed.

households make an open fire outside to heat bath water. In such a context, an improved wood stove is not as effective as, for example, solar water heating, since the energy service required is water heating and not cooking or space heating.

When developing and selecting interventions (Phase 1b), Nova follows a staged approach based on the principle that understanding should precede action, and the scale of implementation can only be increased as it is matched by increased knowledge and control. The intervention development life cycle contains seven stages: 1. Scoping, 2. Pre-feasibility, 3. Feasibility, 4. Pilot, 5. Launch, 6. Scale and 7. Maintenance or Exit. We briefly discuss each stage below:

Stage 1: Scoping

The chances that an intervention will be sustainable increase as the objectives of the critical stakeholders overlap. Investors or sponsors typically have a specific purpose when they invest in development work. This is contained in their mandate or vision statement for a government department or public benefits organisation. Corporate sponsors may have a specific objective related to their corporate responsibility programme or to their environmental and social licence to operate. Examples of the latter include air quality and greenhouse gas offsets (Langerman et al., 2018; Pauw et al., 2022). In the case of air quality offsets, the overall objective may be to reduce ambient air pollution in a particular area by a specific quantum. This, in turn, may lead to identifying specific sources of air pollution as the target of the intervention. An immediate objective for the sponsor of an air quality intervention in the context of air quality offsets will thus typically be to reduce emissions from a specific source by a certain proportion. For the projects implemented by the Nova Institute in the Platinum Belt, for example, the sponsor aimed to reduce ambient fine particulate matter concentrations from domestic wood burning to offset emissions from their own facilities.

The objectives of households in retaining or changing energy-use practices relate to their quality of life. The motivation, for example, to change domestic energy usage patterns may be to fulfil an aspiration or to avoid side effects or trade-offs related to a specific energy usage pattern. Solid fuel use has numerous trade-offs, including ambient and indoor air pollution, odours, the need for extensive storage, handling and preparations, general cost inefficiency as far as cooking is concerned and the danger of burns and fires. Aspirations for a specific material standard of living, such as living in a well-built formal house, are generally present in low-income communities in South Africa. Still, residents often lack the means to achieve those aspirations (Møller & Roberts, 2014).

It is equally important to understand the services that are provided by existing energy usage patterns even though they have inevitable trade-offs. An established energy usage pattern offers users a combination of services where they find the best choice between their current alternatives, given their situation and available information. Typically, multiple energy carriers are used in low-income households, which indicates that households carry out the balancing act between the utilities and pay-offs of their energy choices. During the scoping phase, it is critical to understand how the existing usage pattern targeted for replacement meets the user requirements because any alternative must perform equally in terms of those requirements with fewer trade-offs.

An intervention is possible where there is a specific desire for change, either to avoid something experienced as detracting from the quality of life or to fulfil an aspiration. Intervention development can start once there is a shared definition of the problem and its potential solution, or the ideal and its realisation, between the initiator of the intervention and a sufficiently representative group of intended users.

Baseline information gathered in the programme's first phase is typically used to inform the intervention development and selection scoping. Methods used to obtain baseline information include structured household questionnaires to gather data about the prevalence of specific usage patterns in an area. The services associated with energy carrier-equipment combinations and their relative prevalence can be established in this way.

To accurately quantify domestic energy use, it is advisable to also conduct well-structured in-use measurements of energy or fuel use in a sample of households. When performing in-use evaluations, care should be taken to make the measurement as unintrusive as possible so that household members will act as naturally as possible. Nova uses structured and open-ended interviews to understand users' subjective evaluation of their energy service needs and experiences.

Stage 2: Pre-feasibility

During the pre-feasibility stage, intervention alternatives are formulated and evaluated based on the user requirements for the activities for which the intervention is developed. For complex evaluations where multiple criteria have to be applied, Nova uses a formal approach such as the analytical hierarchy process (Saaty, 1980). Favourably evaluated alternatives proceed to further development and testing during the feasibility and pilot stages.

Stage 3: Feasibility

During the feasibility stage, the intervention concept is elaborated into a detailed design for a prototype. It is highly preferable to involve end users at this stage so that end user preferences and requirements guide the design process from the start. During feasibility, a small number of prototypes are constructed (see prototype examples in Figure 4, developed to address domestic wood burning in Limpopo and the North West provinces) and evaluated by representatives of the end user population. At this stage, implementation remains limited, but intense monitoring occurs since the feasibility stage aims to assess and improve the intervention design. Several iterations may be needed to achieve a design that performs technically and meets end user requirements.

The requirement for passing the feasibility phase is that one or more of the intervention candidates should be free from fatal flaws and test significantly positively on the objectives that it aims to achieve. These objectives can be tested in the form of criteria that an intervention has to comply with. The criteria need to be established to ensure that an intervention is sustainable, in the sense of addressing fundamental human needs in a way that enhances the environment and the social and economic well-being of the household and also in the sense of permanently altering the energy-use practices of the household.

In air quality offsets, for example, an intervention is deemed feasible if it reduces emissions of air pollutants (particulate matter and its precursors), has a positive (or at least neutral) quality-of-life impact on the end users, and is practically implementable. Nova researchers have developed the Nova Particular Impact on Quality-Of-Life Assessment (Piqola) tool to assess the effects of a particular intervention on the quality of life of an individual in the context of household life (see Chapter 12: Case studies in the quality-of-life assessment of cleaner energy interventions through 'narratives of impact'). The Piqola tool is used in feasibility assessments and is based on Max-Neef et al.'s (1991) assertion mentioned above that quality of life depends on the possibilities people have to satisfy their fundamental human needs adequately. What differs between people is not their fundamental human needs but how they are satisfied or actualised (Max-Neef et al., 1991; Murray & Pauw, 2022). This is measured by the Piqola tool.

Stage 4: Pilot

A pilot implementation can be undertaken once a successful design emerges from the feasibility stage. The pilot implementation aims to test the final design's implementation at its intended scale. During this stage, the logistics and management aspects of the full-scale implementation are refined. A successful pilot establishes a replicable implementation method that will enable large-scale implementation at multiple sites.

Stage 5: Launch and Stage 6: Scale

In more extensive programmes, a launch implementation phase may be necessary to evaluate further and refine large-scale implementation processes. In other instances, implementation may proceed after the pilot phase. Most programme resources will typically be invested in implementation. It is ideal to source contractors and human resources from local communities where possible.

Stage 7: Maintenance or exit

The viability of an intervention can be seen as the inverse of the external support needed for it to continue to function. Intervention designs that households can maintain without support (or with minimal support) pose a low risk of social disruption at the end of the intervention cycle, and bridge a medium-term challenge while the long-term solution that is already in process is preferred.

Depending on its objectives, resources and mandate, the entity driving an intervention's development and initial implementation may not be willing or able to sustain it indefinitely. The intervention maintenance exit and handover stage must be planned up front. Where the intervention relates to a service, the handover stage involves integration into the municipal services regime. This may require additional resources and capacity from the local government.

4. Case studies on the development of sustainable household energy interventions in North West and Limpopo provinces

The application of Nova's phased approach to intervention development is illustrated here by drawing on a case study where it was applied in the Platinum Belt in the North West and the western Limpopo provinces in South Africa. The project sponsor's main objective was to reduce air pollutant emissions from household burning for an air quality offset project. This case study demonstrates how energy service needs differed even between communities near one another and with similar household income levels, how the interventions were designed around the user requirements, and how information crucial for a proposed intervention's success (or failure) was gleaned from the quality-of-life assessments conducted during in-community feasibility testing.

Scoping activities encompassed eight low-income communities in the vicinity of two smelting operations (Figure 5). Based on the frequency of and services derived from solid fuel (wood) use in households, three communities were selected for the development of interventions to reduce wood burning in the pre-feasibility phase. The nuanced insights gained during the feasibility testing are explored in detail.

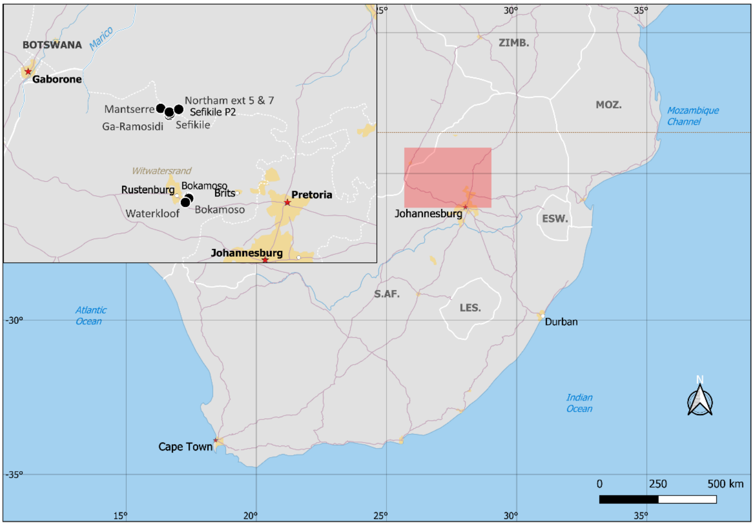

Figure 3: Location of the eight communities in the North West and Limpopo provinces (shown with black dots) where the potential for sustainable household energy interventions was assessed

4.1 Scoping stage

The scoping phase included conducting 1,392 comprehensive household surveys (CHSs) in the eight towns. The frequency of wood burning in households and the services provided by wood burning in summer and winter were determined, and the socio-demographic baseline of the households was established. Although all the communities were designated as low-income, varying government service provision and employment status meant that wood was only regularly used as an energy source in four communities: Mfidikwe, Mantserre, Ga-Ramosidi-Sefikile, and the informal part of Sefikile (labelled here as Sefikile P2) (Figure 3). The communities of Mantserre, Sefikile P2 and Mfidikwe were selected to test the feasibility of interventions targeting wood use reduction.

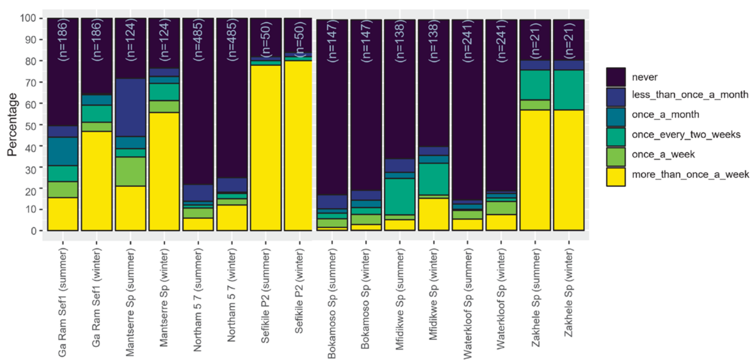

Figure 4: Frequency of wood use at selected households in eight communities in the Platinum Belt in the North West and western Limpopo provinces

Mantserre (Figure 5) is a low-density, formal Tswana settlement with access to electricity, unreliable water supply piped to stands (not into structures) and effective waste services. Key roads are paved; unpaved roads have low traffic. Energy stacking is prevalent: ubiquitous electrification has crowded out paraffin use, but most households practice regular wood burning. Wood burning is used typically for water heating but often also for cooking. Wood is usually purchased, and relatively large volumes are used.

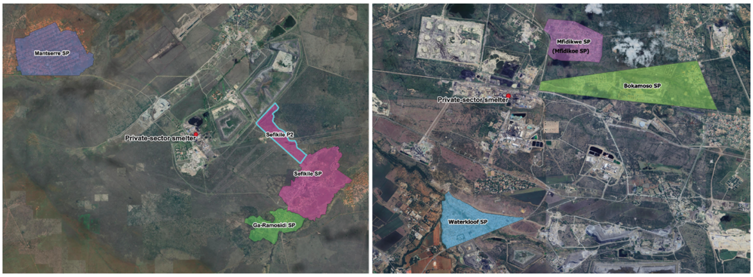

Figure 5: The locations of Mantserre and Sefikile P2 (left) and Mfidikwe (right), where sustainable household energy interventions were developed (credit: Google Earth)

Sefikile P2 is the section of Sefikile northwest of the Sefikile hillock that extends towards the mines. It is treated as a settlement on its own since it has unique characteristics. It is a medium-density, informal Xhosa settlement with no electricity, unpaved roads only (with low traffic), water on most stands, and no waste services. Paraffin and wood are the key energy sources. It has a high proportion of primary and regular wood users (in winter and summer). Almost all wood users do not purchase their wood but gather it in the surrounding area.

Mfidikwe (also spelt Mfidikoe) is a formal rural area in the Rustenburg Local Municipality. It is a dense, formal, multilingual settlement (half Tswana, with isiXhosa the largest of the remaining languages) situated in an area with many industrial pollution sources. Half of the structures are informal. Half of the households are tenants. The settlement has access to electricity, a reasonably reliable water supply piped to stands (typically not into structures) and relatively effective waste removal services. Key roads are paved; unpaved roads have low traffic. Energy stacking is prevalent: ubiquitous electrification has reduced regular paraffin use to only a fifth of households, but almost two-thirds of households still sometimes use paraffin. Wood burning is prevalent amongst about 40% of households, although a relatively low proportion of households are regular wood users. Wood burning is mainly used for cooking, but also for water heating. Wood is typically collected for free, and smaller volumes are used.

4.2 Pre-feasibility stage

Since the primary services provided by wood-burning in the four communities were bath water heating and cooking, four technologies were identified for evaluation in the pre-feasibility stage: solar water heaters, rocket stoves, Wonderbags, and LPG stoves (Figure 6). The solar water heater system comprises vacuum glass tubes in which the water is heated directly by the sun and an insulated storage tank. The hot water is fed out by gravity. The solar water heater systems were installed on specially designed wooden pedestals, avoiding the risks associated with roof mounting on unstable low-income housing. A rocket stove is a wood-burning stove that burns extremely hot and efficiently. The rocket stove model used was the Burn-manufactured *Kuniokoa*. *Wonderbags* are heavily insulated bags that provide for slow cooking and heat retention. The LPG option featured a four-burner stove-oven with a 7 kg gas cylinder.

4.3 Feasibility stage

Intervention combinations were designed for each community based on the energy services that the households required (Table 1). In Mantserre, two of the three intervention combinations included a solar water heater because wood is mainly used for water heating. In Sefikile P2 and Mfidikwe, LPG stoves and rocket stoves were tested because wood (and paraffin in Sefikile P2) is used primarily for cooking. A *Wonderbag* was included in all the intervention combinations because it is of low cost. A control group was included in each community.

Figure 6: The four technologies identified for evaluation in the wood-using households, from left to right: solar water heater on a wooden stand, rocket stove, Wonderbag and LPG stove

Table 1: Wood-burning intervention combinations tested in households in Mantserre, Sefikile P2 and Mfidikwe

Mantserre	Sefikile P2	Mfidikwe
i) Solar water heater and Wonderbag (20 households) ii) Rocket stove and Wonderbag (20 households) iii) Solar water heater, rocket stove and Wonderbag (20 households) iv) Control (20 households)	i) LPG stove, rocket stove and Wonderbag (20 households) ii) Control (20 households)	i) Rocket stove and Wonderbag (20 households) ii) LPG stove and Wonderbag (20 households)

Three criteria were used to evaluate the success of an intervention combination in the feasibility stage:

1. Emission reduction: The amount of wood used by a household was considered to be a direct indicator of total emissions from the burning of the wood. Wood weighing surveys and temperature measurements of the stoves or fires using an iButton were employed to determine if interventions significantly lowered wood use against a baseline. iButtons, which are temperature loggers, were

attached to rocket stoves, inside *Wonderbags*, and on LPG stoves to track adoption rates.

2. Quality of life impact: The Piqola survey[11] was applied to evaluate the effects of the intervention combinations on quality of life. Designed by Nova, the Piqola assesses the quality-of-life shifts when household technological changes occur. The survey encompasses narrative interviews, satisfaction ratings, and Likert scale statements to compare pre- and post-intervention scenarios. Piqola's strength lies in its user-centric approach, ensuring that researchers treat participants as individuals with fundamental human needs rather than mere data points for external objectives.
3. Practicality of implementation: The practicality of the intervention in the specific community was assessed by drawing from the experiences of the household members and installers during the in-community tests.

4.3.1 Mantserre

In Mantserre, where wood is mainly used for bath water heating, the wood weighing survey results indicate that the solar water heater plus *Wonderbag* intervention led to the most significant reduction in wood use. While the control group's average monthly wood use was 125.53 kg, the switch to the rocket stove and *Wonderbag* resulted in a slight increase in wood use by 9.89 kg, which was not significant (p=0.61). Combining the solar water heater, rocket stove and *Wonderbag* resulted in a modest reduction in monthly wood use of 8.26 kg, which was not significant (p=0.39). By far the most significant decrease in monthly wood use occurred in the solar water heater and *Wonderbag* group, with a reduction of 51.41 kg, proving statistically significant (p=0.03).

The iButton data showed varied usage of the Rocket Stoves. Of the households where iButtons were installed in the rocket stove and *Wonderbag* group, five households used the rocket stove regularly, four occasionally, and two not at all. In the solar water heater, rocket stove and *Wonderbag* group,

11 Editors' note: Reminder! Dealt with intensively in Chapter 12.

the rocket stove was routinely used in three households, used occasionally in three, and not used in two.

From a quality-of-life perspective, participants were asked to rate their satisfaction with their households' energy use before and after the intervention on a scale from zero to ten, where zero is not satisfied and ten is completely satisfied (Figure 7). All groups in Mantserre were more satisfied with their ability to cook and heat bath water after the interventions. The most significant increases in satisfaction with water heating, clothes washing, and dishwashing occurred in the groups that received solar water heaters.

Figure 7: The pre- and post-intervention satisfaction ratings of households for several household energy services – cooking, bathing, ironing, clothes washing and dishwashing – in Mantserre. The pre-intervention responses are in blue; post-intervention responses are in orange. The boxplots depict the minimum, first quartile, median, third quartile, and maximum responses.

Considering the practicalities of implementation, the solar water heater is user-friendly and durable, with a structure that is easy to assemble and plumbing fixtures that are widely accessible. However, the need for a pedestal because of poor roof conditions presented challenges, mainly caused by the complex engineering of the wooden pedestal, which was more difficult and costly to construct than anticipated.

When the results of the in-community testing were assessed relative to the feasibility criteria (emission reduction, quality of life improvement and practicality), a solar water heater intervention was selected for full-scale implementation in Mantserre. The solar water heater intervention was also deemed likely to succeed in the neighbouring communities of Ga-Ramosidi and Sefikile because of their similarities with Mantserre (identified during the scoping phase).

4.3.2 Sefikile P2

The iButton data in Sefikile P2 revealed that most households adopted the LPG stove as their primary energy carrier, while enthusiasm for rocket stove and *Wonderbag* adoption was not convincing. The wood-weighing survey showed that the control group had an average monthly wood use of 147.27 kg. In comparison, the intervention group that received the LPG stove, rocket stove and *Wonderbag* used significantly less wood, averaging 102.11 kg per month, which is a substantial decrease of 31%. This reduction is statistically significant, with a p-value of 0.04.

The quality-of-life assessment showed that there were substantial improvements in household energy service satisfaction following the intervention (Figure 8). Across all services – cooking, bathing, ironing, clothes washing and dishwashing – there is a marked improvement in user satisfaction. Cooking satisfaction particularly stands out: respondents rated their pre-intervention satisfaction at a mediocre 5 out of 10, which soared to 10 out of 10 post-intervention. This remarkable improvement highlights the intervention's success in meeting the cooking needs of the households, which likely translates into better overall daily living experiences. This significant uptick in satisfaction suggests that the intervention effectively addressed the primary cooking challenges faced by the community.

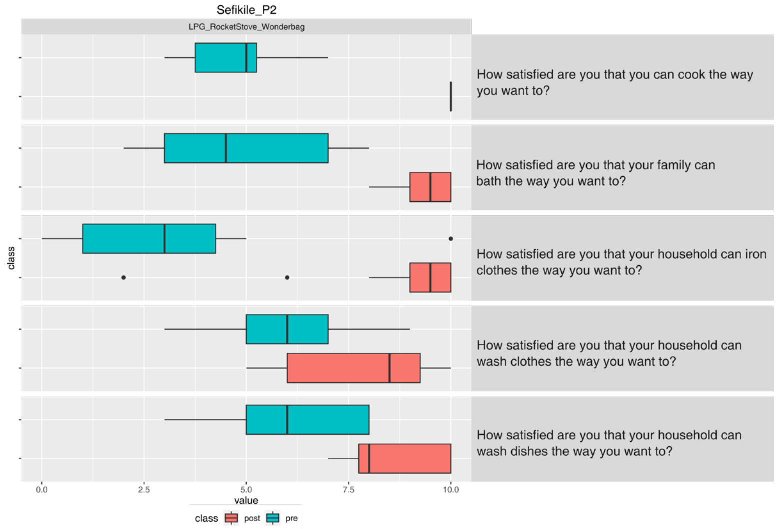

Figure 8: The pre- and post-intervention satisfaction ratings of households for several household energy services – cooking, bathing, ironing, clothes washing and dishwashing – in Sefikile P2. The pre-intervention responses are in blue; post-intervention responses are in orange. The boxplots depict the minimum, first quartile, median, third quartile, and maximum responses.

From a practical perspective, the rocket stove and *Wonderbag* were both straightforward to distribute and operate. Necessary safety protocols need to be followed for the LPG stove implementation, but they do not introduce significant technical hurdles. Opting for a 7 kg LPG cylinder and a suitable regulator proved to be practical for dissemination and for post-implementation transport and refilling by community members. It is essential for project implementers to involve experienced LPG safety trainers for household training and to coordinate with suppliers early on to accommodate procurement lag times.

Considering the results of the feasibility testing, it was decided that an LPG stove implementation is likely to meet all three feasibility criteria at Sefikile P2.

4.3.3 Mfidikwe

In Mfidikwe, when compared to the control group that had an average monthly wood use of 78.67 kg, the group that received the LPG stove and *Wonderbag* showed a slight decrease in wood use with a monthly average of 65.66 kg; however, this was not statistically significant with a *p*-value of 0.28. The rocket stove and *Wonderbag* group exhibited the largest decline in wood use, with an average monthly use of 50.36 kg, 36% lower than the control group. This reduction nearly reached statistical significance with a *p*-value of 0.07.

The iButton data from Mfidikwe households showed LPG entering the household energy stack alongside electricity. This contrasts with the unelectrified community of Sefikile P2, where LPG was adopted as the primary energy carrier.

The quality-of-life assessment suggests modest changes in satisfaction with household utilities following the interventions (Figure 9). There is a slight improvement in cooking satisfaction for LPG and rocket stove interventions, more so for the LPG stove. In contrast to Sefikile P2, which lacks electricity, and Mantserre, where water heating drives wood use, Mfidikwe's results are not as pronounced. The data implies that while LPG offers more efficient cooking and the rocket stove potentially lowers electricity costs, the impact on satisfaction levels is not as significant as observed in the other communities.

It was concluded that wood interventions are unlikely to succeed in Mfidikwe, since unconvincing feasibility results were achieved for both the emission reduction and quality-of-life impact measures.

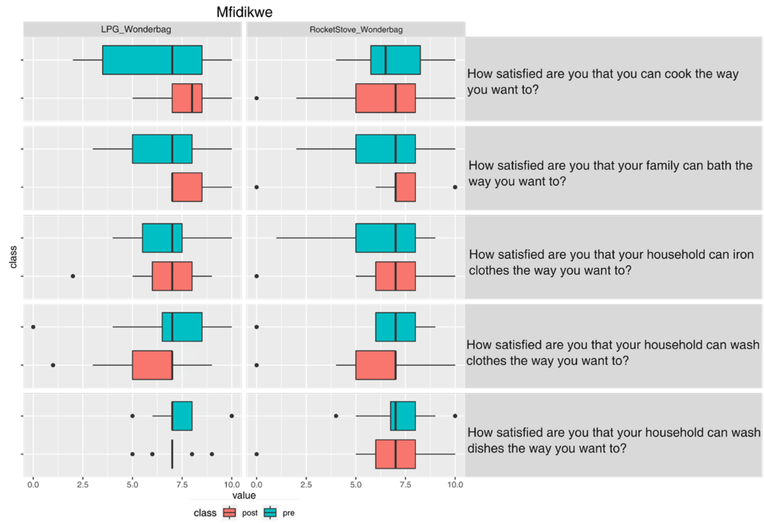

Figure 9: The pre- and post-intervention satisfaction ratings of households for several household energy services – cooking, bathing, ironing, clothes washing and dishwashing – in Mfidikwe. The pre-intervention responses are in blue; post-intervention responses are in orange. The boxplots depict the minimum, first quartile, median, third quartile, and maximum responses.

5. Conclusion

In household energy interventions, sustainability needs to be understood from the recipients' perspective, as improving a household's ability to sustainably actualise their domestic energy needs. Such an understanding implicitly incorporates an intervention's economic, social, and environmental benefits to a household. Household energy interventions should be designed based on user requirements and deliberately plan for maintenance and handover after a roll-out. Such an approach inevitably needs to be customised per community.

The Nova Institute's phased approach to the development of household interventions incorporates these aspects and employs several tools and strategies to design for sustainability. Nova adopts a rational life cycle approach, basing intervention selection and design decisions on detailed socioeconomic and fuel or technology stacking information gathered from households, and scaling up implementation as knowledge and control increase. A quality-of-life assessment is performed during the in-community testing of interventions to gauge the impact of interventions on satisfaction with energy services and overall quality of life.

A case study from the Platinum Belt in the North West and Limpopo provinces in South Africa illustrates that household energy interventions need to be informed by the need for a specific intervention – of the eight communities assessed initially, only four passed the feasibility testing. A thorough understanding of how households use fuels and technologies to provide energy services informed the selection of interventions for feasibility testing. Even though the communities were all low-income and situated within close proximity to one another, the energy services provided by wood (the solid fuel of choice) differed between communities. In Mantserre, wood was mainly used to heat bath water, while in the informal and unelectrified Sefikile P2 and the formal and serviced Mfidikwe, wood was used primarily for cooking. Measurements of the change in the amount of wood burnt and quality-of-life assessments informed the final decision on intervention selection. A solar water heater significantly reduced wood use and increased user satisfaction in Mantserre (where wood was used to heat water). The other two communities (where wood was mainly used for cooking) responded differently to the alternative stoves provided. In unelectrified Sefikile P2, the households readily adopted an LPG stove, while in Mfidikwe, households did not willingly embrace either the rocket stove or the LPG stove.

The positive adoption and retention rates of the coal-burning interventions designed using Nova's approach on the Mpumalanga Highveld (Murray et al., 2023; Phogole et al., 2023) and the promising reception of these wood-burning interventions in the North West and Limpopo provinces discussed here provide an optimistic outlook for facilitating the energy transition in low-income households internationally, particularly in sub-Saharan Africa. Moreover, the concurrent achievement of the aims of the sponsors of these interventions bodes well for securing funding for similar clean energy household initiatives in future.

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