A review of the standards, methodologies, technical needs and available resources related to digital monitoring, reporting and verification for modern cooking devices in the context of carbon finance

Date: 22/12/23

Organisation: RE-Innovation

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This material has been funded by UKAid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.'

Executive summary

There is a large potential market for modern energy cooking systems, with over 1.5 billion people still cooking using biomass, despite having access to electricity. Many modern cooking solutions exist that are practical, time-saving, economic and have real benefits for the end user. Electric cooking systems also help drive demand for electricity and so provide an ideal opportunity for combination with rural electrification programmes. However, several challenges remain preventing wide scale adoption, an important one being the costs for modern cooking appliances and fuels, which are often higher than those for traditional cooking systems.

Carbon finance can help to overcome this barrier by monetising the emission reductions associated with fuel switches and efficiency gains. In order to get modern cooking activities certified under a carbon standard, project developers need to follow standardised impact quantification methodologies and undergo independent assessment from third-party validation and verification bodies. Recent developments in carbon markets and standards drive the need to directly measure the energy consumption of cooking devices with digital systems and hardware, in order to more accurately monitor, report, and verify emission reductions.

This technical needs review aims to provide project developers with an overview of the present ecosystem relating to digitisation for modern cooking devices, suggesting available resources, providing technical guidance, and highlighting future trends.

The review has shown that digitisation provides a promising pathway to increased integrity for carbon markets and clean cooking activities in particular. Project developers in the modern cooking space are facing a dynamic methodological landscape, but also growing opportunities to monetise co-benefits. Standard-setting bodies are increasingly embracing digital monitoring, reporting and verification (dMRV) and digitising their tools, though concrete regulation and guidance around dMRV remains scarce. In the meantime, device manufacturers, carbon project developers, climate tech companies and other market actors are developing innovative hardware and software solutions for dMRV, but high costs, a need for technical expertise and a lack of incentives still represent barriers to large-scale uptake. With proprietary systems dominating the existing solutions, project developers face a lack of easily adoptable, interoperable plug-and-play solutions. Fully integrated end-to-end dMRV platforms with automated data onboarding, processing and verification, which are widely regarded as the ultimate goal, will likely only become available in the medium-term. These conclusions are further detailed below.

Standards and Methodologies:

The Gold Standard MMMECD is currently the only methodology specifically addressing modern cooking, but this might change quickly, as Verra and the Clean Cooking and Climate Consortium (4C) are developing new integrated clean cooking methodologies and the transition from CDM to Article 6.4 may see a bigger role emerge for modern cooking technologies.

Existing standards and methodologies for clean cooking currently provide only limited guidelines regarding dMRV. Project developers, technology providers, and verifiers are currently moving faster than the standard-setting bodies, which bears a risk for early-moving project developers having to adapt their solutions later on to new regulation from standards. Still, significant digitisation efforts are underway at all relevant standard-setting bodies.

Carbon markets and methodologies for clean cooking are undergoing major changes. Recent integrity concerns around impact quantification in clean cooking activities have led to increased scrutiny and review of existing methodological requirements. The operationalisation of Article 6 has impacts on the voluntary market as well and host countries are moving to regulate carbon projects, which impacts project economics.

Compliance with methodological requirements from carbon standards alone may not guarantee integrity. dMRV provides a significant opportunity to ensure integrity and reestablish trust in impact quantification of clean cooking activities.

Digital Monitoring, Reporting and Verification Platforms:

Accurate and transparent data is vital to trust and integrity. Carbon markets have suffered from bad press, and investigations into over-estimations by project developers may affect future prices. Through adopting dMRV approaches, an accurate, accountable and transparent record of carbon savings is provided, negating questions on data reliability and potentially increasing the price of credits sold.

Blockchain and Distributed Ledger Technology emerges as a promising avenue to instil trust and transparency in data reporting. By utilising blockchain, the entire lifecycle of carbon credits (from data collection to verification and issuance) can be securely and transparently recorded. This ensures an immutable audit trail, reducing the risk of data tampering and increasing credibility. Some organisations are already using this technology and its deployment is expected to increase.

The implementation of sophisticated dMRV systems is hindered by an IT skills gap, with project developers often shouldering the responsibility for developing in-house technical expertise. High up-front costs for software and building technical capacity present a barrier to project developers wanting to utilise dMRV solutions: availability of coordinated and affordable technical training and open source systems can address this.

Standardisation of APIs, data formats, processing and handling improves interoperability of appliances and systems. The sector currently comprises multiple bespoke and proprietary platforms, frameworks and innovations led by varying stakeholders taking different approaches. An introduction of sector standards for all aspects of data capture, analysis and transfer will enable interoperability, reduce inefficiencies and reduce risk to early adopters of having to make changes.

Verification and Validation Bodies (VVBs) will play a crucial role but need to improve technical capacity to provide automated reporting services. Automation of reporting and data sharing for verification services is identified as a key efficiency gain, and although VVBs have made steps towards full digital atomisation, further development and clarity on integration frameworks is required. End-to-end platforms encompassing all steps from data collection to carbon credit issuance have emerged, although their benefits are yet to be conclusively proven.

Monitoring Technology & Hardware:

Monitored and measured equipment is available for modern cooking services. This report highlights 13 different monitoring systems either directly available or in pilot projects.

Cost of monitoring equipment was highlighted as the most significant barrier, although prices are dropping, especially with economies of scale. Target prices within the range of USD 10 to USD 40 are seen as achievable within the short to medium term.

Most stakeholders highlighted that site visits will still be required, for example to implement surveys to measure co-benefits, investigating fuel stacking and equipment maintenance, although dMRV systems may greatly reduce that requirement.

External or retro-fitted monitoring systems are probably the easiest to implement for project developers in the short term. These systems are appliance and manufacturer agnostic.

Appliances with built-in monitoring and IoT will become commonplace in the longer term, with many appliance providers, including larger appliance manufacturing companies. This will not just be for carbon finance, but also driven by applications such as access to PAYGo finance, providing smart services (such as localised user instructions or app-based control), and electricity grid services (such as load-control strategies and use-based tariffs).

Large-scale implementation of smart meters at the household level could have a significant impact. Machine learning on large datasets of cooking and appliance data from smart meters may lead to robust and reliable algorithms to extract cooking events.

Cellular GPRS and 4G/LTE-M are the main remote communications networks utilised at present. **Low Power Wide Area networks may become more available in LMIC** with roll-outs of NB-IoT, Sigfox and LoRaWAN networks, allowing for longer distance communication, better reception, lower power consumption and lower data costs.

Standardisation of data formatting and communication requirements is needed to ensure monitoring systems are easy to implement and interoperable between different platforms. This could affect early adopters, with some project developers wary of investing heavily in monitoring equipment that could be rendered obsolete by changes in carbon standards.

Co Benefits Review:

Co-benefits are gaining importance in the market with standard-setting bodies increasingly focused on robust quantification of SDG impacts and UNFCCC developing an SDG Tool for Article 6.

Supplementary markets for the sale of SDG impacts are already emerging and may provide additional revenue streams for project developers.

The digital monitoring of co-benefits aims to improve SDG impact monitoring, either calculated from energy consumption data or via additional hardware or technology. The main development required for greater uptake of digital co-benefit monitoring is either regulation or the ability to monetise the data.

It is expected that accurate co-benefit data will help improve the price paid for a project's carbon credits, but this is not yet proven in the market. Indeed, the data from more accurately monitored co-benefits may potentially show that the project has little or no benefit, increasing the risk to project developers of adding expensive sensors to monitoring platforms, but in the longer term strengthening the integrity of SDG impact claims.

While additional sensor hardware is available, their cost, at present, is high. Economies of scale and competition from different markets are driving down the price of sensor hardware, potentially making them economical for use within digital monitoring systems for clean cooking activities in the medium term. There may be additional calibration requirements for quantitative measurements, which may make deployment more complex.

Co-benefits monitoring will provide useful datasets for academia, helping to improve knowledge on climate change and sustainable development, and for manufacturers to improve operation & maintenance and appliance design.

1. Introduction

The use of modern cooking[1] systems (utilising electricity, LPG, or biofuel) is having a significant impact on people who traditionally cook using biomass, enabling access to clean cooking energy (SDG7), reduced local air pollution and related health benefits (SDG3) and reduced time spent collecting fuel for women (SDG5, SDG8). These benefits also link to wider global benefits from reduced deforestation (SDG15) and thereby CO_2e emissions (SDG13). The potential market for modern energy cooking systems is large with over 1.5 billion people still cooking using biomass despite having access to electricity[2]. However, several challenges remain preventing wide scale adoption, an important one being the costs for modern cooking appliances and fuels, which are often higher than those for traditional cooking systems.

Carbon finance can help to overcome this barrier and boost access to modern cooking systems by monetising the emission reductions associated with fuel switches and efficiency gains. There is a long tradition of improved cookstoves programmes being financially supported by carbon revenues, yet this potential remains largely untapped for modern cooking appliances and fuels.

Being one of the most important independent accreditation standards for carbon projects, the Gold Standard for the Global Goals[3] enables climate and development interventions to quantify, certify and maximise their impact, and to measure and report outcomes in the most credible and efficient way. The Gold Standard Methodology for Metered and Measured Energy Cooking Devices (MMMECD)[4], represents the first designated methodology for the quantification of emission reductions and carbon certification of modern cooking activities from a relevant accreditation standard and hence an important milestone in leveraging carbon finance for modern cooking. Previously existing clean cooking methodologies had been developed for improved biomass cookstoves and as such are less suitable to the needs but also the opportunities of modern cooking appliances and fuels. Generally, appliances require baselining and regular monitoring through studies based on user surveying and site visits, which are often time-consuming, expensive and lack reliability. The Methodology for Metered and Measured Energy Cooking Devices aims to make the calculation of CO_2e emissions reductions simpler and more accurate by enabling monitoring of relevant parameters through digital monitoring devices.

An example for a modern cooking system employing dMRV would be an electric cookstove with appliance-level energy monitoring hardware. The monitoring system regularly transmits energy and usage data to an online project data platform managed by the project developer. Transparent analysis of the data is performed by the project developer. Reports are created and provided to the Validation and Verification Body (VVB) through an automated request. The reported data is then stored on a dMRV platform, which is used, along with additional project data from the project developer, to verify project impacts and generate carbon credits.

*1 Note that in this report "**modern cooking**" is used according to the MECS definition, i.e. includes modern clean fuels such as LPG, ethanol, biogas as well as electricity, but no solid biomass. https://mecs.org.uk/blog/no-silver-bullet/*
*The term "**clean cooking**" is used when referring to both modern and solid biomass cooking. This also includes "improved cooking" which is sometimes differentiated from clean cooking.*
2 https://doi.org/10.1016/j.enpol.2021.112619
3 https://www.goldstandard.org/articles/gold-standard-global-goals
4 https://globalgoals.goldstandard.org/431_ee_ics_methodology-for-metered-measured-energy-cooking-devices/

An overview diagram of the main stakeholders, equipment, and data flows in a dMRV process for a modern cooking carbon project is shown in Figure 1.

Ideally this process would provide:

- Calibrated, tamper-proof and error-free monitored energy use data,
- Reliable and secure data transmission,
- Robust and secure data storage platform with user level access control and data back-up,
- Transparent data processing, calculations, and report generation,
- Automated verification and issuance of carbon credits on a regular basis.

Recently, carbon markets and clean cooking projects in particular have been subject to increased scrutiny and criticism from academia[5] and media[6], with criticism mostly relating to projects overestimating climate impacts as a result of flawed impact calculation methodologies and poor data collection procedures on behalf of project developers. Developments in dMRV tools may help to pave a way out of this integrity crisis, as they allow for more accurate, reliable, and transparent data collection and management. These are not only relevant for devices powered by electricity or fuels that can be directly metered, but also for activities deploying improved biomass cookstoves, where advances in digital temperature monitoring or surveying tools can improve data reliability.

In addition to that, there has been increasing interest from carbon credit buyers in co-benefits, i.e. positive impacts on sustainable development aside from climate impact, which represents an important opportunity for clean cooking projects that typically have significant positive impacts on health, economic development and gender equality and digital monitoring may be able to improve accuracy and reduce cost for these wider SDG impacts too.

This review provides guidance and recommendations towards effective use of technology for improved efficiency, accountability, and accuracy, and has been specifically tailored to be accessible and of value to existing and new organisations seeking carbon certification for their modern cooking projects. Accordingly, digital solutions have been assessed against costs, ease of implementation and other constraints imposed by project realities that determine their usefulness for carbon project application.

Section 2 provides a comprehensive overview of the current standards and methodologies relating to emission reduction assessment for modern cooking projects, with a specific focus on the Gold Standard Methodology for Metered and Measured Energy Cooking Devices. Section 3 describes current trends in digitisation within the clean cooking sector, including dMRV platforms available, an introduction of key players and technical guidance. Section 4 offers a comprehensive analysis of the measurement device technology, hardware, and communication systems available to project developers to implement dMRV for modern cooking projects, while Section 5 provides a review of measuring co-benefits.

It is understood that there are multiple technical and organisational approaches for meeting the requirements for measuring cooking device usage, and that the pace of technological innovation in the sector is rapidly changing. This report aims to contribute to a better understanding of the landscape of digital MRV requirements and available solutions.

[5] https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/redd
[6] https://www.theguardian.com/environment/2023/sep/19/do-carbon-credit-reduce-emissions-greenhouse-gases

1.1. Methodology

The analysis presented is based on a review of relevant literature as well as interviews carried out with key players in the sector to gather primary, relevant and recent insight into this area.

Resources used to inform this analysis and review were obtained from:

- International standards,
- Carbon standard-setting bodies,
- Case studies, technical documentation, and white papers on new or novel applications of modern cooking systems monitoring, and
- Academic papers and reports.

A summary of key resources used for analysis and deemed to be of utility for stakeholders is included at the end of each chapter.

Semi-structured interviews with key stakeholders were conducted in September and October 2023 to gather real-world insight into this area. The list of experts and organisations interviewed is outlined in Appendix 8.1.

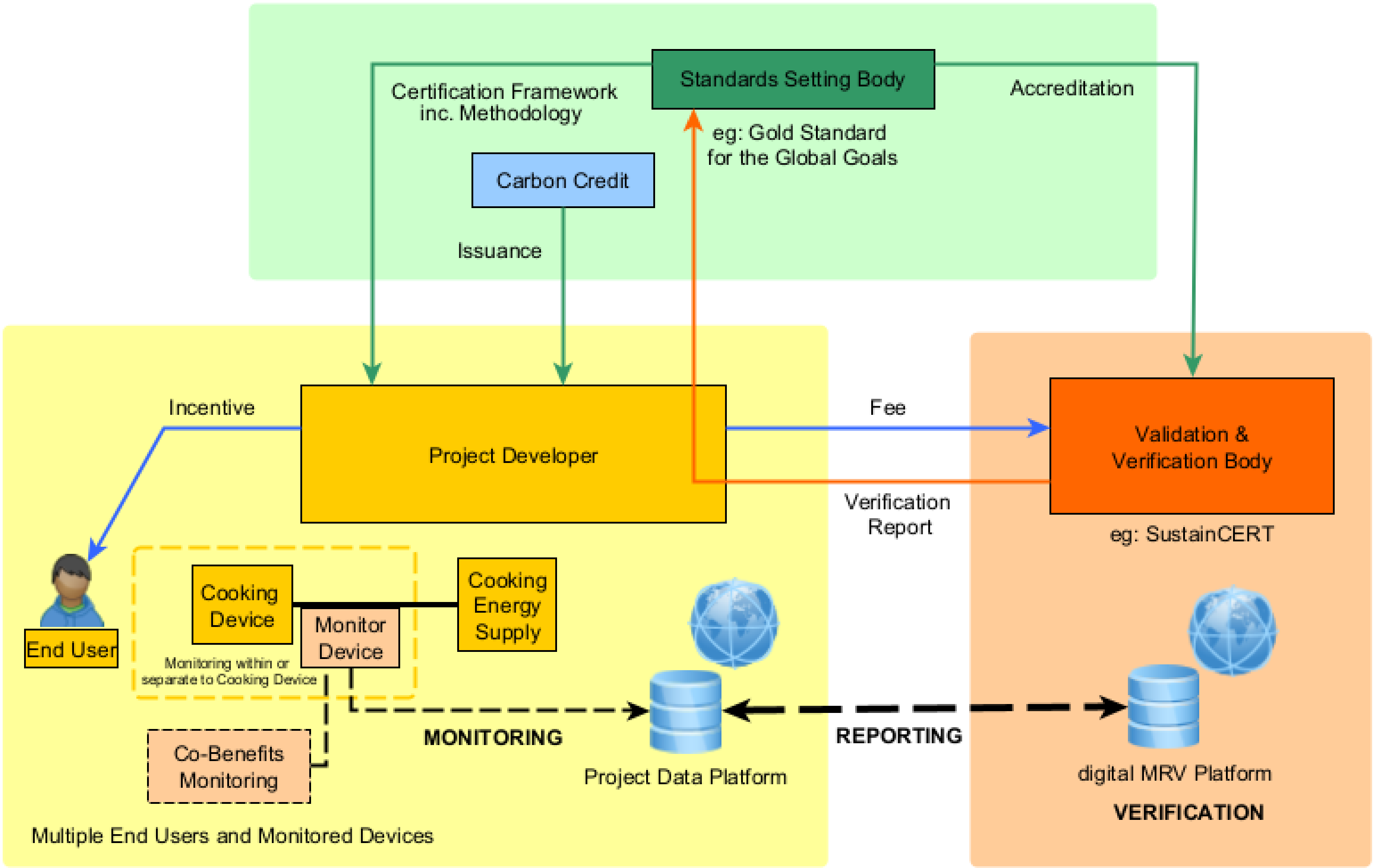

Figure 1: Simplified overview of a possible digitalised MRV process for a modern cooking carbon project.

2. Standards and Methodologies

This section gives an overview of the methodologies available to modern cooking under the most relevant carbon standards, their ongoing developments in digitisation and existing monitoring requirements relevant to dMRV. It also provides some insights on host country regulations and discusses best practice for project developers under the existing conditions.

2.1. The landscape of standards for modern cooking

Carbon finance for clean cooking was first mobilised under the Kyoto Protocol's Clean Development Mechanism (CDM) in 2009. Since then, it has been an indispensable funding source for numerous clean cooking projects around the world. With the second commitment period of the Kyoto Protocol and therewith the CDM coming to a close at the end of 2020, the new cooperative mechanisms under Article 6 of the Paris Agreement are taking over and ushering in a new era of international emission trading.

In the meantime, the voluntary carbon market has significantly gained in importance over the last years with Verra and Gold Standard emerging as the most relevant standard setting bodies. With a total of 1.1 billion carbon credits issued to date, Verra is the largest player in the voluntary carbon market. However, out of those only 15 million have been issued in the clean cooking sector, while credits from renewable energy as well as forestry & land use make up the bulk of the issuances. Gold Standard on the other hand has so far issued a total of 257 million credits, but among those 63 million credits from clean cooking projects. While under the CDM clean cooking activities were centred in South America and Southern Asia, under Verra and Gold Standard, Africa has accounted for 67% of issuances from clean cooking activities.[7,8]

2.1.1. UNFCCC

The United Framework Convention on Climate Change (UNFCCC) secretariat is the United Nations entity tasked with supporting the global response to the threat of climate change. Under the Kyoto Protocol, UNFCCC managed the project-based mechanism, the Clean Development Mechanism, whose second commitment period under the Kyoto Protocol closed at the end of 2020. The secretariat is now facilitating the operationalisation of the new Article 6 mechanisms of the Paris Agreement that succeed the Kyoto mechanisms.

CDM/Article 6.4

Under the CDM, the most relevant methodologies for clean cooking projects were AMS-I.E. and AMS-II.G., both of which were and are currently still usable for Gold Standard and Verra certification, too. AMS-II.G. is only relevant to energy efficiency improvements in biomass cooking and therefore not relevant for modern cooking activities. In Version 9.0 of AMS-I.E., DC-powered electric stoves first became eligible, followed by other electric cooking appliances in Version 11.0, if they are connected to an electricity source that is 100% renewable (with small diesel-powered backup allowed in the case of mini-grids).

[7] *Berkeley Voluntary Registry Offsets Database, state May 2023, https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database*
8 UNEP CCC CDM Pipeline, state October 2023, https://unepccc.org/cdm-ji-pipeline/

Article 6.4 is the succession mechanism to the Clean Development Mechanism and provides a framework for the international trading of emission reductions and removals, which may be counted towards countries' Nationally Determined Contributions (NDCs). It is governed by a Supervisory Body (SB) and will have standardised procedures that projects seeking certification need to follow, which include the methodologies for impact quantification. The operationalisation of Article 6.4 is still ongoing, as the SB's proposals require approval by the meeting of the Parties to the Paris Agreement (CMA) that meets annually at the same time as the Conference of the Parties (COP). Since at COP28 in Dubai no agreement could be reached on key aspects of Article 6, the timeline for the operationalisation is still uncertain.[9]

The transition of CDM methodologies to Article 6.4 is part of the ongoing work of the UNFCCC secretariat and subject to guidance and direction from the SB. It is currently unclear which aspects of the existing methodologies will continue into the revised Article 6.4 methodologies. However, a special review of the clean cooking projects aiming to transition from CDM to Article 6.4 by the secretariat has been ordered by the CDM Executive Board and the SB, spurred by concerns regarding methodological flaws that have been called out by some stakeholder to lead to significant overestimation of achieved impacts. These notably include the unreliable determination of the fraction of non-renewable biomass. At the same time there is acknowledgement by members of the SB of the particular relevance of clean cooking projects to Sub Saharan Africa and Least Developed Countries (LDCs)[10]. Yet, regardless of what transition requirements for existing CDM projects will be agreed, it can be expected that Article 6.4 methodologies will address the described integrity issues, meaning that the existing CDM methodologies will undergo some important changes, which will need to be followed by future projects. This will impact the clean cooking sector as a whole including the independent standards.

Another major point of criticism of clean cooking projects has been the calculation of emission reductions based on user surveys, which have been deemed unreliable and prone to biases. Digital monitoring of key project parameters can provide more accurate, reliable, and transparent data and as such is expected to be incentivised under the Article 6.4 clean cooking methodology(ies). An existing proposal for example is the introduction of a discounting factor to disincentivise traditional survey-based monitoring, which is more likely to overestimate achieved impacts. Regarding the possibility of sampling for modern cooking projects, the UNFCCC secretariat expects this to be included in the Article 6.4 methodology(ies) provided reliability of estimates are addressed. Furthermore, a strong focus on alignment with host country policies as well as reporting requirements on benefit-sharing are expected under the Article 6.4 framework.

The UNFCCC secretariat is currently working on a smart contract system on an exploratory basis to fully digitise its regulatory framework, automatically assess compliance with its requirements and automatically determine GHG mitigation impact. This includes the capability to provide reports, such as Project Design Documents (PDDs), monitoring reports, validation reports and verification reports in a standardised digital format. The system is currently being piloted with a methodology for grid-connected renewable energy.[11]

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[9] https://carbon-pulse.com/244810/
[10] https://www.un.org/ohrlls/content/least-developed-countries
[11] https://www.theclimatewarehouse.org/work/digital-4-climate

Article 6.2

Under Article 6.2 countries can bilaterally or multilaterally enter into carbon trading agreements whereby emission reductions can be transferred from one country to another to be counted towards its NDC. There is no international supervision under Article 6.2 in the form of a standard, but partnering countries can agree between themselves how impacts shall be quantified. First agreements between countries to collaborate under Article 6.2 have been made, e.g. between Switzerland and Peru[12], Malawi[13], Senegal, and Ghana[14], and they include clean cooking activities.

2.1.2. Gold Standard

Gold Standard for the Global Goals is a voluntary carbon standard that puts special emphasis on sustainable development alongside GHG emission reduction. Its relevance for the clean cooking sector is also reflected in the fact that it has developed three proprietary methodologies for clean cooking activities in addition to the CDM methodologies, with eligibility of modern cooking technologies under all of them. The Simplified Methodology for Clean and Efficient Cookstoves (SMEC) was specifically developed for micro-scale clean cooking activities. The methodology Technologies and Practices to Displace Decentralised Thermal Energy Consumption (TPDDTEC) encompasses both efficiency improvements and fuel switching and is applicable for example to non-measured LPG or ethanol stoves. The third methodology, the Methodology for Metered and Measured Energy Cooking Devices, was specifically developed for modern cooking technologies that can be metered continuously. It was published on 5/10/2022 and has since been updated twice to fix errors and include an additional pathway for the baseline emission calculation of electric cooking appliances. The methodology allows for making remote monitoring of cooking devices a reality, however this will in most cases not fully remove the need for site visits, due to the monitoring of co-benefits, which still typically relies on user surveys (see Section 5: Co-Benefits Review).

Gold Standard has a vision for digitising MRV, which is "driving systems changes in climate and sustainability through next-generation digital solutions and governance innovations designed for scale, interoperability, and equitable system access." To this end, it has created an Open Collaboration with the IOTA Foundation, ClimateCHECK and others, with three working groups focussing on Digital Monitoring Reporting and Verification, Digital Assets for Climate Impact, and Digital Infrastructure and Open APIs, respectively. Outputs from the working groups were published in November 2023.[15] Based on this work, Gold Standard is expected to publish a framework vision. They are taking a phased approach, following the framework there will be pilots of different solutions, the learnings of which will refine the framework.

While more specific guidelines for project developers regarding Digital MRV are expected as part of this framework, Gold Standard also emphasises the need to maintain flexibility in recognition of the diversity of project activities.

12 https://www.carbon-mechanisms.de/en/news-details/first-bilateral-agreement-on-article-6-cooperation-signed
13 https://www.qcintel.com/carbon/article/klik-foundation-targets-20m-article-6-2-units-from-malawi-13464.html
14 https://www.green.earth/news/senegal-and-ghana-strike-carbon-credit-deals-with-switzerland-for-clean-cookstoves
15 https://www.goldstandard.org/blog-item/digital-solutions-scale-high-integrity-carbon-markets-final-outputs-open-collaboration

2.1.3. Verra

Verra's Verified Carbon Standard (VCS) currently only has one proprietary methodology for clean cooking: Energy Efficiency and Fuel Switch Measures in Thermal Applications (VMR0006), which is an expansion of the CDM methodology AMS-II.G. to include fuel-switch activities from fossil fuels to renewable biomass cooking activities. VMR0006 however is set to be replaced by a new methodology currently under development titled the Methodology for Improved Thermal Energy Generation Units. This methodology shall include more modern cooking technologies, most notably electric cooking, and introduce direct metering approaches. The publication of a first draft of the methodology for public consultation is expected at the end of 2023.

Verra has set up a Digital MRV Working group with the objective to advise Verra on how to implement the use of dMRV[16] platforms and tools. It focuses on three thematic areas: Digitalising the Project Development Process, Validation and Verification of Digital MRV Platforms, and Integrity, Transparency and Oversight of Digital MRV. It has also launched a pilot together with climate tech company Pachama to develop a dMRV platform for using remote sensing to measure forest carbon.[17]

2.1.4. Clean Cooking and Climate Consortium (4C)

The Clean Cooking and Climate Consortium (4C) convened by the Clean Cooking Alliance is in the process of developing a methodology for clean cooking activities that shall encompass a large variety of cooking technologies, including modern cooking appliances. Regarding metered appliances, a potential alignment with the approaches of MMMECD has been indicated by 4C. A public stakeholder consultation process is currently ongoing with a first version of the methodology expected to be finished in 2024. The use case for this methodology remains to be seen, as it is unclear if it will be approved under the above described standards. One possibility could be that partnering states choose to use it under Article 6.2.

Table 1 provides an overview of the relevant clean cooking methodologies[18] under CDM, Gold Standard and Verra and their applicability to cooking technologies and standards. While AMS-II.G. and VMR0006 may not be relevant to modern cooking, they have been included here as there are many overlaps in project design and tools and advancements in digital MRV are highly relevant to clean cooking projects applying these methodologies as well.

16 Nomenclature for Digital Monitoring Reporting and Validation varies across sector reports, including DMRV, D-MRV, Digital MRV, and dMRV.
17 https://verra.org/worlds-largest-carbon-program-pilots-digital-measuring-of-forest-carbon/
18 Methodologies specifically for solar cookers and household biogas digesters were disregarded for simplicity.

Table 1: Overview of clean cooking methodologies from relevant standard-setting bodies.

Standard / Methodology	Applicable cooking technologies	Standards that accept methodology	Carbon credits issued (millions)[19]
CDM AMS-I.E.: Switch from non-renewable biomass for thermal applications by the user	Cookstoves using renewable biomass, electric cookstoves that receive electricity entirely from 100% renewable sources or from a renewable energy system that feeds more electricity into the grid on an annual basis than is consumed by the electric cookstoves and other connected loads	CDM, Gold Standard, Verra	18.5
CDM AMS-II.G.: Energy efficiency measures in thermal applications of non-renewable biomass	Improved biomass cookstoves displacing baseline cooking activities with non-renewable biomass, thermal efficiency of minimum 25%, project activities limited to energy savings of 60GWh per year	CDM, Gold Standard, Verra	45.0
Gold Standard Simplified Methodology for Clean and Efficient Cookstoves (SMEC)	All types of stoves displacing baseline cooking activities in which more than 90% of thermal energy needs are being met by wood and charcoal, project activities limited to emission reductions of 10,000 tCO2 per year	Gold Standard	2.0
Gold Standard Technologies and Practices to Displace Decentralized Thermal Energy Consumption (TPDDTEC)	Improved biomass cookstoves, non-measured improved fossil fuel cookstoves, solar cookers, heat retention cookers, thermal efficiency of minimum 20%, energy output <150kW per unit	Gold Standard	50.4
Gold Standard Methodology for Metered and Measured Energy Cooking Devices	Electric cooking appliances, measured LPG, biogas cookstoves, bio-ethanol cookstoves, measured improved biomass cookstoves (e.g. pellets), Thermal efficiency of minimum 40% for fuel-based devices, energy output <150 kW per unit	Gold Standard	None
VCS Verra VMR0006 Energy Efficiency and Fuel Switch Measures in Thermal Applications	Improved biomass cookstoves displacing baseline cooking activities with non-renewable biomass, and renewable biomass cookstoves displacing cooking activities with fossil fuels, thermal efficiency of minimum 25%, project activities limited to energy savings of 60GWh per year (Expansion of AMS-II.G.)	Verra	9.0
VCS Verra Methodology for Improved Thermal Energy Generation Units	Expected to cover many different technologies including electric cooking appliances and LPG cookstoves	Verra	None

19 Note that projects applying more than one of the listed methodologies are accounted for in each methodology, hence the sum of the issuances in this column does not add up to the total number of issuances.

2.2. Methodological Requirements and Opportunities for Digital MRV

All considered methodologies calculate GHG emission reductions by establishing baseline, project and leakage emissions. The emission reductions achieved by the activity are then obtained by subtracting project and leakage emissions from baseline emissions.

Baseline emissions in clean cooking activities are determined based on the amount of non-renewable cooking fuel displaced by the activity, with calculation routes and types of eligible baseline studies differing between methodologies. Project emissions are emissions arising through the implementation of the clean cooking activity that do not exist in the baseline scenario. These include emissions from the consumption of non-renewable electricity, the combustion of fossil fuels or the transport of fuels. Leakage emissions are emissions which occur outside the scope of the project, which are measurable and attributable to the project activity. This includes for example the situation where the forest protection impact of a clean cooking activity is reduced by wood harvesting or agricultural activities from actors outside the project boundaries.

All types of emissions are determined based on fixed and monitored parameters that are predefined by the methodologies. The methodologies also prescribe monitoring mechanisms or eligible data sources to determine these parameters, as well as monitoring frequency and quality assurance mechanisms.

In this section, key aspects of the existing methodologies are analysed for their requirements and opportunities with regard to Digital MRV.

2.2.1. User Database

All standards and methodologies included above require the project to keep a user database that includes information such as

- the date of installation of the cooking device or batch of devices,
- geographic area of sale,
- model/type of device sold,
- lifespan of device,
- name and telephone number and address/GPS coordinates of user,
- mode of use: domestic, institutional commercial, other,
- unique identifier of cooking device.

The standards or methodologies don’t provide specific instructions on how to gather, manage and store the data for the user database, however digital tools naturally lend themselves to this purpose. Data collection for the user database can be digitised for example through digital surveying tools, which can reduce human error, increase efficiency and ease of data transmission between field facilitators and database managers. The management and processing of this data can also be significantly enhanced by digital tools, which are discussed in detail in Section 3.2 Digital Survey Tools.

2.2.2. Fuel/electricity consumption monitoring

A key element of the monitoring plan for any clean cooking activity is the ongoing monitoring of fuel or electricity consumption, or usage of the project devices, which is one of the main determinants for the emission reductions achieved by the activity.

Table 2 summarises existing digital monitoring requirements in the considered methodologies for both modern cooking technologies as well as improved biomass cookstoves.

2.2.1. Determination of other fixed and monitored parameters

The calculation of emission reductions also depends on a number of other parameters aside from fuel/electricity consumption. Some of these are monitored regularly, while others are determined once at the beginning of project activities and then revised as required by the methodology. Some parameters have a big impact on the overall outcome of the emission calculation, a notable example being the fraction of non-renewable biomass that determines the non-renewable part of the displaced biomass, which may be considered for emission reductions. The accuracy and transparency of determining this and other fixed parameters has often been questioned. Digital tools currently play only a limited role here, but could in the future help to pave a way out of the integrity crisis of clean cooking project activities.

Table 3 shows an overview of the most relevant parameters in clean cooking methodologies, requirements for determining these and opportunities for digitising this determination. For the sake of simplicity, the accepted data sources across different standards and methodologies are listed together, even though not all data sources are allowed or eligible under all standards.

Table 2: Existing digital monitoring requirements in considered methodologies.

Monitoring parameter	**Applicable cooking technologies and methodologies**	**Requirements relevant for Digital Monitoring**
Amount of electricity used in the project scenario by device	Electric cooking appliances	<u>MMMECD</u> • Direct and continuous measurement, which may be remote. • Data gaps may be filled with average values across all connected devices, as long as the number of connected devices is at least the minimum required sample size. • Measuring device may either be in-built or attached separately to the electric cooking device and must be in conformity with industry standard and manufacturer calibrated. • Exceeding reference value of 1 kWh per capita per day requires substantiation with independent studies or publications. <u>AMS-I.E.</u> • Meters or data loggers may either be in-built or attached separately to the electric cooking appliances. • Data logger shall be in conformity with industry standard and calibrated according to relevant national requirements. • Electricity supplied from backup diesel generators should be no more than 1% of the total electricity supplied to the electric cook stoves. • Sampling is possible according to standard procedures with sample size to achieve 90/10 confidence/precision levels.
Amount of fuel used in the project in by device	Measured cooking fuels such as LPG or ethanol	<u>MMMECD</u> • Measurement using credible and calibrated equipment with mechanisms that ensure alternative use of the measured fuel is not possible. • Measuring device must be in conformity with industry standard and calibrated according to relevant national requirements. • In case direct metering is not applied, fuel purchases, which are summarised on a monthly basis, are automatically captured on a continuous basis. • Measurement may occur cluster-wise where project-specific retailers can clearly be assigned to customers and alternative uses are obviously excluded.

Usage rate of project devices	Improved biomass cookstoves, non-measured LPG, bio-ethanol and biogas stoves	TPDDTEC and SMEC ● Randomly selected representative sample households may be monitored with temperature-sensing data loggers known as Continuous Stove Monitors (CSMs) or other advanced monitoring devices in order to determine usage rate . ● The continuous use monitoring campaign shall be conducted for a minimum of 100 households for at least 90 days, with at least 30 samples for project technologies of each age being credited. ● Continuous use monitoring with temperature-sensing data loggers or other advanced monitoring devices required in order to claim usage rates of > 90%, except for biogas digesters.
	Improved biomass cookstoves	AMS-II.G. and VMR0006 ● Measurement campaigns can be undertaken using data loggers such as stove utilisation monitors (SUMs) which can log the operation of all devices in order to determine the average device utilisation intensity. ● Measurement campaign shall be conducted in at least 10 randomly selected participant households of the project activity for at least 90 days during the year. ● If seasonal variation is observed, the average value determined through the campaign shall be annualised taking into account seasonal variation of device utilisation. ● Different accounting mechanism depending on whether data loggers are able to determine duration of utilisation or not.
Renewable energy supplied to electric cookstoves from grid, mini grid or stand-alone source	Electric cooking appliances	AMS-I.E. ● When appliances are connected to 100% renewable grid, confirmation is required to demonstrate this. This may be based on metered data of electricity consumed by electric stoves or information on connected power plants of the grid or mini grid ● When appliances are connected to renewable energy system that is also connected to the grid via net-metering, this parameter is determined based on the: ○ metered data of renewable energy supplied by the renewable energy system associated with the electric cookstoves and any other loads that are connected to the system; and ○ metered data on amount of electricity exported to the grid; and ○ metered data on electricity imported from the grid.

Table 3: Overview of most relevant parameters in clean cooking methodologies, data sources, challenges and opportunities for digitisation.

Parameter	**Accepted data sources**	**Challenges for accepted data**	**Opportunity for digitisation**
Fraction of non-renewable biomass	• UNFCCC approved standardised baseline • Default value from methodology/tool • CDM Tool 30	Standardised baselines and application of Tool 30 have been shown to overestimate the fraction of non-renewable biomass. In addition to that, there is currently only a single approved UNFCCC standardised baseline that has not expired (Myanmar). The conservative default value may not accurately represent the project region.	Improvement of default values (currently underway in MoFuSS Model)[20]
Annual consumption of baseline fuel	• Standardised baseline studies such as Kitchen Performance Test and Controlled Cooking Test • published literature or studies by academia, NGOs or multilateral institutions • Official government publications or statistics • UNFCCC approved standardised baseline • Default value from methodology/tool	Standardised baseline studies are prone to human error, biases and data is relatively easy to manipulate. Depending on their design, they may not be representative of real life cooking activities. Conservative default values may not accurately represent the project region, while availability for region-specific data is low.	Improving baseline studies, Improvement of default values

20 Modelling fuelwood savings scenarios, GIS-based tool estimating the fraction of non-renewable biomass. Developed by the National Autonomous University of Mexico and the Stockholm Environment Institute and currently being reviewed for approval as a new standard under UNFCCC.
http://mofuss-balanceados-alb-1268046363.us-east-2.elb.amazonaws.com/vmofuss3/

Specific energy consumption in the baseline scenario	• Standardised baseline study: Controlled Cooking Test combined with qualitative data of cooking characteristics	Standardised baseline studies are prone to human error, biases and data is relatively easy to manipulate. Depending on their design, they may not be representative of real life cooking activities.	Improving baseline studies
Wood-to-charcoal conversion factor	• Default value from methodology/tool • Sample test of kilns in the region • UNFCCC approved standardised baseline	Sample tests of kilns are prone to human error, biases and data can be manipulated. Conservative default values exist but may not accurately represent the project region.	Improvement of default values
Percentage of fuel type in the baseline scenario	• User surveys • published literature or studies by academia, NGOs or multilateral institutions • Official government publications or statistics	User surveys are prone to human error and biases. Availability for region-specific data is often low.	Digital survey tools, Improvement of default values
Thermal efficiency	<u>Baseline devices</u> • Standard Water Boiling Test (WBT) • Published literature or studies by academia, NGOs or multilateral institutions • Default value from methodology/tool <u>Project devices</u> • Certification by a national standards body • Standard Water Boiling Test • Manufacturer specifications • Commercial guarantee • Technical reports from installer • For electric appliances, test protocol according to AMS-I.E.	Thermal efficiency tested in a laboratory environment often may not accurately reflect efficiency in real life application, which depends strongly on how the device is used by the cook. This leads to potential overestimation of device performance.	Statistical checks, Plausibility Cross-checks, Improvement of default values

Number of project devices operational	• User surveys	Data collection requires physical site visits.	Continuous monitoring
Emission factor from electricity	• CDM Tool 5 • harmonised grid emission factor dataset provided by UNFCCC	Tool 5 requires data inputs that may not be readily available from reliable sources and requires high technical understanding.	Higher data availability for power grids facilitates use of Tool 5
Leakage emissions	• Default value from methodology/tool • User surveys	User surveys are prone to human error and biases. Default value has been criticised to not sufficiently reflect non-permanence risks of emission reductions.	Satellite monitoring of protected forest areas
Expected technical life of project technology	• Manufacturer specifications • Certification by national standards body or an appropriate certification party recognised by national standards body • Commercial guarantee or guarantee from the installer • Field reports	Available specifications may not accurately reflect real life observation.	Adjustment through modelling of lifetime of monitored devices
Average number of people per household	• User surveys	Data collection requires physical site visits.	Digital survey tools, Integration with database

2.2.2. Sampling

Sampling is a fixed feature of the monitoring plan for most clean cooking activities. Since these typically involve large numbers of users, monitoring every single cooking device distributed may not be feasible. Therefore, monitoring data may be collected on a representative random sample in order to determine achieved emission reductions.

While dMRV opens up new opportunities in remote monitoring that can efficiently and accurately determine the fuel or electricity consumption of all distributed devices, the relatively high cost of monitoring devices, imperfect connectivity and technical reliability means that sampling is likely to still play a role in many modern cooking activities with digital monitoring.

In non-metered clean cooking activities, the random sample to be monitored is drawn anew for each monitoring period and verification. Monitoring devices however need to be installed and connected to the cooking devices at the beginning of the project activity. This could compromise the randomness and representativeness of the monitored sample and bears integrity risks, as high usage-households could be cherry-picked into the monitored sample.

The central documents on sampling are the CDM Standard for Sampling and surveys for CDM project activities and programmes of activities as well as the corresponding guideline. These lay out the general rules for sampling, which may be overridden by specific requirements provided in the applied methodology. The standard requires that the sample is representative of the monitored population and that the parameter estimates calculated from the sample data are unbiased and reliable. Unbiased means that there is no systematic under- or overestimation of the parameter value and reliable means that there is a high probability that the population parameter value falls within a specified distance from the sample-based estimate. The probability, called confidence, needs to be at least 90% for small-scale project activities and 95% for large-scale project activities. The distance, called the precision, needs to be ±10% in both cases. It is also ruled that the sample size may never be smaller than 30. If the estimates from the actual samples fail to achieve the target minimum levels of precision, either more data may be collected or a correction, e.g. a discount factor to the emission reductions, may be applied to the estimates.

Different types of sampling approaches are defined, namely simple random sampling, stratified sampling, systematic sampling, cluster sampling and multi-stage sampling. They all depict different ways of selecting a sample group that is representative of the population depending on the characteristics of the population to be sampled.

Both Gold Standard and Verra refer to the CDM sampling standard with some additional requirements or simplifications applied on methodology-level. In TPDDTEC, Gold Standard defines general requirements for sampling, which are also applicable under MMMECD. These are similar to the CDM sampling standard but allow for a precision of only ±30% in some cases. In MMMECD, it is specified that data gaps in project devices resulting from loss of network connection may be filled with average consumption data of the other connected devices as long as the minimum required sample size is met. A higher than minimum sample size is recommended to accommodate this. It is further specified that “changes in the sample group can be made over time as long as the minimum sample size and representativeness are ensured”. This acknowledges the challenge of changing the sampled group in metered cooking activities and represents an important departure from existing sampling requirements and practices in non-metered clean cooking activities.

2.2.3. Standards of measuring devices

Monitoring devices, such as electricity meters or fuel flow meters, represent a new class of monitoring equipment for clean cooking activities that has previously played a peripheral role at most for this type of activity.

CDM, Gold Standard and Verra all have general requirements provided by the standards regarding the standard and calibration of monitoring equipment, which are summarised below.

UNFCCC (CDM)

In the CDM Project Standard it says that unless stated otherwise in the applied methodologies, standardised baselines or other methodological regulatory documents:

- *Data variables that impact the GHG emission reductions continuously shall be measured continuously.*
- *Data variables that are generally constant shall be measured or calculated at least once a year.*
- *Measuring equipment shall be certified to national or IEC standards.*
- *Calibration of measuring equipment shall be carried out by an accredited person or institution.*
- *Measured data with high levels of uncertainty shall be compared with data from other sources to check the consistency.*

Furthermore, in the CDM Validation and Verification Standard it says that compliance with calibration frequency is to be checked by the Designated Operational Entity (DOE), the equivalent of a VVB under the CDM, and is guided by the principle of conservativeness. Delayed calibration may lead to the obligation to apply the maximum permissible error as specified by the manufacturer or the error identified in the calibration test, whichever is higher.

Gold Standard

Gold Standard states requirements for device calibration in the Validation and Verification Standard: *"Equipment used for monitoring shall be controlled and calibrated in accordance with the registered monitoring plan, the applied methodology(ies) and related documents, GS Technical Advisory Committee guidance, local/national standards, or as per the manufacturer's specification"* Compliance with calibration frequency is to be checked by the VVB and is guided by the principle of conservativeness. Delayed calibration may lead to the obligation to apply the maximum permissible error as specified by the manufacturer or the error identified in the calibration test, whichever is higher.

Further, in MMMECD it is specified that the device to measure energy consumption shall be in conformity with industry standard and manufacturer calibrated. It is the manufacturer's responsibility to provide calibrated equipment and evidence thereof.

Verra

Verra's Project Standard states that "*Where measurement and monitoring equipment is used, the project proponent shall ensure the equipment is calibrated according to the equipment's specifications and/or relevant national or international standards*." In their Validation and Verification Manual it further says that "*cross-referenced data and information is recommended, best practice examples include timing a site visit to align with a calibration event, reviewing calibration logs and/or interviewing the individual(s) conducting the calibration (which often involves outside service providers). Ideally, the project uses calibration organisations accredited to relevant standards. Other non-accredited organisations may also* *perform calibrations if permitted by an equipment manufacturer's specifications and the relevant methodology. Ultimately, VVBs must assess whether calibration practices follow current good practice as required by Clause 5.10 of ISO 14064-2*[21] *and meet any requirements specified in the methodology*."

2.2.4. Data Handling

Projects implementing clean cooking activities collect and manage large amounts of data, much of it personal data of cookstove users, such as name, address and phone number. This is necessary in order to be able to track stove usage during monitoring. However, data protection is a requirement in many countries[22] and concerns have been expressed from various sides[23], as there is very little supervision or transparency of how long this data is stored by project developers or VVBs it was shared with, who has access rights and whether appropriate consent was sought by users.

Measuring devices such as electricity meters only increase the importance of this issue as they have the potential to gather large amounts of data, which may be quite sensitive in nature. Continuous monitoring of cooking activities for example gives information about when users cook, how much they cook, when they are at home etc.

In the absence of robust data protection laws in the host countries of the project activity or the enforcement thereof, project developers often operate in an unregulated space. This is also due to a lack of guidelines from the standard setting bodies. Neither Gold Standard nor Verra mention data protection in their core documents. In the CDM Project standard, it says: *"Disclose sufficient and appropriate project activity-related information in a truthful manner to allow intended users to make decisions with reasonable confidence. Do not disclose proprietary or confidential information marked as such by project participants without the written consent of the provider of the information, except as required by national law. In this context, information used to determine additionality, to describe the baseline methodology and its application, and to support an environmental impact assessment shall not be considered as proprietary or confidential".*

2.3. Host country regulations

Another dynamic impacting modern cooking activities under carbon crediting schemes is the onset of host countries regulation of carbon markets. Many countries, including for example Ghana, Zimbabwe, Kenya, Tanzania and Zambia have recently passed legislation that typically includes the establishment of a national carbon registry and introduces fees and requirements for benefit-sharing with local communities. While under the CDM, project developers were required to obtain approval from host country governments for planned project activities, this is not required under voluntary standards, which means that governments in the past often lacked overview and oversight of carbon activities being implemented in their countries. Under the emerging legislation, project developers are expected to be subjected to project approval procedures and reporting obligations.

Digital tools play an important role in this context to assist countries in tracking NDC progress, facilitating transfers of mitigation outcomes under Article 6 and managing MRV on a national

21 https://www.iso.org/standard/66454.html
22 https://dataprotection.africa/
23 https://www.climateledger.org/resources/Digital_Verification_White_Paper.pdf

level. With support from UNDP, the Governments of Kenya, The Gambia, Uganda and Vanuatu, for example, have developed "an integrated Monitoring Reporting and Verification (iMRV) tool for tracking GHG emissions, the impact of mitigation and adaptation actions, climate finance flows and the impacts on SDGs".[24] This is part of an effort of digitising the entire carbon market ecosystem, which could in the future also see the full integration of project activity-level data with national MRV systems.

Project developers are also impacted by these new developments with regard to project economics, as for the first time, fees and taxes are levied on their carbon credit sales and they are subjected to benefit-sharing obligations. There is currently a lot of variation among different countries' taxation levels, but their finality is doubtful. Zimbabwe shook carbon markets in May 2023 by announcing it would take 50% of all revenue from carbon projects with an additional 20% going to local communities[25], but has since backtracked from this. In Kenya, the current legislation subjects all projects to ceding at least 25% of carbon revenues to local communities[26].

These additional costs may affect project developers' willingness and ability to introduce digital monitoring solutions, which often are more expensive than traditional methods.

2.4. Best Practice Considerations

The discussed integrity concerns around impact quantification of clean cooking activities highlight that compliance with methodological requirements alone may not guarantee high integrity accounting of emission reductions. While the standards are reacting to these concerns by adjusting their requirements, project developers also have the chance to choose practices that can safeguard their activities against public criticism and potential stricter regulation from standards in the future. Below, some key areas and relevant best practice opportunities are discussed that foster transparency and high data quality.

2.4.1. Sampling

As discussed above, sampling of metered devices can bear considerable risks to accurate impact quantification if the sampled group is not representative of the overall user group. This risk is increased due to the fact that in the case of metered energy cooking devices the sampled group is typically selected once during distribution, i.e. only a portion of distributed cooking devices is equipped with meters. Changing the sampled group during project operations is not required by carbon standards and may also be complicated to implement. A fixed sampled group is more likely to receive improved customer care and technical assistance in case of device failure.

When data gaps from non-functioning meters are filled with data from functioning meters, this further bears risks, since when a meter is not sending data it may not be possible to distinguish whether this is a result of technical failure of the meter or of the entire cooking device. In the first case, cooking could still be taking place while in the latter it could not. In the latter case, filling data gaps from unusable cooking devices with data from used devices leads to overestimation of the achieved impact. If poor connectivity leads to gaps in real time data, accumulated energy consumption is often still available. In this case, the total energy

24 https://www.theclimatewarehouse.org/work/digital-4-climate
25 https://carbon-pulse.com/203600/
26 https://www.clydeco.com/en/insights/2023/10/kenyas-step-towards-carbon-market-regulations

consumption metered over the monitoring period should be considered during monitoring rather than filling in data gaps with data from other connected devices.

While costly and potentially technically challenging, the optimal solution to reduce these risks is to avoid sampling and individually monitor every cooking device. Cooking devices with integrated meters that allow for remote data collection represent the most straightforward option to achieve this.

A cheaper solution to achieve higher representativeness of the sampled group can be changing the group regularly, e.g. for every verification. This could for example be achieved by metering every device with a simple, cost-effective meter without remote data collection functionality, and drawing a random sample to be monitored in each monitoring period.

Ultimately, if metering every device is not an option, project developers can maximise representativeness in the distribution of meters among users, e.g. by making sure that different user groups such as urban, peri-urban and rural households are accurately represented or developing robust methods for randomly allocating meters to users. It should further be ensured that this group remains representative over time, as more devices are distributed (early adopters might have different usage patterns than late adopters for example).

2.4.2. Data Protection

In the absence of guidance on data protection from standard-setting bodies or host country governments, project developers may still implement robust data protection practices to demonstrate a commitment to respecting users' privacy and fostering trust among stakeholders. Good practices that project developers can adopt include:

- **Data Minimisation:** Collecting only necessary data for project objectives. Avoid collecting excessive or irrelevant personal information.
- **Informed Consent:** Obtaining explicit and informed consent from users before collecting their data. Clearly communicating the purpose of data collection, how it will be used, and for how long it will be retained.
- **Security Measures:** Implementing robust security measures such as encryption, access controls, and regular security audits to safeguard data from unauthorised access, breaches, or leaks.
- **Data Anonymisation:** Anonymising data wherever possible to reduce the risk of identifying individuals, especially when sharing data for analysis or reporting.
- **Training and Awareness:** Providing training to staff involved in data handling to ensure they understand data protection principles and their responsibilities. Fostering a culture of privacy awareness within the organisation.
- **Data Retention and Disposal:** Establishing clear policies for data retention and deletion. Disposing of data when it's no longer necessary for the intended purpose, following secure deletion practices.
- **Transparency and Accountability:** Being transparent about data handling practices. Maintaining records of data processing activities and being accountable for any breaches or incidents.

2.4.3. Data Reliability

Digital monitoring data provides a special opportunity for automated plausibility checks of data. This can be especially relevant in case sampling is applied or data gaps are present in the collected monitoring data. Checks can include statistical checks and cross-checks against the theoretical maximum (or the cap set by the methodology), other published data, or monitoring parameters such as household size. More details on this are provided in Section 3.6.4 Data Validation in section 3.6 Technical Considerations for dMRV in the Clean Cooking Sector.

2.4.4. Transparency

Another way of promoting integrity and ensuring trust in the carbon accounting of clean cooking activities is to transparently communicate project information with stakeholders. While a lot of this information is typically publicly available in the project documents in the standard-setting bodies' registries, this is only accessible to specialised individuals who are familiar with carbon standards and the relevant impact quantification methodologies. To increase accessibility, project developers can communicate relevant information on methodological choices and key parameters on other channels, facilitated for example through a digital MRV platform as presented in Section 3: Digital MRV.

A major opportunity for data transparency enabled by digital tools is to publish project data in real-time. A great example for this is the Carbon Credit Dashboard developed by ATEC[27] or the Prospect.energy[28] and Appliance Demand Platform[29] by A2EI, which enable carbon credit buyers to directly track the impact of their financial contribution. Fostering accountability and trust in this manner can provide a strong marketing opportunity.

More details on this are provided in Section 3.6.3 Data Transparency in section 3.6 Technical Considerations for dMRV in the Clean Cooking Sector.

2.4.5. Host country engagement

As increased oversight of and interest in carbon project activities from host country governments is expected, proactive engagement with relevant authorities and alignment with relevant domestic priorities and strategies can strengthen the integrity of carbon project activities. Stricter requirements from both standard-setting bodies and host countries in this regard are expected as discussed above. Digital project data and reporting tailored to the host country's requirements or preferences can be helpful in demonstrating compliance or gaining support for a project activity.

2.5. Selected Resources

CDM Methodology AMS-I.E.: Switch from non-renewable biomass for thermal applications by the user, Version 13.0
By: UNFCCC Published: 2022
https://cdm.unfccc.int/methodologies/DB/JB9J7XDIJ3298CLGZ1279ZMB2Y4NPQ

27 https://www.youtube.com/watch?v=7FKrpSVzeBQ
28 https://prospect.energy/
29 https://adp.energy/

CDM Methodology AMS-II.G.: Energy efficiency measures in thermal applications of non-renewable biomass, Version 13.0
By: UNFCCC Published: 2022
https://cdm.unfccc.int/methodologies/DB/GNFWB3Y6GM4WPXFRR2SXKS9XR908IO

CDM project standard for project activities, Version 3.0
By: UNFCCC Published: 2021
https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20210921115752577/reg_stan04_v03.0.pdf

CDM validation and verification standard for project activities, Version 3.0
By: UNFCCC Published: 2021
https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20210921115831128/reg_stan06_v03.0.pdf

CDM Standard for Sampling and surveys for CDM project activities and programmes of activities, Version 9.0
By: UNFCCC Published 2021
https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20210531160756223/Meth_Stan05.pdf

Gold Standard Simplified Methodology for Clean and Efficient Cookstoves (SMEC), Version 3.0
By: Gold Standard Published: 2022
https://www.goldstandard.org/project-developers/standard-documents

Gold Standard Technologies and Practices to Displace Decentralized Thermal Energy Consumption (TPDDTEC), Version 4.0
By: Gold Standard Published 2021
https://www.goldstandard.org/project-developers/standard-documents

Gold Standard Methodology for Metered and Measured Energy Cooking Devices, Version 1.2
By: Gold Standard Published: 2022
https://www.goldstandard.org/project-developers/standard-documents

Gold Standard Validation and Verification Standard, 1.0
By: Gold Standard Published: 2023
https://www.goldstandard.org/project-developers/standard-documents

Gold Standard Requirements and Guidelines: Usage Rate Monitoring, Version 2.0
By: Gold Standard Published: 2020
https://www.goldstandard.org/project-developers/standard-documents

VCS Verra VMR0006 Energy Efficiency and Fuel Switch Measures in Thermal Applications, Version 1.2
By: Verra Published: 2023
https://verra.org/methodologies/vmr0006-methodology-for-installation-of-high-efficiency-firewood-cookstoves/

VCS Verra Methodology for Improved Thermal Energy Generation Units
By: Verra Published: 2020
https://verra.org/methodologies/methodology-for-improved-cookstoves-and-other-distributed-thermal-energy-generation-units/

VCS Verra Project Standard, Version 4.5
By: Verra Published: 2023
https://verra.org/documents/vcs-standard-v4-5/

VCS Verra Validation and Verification Manual, Version 3.2
By: Verra Published: 2016
https://verra.org/wp-content/uploads/2018/03/VCS_Validation_Verification_Manual_v3.2.pdf

3. Digital MRV

This chapter introduces the concept of digital Monitoring, Reporting and Validation (dMRV), starting with an overview of digitisation and introducing digital survey tools used for clean cooking projects. dMRV is then described in detail, including how it is currently being used for clean cooking projects, and the key players currently active in the sector are introduced. Technical considerations for implementing dMRV platforms are outlined for both storing and transferring data and key challenges of dMRV in the clean cooking sector are highlighted.

3.1. Digitisation

The process for determining emission reductions according to the methodologies presented in Section 2: Standards and Methodologies requires an initial baseline assessment and then, throughout project implementation, monitoring of parameters as per a predefined monitoring plan. These parameters are reported to an accredited VVB, and after successful verification of the claimed emission reductions, carbon credits are issued. Currently, these processes are often expensive, time-consuming, and susceptible to human error, as they rely on manual information recording or in-person surveys.

The Integrity Council for the Voluntary Carbon Market (ICVCM), an independent governance body for the voluntary carbon market, has defined 10 Core Carbon Principles (CCPs) for high-integrity carbon credits[30]:

- Effective Governance,
- Tracking,
- Transparency,
- Robust independent third-party validation and verification,
- Additionality,
- Permanence,
- Robust quantification of emission reductions and removals,
- No double counting,
- Sustainable development benefits and safeguards,
- Contribution toward net zero transition.

In order for projects to ensure compliance with these principles, data needs to be recorded, but if the processes are susceptible to human errors, biases and, potentially, tampering, then this reduces the level of trust within carbon markets, questions the integrity of emission reduction claims and raises concerns over the quality of projects being implemented, as previously mentioned in Section 2: Standards and Methodologies. Any effort to improve the trust, integrity and quality of data from carbon mitigation projects will help improve the revenue streams from the sale of carbon credits, with end purchasers willing to pay a premium for proven higher quality emission reductions.

30 https://icvcm.org/the-core-carbon-principles/

‘Digitisation’ broadly refers to the process of converting traditional, manual or paper-based methods of collecting and storing data into automated digital systems. Digitisation and digital technology can help[31]:

- Automate end-to-end data capture and verification, potentially without human intervention,
- Provide a key role in data triangulation, verification, and accountability,
- Improve market visibility for buyers and sellers,
- Allow faster onboarding of smaller and micro-projects,
- Facilitate micro-project aggregation, with digitisation platforms bearing the burden of accreditation for micro-projects,
- Provide a fair share of carbon-based finance to end users at community level.

The digitisation process covers a wide range of activities, tools (including hardware and software), and processes that project developers can implement to improve data collection and organisation. It is worth noting that most project developers are already using various forms of digital tools for various aspects of project implementation. For example, key project documents, such as the Project Design Document, are provided in electronic form and recorded in the registries of the carbon standard-setting bodies. These registries also digitally track the issuance and retirement of carbon credits of each registered project. Excel databases, while simple and prone to human error, are a form of digital data storage and are already being used by many project developers. Cutting-edge digital platforms are also already being implemented for finance control reasons, especially when project developers or equipment suppliers offer PAYGo finance.

The process of improving digitisation techniques is usually incremental and on-going. For most project developers this does not happen overnight and involves a number of small implementation steps, initially taking time and resources. However, in the long-term this can help to reduce the burden of project monitoring, increase the accuracy and transparency of processes, and improve trust and integrity of carbon credits, ultimately enabling higher premiums paid for the credits.

Stakeholder interviews have highlighted almost universally that digital technology and innovation will play an increasingly important role within carbon project activities. However, uptake of such technologies has been limited, with key reasons for this highlighted as:

- The cost, time and resources required to realise and implement digital monitoring hardware and software,
- Lack of availability of technologies and hardware,
- Lack of technical knowledge,
- Lack of people with the technical skills,
- The variety and associated lack of conformity regarding data protection regulations[32], and
- The current verification system does not fully incentivise better data quality.

Project developers need these digitisation processes to be simple and relatively low cost to implement. As this is a relatively new and highly fluid environment, project developers do not

31 https://www.gsma.com/mobilefordevelopment/resources/digitally-enabled-climate-finance/
32 https://dataprotection.africa/

want to be left with obsolete systems or equipment, so they need to have confidence in the digital systems and that carbon standards will ensure long-term investment in any systems.

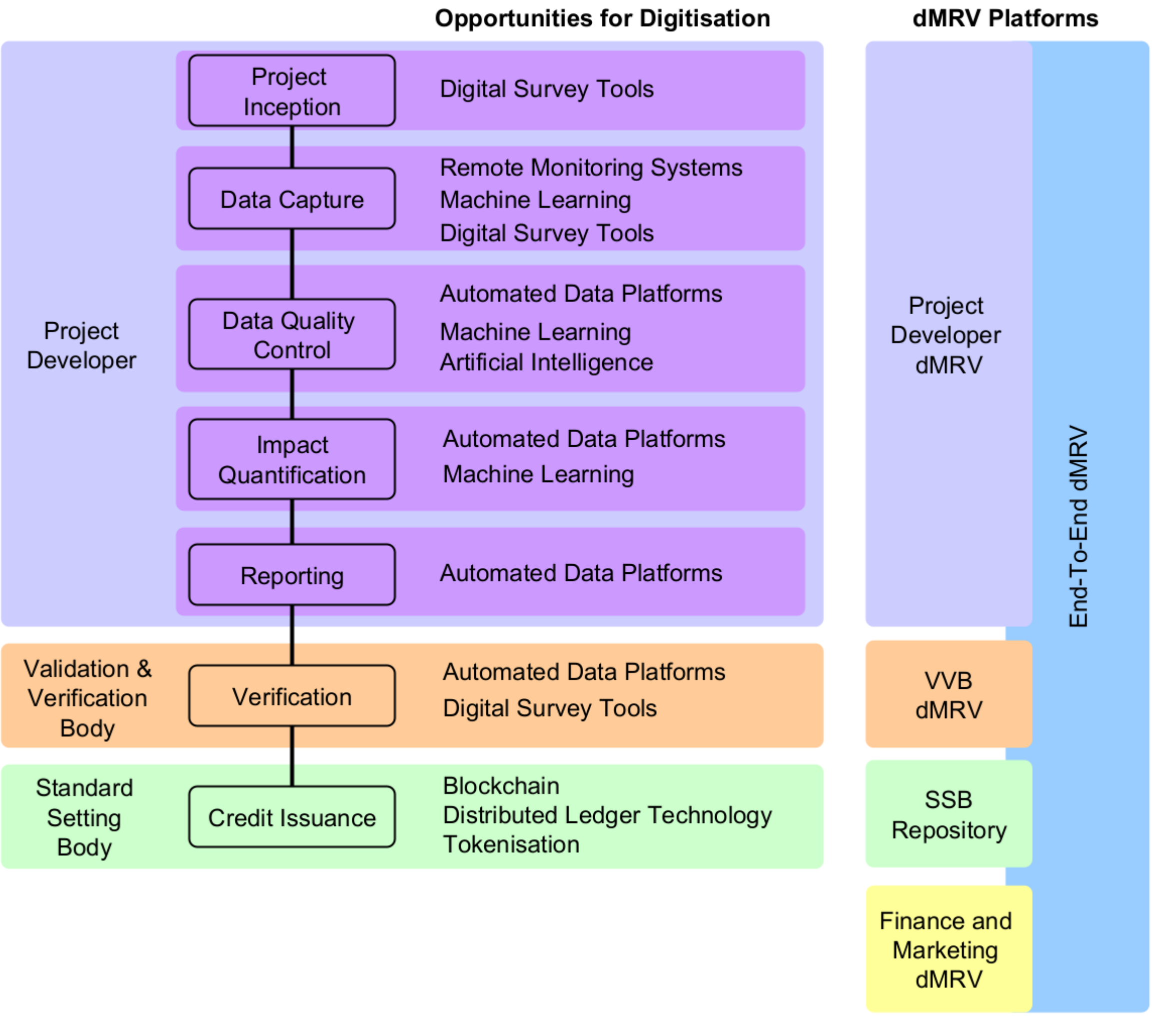


Figure 2: Opportunities for digitisation within different stages of a carbon project.

3.2. Digital Survey Tools

Digital survey tools represent a modern and efficient approach to data collection, offering versatile solutions for various industries and projects. These tools, normally accessible through mobile devices or web interfaces, streamline surveying processes by allowing users to create, distribute, and collect data electronically. Features such as real-time data entry, multimedia support, and GPS tagging enhance the accuracy and depth of collected information. Digital survey tools contribute to increased efficiency, reduced errors, and improved data quality compared to traditional paper-based methods. Their adaptability, often including offline data collection capabilities, makes them invaluable for fieldwork in diverse contexts, ranging from research and humanitarian aid to environmental monitoring and development projects.

In the context of clean cooking initiatives, digital survey tools are valuable for project developers to capture crucial data related to the adoption and impact of clean cooking technologies. Fieldworkers equipped with mobile devices utilise these apps to collect data related to baseline assessments, cooking device usage, fuel consumption, and other relevant metrics. This digital approach streamlines monitoring processes, enabling efficient data collection even in remote areas. A summary of the main digital survey tools being used for clean cooking is summarised below:

KoboCollect

https://www.kobotoolbox.org/

KoBoCollect is an open-source mobile data collection tool designed for field surveys and data gathering, allowing users to create customised forms using a web-based interface, which can then be deployed to Android devices (such as smartphones). Fieldworkers use the KoBoCollect app on their mobile devices to collect data in offline or online mode, with collected information submitted to a central server when an internet connection is available. The offline functionality is particularly beneficial in regions with limited connectivity, ensuring continuous data capture. The collected data, once submitted to a central server, facilitates analysis both online and through spreadsheet download, with an API function recently introduced for transparent reporting and verification of critical project data. The platform is free to use.

Akvo Flow

https://www.akvoflow.org/

Akvo Flow is a data collection and monitoring tool that specifically focuses on aiding the diverse requirements of international development projects. It allows users to design forms and user interfaces for data collection, which can be used on smartphones and tablets. Akvo Flow is designed to be flexible, adaptable, and easy to use in various development sectors, such as water and sanitation, agriculture, and education. It includes data visualisation tools, providing real-time insights into project data and facilitating project management and decision-making. It has different pricing structures, with a free version that allows for up to 300 submissions for a single user.

ODK

https://getodk.org/index.html

ODK (Open Data Kit) is designed to be a user-friendly and versatile method for data collection, operating on an open-source platform and allowing for the creation and implementation of digital forms on Android devices, offering features like GPS tagging and multimedia support. ODK's project space feature provides unlimited forms and users, allowing assignment of specific forms to designated data collectors. Furthermore, it offers API access for custom integrations, enhancing automation in data collection, management, and utilisation. The data, encrypted in transit and at rest in ODK Cloud, is secured by end-to-end encryption with self-managed keys. Users can choose between US or EU data centres, both of which adhere to GDPR compliance and possess ISO27K and SOC 2 certifications. ODK, being open-source, provides the option for self-hosting and self-support if the technical capability is available, while a cloud-based version is available with tiered monthly fees.

DigiESG

https://www.greendatalab.com/

DigiESG is a cloud-based data collection solution designed to address the challenges of ESG data management for SMEs in emerging markets. It addresses challenges with traditional paper-based or MS Office-based document management systems that are often inadequate for consolidating and cross-referencing ESG data in a meaningful, timely, and traceable manner. This lack of robust data management systems hinders SMEs' ability to produce tangible ESG data, which is increasingly demanded by ESG-conscious financiers. DigiESG bridges this gap by providing a secure and user-friendly platform for SMEs to collect, manage, and report their ESG data.

The mobile app, compatible with Android devices, operates offline and the web platform ensures secure access control, with granular permissions defining user roles. Key features encompass easy-to-use predefined forms for data collection, robust data control and monitoring, export capabilities to XLS, CSV, and PDF formats, and automatic generation of ESG KPI dashboards and quarterly reports. Additional benefits include unlimited dedicated ESG data storage with daily backups, separate storage of documents and images in Google Cloud for enhanced security, and a digital version of an Environmental and Social Action Plan for progress tracking. DigiESG stands as a comprehensive solution, enabling SMEs to efficiently manage ESG data, derive insights into their performance, and exhibit a commitment to sustainability to stakeholders.

3.3. What is Digital MRV?

Digital Measurement, Reporting, and Verification (dMRV) is an approach for organisations to accurately measure, report, and verify using digital data and methods, with applications being developed for different parts of the overall carbon credit process. Such approaches leverage advanced technology and data-driven solutions to enhance transparency, accountability, and efficiency in carbon accounting processes. dMRV employs a holistic data collection approach that incorporates mobile and digital technologies, utilising standardised data exchange and application programming interfaces (APIs). These technologies encompass a wide range, such as intelligent sensors, satellite systems, unmanned aerial vehicles (UAVs or drones), cloud computing, artificial intelligence (AI), the Internet of Things (IoT), and blockchain encryption.

The integration of these technologies within a dMRV system facilitates real-time communication of project outcomes, resulting in faster, more consistent, and precise reporting. These platforms employ advanced algorithms and modelling techniques to provide highly accurate measurements of greenhouse gas emissions and removals, reducing the margin for error. They generate automated reports and dashboards that streamline the reporting process, making it easier for organisations to comply with regulatory requirements and communicate their sustainability efforts to stakeholders as well as facilitating third-party verification by providing auditors with access to verified data and audit trails, ensuring the credibility of emission reduction claims.

dMRV platforms help organisations stay compliant with evolving carbon reporting regulations and standards, reducing the risk of non-compliance penalties, provide insights and data analytics that empower organisations to make informed decisions on carbon reduction strategies and investments, and enhance transparency in carbon accounting, allowing stakeholders to access and verify emissions data, which fosters trust and accountability. dMRV also enables projects to establish connections with various sector-specific, national, and international registries. This integration streamlines the Monitoring, Reporting, and Verification processes for national climate action plans and related activities. In this way, dMRV platforms can offer more localised climate financing in Global South countries, and underserved communities can receive immediate financial benefits from investment in climate-adaptive and mitigative methods through these platforms. A comparison of conventional MRV with dMRV is listed in Table 4.

Table 4: Comparison of conventional MRV with dMRV.

	Conventional MRV	**Digital MRV**
Monitoring	Data is manually recorded from various entities within specified boundaries. Entities monitor fuel or electricity consumption/production using methods like paper receipts or Excel files. Multiple individuals are typically involved in these processes, increasing the risk of human error.	Near real-time digital monitoring using smart meters, linked billing systems, and equipment sensors. Reduction of resources dedicated to data collection, allowing a shift towards Quality Assurance/Quality Control (QA/QC) efforts. Decreased time, travel expenses, and effort required to operate the MRV system. Integration of notifications/alerts in the system to proactively address potential data gaps or issues caused by on-site disruptions.
Reporting	Data is recorded and analysed for the creation of a GHG emissions report. The process is labour-intensive, involving considerable human effort. Personnel may need to follow up on incomplete or incorrect reporting. The report requires supervisory review for accuracy and completeness.	Digital MRV systems can automatically generate reports on GHG emissions with predefined templates. Emissions data from both automated and manual monitoring processes can be seamlessly analysed, formatted, and reported. The system is capable of flagging errors or can be programmed to highlight significant deviations in reported values compared to historical reports or similar activities in the same year.

Verification	Step-by-step audit of GHG report to verify adherence to procedures and prevent human errors. Audit facilitated through manual review of supporting records in either paper or electronic format. Hardcopy documents are susceptible to loss or damage over time, adding to the cost and time involved in the review process.	Validation/verification occurs at the digital MRV system level to ensure adherence to GHG emissions reporting standards. GHG emission reports are remotely verified using dedicated verifier user profiles, enhancing speed and cost-effectiveness. Some automation in QA/QC is possible through data screening based on predefined rules.

3.4. How are Digital MRV platforms being used for Clean Cooking?

As the adoption of modern cooking technologies such as improved cookstoves, LPG and electric cooking solutions has increased across various regions in the Global South, dMRV tools are increasing in prominence to monitor and verify the use and impact of these technologies, tracking parameters including reductions in indoor air pollution and greenhouse gas emissions. Key drivers and trends in this sector are summarised in Table 5.

Table 5: Key drivers for using dMRV in the clean cooking sector.

	Purpose	**Impact**
Data-Driven Decision-Making	dMRV platforms are instrumental in collecting, analysing, and sharing data on clean cooking adoption and its impact	Informed decision-making for program design, scaling successful initiatives, and attracting funding from donors and investors.
Results-Based Financing and Carbon Finance	Donor organisations, impact investors and carbon credit buyers tie funding and revenue to specific clean cooking outcomes and emission reductions verified through dMRV	Incentivising project implementers to deliver measurable results, promoting accountability and encouraging the achievement of clean cooking goals.
Behaviour Change Insights	dMRV platforms go beyond tracking stove usage, offering valuable insights into user behaviour	Informing the design of effective behaviour change campaigns and ensuring clean cooking technologies align with the needs and preferences of target populations.
Policy Integration	Some countries in the Global South integrate dMRV data into national policies and strategies for clean cooking	Aligning efforts across government levels, fostering coordination, and promoting the sustainable adoption of clean cooking technologies.

Recent trends in employing dMRV for clean cooking projects showcase a transformative landscape. The integration of Internet of Things (IoT) technology facilitates remote monitoring, enabling real-time tracking of fuel consumption, emissions, and stove usage. Furthermore, the development of mobile applications and cloud-based platforms is addressing connectivity challenges in areas with limited internet access. Field agents can now directly input data using smartphones or tablets, streamlining data collection and reporting processes.

Project developers are forming partnerships with technology providers, data analytics firms, and research institutions in a collaborative approach to harness diverse expertise and resources to develop and implement dMRV solutions, ultimately enhancing MRV capabilities. Within these partnerships there is a growing emphasis to build local capacity in data collection, analysis, and MRV. The dMRV ecosystem for clean cooking is relatively nascent and rapidly evolving, with different players trialling new technologies and methods with ongoing learning emerging.

Within the wider ecosystem and broad scope of dMRV applications in the clean cooking sector, specific areas have been identified which focus on different aspects of monitoring, reporting and verification, summarised below:

Project Developer Data Platforms

Several clean cooking project developers have built their own, in-house data platforms to store a plethora of information relating to project operations and sales. This data provides information on parameters including customers, products and sales, asset monitoring, and in some cases monitored appliance use data. The data is stored on bespoke platforms designed to specific requirements of project developers. Data is processed and analysed primarily to inform and improve project operations and organisational efficiency, but can be adapted and tailored to VVB requirements in order to claim carbon finance. Another purpose of the project developer data platforms is for sharing or displaying data for carbon credit buyers or in some cases increasing transparency through sharing data publicly.

Validation and Verification Bodies (VVBs)

VVBs are responsible for independently assessing and confirming the accuracy and credibility of data collected through digital monitoring systems. In the clean cooking sector, VVBs ensure that the reported information, such as fuel consumption, emissions, and stove usage, is accurate and aligns with established standards and methodologies. Their verification process involves a thorough review of data, often considering historical reports and benchmarking against predefined criteria. Some VVBs are currently in the process of digitising their verification processes for increased efficiency.

End-to-End platforms

Some digital platforms within the clean cooking sector encompass both areas listed above, collecting field data through surveys and monitoring hardware, storing and analysing it on an online database before conducting necessary checks and data validation required for the verification process. In addition, some end-to-end platforms replace traditional verification processes entirely, such as Cavex.

Finance & Marketing applications

Finally, some organisations are focussed on selling ‘higher quality’ carbon credits, and are using dMRV to increase the accountability and transparency of the data collected, offering less risk of over-counting. Through dMRV they are offering verified carbon credits backed up by robust data, and in doing so are able to charge a premium on the credits sold. These platforms are using dMRV principles and technology but are primarily concerned with marketing and selling carbon credits.

3.5. Key Players

The clean cooking ecosystem showcases multifaceted applications of dMRV, with platforms catering to project development, independent verification, end-to-end solutions, and specialised finance and marketing endeavours, each contributing to the overall transparency, efficiency, and credibility of clean cooking initiatives. A summary of some relevant dMRV platforms and their functionalities are presented Table 6. Many of the digital practices described are common across many project developers, and the list presented is by no means exhaustive of all players in the sector.

Table 6: Summary of functionalities of existing dMRV platforms.

Functionality	ATEC	A2EI	Cavex	Cynk	ixo	Nithio	Power Solve	Pulse (BBOXX)	Shift Carbon	Sustain CERT	TraceEx	Verst Carbon
Project data management	✓	✓	✓		✓		✓	✓		✓		✓
IoT Integration	✓	✓	✓	✓	✓			✓	✓			✓
Automated emission calculation	✓		✓	✓	✓		✓			✓	✓	✓
Data showcasing[33]	✓	✓	✓	✓	✓	✓			✓		✓	✓
Carbon credit sales			✓	✓	✓				✓			✓
Defined own standard/ methodology			✓		✓							
Relevance to clean cooking[34]	BG, eC	eC, BD, ICS	eC, BD		ICS	eC	ICS	LPG				ICS, eC
Blockchain/DLT			✓	✓	✓						✓	✓
Revenue sharing with users	✓		✓		✓							✓
Open Source		✓										

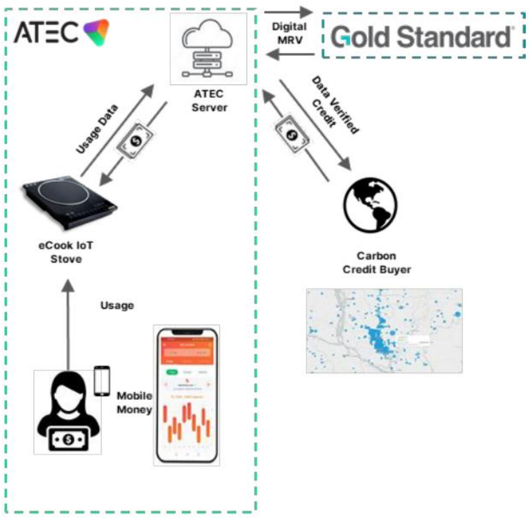
33 (to the public/investors/buyers),
34 LPG, eCook (eC), biogas (BG), Improved Cook Stoves (ICS)

3.5.1. Project Developer Data Platforms

ATEC

ATEC operates as a global provider of affordable and accessible clean cooking solutions for Base of the Pyramid households, offering two products: biodigesters and electric induction stoves. ATEC leverages data-driven insights to reduce carbon emissions and improve household livelihoods, embedding finance PAYGO technology facilitating affordable monthly repayments.

ATEC's patented IoT-enabled induction stove tracks usage data and feeds real-time information into their proprietary dMRV Platform. Their platform facilitates data verification through enabling API access to verifiers, enabling the issuance of authentic carbon credits. ATEC's data-verified carbon credits ensure transparency and accountability, eliminate over-crediting risks, and foster trust among stakeholders. Revenue sharing with cooking appliance users based on verifiable usage data incentivises households to adopt modern cooking practices.



Currently, ATEC is piloting their cook-to-earn model in Bangladesh and Cambodia. This unique approach incentivises households through direct carbon credit micropayments linked to usage levels. By promoting the adoption of modern cooking solutions, ATEC aims to achieve significant carbon emission reductions and enhance household well-being. (Image source [35])

https://www.atecglobal.io/

Pulse (BBOXX)

BBOXX is a leading provider of off-grid solar solutions, and their Pulse data platform serves as a centralised system for managing and monitoring BBOXX's solar home systems. It leverages Internet of Things (IoT) technology to enable efficient data aggregation and analysis, allowing real-time tracking of energy usage, system performance and sales, as well as having functionality to remotely monitor, control and troubleshoot solar systems, ensuring optimal functionality. The platform also facilitates affordable access to electricity through flexible instalment payments with an integrated PAYGO model. With regards to clean cooking, Pulse is currently being used for LPG stoves, where monitoring of canister sales can be manually entered into the pulse platform for analysis. Electric cooking solutions for off-grid solar solutions are currently unfeasible due to constraints on cost and energy supply, but Pulse will have full capability for dMRV for off-grid clean cooking if and when this changes. Pulse is currently only functional for BBOXX products, with plans to expand the service to third parties in the future.

https://www.bboxx.com/technology/

35 https://www.atecglobal.io/our-products

Power Solve (TASC)

TASC operates across Sub-Saharan Africa distributing Improved Cook Stoves (ICS) and monitoring reductions in wood fuel use among recipient households. Projects are registered with reputable international carbon standards including Gold Standard and VCS Verra to obtain verified carbon credits. Real cooking habits and fuel use are measured through field testing and surveys in a statistically sampled group of participant households, chosen randomly. TASC employs a proprietary cloud-hosted database for recording stove distribution details, financial accounts, and GPS locations, cross-referenced by third-party auditors. Monitoring data is collected through a Survey CTO web-based tool on mobile phones, which is securely transmitted to their bespoke database system, Power Solve, which manages all records and facilitates automated emission reduction calculations directly on the database. The system outputs spreadsheets for auditors, ensuring transparency and accuracy in the distribution and impact assessment of Improved Cook Stoves.

https://tasc.je/who-we-are/

Prospect.energy and Appliance Demand Platform (A2EI)

Prospect Energy, an open-source data platform by the Access to Energy Institute (A2EI) and GET.invest, allows customisation of data flows from on-grid, mini-grid, and off-grid sources and demand including productive use appliances and clean cooking devices. The platform aggregates data and offers fully customisable visualisations, as well as real-time monitoring capabilities and facilitation of remote analysis of technical and payment data. The platform supports automated reporting and analysis, providing a transparent summary of key metrics, efficiency, financial viability, and impact, reducing the need for field visits. The benefits include real-time assessment, enhanced reporting precision, and informed decision-making for energy solutions, ultimately fostering efficiency and attracting additional funding. Data-driven decision-making is enabled through displaying location and concentration of energy solutions on intuitive dashboards.

A2EI's Energy's Appliance Demand Platform (ADP) is a similar cloud-based software specifically focused on appliance data. Their solution helps energy providers, appliance manufacturers, and retailers manage and optimise appliance demand, through: reducing energy consumption by providing insights into appliance use and identification of efficiency improvement opportunities; promoting energy-efficient appliances by providing performance data; and encouraging customer adoption of energy-efficient appliances.

ADP and Prospect Energy are built on the same technology stack, with similar core functionality and features, and can both be used to track and monitor the deployment and impact of clean cooking solutions such as improved cookstoves, biogas digesters, and electric cooking devices. The platforms can be used to create maps that show the location and concentration of clean cooking solutions and analyse the impact of clean cooking solutions on health and the environment. Prospect Energy is designed for managing Results Based Financing (RBF) programs and validating sales data, with ADP designed for analysing individual appliance data in research projects. Modern cooking projects can be monitored in either, but most commonly under ADP.

https://prospect.energy/
https://adp.energy/

3.5.2. Verification and Validation Body Platforms

SustainCERT

SustainCERT is an independent climate impact verifier that was founded in 2018 by the Gold Standard Foundation. The company's mission is to bring credibility to climate action by providing verification services for carbon offset projects and value chain decarbonisation initiatives. SustainCERT is piloting a dMRV Platform to improve the efficiency and transparency of its verification services, by tracking the progress of carbon offset projects in real time. A summary of SustainCERTs proposed Digital Verification Process, comprising onboarding, digital data capture, smart verification, automated emission calculations and verification report issuing is summarised below. The VVB is currently piloting dMRV with renewable energy projects including wind and solar, while also developing methods and tools to expand their dMRV operation to modern cooking projects soon. This may involve digital survey tools with standardised and codified answers, employing algorithms to analyse survey data, and checking parameters for Emission Reduction (ER) calculations. While there's a current emphasis on traditional cookstove surveys, SustainCERT is also exploring ways to access and verify monitored eCook devices usage data for broader applicability of their dMRV platform within the modern cooking sector.

https://www.sustain-cert.com/

Earthood

Earthood operates as a Carbon Verifier under various carbon standards, including CDM, VCS Verra and Gold Standard, engaging in over 2500 carbon offset projects worldwide. They specialise in providing verification report services for project developers and serve as auditors for carbon projects. Notably, Earthood focuses on clean cooking carbon projects in Africa and Southeast Asia, predominantly involving cook stoves and utilising the TPDDTEC methodology. In the realm of Earthood's dMRV initiatives, they are actively collaborating with a technology provider to merge their carbon and auditor expertise with technological capabilities, aiming to develop a robust dMRV plan. Their motivation lies in encouraging more VVBs to adopt digital solutions for project developers.

Earthood envisions an ideal scenario where data from projects is seamlessly integrated into software that generates standardised reports. These reports undergo cross-verification in auditing tables, addressing any raised issues online, and facilitating the online submission of verified data to established standards. This digital approach will allow standards to access data on cloud-based platforms, ensuring transparency in protocol adherence and calculation accuracy. Recognising the potential of dMRV, Earthood emphasises the importance of it being able to reduce on-site visits in order to be truly valuable to project developers.

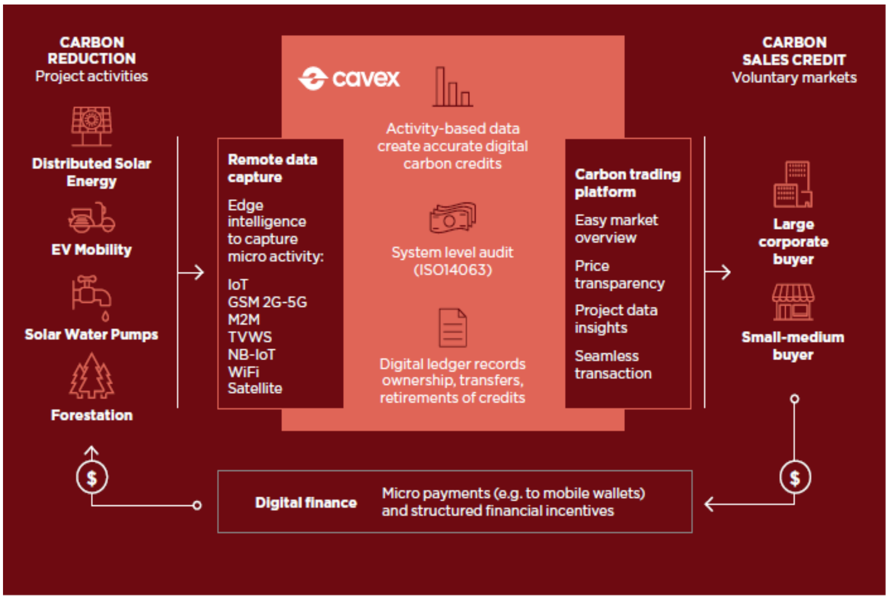
https://www.earthood.in/

3.5.3. End-to-end Platforms

Cavex (4R Digital)

The Carbon Value Exchange Platform (Cavex), developed by 4R Digital, operates as a cloud-based marketplace that simplifies the gathering, validation, and monitoring of data for small climate-positive projects, fostering transparent trading. Leveraging IoT and Machine to Machine (M2M) connectivity, it remotely oversees project activities to evaluate their carbon impact, consolidating the verification process and substantially lowering the expenses associated with issuing high-quality carbon credits. Additionally, the platform directly enables micropayments from carbon credit sales to participants in the projects, promoting increased financial support for local initiatives addressing climate change and sustaining livelihoods in the Global South.

Cavex offer the first end-to-end platform that collects data from devices, analyses it, verifies it and sells the carbon impact. This carbon impact is not certified by an existing standard-setting body, but represents a proprietary product. Cavex wants to rely on best-practice and scientific consensus for carbon impact valuation, which may draw on existing methodologies from the standards. They are trialling clean cooking prototypes with electric cooking and biodigesters, as well as projects related to reforestation, electric vehicles, distributed solar, and solar irrigation. Currently, the platform is in its pre-commercial development phase, with the minimum viable product undergoing testing. Upon its launch, the Cavex platform will be designed for scalability across diverse use cases and geographic regions, both within and beyond Africa. (Image Source [36]).



https://www.cavex.io/

Verst Carbon

Verst Carbon is a comprehensive carbon markets technology provider, offering a platform that connects project developers with investors through their integrated dMRV system, a technology-driven approach that significantly reduces lead times for project verification and credit issuance, leading to both time and cost savings. Verst Carbon leverages technology partnerships to incorporate IoT devices for energy projects, satellite imagery for nature-based projects, and blockchain for transparent MRV processes, ensuring visibility and auditability. They offer pre-financing solutions to take down the cost barrier for project development, and

36 https://www.gsma.com/mobilefordevelopment/resources/digitalising-innovative-finance-emerging-instruments-for-early-stage-innovators-in-low-and-middle-income-countries/

they disintermediate the carbon markets value chain to avoid revenue leaks through intermediaries.

As a blockchain-based platform, Verst Carbon ensures the prevention of fraudulent activities by providing full transparency and auditability of all transactions. Through the tokenization of carbon credits, the platform employs smart contracts to handle various aspects, such as revenue repatriation and credit custody tracking, eliminating human error. The dMRV system developed by Verst Carbon extends to monitoring Improved Cookstoves and electric (induction cookstoves) projects, among other carbon initiatives.

A notable feature of Verst Carbon is its commitment to community impact and the facility for carbon revenue to be repatriated back to the community. While the platform facilitates data sharing between project developers and VVBs, its primary users are investors and project developers. There is an envisioned future where VVBs may adjust their standards to potentially replace the need for physical visits to project locations, particularly in Africa.

https://verst.earth/

ixo

ixo provide an end-to-end digital platform for clean cooking. This includes collecting verifiable data from IoT sensors, mobile money services and engagement surveys, amongst other sources. Claims are processed using artificial intelligence engines to apply methodologies, with tokenised carbon credit issued. A decentralised blockchain based digital registry is used for exchanging and retiring credits. This is interoperable with other digital exchanges and traditional registries. The marketplace platform provides peer-to-peer sales and trading of the carbon credits issued.

ixo has introduced a unique financing mechanism by selling digital twins for clean cookstoves. These digital twins confer ownership rights to future Impact Credits generated by the stove. This innovative financing approach accelerates the scalability of clean cooking projects, allowing for the deployment of two additional cookstoves to households for each digital twin sold.

https://www.ixo.world/solutions/clean-cooking

3.5.4. Financial & Marketing Platforms

CarbonClear

CarbonClear is a new data-driven carbon credit model that aims to make the carbon market more transparent and inclusive. They use technology to track carbon credits and make them more accessible to buyers and sellers. CarbonClear is leveraging its success in the off-grid solar sector to expedite the advancement and dissemination of next-generation clean cooking solutions. The focus is on facilitating access to the carbon market for manufacturers and distributors of such technologies. To realise this goal, CarbonClear has established the Clean Cooking Carbon Finance Initiative (CCCFI), a collaborative working group comprising industry stakeholders. The CCCFI aims to foster the development of tech-enabled and data-driven solutions, mobilising climate finance for the emerging clean cooking 2.0 sector. Key initiatives within CCCFI include designing and implementing pilot projects, creating and validating data-driven methodologies, showcasing technology demonstrations, and testing and implementing innovative financial instruments. These efforts collectively seek to attract upfront capital and drive sustainable growth in the clean cooking sector.

https://www.carbonclear.earth/

Nithio

Nithio is a digital platform that connects solar energy project developers with investors. The platform uses artificial intelligence (AI) to review and assess project proposals, and it provides investors with a secure and transparent way to invest in solar energy projects. Nithio's niche as an energy financing platform is provided by its cutting-edge credit risk analytics engine. The platform harnesses extensive sector knowledge, geospatial data, and AI capabilities to predict repayment patterns across consumer segments. Nithio can offer detailed insights into projected cash flows, facilitating the financing of energy access technologies. Nitio have recently partnered with CLASP to launch a financing facility to catalyse uptake of productive use appliances across Africa, including electric cooking devices[37]. The move to the modern cooking sector coupled with the adaptable data approach of Nithio positions it seamlessly for integration into the requirements of dMRV for climate finance.

https://nithio.com/

3.5.5. Potentially Relevant Non-Cooking dMRV platforms

Cynk

CYNK utilises distributed ledger technology (DLT) to build a blockchain-empowered financial and technology platform that facilitates the creation of high-quality carbon credits and financing of climate action projects at scale. CYNK's technology is designed to address the challenges of the existing carbon market, such as transparency, fragmentation, and lack of accessibility. Key features of CYNK's technology include data capture and verification including IoT sensors, satellite imagery, and trackers; creation, management, and trading of high-quality carbon credits; a decentralised exchange specifically designed for climate assets through structured token offerings (STOs) to provide financing for climate action projects; and real-time monitoring and reporting of project performance. The use cases are currently in renewable biomass, nature-based solutions, blue carbon, regenerative agriculture, renewable energy and biodiversity.

https://cynk.io/technology

ShiftCarbon

Shift Carbon was created to provide a rigorous and transparent framework for developing and trading high-quality carbon credits that can be used to meet corporate sustainability goals, offset emissions, and invest in climate action. ShiftCarbon's dMRV Automation offers a precise and error-free method for verifying carbon credits, enhancing the voluntary carbon market through intelligent, cost-efficient, and self-service technology, all powered by an award-winning enterprise cloud platform. The current primary application of this technology is the monitoring of energy consumption in buildings, including lighting and HVAC through the use of IoT to provide real-time usage data. This data enables the identification of high energy

37 https://www.clasp.ngo/updates/press-release-clasp-nithio-with-support-from-the-global-energy-alliance-for-people-and-planet-launch-financing-facility-for-productive-use-appliances/

consumption areas and allows for optimization to reduce emissions. The platform does not currently cater for clean cooking projects.

https://www.shiftcarbon.io/product/shiftcarbon-mrv-automation

TraceEx

TraceX is an innovative sustainability platform that harnesses the power of blockchain technology to accurately measure and report climate-related outcomes. Key features include its ability to capture and record data in a secure and transparent manner through blockchain technology, firstly to build traceable, transparent and sustainable supply chains, and secondly to measure, reduce, offset and report on carbon within supply chains. Their blockchain approach with digital distributed ledgers ensures data integrity and reduces the risk of manipulation, providing users with trustworthy information. One of the platform's standout capabilities is its capacity to monitor and report on various climate metrics, such as greenhouse gas emissions, energy consumption, and resource utilisation. This real-time data tracking empowers users to make informed decisions, set meaningful sustainability goals, and assess the effectiveness of their eco-friendly initiatives. TraceEx differs from many other players mentioned here in that its platform targets the demand side rather than the supply side of carbon markets, i.e. companies that want to quantify their carbon footprint and offset. Currently the primary target industries are agricultural value chains including dairy, livestock, poultry and seafood.

https://tracextech.com/

3.6. Technical Considerations for dMRV in the Clean Cooking Sector

Having outlined why dMRV can benefit modern cooking projects, as well as the guiding principles and key dMRV players within the sector, this section provides critical technical considerations for project developers to integrate into their projects when embarking on dMRV. Specific guidance from the Gold Standard MMMECD and other methodologies is sparse, with only some requirements regarding monitoring frequency, calibration and that project developers should keep an up-to-date database of relevant data (see Table 2).

With a lack of specific guidelines from the standards, the considerations presented here have been collated through an assessment of current working project developers and relevant literature[38] [39]. The motivations for a project developer to consider the aspects listed below are to improve the accuracy, transparency and authority of carbon credits claimed. This addresses a current perceived lack of trust and integrity in carbon markets, improved through digital monitoring systems to ensure data is accurately and transparently reported. Ultimately, following these considerations will improve integrity and associated carbon revenue. The technical considerations are focussed on data handling and aimed at project developers looking to set up or improve their dMRV processes and are summarised in themes of data validation, transparency, calculating emissions, user access control, security of databases, permanence of data and inter-platform communication. Considerations and costs for hardware are covered in the next chapter.

38 https://www.climateledger.org/resources/Digital_Verification_White_Paper.pdf
39 https://www.ebrd.com/digitised-mrv-protocol.html

3.6.1. Setting up a data platform

Many project developers implementing monitoring systems for modern cooking activities have already developed their own proprietary data management platforms for fuel or appliance sales, finance or asset monitoring, with energy consumption and other data required for carbon certification integrated within the platform, potentially including baseline data and calculated emission reductions.

Implementing a full data platform from scratch requires a relatively high level of technical expertise and requires time and financial resources, along with on-going IT support for security and maintenance. The information provided here is a high-level overview of some options available. If the project developer does not have the resources available to implement a full data platform then it is strongly recommended that they work with a partner organisation who is able to provide those services.

Data platform servers

Traditionally a data platform would be implemented on a server (a computer optimised for connection to the internet) with database and associated software packages. It would be the server owner's job to ensure the server remains powered and connected to the internet, including backing up any data and keeping all software packages up to date. This requires time and resources to implement and maintain. If the server is only in one physical location then there could also be issues with loss of data and, depending upon the server and local network capabilities, communication congestion.

Recent trends in cloud-based computing utilise a PAAS ('platform as a service') or SaaS ('software as a service') provider, so that the processing requirements and costs can be quickly scaled up and down as required. This also allows secure and robust data, with back-ups on multiple server locations. The network capabilities are maintained to ensure connections can be made, even with multiple simultaneous requests from monitoring devices. The cloud-based computing provider also updates software packages and implements security patches. Cloud based computing services are priced highly competitively and are probably the most economical solution. Current providers of cloud-based software and platform services are outlined in Table 7.

Table 7: Current providers of cloud-based software and platform services for clean cooking dMRV.

Azure https://azure.microsoft.com/	A cloud computing platform run by Microsoft. Azure can provide software as a service, platform as a service and infrastructure as a service. More than 600 applications and services offered, including IoT services and data storage.
Amazon Web Services (AWS) https://aws.amazon.com/	Subsidiary of Amazon that provides cloud computing platforms. AWS provides more than 200 services and applications, including IoT services and data storage.

Google Cloud https://cloud.google.com/	Google cloud provides over 150 products including databases, artificial intelligence and smart analytics.
IBM Cloud Services https://www.ibm.com/cloud	IBM cloud can provide a full stack cloud platform with over 170 products and services covering data, containers, AI, IoT, and blockchain.
Heroku https://www.heroku.com/	Heroku is a platform as a service based on a managed container system, with integrated data services, for deploying and running modern apps. Heroku offers support for a wide range of programming languages such as Java, Ruby, PHP, Node.js, Python, Scala, and Clojure and runs applications through virtual containers known as Dynos.
Dokku https://dokku.com/	Dokku is an open source PAAS, billed as an alternative to Heroku. Dokku is available to be installed on any hardware, including the cloud-based services listed above.

Database solutions

Within the cloud-based server, data from the monitored devices must be stored within some form of database. A wide variety of databases available can be implemented, with some options outlined in Table 8.

Table 8: Database solutions available for clean cooking dMRV.

Microsoft IoT Hub and **Microsoft IoT Central** https://azure.microsoft.com/en-gb/products/iot-hub https://azure.microsoft.com/en-gb/products/iot-central	Azure IoT Hub provides a cloud-hosted backend solution to connect virtually any device and enable highly secure and reliable bi-directional communication between Internet of Things (IoT) applications and the devices it manages. Azure IoT Central is a ready-made user interface and API surface for connecting and managing devices at scale. It is a pre-assembled PAAS offering which can be easily implemented on Azure.
AWS IoT Analytics https://aws.amazon.com/iot-analytics/	AWS IoT Analytics is a fully-managed service to run custom analytics (such as onboarding checks and statistical analysis) and machine learning on large volumes of IoT data. It filters, transforms, and enriches IoT data before storing it in a time-series sequential (SQL) data store for analysis.
MongoDB https://www.mongodb.com/	MongoDB provides multi-cloud database services with scalability, privacy and security built in. Time series data can be uploaded, which can activate triggers and

	functions. It has a non-relational ('NoSQL') database design that focuses on methods for data storage and retrieval.
MySQL HeatWave https://www.mysql.com/products/mysqlheatwave/	MySQL is an open-source relational database. MySQL HeatWave is a fully managed database service that combines transactions, analytics, and machine learning services into one MySQL Database.
InfluxDB https://www.influxdata.com/	InfluxDB is an open source database for storage and retrieval of any time-series data, including Internet of Things sensor data and providing real-time analytics

Visualisation Solutions

Visualisation solutions can be implemented to allow reports to be generated and data to be viewed by different stakeholders. For example, funding organisations may be interested in seeing high level project impacts, while more detailed operational and maintenance reporting could be provided to field agents. A selection of visualisation solutions available, which can be integrated with the databases listed above within the suite of cloud-based solutions, are listed in Table 9

Table 9: Visualisation solutions for clean cooking dMRV.

Grafana https://grafana.com/	Grafana provides flexible dashboard and visualisation services for any type of data from multiple existing sources. It does not require the data to be ingested, but unifies existing data from different locations. Grafana is open-source, but also provides full-managed cloud-based services.
PowerBI https://powerbi.microsoft.com/	Power BI from Microsoft is an interactive data visualisation software package. It was originally developed to provide static and interactive business analytics reporting. Data can be ingested from various sources, including pdf and excel, and then processed, visualised and shared.
Tableau https://www.tableau.com/	Tableau is a data analytics platform focussed on business intelligence. It can connect to multiple data sources, including pdf and excel, to provide report and visualisations.
Quicksight https://aws.amazon.com/pm/quicksight/	Quicksight from Amazon is a cloud-based business analytics service to build visualisations, perform analysis and provide insights from data sources. It is scalable and designed for seamless integration with AWS data sources.

The information provided within this 'Setting up a data platform' section is a very brief overview of the wide variety of options available for different solutions. Working with an IT solutions company that has provided similar systems and who can guide the project developer through this process is highly recommended.

3.6.2. Data Security

Data is the keystone of any dMRV system and security of databases to provide a robust and protected environment data is of paramount importance. The encryption of databases within all stages of dMRV platforms is a fundamental safeguarding measure. While encryption methods may vary, industry-standard protocols, such as Advanced Encryption Standard (AES), covered in Section 4: Monitoring Technology & Hardware are commonly employed to secure data at rest and in transit. This ensures that even if unauthorised access occurs, the data remains unintelligible without the corresponding decryption key. Employing firewalls, and regularly updating security patches to defend against potential vulnerabilities adds to data security.

Data backup is another crucial component of database security. Regular and automated backups are conducted to prevent data loss due to unforeseen circumstances. Many dMRV platforms adopt a strategy of storing data on multiple servers or utilising redundant systems. This redundancy ensures data availability even in the event of server failures, contributing to the overall resilience of the platform.

dMRV platforms often rely on cloud solutions that adhere to industry standards and regulations, implementing robust privacy controls and compliance measures to safeguard user data. These solutions encompass encryption during data transmission, strict access controls, and compliance with data protection regulations.

While individual dMRV platforms may have unique implementations, the prevailing industry practices emphasise a multi-faceted approach to database security. By adopting encryption, stringent access controls, robust backup strategies, and leveraging secure cloud solutions, the clean cooking sector can instil confidence in the integrity and security of its dMRV processes, while still allowing transparency of data processes.

3.6.3. Data Transparency

Enhancing transparency and traceability in dMRV for clean cooking projects is crucial as it significantly boosts credibility. Specifically, dedicated digital solutions are purposefully designed to increase transparency, thereby enhancing the value of carbon credits, particularly in cookstove projects. Utilising dedicated data platforms and public dashboards, accessible to various stakeholders, ensures that credit buyers can obtain detailed insights into projects, thereby understanding the origins of the associated carbon credits. Additionally, in certain instances, clean cookstove users are provided access to dashboards, leading to reported increases in usage, further emphasising the positive impact of transparency in the dMRV process.

Transparency can be improved through design by structuring the database in a way that limits raw data manipulation. Restrictions can enable ‘append only’ operations including tagging, labelling, new data derivations and calculations, but not allowing changes to be made to original data itself. Additionally, ‘status’ labelling, such as “passed statistical check”, “approved by VVB”, “rejected”, allows for further transparency, as does allowing each event, operation, or status change to be logged and ascribed to the specific users responsible for the event.

3.6.4. Data Validation

Ensuring integrity and reliability of data is paramount and achieved through robust data validation procedures, encompassing various checks and measures to guarantee the accuracy and reasonability of the collected data. These are summarised in Table 10 taken from a dMRV protocol proposed by South Pole[40]:

Table 10: Recommended checks and measures to guarantee accuracy and reasonability of collected dMRV data.

Onboarding/ Import Checks	During the initial data onboarding or import, the system can perform rigorous checks to verify the format, file size, file type, and originating server address. Additionally, it can validate other identifiers such as meter ID, ensuring that the incoming data adheres to the expected standards. The system should have the ability to raise alerts in case of discrepancies. The system can also perform a comprehensive data transfer test, assessing potential challenges such as connection failures, outages, and missing values.
Numerical/ Statistical Checks and Quality Control	To maintain data accuracy within the expected range, numerical and statistical checks can be implemented. This includes as a minimum ensuring that the data falls within the operational range of the logging device. Advanced mathematical and statistical methods can detect and assess irregularities or inconsistencies in project performance. Artificial Intelligence and machine learning can contribute to improving these assessments over time. The dMRV system can employ rigorous quality control measures to identify outliers, inconsistencies with comparable projects, and missing values. Checks include verifying data against plausible ranges, assessing distribution patterns, and conducting dynamic checks to identify implausible jumps in consecutive data points. This ensures the overall reliability and coherence of the data.
Plausibility Cross-Checks	Peripheral information can also be collected to allow cross-checks for plausibility, with the key check being the theoretical maximum output is based on parameters that influence (and correlate with) the project's performance. For instance, in renewable energy projects, theoretical maximum output is calculated based on solar irradiance from onsite measurement and/or online irradiation databases. While this is more challenging for cooking projects, ongoing data collection efforts allow for comparison against established patterns and historical data. Additionally, a portfolio of peer projects with similar features can be compared, assessing deviations from simulation data, and establishing correlations with internal data such as journal/logbooks, inventories, and purchase receipts. External data sources, such as weather or temperature data, can provide further sources of cross-checks.

40 https://www.ebrd.com/digitised-mrv-protocol.html

Handling Discrepancies	In case of discrepancies during cross-checks, the dMRV system flags instances and allows for additional evidence and explanations, ensuring the use of conservative values in calculations. Alarms and alerts are sent for major data gaps, system malfunctions, or non-compliance with integrity checks. Regular maintenance and testing triggers alarms, and calibration checks are addressed conservatively.
Error Resolution Process	For errors, data gaps, or failed automatic checks, database operators should be informed promptly. The system should offer the option to complete or correct faulty datasets through manual submission of commented information to the dMRV platform, ensuring data accuracy and completeness.

3.6.5. Emissions Calculations

In order to calculate GHG emission reductions, the energy consumption data from monitored cooking devices needs to be processed in accordance with the applied carbon methodology. This includes a comparison of baseline data with project data, while also accounting for leakage emissions as detailed in Section 2.2 Methodological Requirements and Opportunities for dMRV. In an integrated dMRV system, this calculation could be automated and the algorithm only verified once at the beginning of the project activity. Once verified, the algorithm has to be securely controlled and may not be accessed and changed, in order to make carbon claims.

To ensure accountability, the algorithm must be securely controlled in all locations it is stored or used, including project developer data platforms or “end-to-end” platforms. Measures to ensure this accountability include:

- restricting and monitoring access to the algorithm,
- applying version control to track any updates,
- ensuring all conversion factors are open and recorded during any calculation, and
- ensuring any adjustments are recorded with a name/date and verified.

These measures make any changes available for a VVB to see if needed and ultimately improve the integrity of data and hence confidence in the reported emissions reductions.

To maintain traceability and facilitate auditing, the processed data at each step of the calculation should be stored in a distinct column or section within the dMRV database. This separation ensures that every calculation step can be thoroughly verified and examined at any given time.

3.6.6. User Access Control

To ensure accountability of any data stored, it is imperative to establish a robust framework that provides control over access levels for different users to distinct datasets. This involves implementing customisable access rights and functions tailored to various user roles, such as project owners (PO), Coordinating/Management Entity (CME)[41], VVB, standards bodies, and potentially cookstove manufacturers and entrepreneurs. The objective is to ensure that each

41 The CME in UNFCCC nomenclature is the entity in charge of a Programme of Activities (PoA), that is authorised by host country DNAs and the one that communicates with the standard-setting body.

user has access only to the relevant information and functionalities necessary for their role in the dMRV process.

Furthermore, stringent measures must be in place to guarantee compliance with local and national data regulations. This involves imposing restrictions on the accessibility of detailed (raw) data based on predefined access rights. For instance, specific limitations may be set for the execution of non-automated audits, and access to comprehensive information and reports may vary according to the user's role and responsibilities. By addressing these technical considerations in User Access Control, the dMRV system can maintain data integrity, confidentiality, and regulatory compliance while facilitating efficient collaboration among diverse stakeholders in the clean cooking sector. Recommended user roles and their access rights to data are outlined in Table 11.

Table 11: Recommended user roles and their access rights to data[42].

Data Point / User Role	Project Owner	CME / Consultant / Portfolio Manager	VVB	Standards Body
Emission factor	Read	Create / Read	Read	Read
Generation data	Read	Read	Read	Read
Emission reductions	Read	Read	Read / Approve	Read
Data for cross-checks and notifications	Read	Read	Read	Read
Calibration certificates	Read / Update (via upload)	Read	Read / Approve	Read
Issuance request forms	Create / Read / Update (automated preparation of issuance request forms)	Create / Read / Update (automated preparation of issuance request forms)	Read	Read
Issuance confirmation (status information fed back from issuing body)	Read	Read	Read	Create / Read / Update

3.6.7. Permanence of data

Data permanence is a crucial aspect of dMRV in the clean cooking sector, as without ensuring data immutability, trust and reliability of dMRV systems are at risk of being undermined. To address this challenge, several approaches can be employed:

DLT (Distributed Ledger Technology), including blockchain technology, offers a decentralised and transparent ledger system, providing a tamper-proof record of data. This ensures that once data is recorded, it cannot be altered or deleted, fostering trust in the dMRV process. Project developers can utilise readily available blockchain solutions offered by cloud providers like Amazon Web Services (AWS) or Microsoft Azure. These platforms provide a convenient and scalable way to implement blockchain-based dMRV systems.

Tokenization of Data involves converting data into digital assets, such as tokens, that can be traded or exchanged. Once data is converted into tokens it is recorded on a blockchain and

42 https://www.ebrd.com/digitised-mrv-protocol.html

becomes immutable. This approach can be particularly valuable in carbon finance, enabling fractional ownership of carbon credits and is being explored by Verst Carbon to facilitate more accessible and transparent carbon markets. By adopting these approaches and achieving data permanence, dMRV systems can solidify trust and credibility in the clean cooking sector.

3.6.8. Inter-platform Communications: Ensuring Secure Data Transfer

In the dynamic landscape of dMRV within the Clean Cooking Sector, inter-platform communication arises as project developers engage in various dMRV processes that require the exchange of data between different stakeholders. In order to ensure accountability, security of this data transfer between platforms becomes paramount. Project developers currently typically generate reports summarising data, controlling data access within their platforms. However, direct data transfer may become necessary, such as when interacting with a VVB or sharing raw data with funders or other stakeholders. These interactions often occur over the internet between the project developer's database and another data storage entity linked to an external dMRV stakeholder or another third-party service.

Ensuring the security of data during these inter-platform communications is imperative to prevent unauthorised alterations or interference. Here, encryption plays a pivotal role in safeguarding data integrity. Typically, automated API calls are employed for these communications, and HTTPS (Hypertext Transfer Protocol Secure) serves as the primary encryption protocol. API calls can be kept secure through the use of unique and confidential API keys, adding an extra layer of protection against unauthorised access. Special attention is given to the security of automated requests made by VVBs, emphasising the need for robust measures to guarantee the integrity and confidentiality of the transferred data. By adopting secure protocols and technologies, the clean cooking sector can establish a foundation for trust and reliability in its dMRV processes.

3.6.9. Challenges

Despite the identified advantages of dMRV for clean cooking projects, several obstacles to successfully deploying these systems encompass multiple challenges including connectivity, cost, lack of coordination and quality of data. These challenges specific to setting up data platforms and wider dMRV are highlighted below, while challenges specific to hardware technology for monitoring data are included in the next chapter.

Limited Technical Expertise

Stakeholders indicated that a high level of IT technical competence is required by a project developer using advanced dMRV systems, with such requirements creating a high barrier to entry for smaller or new project developers looking to implement dMRV for clean cooking projects. Knowledge of implementing data management platforms has been indicated to be paramount and that there is currently a deficiency in technical proficiency during the design and implementation of digital solutions. It is advised that project developers who lack the relevant IT technical competence should partner with or engage the services of an IT specialist.

Addressing these barriers requires concerted efforts to enhance technical skills and foster awareness and understanding of the evolving technologies integral to dMRV systems. Investments of both time and money are needed to overcome these obstacles to build capacity to achieve all the functions that separate dMRV systems from conventional MRVs[43]. Donors, including both bilateral and multilateral entities, are strategically well positioned to support technical assistance programs, specifically targeting dMRV processes in emerging markets. By consolidating insights and opportunities from capacity-building initiatives, such as technology incubation programs, there is potential to generate opportunities for specialised training providers, hardware/software vendors, social enterprises, and public entities[44].

Connectivity

Many areas where clean cooking activities are implemented have limited or unreliable communication connectivity (such as cellular and wired telecoms), hindering the transmission of data collected from monitoring devices to centralised databases or cloud platforms and compromising integrity of datasets. This connectivity challenge can jeopardise the availability and quality of data received and transmitted through dMRV systems, discussed in more detail in Section 4.7: Communication.

Lagging Standards

The methodologies and overarching guidelines provided by carbon standards to assess emission reductions precede the advent of many emerging digital technologies, but they currently lack specific provisions for incorporating innovative dMRV systems. This poses a hurdle as standard-setting bodies may require real-world experience and practical insights from operating such systems before integrating them into the established carbon project cycle. The misalignment between standards and evolving digital solutions creates a need for an iterative process to ensure seamless integration and effectiveness in monitoring, reporting, and verifying emissions in clean cooking projects.

Cost

The implementation of dMRV incurs initial expenses for setting up digital infrastructure, encompassing sensor and meter deployment, data transfer mechanisms, platform development, software integration, and analytics tools. However, in operational phases, dMRV offers the prospect of long-term cost savings and other advantages as manual procedures for data capture, transfer, and processing can be significantly diminished. Quantifying the specific cost and cost-saving potentials is challenging and varies based on technology choices.

Implementation of dMRV necessitates significant investments in two key areas: monitoring hardware and software for the capture, transmission, storage, and management of the data. A white paper on dMRV by The Climate Ledger Initiative prepared for SustainCERT[45] estimates hardware costs at around USD 20-40 per cooking device, which could drop to USD 5-10 through economies of scale and integration of sensors into the cooking device. Regarding

43 dMRV Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets https://documents1.worldbank.org/curated/en/099605006272210909/pdf/IDU0ca02ce8009a2404bb70bb6d0233b54ffad5e.pdf
44 https://www.gsma.com/mobilefordevelopment/resources/digitalising-innovative-finance-emerging-instruments-for-early-stage-innovators-in-low-and-middle-income-countries/
45 https://www.climateledger.org/resources/3701a-Digital-MRV-report-master1.pdf

software, it assumes that a robust system including APIs, databases, a dashboard with user management system, data checks and carbon calculation would cost around USD 100k-300k. Chapter 4 contains detailed information on the roles and requirements for a project developer setting up a dMRV system and what these costs comprise.

Digital infrastructure susceptible to climate change related damage

A key challenge facing dMRV systems arises due to the vulnerability of digital infrastructure to climate change-related damage, specifically from the potential impacts of extreme weather events, such as floods, storms, or extreme temperatures, which can damage or disrupt the functioning of sensors, meters, and communication networks. This risk is increased as clean cooking projects are implemented exclusively in the Global South which suffers the worst impacts of climate-induced extreme weather (REF). The reliability and effectiveness of dMRV systems are compromised when digital infrastructure including hardware and communication channels, is adversely affected by climate-induced events. Strategies to mitigate this challenge involve incorporating resilient design features into the digital infrastructure and adopting climate-smart technologies that can withstand environmental stresses, ensuring robustness and longevity in the face of climate change impacts.

Lack of incentives for data accuracy

A challenge regarding the adoption of digital monitoring systems also arises from the fact that higher data accuracy and reliability is not necessarily in the interest of project stakeholders, when the aim is to maximise carbon credit volume. Traditional monitoring methods that rely on surveying have often been criticised for overestimating GHG emission reductions, as users tend to overstate the usage of the project cooking device. More accurate usage monitoring could lead to significant reductions in claimable emission reductions. It is not only project developers that may have an interest in maximising impact claims, but also host countries, if the achieved emission reductions are counted towards their NDC or are traded as ITMOs.

As more robust monitoring techniques will likely reduce the amount of GHG emission reductions to be expected from clean cooking activities, higher prices for the resulting carbon credits are necessary to balance this. Furthermore, it can be expected that many project participants will be hesitant to adopt these techniques, as long as they are not required or incentivised to do so by the standard setting bodies. For modern cooking technologies to be able to compete in carbon markets, this means that reliable monitoring needs to also become a reality for biomass cooking activities, which otherwise may be considered to have an unfair advantage.

3.6.10. Lack of coordination

Effective dMRV systems rely on collaboration among various entities, including project developers, standard-setting bodies, VVBs, technology providers, data analytics firms, and research institutions. The identified current absence of streamlined coordination within the clean cooking dMRV sector hampers integration of technologies, data sharing, and the development of standardised protocols. This challenge is evident by the lack of industry standards and can result in inefficient data collection, inconsistent reporting, and difficulties in aligning efforts across different areas within the ecosystem. Overcoming the lack of coordination requires enhanced collaboration, partnerships, information sharing and communication strategies among stakeholders to ensure the successful implementation and scalability of dMRV initiatives in the clean cooking sector.

Despite encountering obstacles to widespread adoption, such as the complexities and initial expenses associated with implementation, the anticipated advantages of dMRV systems in the context of clean cooking projects are substantial. These systems are expected to decrease the overall cost of creating carbon assets, enhance transparency and security in transactions within the carbon market, and potentially enable the tokenisation of carbon assets. Furthermore, they facilitate intermittent, system-wide verification of monitoring systems, paving the way for a shift towards the real-time generation of carbon credits in the realm of clean cooking initiatives.

3.7. Future developments

The dMRV landscape for clean cooking projects is poised for significant advancements in the coming years, driven by technological innovations, evolving methodologies, and a growing emphasis on data integrity and transparency. These developments hold potential to enhance the effectiveness and credibility of clean cooking interventions, through enhancing efficiency and accuracy in monitoring and reporting emissions reductions. Key areas of focus include:

Integration of Advanced Sensors and IoT Technologies: Future dMRV systems are expected to increase leverage of advanced sensor technologies and Internet of Things (IoT) devices to capture real-time, granular data on cooking activities. Integration with smart cookstoves equipped with sensors can provide detailed insights into usage patterns, fuel consumption, and emissions, offering a more comprehensive understanding of project performance, discussed in more detail in Section 4.

Blockchain for Enhanced Transparency: Blockchain technology is anticipated to play a role in providing enhanced transparency and traceability in the dMRV process. By utilising blockchain, the entire lifecycle of carbon credits—from data collection to verification and issuance—can be securely and transparently recorded. This ensures an immutable audit trail, reducing the risk of data tampering and increasing credibility.

Standardisation and Interoperability: Future developments will likely focus on standardising data formats and interoperability among different dMRV systems. Standardisation can facilitate smoother data exchange and collaboration between stakeholders. This interoperability is crucial for creating a cohesive ecosystem where multiple projects and systems can seamlessly interact.

Machine Learning, Predictive Analytics and AI: The incorporation of machine learning algorithms, predictive analytics and AI holds significant potential in optimising data analysis. These technologies can forecast trends, identify anomalies, and enhance the accuracy of emission reduction calculations. Such models can adapt and improve over time, refining their understanding of project-specific dynamics leading to more efficient verification processes.

Enhanced User Accessibility and Training: Future developments will prioritise user-friendly interfaces and accessibility, ensuring that project developers, verification bodies, and other stakeholders can easily navigate and utilise dMRV systems. Robust training programs and support mechanisms will be crucial to empower users with the skills needed to maximise the benefits of digital monitoring and reporting.

Global Collaboration and Knowledge Sharing: The clean cooking sector will benefit from increased collaboration among stakeholders globally. Platforms for sharing best practices, lessons learned, and innovative approaches to dMRV will foster a community-driven approach to addressing challenges and advancing the field collectively.

An initiative promoting this approach is the Digital 4 Climate (D4C) initiative[46] which aims to promote the adoption of digital technologies, including blockchain and tokenisation, in dMRV systems for carbon markets. The initiative recognizes the crucial role of data permanence in ensuring the integrity and credibility of dMRV systems, which are essential for verifying the carbon emission reductions or removals achieved by clean cooking projects. It is a collaboration between large international players including the European Bank for Reconstruction and Development, the United Nations Development Program, UNFCCC, the European Space Agency, the International Emissions Trading Association, and the World Bank Group and has an aim to coordinate the respective work streams and creation of an end-to-end digital ecosystem for the carbon market.

The joint initiative aims to establish a unified framework for the modular components of ecosystems encompassing digitised methodologies, dMRV systems, data management practices, registry systems, and issuance engines. All these components will be interconnected through a metadata layer maintained by the Climate Action Data Trust and coordinated via a standardised digital workflow. The initiative has developed the South Pole authored dMRV standardised protocol which has been piloted on renewable energy facilities and referenced frequently in this chapter (see Table 10 and Table 11). The cloud-based software solution collects real-time data from renewable energy plants, automatically validates and cross-checks the collected data, calculates greenhouse gas (GHG) emission reductions based on the applicable methodology, and generates comprehensive monitoring reports on system-verified GHG emission reductions. Such a system has high applicability for the clean cooking sector, and the move towards standardisation will offer clear guidelines to project developers.

3.8. Selected Resources

Protocol for Digitalised MRV: enhancing efficiency and trust in carbon markets
By: South Pole Published: 2020
https://www.ebrd.com/digitised-mrv-protocol.html

Assessment of Digital Measurement, Reporting, and Verification
By: CLI Published: 2022
https://www.climateledger.org/resources/3701a-Digital-MRV-report-master2.pdf

46 https://www.theclimatewarehouse.org/work/digital-4-climate

Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets
By: World Bank Published: 2022
https://openknowledge.worldbank.org/entities/publication/65c60731-7b65-5ab6-a083-9c4243183607

Digitally Enabled Climate Finance
By: GSMA Published: 2023
https://www.gsma.com/mobilefordevelopment/resources/digitally-enabled-climate-finance/

Principles for Best-Practice Digital Verification
By: SustainCERT Published: 2022
https://www.sustain-cert.com/documents/principles-for-best-practice-digital-verification/download

4. Monitoring Technology & Hardware

This section reviews the requirements for, and availability of, cooking device monitoring hardware specifically in relation to the MMMECD and more generally for future methodologies. A summary of available monitoring equipment is listed, along with a summary of energy measurement techniques and communication methods available.

For monitoring device manufacturers or project developers wishing to gain more in-depth knowledge this section then provides more detailed information. Potential modern cooking device scenarios are highlighted with the aim to standardise terminology within this report. Accurate energy measurement techniques for modern cooking equipment are reviewed and discussed. Communications technology systems for encrypting and transmitting energy consumption data are also reviewed, with a focus on lower cost remote sensing in the Global South. Future trends, challenges and opportunities within this area arising from expert interviews are also highlighted.

4.1. Remote Monitoring Systems

Emission reductions as per the requirements of the MMMECD and other methodologies are calculated from the energy consumption of the modern cookstove used within the project. The cookstove energy consumption data must be:

- accurately recorded,
- securely communicated to the project developer,
- reliably stored within a database which allows:
    - data validation,
    - transparency of data manipulation,
    - compliance with data protection regulations,
    - and control over user data access levels.

This data is provided to the third party VVB for verification in order for the project developer to claim verified emission reductions.

Figure 3 gives an overview of a typical cookstove energy consumption monitoring system from the end user through to reporting to the VVB. Within this chapter the ‘Measurement and Collection’ and the ‘Communication’ areas of a typical monitoring system are covered. The “Processing and Storage” area is part of the dMRV system or project developer’s data platform, which has previously been covered in Section 3: “Digital MRV”.

Clean cooking methodologies, including the GS MMMECD, places the burden of installing and maintaining the full monitoring system on the project developer, including any physical hardware installed, any communications path and any data storage platform.

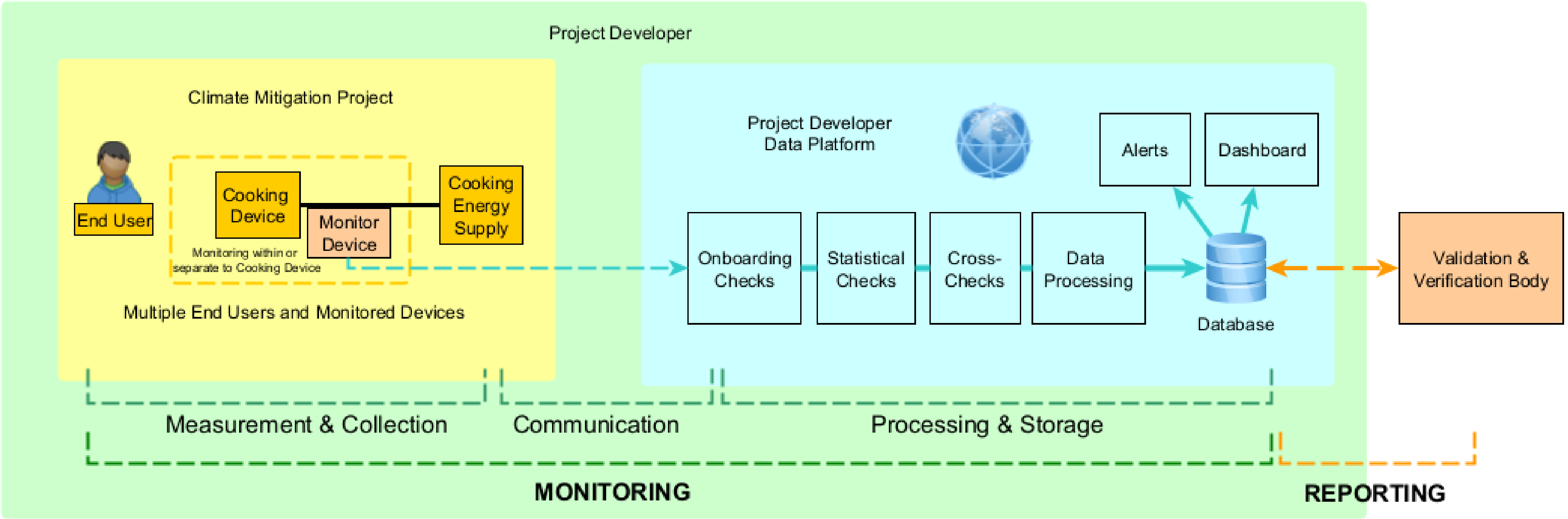


Figure 3: A simplified overview highlighting the measurement & collection hardware and communication systems within dMRV.

(Note: Processing & Storage on the data platform is covered in Section 3: Digital MRV)

The main challenges to implementing monitoring systems, with regards to hardware, are:

- Cost of hardware
- Availability of hardware
- Cost of software and IT services
- Availability of hardware and IT systems expertise
- Connectivity issues
- Lack of standardisation of data formats and systems
- Lack of coordination of stakeholders
- Lack of long-term support for monitoring systems

These are discussed in more detail, as needed, within this section. This technical review has been written with the aim of helping project developers and equipment manufacturers understand and address, and hopefully overcome, these challenges.

4.2. Measurement and Collection: Summary of Equipment

An overview of data monitoring devices already available which may be suitable for use in modern cooking activities is given in Table 12[47]. There are four main forms of monitoring system highlighted here:

4.2.1. Internal

The monitoring device is seamlessly integrated within the cooking device. There are potential cost savings, as the monitoring system can be incorporated alongside or integrated within other control electronics already present, and an additional enclosure is not required. There are also potential benefits with quality control, as this will be added within the clean manufacturing facilities, and economies of scale. The monitoring function is not immediately visible to the end-user, which may reduce tampering issues, but does bring in privacy issues. In-built monitoring units are difficult to repair or replace and project developers may be tied to one appliance provider for the duration of the emission reduction intervention. There are four manufacturers and five units highlighted here, three induction hobs (from ATEC, BURN and Pesitho) and two electric pressure cookers (EPCs) (from BURN and UpEnergy).

4.2.2. External

External monitoring devices are available from A2EI, 4R Digital, Sparkmeter and SteamaCo. Sparkmeter and SteamaCo provide smart meters for grid and mini-grid connections, and data from these meters could be used for monitoring cooking devices and extracting cooking events. A2EI can provide an external meter which can be attached to a cooking device. 4R Digital has a prototype extension lead with two monitored output sockets to supply electric cooking devices (or other appliances). External monitoring devices can be used with any electric cooking device so the project developer is not tied to one appliance manufacturer. Potentially the monitoring devices are more prone to tampering and care must be taken to ensure that cooking data is obtained, as other appliances may be plugged in. For multi-

47 Please note that this is not an exhaustive list, with new products and technology rapidly developing within this emerging market.

appliance monitoring devices, software algorithms are required to pick out individual appliance types, which is covered in more detail within “Energy Measurement Techniques”.

4.2.3. Work with Manufacturers

K-Pay and PowerPay work with appliance manufacturers to add internal monitoring equipment. K-Pay is a technology and software company which provides information to manufacturers to implement monitoring systems, rather than physical devices. Working directly with the appliance manufacturer allows the monitoring solution to be inbuilt, as discussed above.

PowerPay provides both hardware and software services, and, if needed, their monitoring devices can be retro-fitted into appliances. Retro-fitting monitoring equipment requires opening the appliance, potentially voiding any appliance warranty, and there may also be safety implications. Retro-fitted devices can be added to cooking equipment from different manufacturers allowing project developers more flexibility in the appliances they can provide. Retro-fitting can also be relatively low cost for smaller projects.

4.2.4. Gas

LPG monitoring valves are available from BBOXX and PayGo (Sun King). These were developed initially to add PAYGo services to LPG systems, but data from gas consumption can be used for carbon finance. Biogas monitoring systems are available from Inclusive Energy, which were originally developed for operation and maintenance monitoring, but the data can also be used for carbon finance. Safe monitoring devices for gas systems require specialist design knowledge.

More detailed parameters and information regarding these devices is given later in Section 4.8: Equipment Currently Available, if needed.

Table 12: Overview of data monitoring devices already available which may be suitable for use in modern cooking activities.

Organisation:	**ATEC**	**BURN**	**Pesitho**	**UpEnergy**	**KPay Innovation Pvt Ltd**	**PowerPay Africa (GIVE Ltd)**
Product Name:	eCook	ECOA	ECOCA	PowerUP EPC V2	PayGo Technology Provider	PowerPay Africa
					Work with manufacturers to add internal monitoring equipment & PayGo functionality	
Website:	https://www.ecookstove.com/	https://www.burnstoves.com/products/electric/	https://pesitho.com/	www.upenergygroup.com https://www.powerup.works/	https://kpayasyougo.com	https://www.powerpayafrica.com/
Monitor Type:	Internal	Internal	Internal	Internal	Work with Manufacturers	Work with Manufacturers
Overview:	Induction hob - 1 or 2 ring.	EPC and Induction hob versions available.	Induction hob using solar.	EPC with local data monitoring.	Provide monitoring solutions for manufacturers.	Work with manufacturers to add internal monitoring equipment.
Comms:	GSM	GSM	-	Physical: Wired OTG with smartphone	Offline: SMS Online: GSM/Wi-Fi	Different versions: GSM/Wi-Fi/BLE

Organisation:	A2EI	4R Digital	Sparkmeter	SteamaCo	BBOXX	Inclusive Energy	PayGo (Sun King)
Product Name:	A2EI Smart Meter (DDZ1737)	Smart Cookstove Meter	SMRSD - 1 Phase SMRPI - 3 Phase	SAVI smart meters	Smart Cooking Valve	Smart Biogas	CSM Cylinder Smart Meter
		 (Prototype)					
Website:	https://a2ei.org/	https://4rdigital.com https://www.cavex.io/	https://www.sparkmeter.io/	https://steama.co/savi-meters	https://www.bboxx.com/products/smart-cooking-valve/	https://inclusive.energy/smart-biogas	https://www.paygoenergy.co/cylinder-smart-meter
Monitor Type:	External	External	External	External	Gas	Gas	Gas
Overview:	An external smart meter. 60A max. 1 or 3 phase.	An external 2 socket extension lead.	An external smart meter. 60A/100A versions. 1 or 3 phase.	An external smart meter. 60A/100A versions. 1 or 3 phase.	LPG cylinder control and monitoring system.	Range of devices for monitoring biogas systems.	LPG cylinder control and monitoring system.
Comms:	GSM	Prototype: GSM/Wi-Fi/BLE	RF Mesh & GSM	2G/4G & G3-PLC & RF Mesh	GSM	GSM	V1: GSM V2: BLE

4.3. Measurement and Collection: Summary of Techniques

A summary of the main techniques for monitoring cooking device energy consumption is presented in Table 13, with more detail provided later in this section. Note that some of these techniques are currently used in the monitoring devices listed above, while some are still at a development stage and/or not currently approved under existing carbon standards.

Table 13: Summary of main techniques for monitoring cooking device energy consumption.

Technique	Description	Cost to Implement	Suitable for MMMECD?
Economic Records Monitoring	Data regarding the sale of fuel, either LPG & biofuel volumes or PAYGo energy credits can be used for calculating energy used per cooking device. Must ensure that the fuel is used only for the cooking device. Data will not provide real-time cooking events or durations.	LOW	Only for fuel monitoring (not electricity)
Power Setting Monitoring	The power setting of the cooking device is recorded, along with the duration, to calculate the energy consumed. If already measured within the device this may be low cost to implement, but calibration is required to prove the link between power setting and energy consumption.	LOW	Yes - if calibrated
Non-intrusive Load Measurement	If the end user has a 'smart' meter, trained software algorithms could be used to extract cooking events from the energy consumption data. Requires a smart meter to be installed. Algorithms are not yet proven to accurately report cooking events.	LOW	No - Development stage
Current shunt	A resistive element in the load path provides the current value. Provides power and energy values when measured alongside voltage, typically using a specialist power measurement integrated circuit. This is a standard technique, but would require additional circuitry at additional cost. Suitable for AC and DC systems.	MID	Yes
Current transformer	A transformer used on AC systems to reduce the current to smaller values, more suitable for measurement devices. Provides power and energy values when measured alongside	HIGH	Yes

	voltage, typically using a specialist power measurement integrated circuit. Only suitable for AC systems. Potentially isolated measurements, but the transformer & circuitry has additional cost.		
Hall effect sensor	Measures the current through its magnetic field, which is proportional to the current flowing in a conductor. Provides power and energy values when measured alongside voltage, typically using a specialist power measurement integrated circuit. Suitable for AC and DC systems. Hall effect sensors & circuitry can be expensive.	HIGH	Yes
Fuel Monitoring	Use gas flow sensors to record actual gas consumption in real time. Requires specialist flow sensors & circuitry at associated cost.	MID-HIGH	Yes

4.4. Communication: Summary of Techniques

There are many different techniques to communicate data from a monitoring system on a cooking device to an online database. An overview diagram of the main methods for data transfer is given in Figure 4, with detail about each communication method given later in this section. This diagram is designed to help project developers understand the options available from monitoring equipment suppliers.

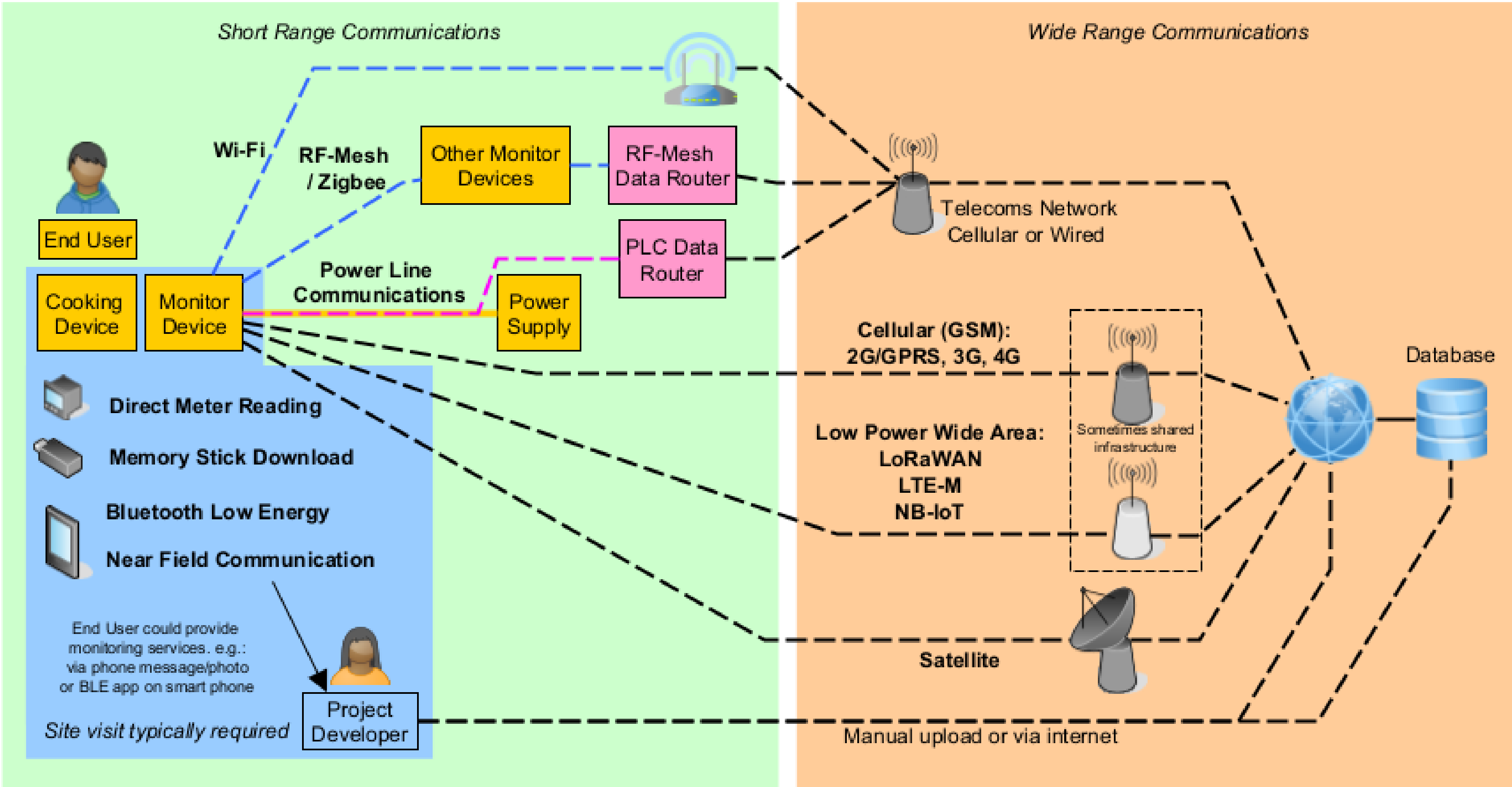


Figure 4: An overview highlighting the communications paths for the main data transfer methods.

4.5. Detailed Information on Monitoring Technology

In this section more in-depth information is given covering the terminology, highlighting the technical challenges and potential techniques available for measurement and communication of energy consumption data.

4.5.1. IoT and M2M

The Internet of Things (IoT) covers an ecosystem where devices share data using the internet as a communication network. Machine to Machine communication (M2M) is a concept where two or more devices communicate with each other without human interaction using a wired or wireless network. As data from the measurement devices discussed here will report back to some internet-based data platform, 'IoT devices' is the term used within this report.

Due to their relative complexity, IoT solutions are typically discussed in terms of layers, with the Open System Interconnection (OSI) conceptual model splitting the system into 7 different abstraction layers, sometimes simplified into a three-layer model, as shown in Figure 5[48].

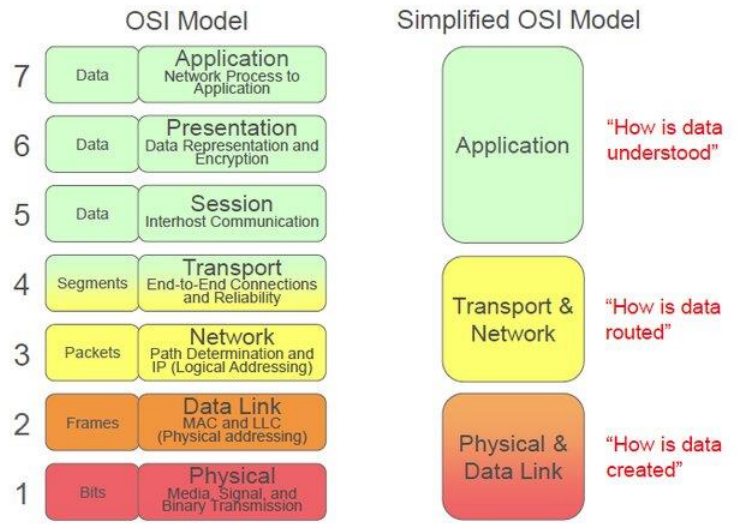


Figure 5: The 7-layer OSI abstraction model within an IoT solution, alongside the 3 simplified layers.

Within this section of the report, the layers 1 to 4 are covered, looking at the physical data collection, the data link to the network and then routing the data to the internet.

4.6. Measurement and Collection

A suitable monitoring device must accurately report the cumulative energy consumption of the cookstove. This either requires measurement of the mass of the fuel used (for LPG or biofuel cookstoves) or monitoring of the power consumption and the length of time the cookstove is used, with energy calculated by integrating the power consumption within the time period.

The data from these monitoring devices can either be sent directly to the database, or could be collected and aggregated via additional device(s) (such as a local router or smartphone),

48 http://dx.doi.org/10.13140/RG.2.1.2800.7929

which then sends the data to the monitoring database. Monitoring devices can be in-built to the cookstove equipment or be connected externally to the cookstove.

4.6.1. Modern Cooking Device Scenarios

To categorise the monitoring hardware technology, typical modern cooking system scenarios are proposed (see Figure 6). In this diagram the dashed line around the monitoring device means that it may not be required, as there are other monitoring systems already available, in the form of an electricity meter for payments. It can be seen that there are three main monitoring device types required: **AC systems**, **DC systems** and **Fuel Monitoring systems**.

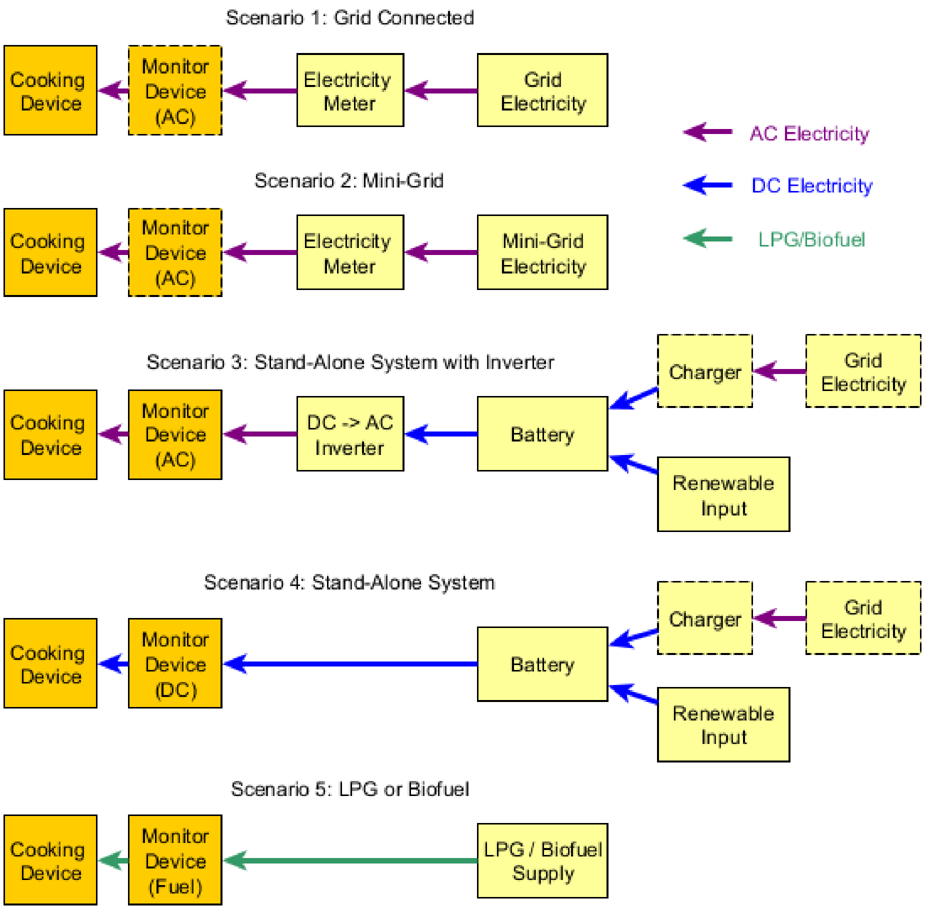


Figure 6: Modern cooking scenarios to highlight the main types of monitoring system.

4.6.2. Energy Measurement Techniques

Knowing the different types of modern cooking scenarios that may be implemented, the main techniques for monitoring cooking device energy consumption are reviewed here. Some of these techniques are currently used, while some are still at a development stage and/or not currently approved under existing carbon standards.

Economic Records Monitoring

Data regarding the sale of fuel, either LPG & biofuel volumes or PAYGo energy credits supplied to the end user can be used for calculating emission reductions[49]. Monitoring of this data will already be implemented by the energy supply company for financial reasons, so this may have zero or very low additional monitoring cost. The main issue is if the fuel or energy credit could be used for other applications, rather than modern cooking; for example, electrical energy credits could be used for other electrical appliances. In this case, the project developer must be able to prove that the sales data only relates to carbon reduction activities. This data would not give feedback on the time and duration of the actual cooking event.

Power Setting Monitoring

If the power setting (or level) of the cooking device can be monitored then this data can be used, along with the duration of that power level, to calculate the energy consumed, as energy is power integrated over time. Within some electrical cooking equipment, the internal control system may already use the power setting and it would not require significant additional circuitry, so this may be low cost to implement. As the power setting may not directly relate to the energy consumed, for example if the heating device switches on and off to maintain a temperature, proof that the power setting monitoring method gives accurate energy consumption data would need to be provided for verification of any emission reduction, which may require additional laboratory testing.

AC Power Monitoring

At present, the majority of monitored cookstove devices are connected to an AC (national) grid power supply. Measurement of alternating current (AC) power requires both current and voltage to be measured concurrently at relatively high sampling frequencies (>100Hz). Within AC power systems, especially induction cooking devices, current can be out of phase with voltage (called the power factor) and this must be accounted for within the monitoring system.

Non-intrusive Load Measurement

Customers on grid connections provided either by a national grid or a mini/micro grid are typically monitored with a payment meter. If the payment meter is a 'smart' meter then accurately recorded energy consumption data is available, with associated time data. These connections supply various appliances within the household, but trained software algorithms could be used to extract cooking events, termed as "non-intrusive load measurement". For example, a 1kW cookstove switching on and off for 30 minutes of cooking will give a different power pattern to a 10W light bulb switched on for a few hours. These types of algorithms are being developed for smart home energy monitoring in many applications, but they require training data, which may be different for different implementation locations, cookstove products and styles of cooking. Comprehensive proof that the algorithm provides accurate data on emission reductions would be required to claim carbon credits. There are initiatives underway that are working on developing this monitoring technology, but its use for carbon certification would require changes in the approved methodologies by the carbon standards.

[49] *Note that under GS MMMECD this is currently only available for fuel monitoring and not electricity.*

Current shunt

A current shunt is a small resistive element placed into the current path of the device. The voltage dropped across this low value resistor provides the current value to the measurement device. Recording the current along with the voltage would provide energy data. This is typically how payment and smart meters record energy consumption. This method provides accurate data, but does require additional components, specialist design of the monitoring circuitry and consideration of electrical safety which adds to the cost of the monitoring device. Careful design is required, as the shunt will introduce a voltage drop, and needs to be rated for the correct power dissipation level.

Specialist power and energy measurement integrated circuits (IC's) and design reference documents are available from numerous manufacturers including:

- Microchip (https://www.microchip.com/)
- Analog Devices (https://www.analog.com/)
- Cirrus Logic (https://www.cirrus.com/)
- Texas Instruments (https://www.ti.com/solution/electricity-meter)

Current transformer

A current transformer (CT) is a transformer used on AC systems to reduce the current to smaller standardised values, more suitable for measurement devices. These can be used on higher power systems and they also provide isolation of the power system from the measurement device. A CT could be used along with a resistor (called a 'burden resistor') with the specialist power and energy measurement IC's listed above.

Hall effect sensor

A hall effect sensor measures the presence and magnitude of a magnetic field, which is proportional to the current flowing in a conductor. They can measure both AC and DC current. They can be non-intrusive and used around the current carrying conductor. As they are not a resistive element then there is no power or voltage drop on the cable. They are more specialist and complex and therefore more expensive. They will also require simultaneous measurement of the voltage and calculation of power and energy, which will require additional circuitry.

Specialist hall effect sensors are available from several manufacturers including:

- Allegro Microsystems (https://www.allegromicro.com/en/)
- LEM (https://www.lem.com/en/hall-effect-current-sensors)

DC Power Monitoring

There are fewer direct current (DC) powered cooking devices available, but systems that connect to battery-based systems fed by renewable energy (typically solar) are seen as one solution for projects in remote areas, so more DC cookstoves may become available. DC power is slightly easier to measure as the current is not alternating so sampling frequencies can be lower, although 'switching' type power supplies and converters may have a high frequency component within the current signal. Techniques for measuring DC power are similar to the current shunt and hall-effect sensor techniques listed above with the same IC manufacturers providing solutions for DC systems, but current transformers will not work with DC systems.

Fuel Monitoring

Within cookstoves that use a modern fuel, such as LPG or biofuel, the measurement of energy consumption is very different to electrical systems. Using economic records monitoring (as described above) would be the simplest technique, but would not provide time of use, duration or energy used per cooking event. A number of equipment suppliers have developed LPG monitoring and control systems (reviewed later in this chapter). They have usually been developed for controlling the flow of gas to the end user cookstove for PAYGo applications, rather than carbon certification, but some units also record actual gas consumption in real time.

Within an LPG system the gas flow can be measured using a **thermal mass flow sensor**. These can be anemometric, calorimetric or time-of-flight (TOF).

An anemometric or calorimetric sensor measures the energy required to maintain a sensor probe at a constant temperature. If the gas flow is high, then more energy is required to maintain the constant temperature which can be measured.

A time-of-flight sensor measures the time taken for the heat wave from a small heating element to be carried through the sensor. TOF sensors are potentially superior for low flow rates.

Implementing flow sensor gas consumption monitoring is a highly specialist field and must comply with all relevant gas safety standards. Thermal mass flow sensors are typically used on large scale LPG systems, but miniature gas flow sensors are being developed by specialist suppliers including:

- Flusso (https://flussoltd.com/)
- Renesas (https://www.renesas.com/)
- Innovative Sensor Technology (https://www.ist-ag.com/)

4.6.3. Measurement Device Accuracy Classification

The GS MMMECD does not provide any specific information regarding the accuracy of the measurement devices, apart from requiring is *“shall be in conformity with industry standard”.* The accuracy class of the measurement device used should be in accordance with any local or national standards or requirements. There are four main accuracy classifications proposed by the IEC (International Electrotechnical Commission) and three proposed by the MID (Measuring Instruments Directive), given in Table 14.

Table 14: Accuracy classes for electricity meters.

Accuracy Class IEC 62053-21	Accuracy Class MID EN 50470-3	Measurement Error
2.0	A	±2%
1.0	B	±1%
0.5 or 0.5S	C	±0.5%
0.2 or 0.2S		±0.2%

The ‘S’ on the accuracy class highlights that there are different measurement errors for low or high loading on the meter, improving the measurement characteristics of the meter.

Class 2.0 or 1.0 are usually used for household or basic industry metering requirements. A lower measurement error will require more expensive and complex circuitry and calibration routines. The measurement error or accuracy class should be available from the monitoring device manufacturer and may need to be proven to the VVB.

4.6.4. Measurement Device Calibration

As reviewed in the Standards section, the GS MMMECD requires that measurements are taken with "*credible and calibrated equipment with mechanisms that ensure alternative use of the measured fuel is not possible"* and that the *"device to measure energy consumption shall be in conformity with industry standard and manufacturer calibrated."* with the responsibility of the manufacturer to provide calibrated equipment and evidence of the calibration. Similar provisions are in place under CDM and Verra methodologies.

The project developer must ensure they work closely with the equipment manufacturer to ensure measurement devices are compliant and that they receive evidence of calibration, usually as a calibration certificate, which may need to be provided to the VVB for validation and verification.

Typically, the measurement device manufacturer will test and calibrate each measurement device against calibrated test equipment within their factory to a specified accuracy level. The test equipment used by the device manufacturer will need to have regular traceable calibration either using a third-party testing facility or having the manufacturers facility accredited to an international standard. The device manufacturer may also provide samples to a testing laboratory for full certification. Each measurement device should be traceable back to a recognised calibration certificate. The manufacturer ought to ensure their testing devices have traceable calibration certificates.

The main international standards for traceable energy meter calibration are:

- ISO/IEC 17025 for Testing and Calibration Laboratories
  https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html
- BS EN IEC 62053 for Electricity metering equipment
  https://webstore.iec.ch/publication/28660
- EU Measuring Instruments Directive 2014/32/EU
  https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0032

The project developer must ensure they comply with any local and national regulations and guidelines within the implementation territory(ies).

There is no specific guidance within the GS MMMECD for any on-going calibration routine, but VVBs are required to assess whether equipment calibration is adequate, taking calibration frequency into account. Measurement sensors may 'drift' due to temperature or humidity cycling. Electricity meter manufacturers do not regularly re-calibrate installed equipment, but a recommended lifetime, typically of 10 or 15 years, is sometimes given, after which it is suggested the meter is replaced. For the highest level of confidence in the measured data, the project developers could instigate a regular re-calibration process, but this would be expensive and time consuming. The Protocol for Digitalised Monitoring, Reporting and Verification developed by South Pole suggest calibrating the meters every 3 years, if national standards or requirements are not available[50], although this is for the exemplary case of solar farms.

4.6.5. Measurement Device Firmware

Within a typical measurement device there is a microcontroller that handles reading the sensors, converting the sensor data to a power or energy value, averaging the data, adding a timestamp and communicating to the project developer data platform. The code that performs these tasks is called the firmware and is uploaded onto the microcontroller within the measurement device. The microcontroller circuitry and firmware must be designed for security and long-term reliability and stability. There are a huge variety of microcontrollers available on the market with a huge variety of specifications and functions. The trade-off between cost and functionality must be made by the measurement device manufacturer.

Measurement Device Data Processing

The data from the monitoring circuitry is typically converted from an analog to a digital signal using an analog to digital converter (ADC). The resolution (number of measurement levels) must be appropriate to the size of the signal being measured, for example a current reading may only provide a few millivolt signal, so the measurement levels must be small. The digital signal may also need conversion into the correct range, for example: an ADC may provide a digital reading of 0-1024 which may relate to a voltage of 0-24V. This conversion is usually provided by the manufacturers of the monitoring ICs used, but this may need factory calibration.

There is the potential for the measurement device to provide some data processing within the firmware, such as averaging high-resolution data to provide mean or peak values, or for a variety of other reasons. The firmware could also provide error checking on the data, for example testing that the data is within a certain range. Processing the data has the potential to reduce the amount of data communicated back to the monitoring platform, which may reduce data costs. Data reported for verification would need to show all the processing steps applied to ensure it is accurate and transparent, so any data processing on the measurement device must be explained, or provide proof of calibration.

It is expected that the level of data processing applied within the measurement device itself will increase significantly, especially with machine learning algorithms being developed. As larger data sets for cookstoves become available there may be more confidence in data processing algorithms implemented within firmware.

A timestamp may also be required for the reported data. The timestamp could be applied when the data is uploaded, but this may not align with the cooking event. A number of measurement devices also include a timestamp from a real time clock (RTC) within the circuitry. Although very standard, this is an additional component and hence will increase the device cost and it may need additional power circuitry to ensure it stays powered. The RTC will also need adjusting for correct time during manufacture or installation and must stay accurate to universal standard time. If a RTC is used, then timestamped cooking data could be stored in memory and only uploaded at regular intervals or when reception is available.

50 https://www.ebrd.com/digitised-mrv-protocol.html

Measurement Device Firmware Updating

The firmware within the measurement device may need to be updated for reasons such as:

- Bug fixing
- Security of firmware
- Data format changes
- Communications protocol changes

Devices that connect to the internet are especially vulnerable to security breaches, with many examples of internet connected devices being hacked[51]. Being able to update the firmware to patch for any vulnerability may be required for the long-term reliability of the carbon project data.

Firmware must be extensively tested before large-scale deployment of any measurement device. Some firmware bugs may take time to be highlighted and may not be apparent during laboratory or initial testing. For new projects it is highly recommended to pilot any measurement device in the location of the full project to ensure that problems are highlighted and fixed before large-scale roll out.

Version control of the firmware must be carefully managed so measurement devices can be kept up to date.

Ideally measurement devices deployed in the field can be updated remotely via secure remote firmware upgrades. This may be difficult due to the reliability of the communication network, the cost of data for updating firmware and the sporadic nature of device usage which may affect when the device is switched on and available for updates.

If remote updates are not possible then the possibility of performing a local firmware upgrade into each device must be considered. A local firmware upgrade could be performed via Bluetooth connection, by inserting a pen drive into the unit, or it may be necessary to open the measurement device/cookstove and upload new firmware with specialist programming tools.

Measurement Device Firmware Security

Security of the firmware and the measurement device must be considered, especially when large numbers of products are to be deployed. This is required for devices that can connect to the internet. A European Standard has been developed for internet connected devices: ETSI EN 303 645 “Cyber Security for Consumer Internet of Things: Baseline Requirements”[52]. The main recommendations from this are:

- No universal default passwords
- Implement a means to manage reports of vulnerabilities
- Keep software updated
- Securely store sensitive security parameters
- Communicate securely
- Minimise exposed attack surfaces
- Ensure software integrity
- Ensure that personal data is secure
- Make systems resilient to outages

51 https://www.bbc.co.uk/news/technology-65975446
52 https://www.etsi.org/deliver/etsi_en/303600_303699/303645/02.01.01_60/en_303645v020101p.pdf

- Examine system telemetry data
- Make it easy for users to delete user data
- Make installation and maintenance of devices easy
- Validate input data

Firmware encryption is a method of protecting the firmware of a device from unauthorised access[53]. Firmware encryption takes the final compiled firmware image that is in readable plain text format and applies an encryption algorithm (e.g. RSA algorithm[54]) to transform it into encrypted data or text that has been transformed into a form that is unreadable without the appropriate decryption key or password.

Security and encryption of the firmware is usually organised by the equipment manufacturer.

Measurement Device Power Supply

Power supply requirements of measurement devices must be taken into account by the device manufacturer and careful consideration given to the design of any power supply circuitry. This is especially true if measurement devices are to be used on energy limited systems, such as battery-based power supplies. The power supply ought to be high-efficiency, have low quiescent (standby) current but also be able to provide any peak pulses of power that might be required for communications systems. The measurement device may also need to function when the power supply to the cookstove is not available, for example sending data even when the cooking device is not plugged in. This may require internal rechargeable batteries or super capacitors which are recharged while plugged in, but can provide days or weeks of operation when unplugged. The design of the firmware must also take this into consideration and potentially monitor the power supply voltage. If communication with the cooking device is vital for its operation, such as for PAYGo systems, or economics, such as carbon finance, then the situation where any internal batteries discharge fully must be avoided. Power supply design is highly specialist and is typically implemented and tested by the equipment manufacturer.

4.7. Communication

Connectivity options for transmitting data from the measurement device to the data monitoring platform are covered in this section. The method for communicating data from the measurement device to the project developer database must:

- Be robust & reliable,
- Be cost effective,
- Be time & resource effective,
- Be secure,
- Ensure accuracy of data, and
- Reduce chances for errors to occur.

An ideal cookstove measurement device would seamlessly provide high resolution energy consumption data to the project developers database from any location without any human interaction. But these ideals must be considered against the cost of the hardware, the device power requirements and the data communication costs.

53 https://bugprove.com/knowledge-hub/enhancing-device-security-beyond-firmware-encryption
54 https://dl.acm.org/doi/10.1145/359340.359342

Figure 4 provides an overview of the communications paths for the main data transfer methods. In this section these methods are discussed in more detail.

4.7.1. Bandwidth & Latency

The bandwidth of a communication system is the maximum rate of data transfer across a given path and is measured in bits per second (b/s). For example, ethernet communications are in the range of 10,000,000 to 100,000,000 bits per second (usually called 10-100 Mb/s). Data from a cookstove measurement device is low-bandwidth, meaning that only small amounts of data need to be sent and that data does not need to be sent very quickly. Communicating an energy data value with a timestamp every hour would require around 1,000-10,000 bits (or 1-10 kb) of data every hour, potentially less if the data is compressed. This is a very low bandwidth, at around 1-5 b/s.

Latency is time taken from the data to be measured to the time for it to be processed. For example, an autonomous electric vehicle would need very low latency, as the data must be measured & processed quickly to allow real time feedback. Low latency is not required when taking data from a smart meter or from a measured cooking device. Delays in receiving the data are relatively unimportant, although very long delays (weeks/months) would affect the timeline of carbon credit issuances and revenues. A timestamp should be recorded along with the measured data which helps organise the data within the database, even if the data is collected at irregular or long intervals.

The measured data from a clean cooking device for carbon finance applications can be **low bandwidth** and can cope with **high latency**.

4.7.2. Short Range Communications

Short range communications are communications methods with transmission distances typically up to tens of metres, up to a maximum of a couple of hundred metres. Some of these methods would require a site visit to the location of the measurement device or cooking device, which is inefficient in terms of cost, time and resources, but if regular site visits need to occur for other reasons then this might be the most suitable method of collecting energy consumption data. Short range communications typically have lower hardware costs and low or zero-cost data transmission within the short-range.

Direct meter reading

In the most basic form of energy monitoring, the cooking device has an in-built or external energy meter. This has the energy consumption value displayed (digital or analogue) which is manually recorded through a site visit, e.g. through a digital survey tool. At each site visit the data can be collected and then uploaded at a later time for reporting. Potentially the end user could regularly report this information themselves, either by an SMS or via a photo of the meter, back to the project developer, which would reduce the number of site visits required.

The hardware requirements for this method are low and initial costs are low. It does not require the end user to be connected to wider communications methods, such as GSM.

This method requires on-going site visits, which may be expensive and time consuming. This method may be highly error prone & there are many points at which human error may affect the data. It may also be prone to data tampering. The time resolution of the data will be low, which would hinder near real-time carbon credit issuances in a fully digitalised MRV process.

Memory Stick Download

The cooking device has an in-built energy meter and data memory. The data from the device can be downloaded onto a memory stick during a site visit. This data can then be uploaded onto the project developer’s reporting platform.

While this still requires a site visit, the data obtained is less error-prone and the time resolution can be high, providing higher quality data sets of cooking events. It does not require the end user to be connected to wider communications methods, such as GSM.

As the data is obtained only during site visits, continuous carbon credit issuances would not be possible.

Bluetooth Low Energy

The cooking device has an in-built energy meter and data memory, alongside a Bluetooth Low Energy (BLE)[55] communication module. BLE is a 2.4GHz unlicensed ISM (Industrial, Scientific & Medical) frequency band radio transmission method, designed for very low power operation. It is designed for short range transmission in the range of up to 10m, with locally regulated transmission power limiting the range. Many low-cost BLE communications modules are available and smart phones with BLE communication built in are readily available. BLE measurement devices can be very low power, potentially allowing the devices to run for over 5 years on internal batteries. Data can be obtained by taking a BLE data recording unit within range of the measurement device and downloading the data. The most cost-effective way to obtain the data is through a smartphone with a data downloading app. The data from the measurement device then stays on the smartphone until the smartphone is taken to an area with internet connectivity, where the data can then be uploaded to the project developer’s data platform either via GSM or Wi-Fi. The ‘data collection and then transmission’ method could be implemented as a background app on a smartphone, as long as the smartphone user installs the app and enables it to run.

If the end user has a smartphone and is willing to install a background app, then the end user could provide the data upload path. This would allow up to real-time monitoring of the cookstove, but it would have a data cost to the end user, so some incentive must be provided. The project developer would need methods to handle end users that do not have a smartphone and the re-installing of the data monitoring app if there is loss or replacement of the end user's phone.

If end user participation is not viable, then site visits will be required to download the data from each cooking device. As the data is transferred wirelessly, this could be performed relatively quickly and without direct access to each physical device (e.g. data transmission through wall to building).

RFID and NFC

The cookstove has an in-built energy meter, small data memory and NFC ‘tag’.

55 https://www.bluetooth.com/learn-about-bluetooth/tech-overview/

Radio Frequency Identification (RFID) is a method to uniquely identify an item or asset. An RFID tag is attached to the asset which can be read wirelessly using a reader at a range of up to 100m. The tag does not require a power supply. This type of system is one-way communication and is not suitable for reading energy consumption data, as only a unique ID number can be transferred, but it could be used for ensuring cooking devices are correctly identified.

Near Field Communications (NFC) is a two-way wireless communication system where a small NFC tag stores the data and a wireless reader can download that data. NFC can be active, where the tag has a power supply and broadcasts data up to 100m or passive, where the tag does not have a power supply and the reader must be within 0.1m to be read. Some smartphones have wireless readers for NFC built in. NFC tags can typically store up to 4kB of data.

Using an NFC tag within the cooking device, energy consumption data could then be read by a smartphone with an in-built NFC reader. This would be similar to a BLE connection, but the smartphone may have to be located closer to the device for communication.

Wi-Fi

The cooking device has an in-built energy meter and data memory, alongside a Wi-Fi communication module. Reliable connection to a Wi-Fi router, while available in some urban areas, is not readily available in remote locations. Wi-Fi is a family of wireless network protocols based on the IEEE 802.11 family of standards for local area networking. Wi-Fi most commonly uses the 2.4 gigahertz and 5 gigahertz radio bands, with communications distances of up to 20m (indoors) and 150m (outdoors). Security of data transmission can be enabled using WEP, WPA, WPA2, and other Wi-Fi security protocols. These are only for the Wi-Fi data transmission, with the data un-encrypted at each end of the Wi-Fi communication channel. Wi-Fi requires more power than a BLE connection which can affect the measurement device energy requirement and power supply design. A small rechargeable battery could be used to provide data communications when the cooking device does not have power, but these internal batteries are expensive and only provide a few days or weeks of data communications before needing to be recharged.

If a dedicated Wi-Fi router is available then using Wi-Fi is probably the lowest cost and easiest to implement solution for real-time device to database communications. But in the majority of clean cooking project areas Wi-Fi connections are non-existent or, if available, are unreliable, power supplies are intermittent and the routers and equipment required are unavailable or too expensive.

One solution to this would be similar to the BLE method, where data could be sent via Wi-Fi to the end user's smartphone and from there sent via the mobile network to the project database when next in network range. This would require participation of the end user (including their data costs), end user access to smartphones, installation of a dedicated application onto the phone and also control of the Wi-Fi connection on the phone, making this solution more complex than the BLE method already mentioned.

RF-Mesh / Zigbee

The cooking device has an in-built energy meter and data memory, alongside a Radio Frequency mesh (RF-Mesh, such as Zigbee) communication module. There are different RF-

Mesh systems, with Zigbee being one of the most widely used. Zigbee[56] is a suite of wireless network protocols based on the IEEE 802.15.4[57] standards for local area networking. It was designed by the Connectivity Standards Alliance as a low-power, low data rate wireless ad-hoc network for close proximity. Zigbee usually operates on the 2.4GHz ISM band. Zigbee transmission distances are in the region of 10-100 metres, but these devices can form a 'mesh network' so data can be transmitted through intermediate devices to increase the transmission distance. Zigbee allows data rates of up to 250 kb/S and utilises secure AES-128-CCM data encryption.

A mesh network might work very well in a project where many measurement devices are in relatively close proximity clusters. Within a mesh network there will need to be a communication or data logging device that records the data from all the devices on the Zigbee network and communicates this to the project developer database.

Zigbee has been implemented within smart meter technologies to improve reception to these devices.

4.7.3. Wide Range Communications

Wide range communications are communication systems that transmit data over further distances than short range communications, from 100m up to tens or hundreds of kilometres.

Wide range communications typically require more complex and expensive hardware and also may require data contracts for use of the wide range communications networks.

Cellular Communications

The cookstove has an in-built energy meter and data memory, alongside a cellular communication module, alongside a SIM card and data plan. Cellular communications are utilised within many of the measurement devices reviewed here.

The Global System for Mobile Communications (GSM) is a standard for secure wireless communications developed by the European Telecommunications Standards Institute. It has become the most ubiquitous mobile communications standard, operating in over 212 territories and with 80% of the global market share. The GSM association[58] aims to unify the mobile ecosystem ensuring the many stakeholders work towards common standards and implementation.

2G (second-generation) GSM networks use time-division multiple-access (TDMA) spectrum-sharing, typically working on 850, 900, 1800 or 1900 MHz frequencies, depending upon the implementing country. **GPRS** (General Packet Radio Service (sometimes called 2.5G)) covers 2G systems that have implemented packet oriented mobile data standards. GPRS provides moderate data rates of 56-114 kb/s. Communications modules that connect to the 2G/GPRS network are usually 'quad-band', which means they can be used in all four frequency areas. 2G/GPRS networks are still available in most LMIC and are often used for low data rate transfer. 2G/GPRS data communication modules are readily available[59] for low prices of around $3-$6 in bulk quantities[60].

56 https://csa-iot.org/all-solutions/zigbee/
57 https://standards.ieee.org/ieee/802.15.4/7029/
58 https://www.gsma.com/
59 https://en.simcom.com/module/2g.html
60 https://www.alibaba.com/product-detail/SIM800C-New-Original-In-Stock-Electronics_1600781602388.html

3G (third-generation) networks were an upgrade over 2G/GPRS providing faster data transfer of at least 144 kb/s. 3G systems use spread-spectrum radio transmission technology. The use of 3G network is declining as it has generally been superseded by 4G.

4G (fourth-generation) networks can provide data transfer speeds of up to 100Mb/s, potentially more for stationary applications. 4G systems work within the 600MHz to 2.5GHz radio frequency bands and only use packet switching techniques with advanced antenna techniques to provide better signal quality and transfer efficiency. 4G data communications modules are readily available[61], but still cost more than 2G/GPRS modules, at around $10-$20 in bulk quantities[62].

The **5G** (fifth-generation) cellular network technology standard improves the data bandwidth for faster download speeds (up to 20Gb/s) and higher numbers of connected devices per cellular node. 5G networks divide the service area into smaller geographical areas (called cells). 5G networks have three radio frequency bands (low, mid and high), with low similar to 4G, mid using 1.7-4.7GHz and high using 24-47GHz. 5G networks were developed for end users to stream high speed and high-quality data to their devices. Modules to connect measurement devices to 5G networks are available but at a relatively high cost, compared to 4G and 2G/GPRS modules. Measurement devices do not need the bandwidth available through 5G, so the additional cost of implementing 5G is not economically viable at present.

Sunsetting

2G/GPRS and 3G networks are being “sunsetted” (shut-down) in different countries at different times. For example, South Africa has proposed the switch off of 2G and 3G networks in 2025, but most LMIC will maintain 2G/GPRS/3G services for several years. There is no database of sunsetting information, and the decision is up to the mobile network operators (MNOs) within individual countries, so it is important that the project developer makes enquiries into network availability within the project implementation region for the timescale of the potential project.

SIM Cards

To connect to a cellular network a SIM (Subscriber Identity Module) card is required, provided by a large number of vendors. Within different territories there are different MNOs who install, control and maintain the local cellular network infrastructure, and most also provide SIM cards and data packages for their networks. Other companies just provide SIM cards and data packages for use on the different networks available. Depending upon the project implementation, the developer may choose to use locally sourced SIM cards, but these may only work in one territory or only on one specific network. Some companies provide ‘global’ SIM cards which have agreements with multiple network providers, so data connections are available in multiple territories and on multiple networks within these territories. The choice and cost of SIM card and data package provider will depend upon the implementation territory(ies), the number of units being installed, and the amount of data to transfer.

Usually a SIM card is an external physical card which can be inserted into a special slot within the measurement device or communications module. Removable SIM cards are typically supplied in standard mini, micro and nano sizes, which must match the measurement device SIM slot.

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61 https://www.simcom.com/module/4g.html
62 https://www.alibaba.com/product-detail/SIMCOM-SIM7600-SIM7600G-SIM7600G-R2-LTE_1600714942136.html

A newer development is the embedded SIM (or eSIM), which is embedded directly into the device and not removable. This improves reliability and stops unauthorised removal. The eSIM can be provisioned remotely and different data contracts and network providers information can be applied during manufacture or later, via remote upload.

Wireless Connection Modules

To connect a measurement device to a cellular network a wireless connection module can be used. These are integrated modules which include the circuitry, firmware, SIM card slot and antenna or antenna connection for a microcontroller to communicate with the wireless network. Wireless connection modules are available from a number of suppliers, with some of the main manufacturers being:

- SIMCom Wireless Solutions Ltd (www.simcom.com)
- u-Blox (https://www.u-blox.com/en/cellular-modules)
- Sierra Wireless (www.sierrawireless.com/)
- Quectel (https://www.quectel.com/)
- Telit (https://www.telit.com/modules-overview/)
- Fibocom (https://www.fibocom.com/en/)

Satellite

Satellite IoT systems use Low Earth Orbit (LEO) or Geostationary Orbit (GEO) satellite networks to provide global connectivity. These systems can provide communications to very remote locations[63]. Potentially satellite IoT could be used to help with the provision of 5G NB-IoT and LTE-M coverage in the future.

Direct satellite communication methods are not known to be used by any cookstove monitoring projects at present due to the expensive hardware requirements and high data transmission costs. It is mentioned here for completeness, with satellite systems potentially providing wider communications coverage at lower costs in the future.

Power Line Communication

Power Line Communication (PLC) allows data communications to be carried on the interconnected power lines within an electricity transmission system. Data rates and transmission distances vary greatly between different PLC standards. Low frequency PLC is used for telemetry and control signals. This technique is often used to transfer data between multiple smart meters within an electricity network, sometimes with intermediate devices boosting or re-transmitting the data.

A hybrid technique of using PLC and some form of radio frequency network (such as Zigbee) could also be implemented to create a ‘mesh’ of interconnected devices which can ensure data is transferred from the measurement device to the required end point.

This form of data transmission can be highly cost-effective as it does not require additional wiring and does not have additional data costs, but it can be susceptible to noise on the electricity transmission system and is only suitable for devices connected to the same transmission system. A communications node between the power line and the data monitoring

63 https://www.starlink.com/

platform (usually on the internet) will also be required, which may have additional data and hardware costs.

Two of the main PLC standards organisations are:

- Open Smart Grid Protocol from the OSGP Alliance (https://www.osgp.org/en)
- G3 PLC and G3 Hybrid from the G3 Alliance (https://g3-alliance.com/)

Low Power Wide Area communications

A Low Power Wide Area Network (LPWAN) is a form of wireless communications network designed for low bandwidth data communications, such as remote telemetry. Data rates on a LPWAN are low, less than 50 kb/s. LPWANs can be privately implemented sensor networks, or utilise infrastructure from a third party. Typically data is sent from a measurement device (typically called a node) to a gateway unit which will then transmit the data to some form of online data platform via the internet. There are numerous LPWAN protocols and specifications with a main split between unlicensed services, which utilise licence-free radio frequency bands, and licenced spectrums services, where radio frequency bands have been licenced by communications providers.

LoRaWAN

Long Range Wide Area Network (LoRaWAN) is an open standard that defines the communication protocol and system architecture required to implement the Long Range (LoRa) spread-spectrum radio communication technique. LoRa uses unlicensed radio frequency bands in the range of 863 to 928MHz, depending upon the territory. It allows long-range transmission of up to several kilometres with low power consumption. LoRaWAN adds a level of encryption onto data transmitted with robust encryption protocols. LoRaWAN can be implemented as private, public or hybrid networks.

The LoRa Alliance (https://lora-alliance.org/) is a non-profit organisation which aims to support and promote global adoption of the LoRaWAN standard.

LoRaWAN requires gateways to be implemented within range of the deployed measurement devices. One gateway can service up to 10,000 devices, depending upon the number of messages sent. The project developer could implement gateways for their monitoring devices, or they could utilise third party gateways if they are available.

The Things Network (https://www.thethingsnetwork.org/) is a global LoRaWAN network with many gateways publicly available (a map of the network is available here: https://ttnmapper.org/heatmap/), although it can be seen that large areas of Africa are not yet covered.

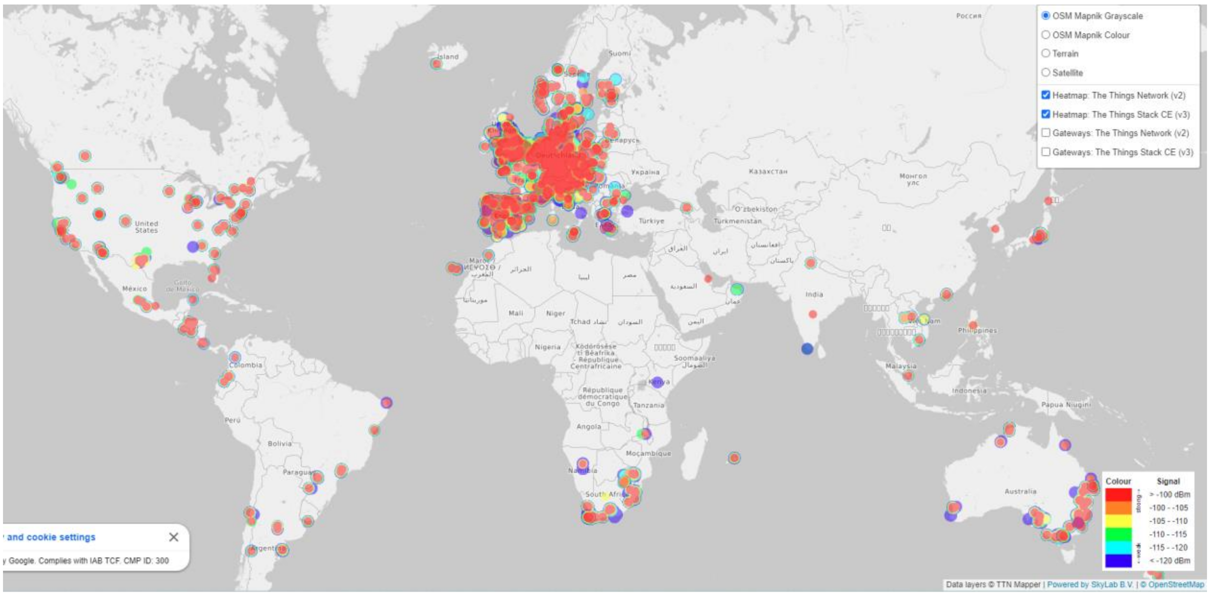

Figure 7: The Things Network global LoRaWAN network coverage map (Nov, 2023). [64]

In India, Tata Communications is developing the biggest LoRa network in the world, aiming to cover 400 million people (https://iot.tatacommunications.com/network).

LoRaWAN communication modules are readily available to enable devices to easily connect to a LoRaWAN from manufacturers: Murata[65], RAK wireless[66] and Microchip[67], amongst others.

Sigfox

Sigfox (https://www.sigfox.com/) is a proprietary wireless network for connecting low power devices sending small amounts of data. Sigfox uses ultra-narrowband techniques in the unlicensed sub-GHz spectrum (specifically the 915 MHz ISM band in the U.S. and the 868 MHz band in Europe) to provide long-range connectivity of up to 30 km. Data transfer is very low, up to 100b/s. The network of gateways is provided by Sigfox and connectivity must be bought from Sigfox or their partner companies.

Coverage of this network in Africa is low, but more network rollouts are planned, with a coverage map available here: https://www.sigfox.com/coverage/, with a screenshot given in Figure 8.

64 https://ttnmapper.org/heatmap/
65 https://www.murata.com/en-eu/products/connectivitymodule/lora
66 https://www.rakwireless.com/en-us/technology/lorawan
67 https://www.microchip.com/en-us/products/wireless-connectivity/sub-ghz/lora

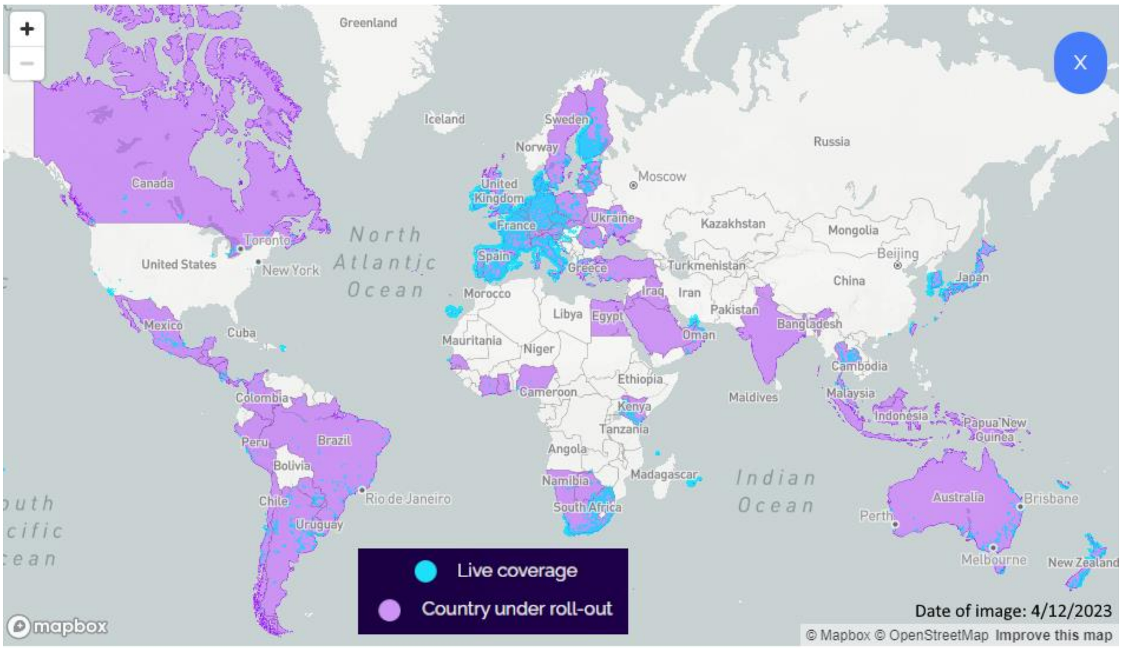

Figure 8: The Sigfox network coverage map (Dec, 2023) [68]

Modules to connect measurement devices to the Sigfox network are available from SJI, AcSiP and Murata, amongst others[69].

Other unlicensed spectrum protocols

There are a number of other wireless protocols which operate in the unlicensed 433 MHz, 868 MHz and 915 MHz RF bands. These protocols are usually installed as private networks or for more specific applications, and there are fewer communications module manufacturers for these protocols. At present these networks are not used for clean cooking monitoring devices. This includes:

- Wireless M-Bus (https://m-bus.com/)
  - The meter bus EU standard for remote reading of smart meters.
- DASH7 (https://www.dash7-alliance.org/)
- Z-Wave (https://www.z-wave.com/)
  - Typically used for smart home appliances.

LTE-M

Long-Term Evolution (LTE) is a full cellular standard, optimised for higher bandwidth and mobile applications, which underpins the 4G cellular network. It has various categories for different applications. Long-Term Evolution Machine Type Communication (LTE-M) (also known as eMTC and Cat-M1) is a category of LTE more suitable for lower-bandwidth IoT applications. It utilises the 1.4 MHz licensed radio frequency band and allows voice over internet and good mobility, with data rates of typically 300 kb/s and range of up to 11km. IoT applications requiring high speed and low latency, such as drones or autonomous vehicles, are typically more suited to LTE-M.

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68 *https://www.sigfox.com/coverage/*
69 *https://partners.sigfox.com/products/module*

Communications modules are available allowing connection to 4G/LTE cellular networks and hence allowing connection to LTE-M. Communications modules allowing connections to both LTE-M and NB-IoT are available[70].

NB-IoT

Narrow Band Internet of Things (NB-IoT) (sometimes referred to as CAT-NB1) is a wireless standard developed for low cost, low power (and hence long battery life) and extended coverage for rural and deep indoor applications. It uses a single 200kHz licensed radio frequency band and can co-exist with 2G, 3G and 4G mobile networks. It is designed for high device penetration and long range of up to 15km, with relatively low data rates of 30-60 kb/s. Applications requiring lower speed and which are tolerant of high latency are typically more suited to NB-IoT.

Initial costs of NB-IoT communication modules are similar to GSM/GPRS modules and prices are expected to drop with increased deployment, with dedicated NB-IoT[71] and LTE-M/NB-IoT modules available[72].

A deployment map, covering NB-IoT and LTE-M is available from the GSMA here: https://www.gsma.com/iot/deployment-map/, with a screenshot given in Figure 9. It can be seen that coverage for both LTE-M and NB-IoT is low within Africa and LMIC.

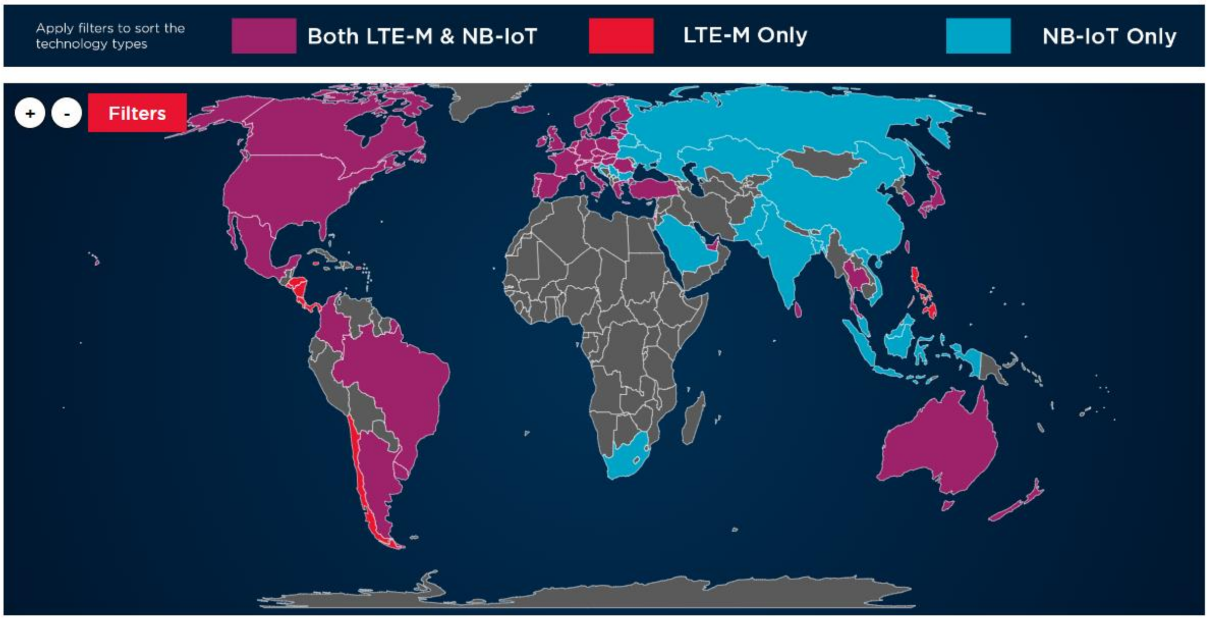


Figure 9: The LTE-M and NB-IoT network coverage map (Nov, 2023). [73]

4.7.4. Overview of Communication Networks

A simple overview of the different technologies, including data rates and range has been produced by the GSMA[74], shown in Figure 10.

70 https://www.u-blox.com/en/product/sara-r5-series
71 https://www.st.com/en/wireless-connectivity/nb-iot-products.html
72 https://www.u-blox.com/en/cellular-modules#LTE-M-/-NB-IoT
73 https://www.gsma.com/iot/deployment-map/
74 https://www.gsma.com/mobilefordevelopment/resources/iot-for-development-use-cases-delivering-impact/

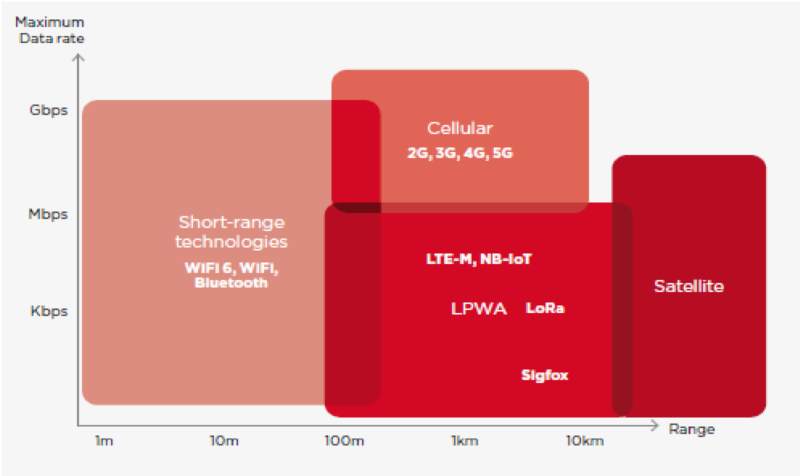


Figure 10: GSMA overview diagram of different wireless communications technologies against bandwidth and range. [75]

Key attributes of the wide area communications networks have also been reviewed by the GSMA, shown in Figure 11.

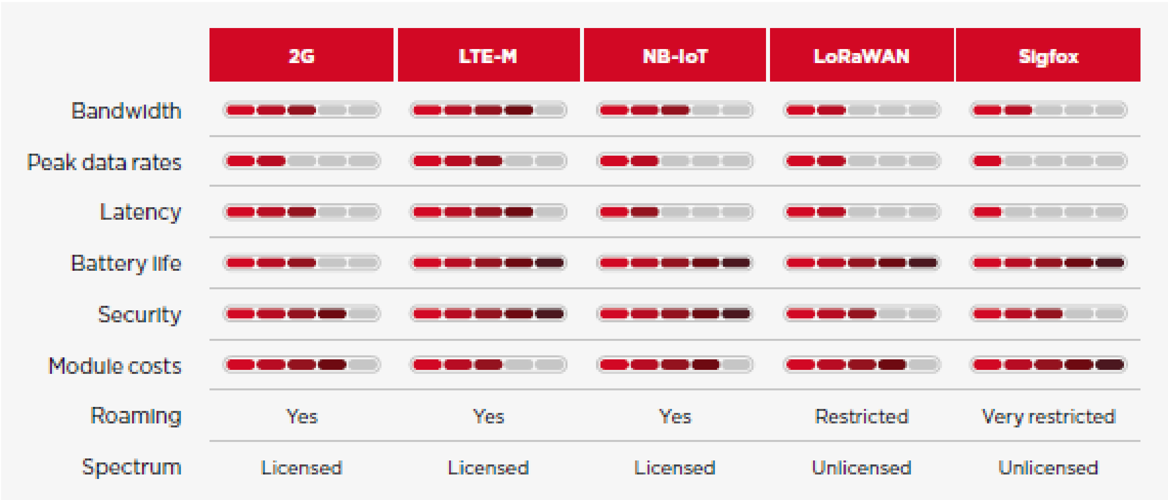


Figure 11: GSMA comparison of different wireless communications technologies. [76]

Within the GSMA "IoT for Development" report the status of various wide area networks within LMIC was reviewed, with a map shown in Figure 12. It is worth noting that there is no complete database of network availability. Project developers will have to review the implementation areas to ensure the communications system used is suitable for long-term monitoring projects. The GSMA provides two public access mobile coverage maps:

- https://www.mobilecoveragemaps.com/
- https://www.gsma.com/coverage/

75 https://www.gsma.com/mobilefordevelopment/resources/iot-for-development-use-cases-delivering-impact/
76 https://www.gsma.com/mobilefordevelopment/resources/iot-for-development-use-cases-delivering-impact/

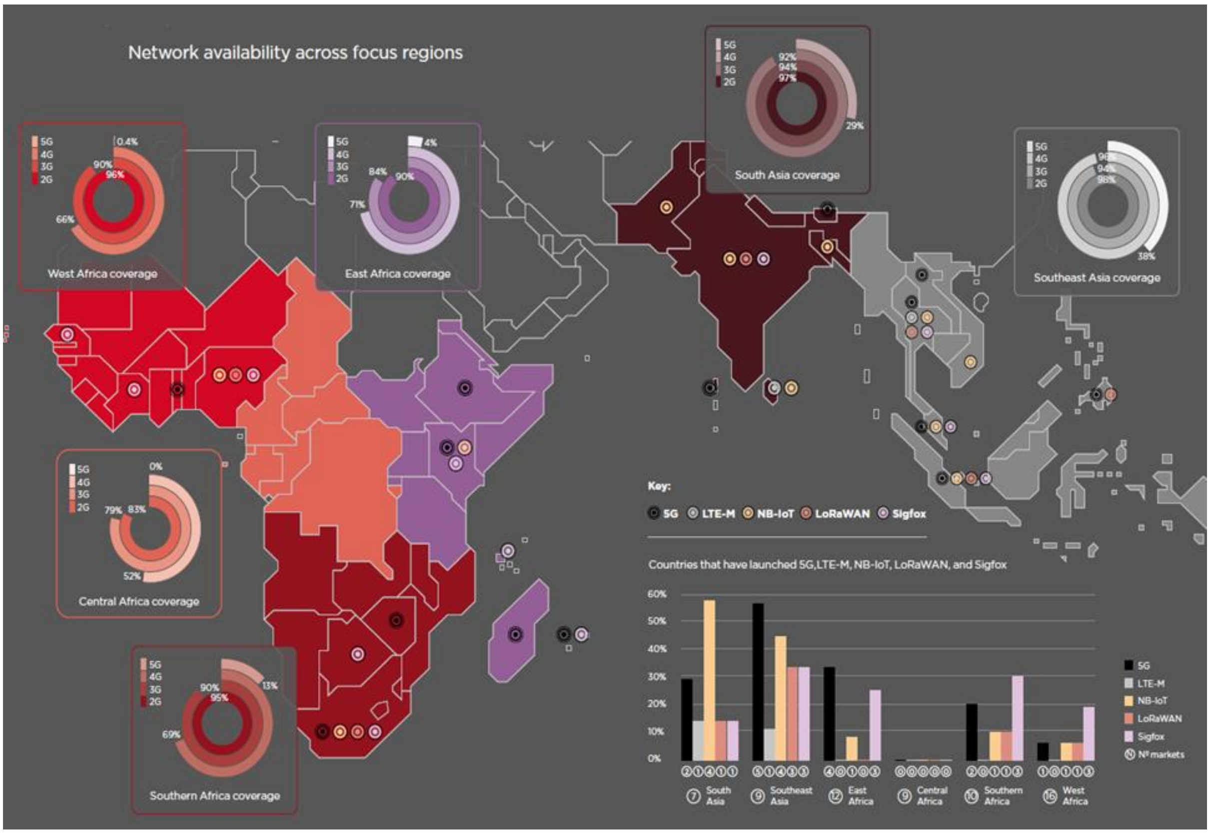


Figure 12: GSMA map of different wireless communications technologies for focus regions.[77]

4.7.5. Communication Data Transfer Protocols

Once the measured data is available and some form of communications network has been implemented, then a data transfer protocol (DTP) is required to share data across devices and with the cloud. The most popular protocols used in IoT ecosystems are highlighted here.

MQTT

Message Queue Telemetry Transport (MQTT) is a lightweight and efficient protocol with publish/subscribe architecture (https://mqtt.org/), originally designed by IBM. It is a widely used protocol in the IoT domain due to its open-source nature and suitability for small microcontroller-based devices located in remote areas with poor internet connectivity. An MQTT system will require an MQTT client (the measurement device) which publishes data messages to an MQTT broker (usually an internet-based service). Other MQTT clients, including backend systems, can subscribe to the published data channel to view and report the data. An overview of the MQTT architecture is given in Figure 13.

77 https://www.gsma.com/mobilefordevelopment/resources/iot-for-development-use-cases-delivering-impact/

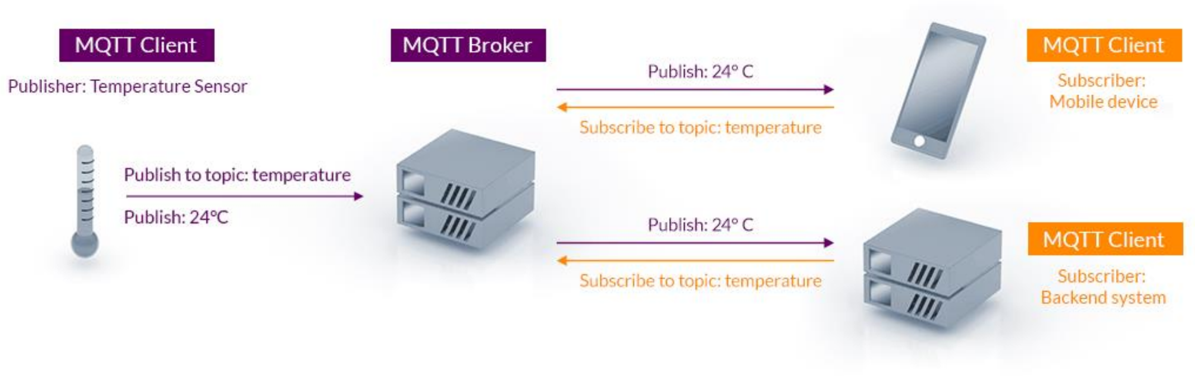


Figure 13: MQTT simplified architecture overview. [78]

HTTP

HyperText Transfer Protocol (HTTP) is used for data communication for the World Wide Web (WWW) hence it is being used for IoT devices. An HTTP request is made from a client to a server in order to update or send information on the server. It relies upon the Transmission Control Protocol (TCP) which requires significant computational resources, so this method is not optimal for low-power and low-resource measurement devices. Hypertext Transfer Protocol Secure (HTTPS) is an extension of HTTP which adds an encryption layer for secure communications, but this requires more computational power and storage memory for the security 'certificates' used.

Modbus

Modbus[79] is a client/server data communications protocol originally designed for use with the programmable logic controllers. It is openly published and royalty-free and used in many industrial sensor environments. The server requests to read the data from a specific address within the client. If correctly parsed, then the client responds with the data, along with error checking information. Modbus is typically used between sensor devices and a control or data acquisition system.

CoAP

The Constrained Application Protocol (CoAP)[80] was designed for resource-constrained devices with limited memory and power to connect to the internet. CoAP uses request and response message types with a simple binary based header format

4.7.6. Communication Reliability

Reliability of the communication network must be considered, as remote locations and intermittent communications systems may impact the quality of data received and hence the emission reductions claimed. The GS MMMECD requires that "*for project devices that experienced intermittent or continuous loss of network connection to monitor energy consumption during project implementation, for each day of non-connectivity the average energy consumption of all connected project devices may be applied as that day's energy*

78 https://mqtt.org/
79 https://www.modbus.org/
80 https://coap.space/

consumption, as long as the number of connected devices that day is at least or higher than the minimum required sample size".

Communication systems have been discussed previously and the project developer should investigate the availability and reliability of any communication system used specifically within the project implementation area. Potentially online maps may show network coverage but the reality in the specific location may be different. Topology and weather systems may also affect wireless reception in a highly localised way.

The project developer or device manufacturer may consider ensuring a back-up data collection facility in case of communication network failure. This could include:

- The ability to locally read the total energy consumed by the cooking device, either directly or through some local data transfer method.
- Storing energy consumption data on a removable memory card.
- Storing energy consumption data within internal memory and re-sending the data if a reception issue is highlighted.

The project developer must also consider the implications of a failed monitoring device or sensor and how that is rectified.

4.7.7. Communication Security

The project developer must ensure data is kept secure while transferred within the communication network. This is to maintain the data integrity and to reduce the risk of data-tampering. The VVB may request to see the methods used to ensure data security while the data is in transit. It may also be a national requirement if any of the data includes personal information. Adding encryption onto the data communication system may increase the computational and power requirements and may also increase the data transfer size. There are standard techniques for encrypting communications data including:

Device Identification

As a minimum, the measurement device should have a unique identifier which is reported to the server and checked against the server's list of device ID. A username and password may also be implemented for each device and checked each time the measurement device connects. Device identification is simple to implement but is not very secure, as this information can be easily intercepted.

AES

Advanced Encryption Standard (AES) is a method for the symmetric encryption of electronic data, typically using a 128 or 256 bit key for encryption and decryption. This key is used multiple times to very securely encrypt or decrypt the plain input data into the cipher output data.

TLS

Transport Layer Security (TLS) is a cryptographic protocol for communications security over a computer network, used by HTTPS and, if implemented, on MQTT messages. TLS can use the AES encryption technique, amongst others. It uses a client-server communication where handshaking occurs when the client requests a secure connection to the server. Usually, the server provides a digital certificate for identification, with a trusted certificate authority vouching for the authenticity of that certificate and the server's public encryption key. Session keys are then generated to encrypt the data along with the public key but can only be decrypted using the server private key. A new session key is used each time.

IoT SAFE

IoT SAFE (IoT SIM Applet For Secure End-2-End Communication)[81] enables IoT device manufacturers and IoT service providers to leverage the SIM as a robust, scalable and standardised hardware "Root of Trust" to protect IoT data communications. IoT SAFE provides a common mechanism to secure IoT data communications using a highly trusted SIM, rather than using proprietary and potentially less trusted hardware secure elements implemented elsewhere within the device. The SIM is used as an internal 'crypto-safe' to securely establish a TLS connection with the corresponding server.

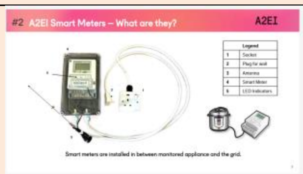
4.8. Equipment Currently Available

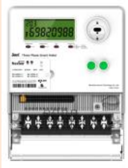
Table 15 gives a more detailed overview of the technical specifications of a range of monitoring equipment available at the time of this report (December, 2023).

81 https://www.gsma.com/iot/iot-safe/

Table 15: Detailed overview of the technical specifications of a range of monitoring equipment available at the time of this report.

Organisation:	**ATEC**	**BURN**	**Pesitho**
Product Name:	eCook	ECOA	ECOCA
			
			
Website:	https://www.ecookstove.com/	https://www.burnstoves.com/products/electric/	https://pesitho.com/
Cookstove Type:	Induction Hob (1 and 2 ring) (Grid)	EPC & Induction Hob (Grid)	Induction Hob (Solar)
Monitoring Type:	Internal	Internal	Internal
Suitability for Carbon Finance:	Yes	Yes	Yes
Availability:	Yes	Yes	Pilot Trial
Rating:	Induction: AC 1.5kWx1 / 1 kWx2	Induction: 2000W 240V 13A EPC: 1200W 240V 13A	-
Approximate Cookstove Cost:	$120 (Induction 1 ring)	$120 (Induction 1 ring) $100 (EPC)	-
Monitoring System Cost:	-	$3/month/device	-
Manufacturing Location:	China	China, Kenya, Ghana, Zambia, Tanzania	-
Metering Technology:	Power level and time recorded and converted to energy consumed.	Electronic (Embedded Controller)	-
Communication Technology:	GSM 2G/GPRS (with 4G-LTE available)	GSM	-
Data and Communications Security:	Unique ID of cookstove.	SSL/PKI	-
Data Plan:	Global eSIM	$0.2/month/device	-
Device Data Storage:	Yes	-	Yes
Data Sampling:	When stove on	5-minute intervals	-
Data Reporting:	Different sampling frequencies depending upon data point	Real Time Cooking Events, Energy Usage	-
Location Monitoring:	Yes (triangulation)	At Point of Sale – End User Residence (GPS Location)	-
Tamper Alert:	Yes	Available (Physical Dead Man Switch)	-
Data Platform Info:	dMRV platform from ATEC	AWS Cloud, IoT Core	-
Proprietary or Open Design:	Proprietary	Proprietary	-

Organisation:	UpEnergy	A2EI	4R Digital
Product Name:	PowerUP EPC V2	A2EI Smart Meter (DDZ1737)	Smart Cookstove Meter
			
			Prototype (2 Socket Extension Lead)
Website:	www.upenergygroup.com https://www.powerup.works/	https://a2ei.org/ https://a2ei.org/resources/uploads/2021/03/A2EI-Smart-Meter.pdf	https://www.cavex.io/
Cookstove Type:	Electric Pressure Cooker (Grid)	N/A (external)	Compatible with electric cookstoves such as EPC and induction (external)
Monitoring Type:	Internal	External	External
Suitability for Carbon Finance:	Yes	Yes	Prototype hardware
Availability:	Available in Uganda and Tanzania with pilot projects underway in Zambia and Ghana.	Yes	No - Prototype
Rating:	EPC: 1200 W	AC 1/3phase 60A	AC 1phase 13A
Approximate Cookstove Cost:	Depending on market and time of distribution	N/A	N/A
Monitoring System Cost:	Up to 18% of the cookstove cost.	$60 (approx.) (+shipping/import duty)	GSM version: $35 (target) BLE version: $10 (target)
Manufacturing Location:	China	N/A	United Kingdom and United States (Prototype)
Metering Technology:	Energy consumption data logger	Full AC monitoring: Timestamp, Energy, Voltage, Current, Power, Power Factor & Frequency.	Full AC monitoring: Each Socket: Timestamp, Voltage, Current, Power
Communication Technology:	Physical: Wired communication standard using OTG cable to establish communication between the EPC and Smartphone.	GSM 2G/GPRS and 4G	Prototype has: Wi-Fi / GSM / BLE
Data and Communications Security:		Unique ID of meter, Unique ID of account	Unique device ID and certificate and industry-standard security protocols for complete monitoring system
Data Plan:	N/A	Global SIM (AERIS)	Local data plan for prototype testing
Device Data Storage:	Flash Storage: Uses flash memory for data storage.	Yes (3-9 months)	Yes
Data Sampling:	Simple random sampling	1-15 mins (adjustable)	1 min (prototype)
Data Reporting:	Periodic following guidelines from the standards	Real-time, unless connectivity issue	1 min (prototype) 24 hour event data series upload (production)
Location Monitoring:	No	No	Through GSM only
Tamper Alert:	N/A (tamper sticker)	No	No
Data Platform Info:	Third-party data application	Appliance Demand Platform / Prospect Energy platform	MQTT protocol to Microsoft Azure IoT Hub. Then cavex dMRV platform
Proprietary or Open Design:	Proprietary	Open	Open meter design documentation. Tested with proprietary dMRV solution (Cavex)

Organisation:	Sparkmeter	SteamaCo	KPay Innovation Pvt Ltd
Product Name:	SMRSD - 1 Phase SMRPI - 3 Phase	SAVI smart meters	PayGo Technology Provider
			Work with manufacturers to add internal monitoring equipment & PayGo functionality
			
Website:	https://www.sparkmeter.io/	https://steama.co/off-grid-smart-metering-platform https://steama.co/savi-meters	https://kpayasyougo.com
Cookstove Type:	N/A (external)	N/A (external)	All electric types
Monitoring Type:	External	External	Work with Manufacturers
Suitability for Carbon Finance:	Use per cooking device or Process data to determine cooking events	Use per cooking device or Process data to determine cooking events	Yes
Availability:	Yes	Yes	Works with manufacturers Built into equipment
Rating:	AC 1/3phase 60/100A	AC 1/3phase 60/100A	Designed for equipment
Approximate Cookstove Cost:	N/A	N/A	N/A
Monitoring System Cost:	Meters: $40-$160 Monitoring Station: $600	$60-$110 (landed cost after import)	Around 10% of Induction stove cost per year per stove (approx.)
Manufacturing Location:		China	
Metering Technology:	Full AC monitoring: Timestamp, average kW, Voltage, Current, Peak Current, Power Factor & Frequency.	Full AC monitoring: Timestamp, Energy, Voltage, Current, Power, Power Factor & Frequency.	Data taken via manufacturer circuitry (if available). Offline version: Uses AI based data of charge/recharge cycles in case of PayGo functionality to provide energy consumption. Online version: Uses GSM to view real-time data such as Power consumption, Temperature & Time of usage
Communication Technology:	Meter data sent up to 2km via proprietary RF Mesh Network on 2.4GHz RF band to Nova 'head end'. Data then sent using 2G/GPRS or better.	2G GPRS/4G, G3-PLC & RF-Mesh (switches between comms)"	Offline version via SMS Online version with GSM/WiFi
Data and Communications Security:	-	AES-128 comms Encryption. DLMS/COSEM (IEEE standard comms protocol).	Usage secured hash algorithm
Data Plan:	Local/Global SIM	Global SIM (6MB/month)	
Device Data Storage:	Yes	Yes (12 months)	Yes (if needed)
Data Sampling:	-	>100Hz	-
Data Reporting:	15 mins	1 hour	-
Location Monitoring:	-	Yes, location captured in SteamaCo Nimbus AMI platform at time of meter commissioning.	Yes (if needed with additional hardware)
Tamper Alert:	Yes	Yes - multiple alerts supported on-board meter	Yes (if needed with additional hardware)
Data Platform Info:	Koios Cloud Software	SteamaCo Nimbus AMI platform. Using AWS	
Proprietary or Open Design:	Proprietary	Proprietary	Proprietary or Open source (via manufacturer)

Organisation:	PowerPay Africa (GIVE Ltd)	BBOXX	Inclusive Energy
Product Name:	PowerPay Africa	Smart Cooking Valve	Smart Biogas
			
			
Website:	https://www.powerpayafrica.com/ https://www.greeninnovationventures.com/	https://www.bboxx.com/products/smart-cooking-valve/	https://inclusive.energy/smart-biogas
Cookstove Type:	All electric types	LPG	Biogas (external)
Monitoring Type:	Work with Manufacturers	Gas (on cylinder)	External
Suitability for Carbon Finance:	Yes	Yes - Sales data	Yes
Availability:	Works with manufacturers Built into equipment	Yes	Yes
Rating:	Designed for equipment	Low pressure gas	External Sensors for different size systems
Approximate Cookstove Cost:	N/A	-	N/A
Monitoring System Cost:	Variable based on quantity	-	$105 - $400 (depending on sensors)
Manufacturing Location:	Kenya	China	India
Metering Technology:	AC monitoring: Timestamp, average kW, Voltage, Current. Depends upon client.	The Smart Valve is used to unlock the LPG cylinder. LPG sales linked to customer for monitoring	Pressure and Flow
Communication Technology:	Several versions available: Wi-Fi / GSM/GPRS / BLE	GSM 2G/Token and Keypad	GSM 2G (with 4G-LTE module available)
Data and Communications Security:	Yes	Unique ID of valve Unique ID of gas cylinder	Network security: TLS 1.2 on HTTPS Database security: TLS 1.2 with AES-256 encryption. Database backups: AES-256 encrypted AWS S3 bucket
Data Plan:	Included in SaaS	Global SIM (Wireless Logic)	Global SIM (5MB/month)
Device Data Storage:	Yes	N/A	Yes (42 days)
Data Sampling:	1 Hz Sampling rate	N/A	1 second (1 min average stored)
Data Reporting:	Per client request	Real-time LPG sales data via smartphone app	1 hour
Location Monitoring:	Yes	N/A	Available at additional cost
Tamper Alert:	No	N/A	No (software only)
Data Platform Info:	PowerPay Cloud Software	BBOXX Pulse 2.0 Platform.	Smart Biogas platform & API
Proprietary or Open Design:	Proprietary (via manufacturer)	Proprietary	Proprietary

Organisation:	PayGo (Sun King)
Product Name:	CSM Cylinder Smart Meter
	
	
Website:	https://www.paygoenergy.co/cylinder-smart-meter
Cookstove Type:	LPG
Monitoring Type:	Gas (on cylinder)
Suitability for Carbon Finance:	Yes
Availability:	Yes
Rating:	Low pressure gas
Approximate Cookstove Cost:	-
Monitoring System Cost:	$40 (target)
Manufacturing Location:	China
Metering Technology:	V1: Time of flight sensor for gas flow. V2: Patented sensor technology
Communication Technology:	V1: GSM 2G V2: Bluetooth download
Data and Communications Security:	-
Data Plan:	-
Device Data Storage:	Yes
Data Sampling:	-
Data Reporting:	-
Location Monitoring:	-
Tamper Alert:	-
Data Platform Info:	PayGo cloud
Proprietary or Open Design:	Proprietary

4.9. Future Developments

In the nascent field of monitoring technology for clean cooking it is expected that there will be wide ranging innovation within all areas: from measurement devices available through to the communication systems and protocols. However, expert interviews repeatedly highlighted that site visits will still be required for surveys to measure co-benefits, investigating fuel stacking or equipment maintenance, although highly automated digital monitoring systems may greatly reduce that requirement.

The cost of monitoring equipment was highlighted as the most significant barrier to implementing digital monitoring systems for carbon finance. Monitoring equipment prices are dropping, especially with economies of scale. Target prices of $40 down to $10 per device are seen as achievable within the short to medium term.

Standardisation of data formatting and communication requirements is needed to make it easy for project developers to implement monitoring systems. It is hoped that open data protocols are adopted for connection to different data platforms and that standards bodies work together to ensure monitoring systems are interoperable. This could affect early adopters, and some project developers are wary of investing heavily in monitoring equipment that could be rendered obsolete by changes in standards.

The need for off-the-shelf and plug-and-play devices for monitoring energy consumption for carbon finance has been highlighted, with a relatively small list of monitored modern cooking device equipment available from early adopters. It is expected that this list will significantly and quickly expand as more manufacturers move from pilots to large-scale equipment roll out.

Monitoring aligns with other aspects, such as PAYGo financing, fuel refilling or operation & maintenance. This will help with uptake and be the easiest systems to onboard to dMRV platforms.

Larger appliance manufacturing companies are starting to produce equipment with energy consumption monitoring and communications equipment in-built to allow PAYGo (enabling last-mile distribution), adding smart facilities (such as providing tailored, localised recipes) and providing smart grid services (such as load balancing and type-of-use tariffs), which highlights that carbon finance is not the only driver of digitisation.

Although happening slowly, the roll-out of low-power wide area networks, such as NB-IoT, Sigfox and LoRaWAN, in LMIC will reduce communication data costs and improve reception for remote area interventions.

The large-scale implementation of property- or household-level smart meters could have a significant impact. If smart meters are used for new grid connections, very large datasets comprising cooking and appliance data could be generated, leading to robust and reliable algorithms to extract cooking events. This could allow extremely low-cost monitoring of cooking events, and hence carbon finance.

With increasing datasets from monitored cooking equipment and smart meters, machine learning algorithms can be trained to ensure highly accurate emission reduction monitoring. Artificial Intelligence (AI) software can be applied to these datasets to extract interesting and economically valuable data, such as operation and maintenance requirements on power systems and appliances or load balancing for national grid management.

4.10. Selected Resources

IoT for Development: Use cases delivering impact
By: GSMA Published: 2023
https://www.gsma.com/mobilefordevelopment/resources/iot-for-development-use-cases-delivering-impact/

IoT and Essential Utility Services: Opportunities in low- and middle income countries
By: GSMA Published: 2023
https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2023/04/IoT-and-Essential-Utility-Services-Opportunities-in-low-and-middle-income-countries.pdf

Digitally Enabled Climate Finance
By: GSMA Published: 2023
https://www.gsma.com/mobilefordevelopment/resources/digitally-enabled-climate-finance/

Protocol for Digitalised MRV: enhancing efficiency and trust in carbon markets
By: South Pole Published: 2020
https://www.ebrd.com/digitised-mrv-protocol.html

5. Co-Benefits Review

Quantified sustainable development contributions beyond CO_2e emission reductions, also called co-benefits, are becoming increasingly important in the context of carbon markets and climate change mitigation. This means that carbon credits with certified co-benefits have the potential to fetch higher prices.[82] There is also potential for directly monetising sustainable development impacts independently of climate impacts, which might play an increasing role for clean cooking activities in the future. An example for the successful monetisation of health impacts is Clean Impact Bond by Cardano[83].

Co-benefits are typically measured against the UN's 17 Sustainable Development Goals[84] (SDGs), the most relevant ones associated with modern cooking being SDG 3 (Good Health and Wellbeing), SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth) and SDG 15 (Life on Land). Black carbon emissions from cookstoves are also highlighted as having both carbon emission and health impacts, with quantification helping to assess those impacts.

With the rising importance of co-benefits, the need for thorough monitoring is also increasing, opening up opportunities for digitisation. Fuel or electricity consumption data of modern cooking appliances, already being monitored for emission reduction calculations, may be used directly to derive data for some of these co-benefit indicators, without any additional hardware cost. Similarly, additional sensing equipment could be integrated with an energy consumption monitoring device to help minimise the cost, effort, and human error of assessing the impacts of these co-benefits.

Modern measuring devices also provide opportunities for the collection of data that does not directly quantify co-benefits but can be of value for researchers or project developers to improve their modern cooking programmes, such as information on the type of cooking activity, dishes cooked or the availability and stability of the electricity grid.

In this chapter, the co-benefit monitoring requirements from the standard-setting bodies are reviewed. Monitoring tools used at present are briefly reviewed and the calculation of co-benefits from measured energy consumption is highlighted for the applicable SDG impacts. Sensing devices that could help improve the accuracy of co-benefit monitoring are investigated and a number of relevant initiatives are highlighted.

5.1. Monitoring requirements and tools from standards

In this section the requirements, recommendations and tools provided by the major carbon standard-setting bodies are reviewed.

82 https://www.ecosystemmarketplace.com/publications/state-of-the-voluntary-carbon-market-report-2023/
83 https://mecs.org.uk/clean-impact-bond-profiled-by-ifc-at-the-innovate4climate-forum-2023/
84 https://sdgs.un.org/goals

5.1.1. Gold Standard

The Gold Standard has developed its carbon certification standard with the SDGs at the heart of it. Every carbon project seeking certification needs to contribute to at least two SDGs in addition to SDG 13, and the SDG contributions need to be quantified by regular monitoring of activity-level indicators. Co-benefits are verified by an independent VVB just like GHG emission reductions. In addition to carbon credits, Gold Standard also provides certification standards for a number of other impacts, namely renewable energy certificates, water benefit certificates, gender equality impacts, improved health outcomes and black carbon reductions. Gold Standard is also part of the Sustainable Development Initiative that advocates for "strong sustainable development provisions in Article 6 of the Paris Agreement".

Gold Standard was the first standard to develop a comprehensive SDG Impact Tool that enables standardised reporting on SDG contributions. The first, excel-based version of the tool was published in 2021 and made a mandatory part of project certification in March 2022. It has since been replaced by a fully online tool, where project developers define and report on their project activities' contributions. The digital SDG Impact Tool predefines indicators eligible by project type and provides guidance on activity-level indicators and their monitoring. This means that project developers may no longer freely define those indicators themselves. Gold Standard indicators that are eligible and relevant for clean cooking activities are listed in Table 16. The SDG Impact tool also includes supporting resources for streamlined implementation, and reference values aiding auditors in efficient assessment and prevention of over-claiming. Gold Standard is working on enhancing the tool further to enable monitoring against host country's SDG objectives.

5.1.2. Verra

Projects certified under VCS Verra are also required to contribute to three SDGs by the end of the first monitoring period and, where possible, demonstrate how the project aligns with the SDG objectives of the host country. However, these contributions only need to be reported on in a standardised Sustainable Development Contributions Report and are not verified in the VCS. In the report, the VCS requires project developers to provide quantitative descriptions of achieved contributions to selected SDG targets, but does not require defining activity-level indicators that need to be monitored.

For verified co-benefits, Verra has developed additional standards that VCS credits may be labelled with, namely the Sustainable Development Verified Impact Standard (SD VISta) and the Climate, Community and Biodiversity Standards (CCB).

SD VISta is a standard specifically developed to certify sustainable development impacts and is not exclusive to carbon or climate change mitigation projects. It distinguishes between the three categories "People and their Prosperity", "People, their Prosperity and Planet" and "Planet" with individual requirements. All projects need to demonstrate a contribution to at least one SDG and can choose to generate either SD VISta claims or SD VISta assets. SD VISta claims serve to highlight a project's unique benefits and only require assessment by a VVB, but do not generate units in the Verra registry that can be traded or retired. SD VISta assets on the other hand are standardised, transactable units, which are quantified according to an SD VISta-approved methodology, verified by a VVB and subsequently issued. Project developers can develop their own SD VISta asset methodologies for SD VISta approval or use approved methodologies. Currently there is only one approved methodology, a Methodology for Time Savings from Improved Cookstoves (ICS) with two more under development.

The Climate, Community and Biodiversity Standards (CCB) is only relevant to land management projects and is therefore not further discussed here.

5.1.3. UNFCCC

While sustainable development impacts played less of a role under the CDM, they are a requirement in the new cooperative mechanisms enshrined in Article 6 of the Paris Agreement. The Article 6.4 Supervisory Body (SB) is in the process of developing a Sustainable Development Tool (SD Tool), a first draft of which was agreed upon at the SB's 8th meeting from 30 October - 2 November 2023 and published subsequently.

The draft SD Tool rules that its use is mandatory for all projects transitioning from CDM. It introduces the requirement to assess, demonstrate and monitor potential positive and negative contributions to the SDGs. In order to do so, project developers need to demonstrate the direct impact of the project activity(ies) to sustainable development objectives and priorities of the host countries. There is emphasis on the activity being the main driver of the change and on the impact needing to last at least for the duration of the whole crediting period. As opposed to the Gold Standard SDG Tool, which provides a list of default sustainable development monitoring indicators based on the individual activity type, the Article 6.4 SD Tool takes a bottom-up approach for now, i.e. allowing project developers to select relevant SDGs and define the pertinent SDG indicator themselves. A top-down approach similar to Gold Standard's, which the SB acknowledged to require extensive work, may be developed at a later stage.

In order to report on co-benefits, project developers will need to complete the A6.4 Sustainable Development form, including:

- A description of the activity level indicators and corresponding SDG targets and SDG indicators
- the data unit and source of data for the indicator
- Information on monitoring/measurement procedures/methods
- Monitoring frequency (at least annual)

As part of the work on the SD Tool, the UNFCCC secretariat has also surveyed relevant Article 6.4 stakeholders regarding sustainable development impacts. This included a survey of 41 Designated National Authorities (DNAs), the host country organisations supervising Article 6.4 activities, on their plans to address sustainable development impacts from Article 6.4 project activities. Over half of them expressed interest in developing and applying country-specific sustainable development objectives, while others are considering assessing impacts based on the 17 SDGs.

5.2. Current monitoring practices

Currently, co-benefits in clean cooking projects are often monitored through surveys, deriving co-benefits from cooking data, and/or reviewing economic records for sale of fuel or purchase of feedstock materials.

Surveys require interviewing a sample of users regarding, for example, the air quality in their households or savings in time and money they have made by adopting the new cooking technology. Apart from the fact that such interviews are time-consuming for both the project developer and the user and thereby costly, the reliability of the data is often low. Data is highly qualitative and sometimes prescriptive, for example monitoring health benefits by asking questions about reduction in coughs with just a binary “yes or no” answer. Paper-based surveys also introduce multiple stages for the introduction of human error, for example through transcription or translation of answers.

Table 16: Relevant SDGs and co-benefit indicators for clean cooking activities.

SDG	Indicator[85]		GS SDG Tool Guidance	Available methodologies, guidelines or resources	Calculation from Energy Consumption Data[86]	Relevance for modern cooking
	1.1.1. / GSDG-I1.1.1	Proportion of the population living below the international poverty line by sex, age, employment status and geographic location (urban/rural)	no			
	GSDM-I1.1.1	Average household savings i.e., decrease in expenditure on basic service such as cooking, lighting, drinking	yes		yes	
	1.2.1 / GSDG-I1.2.1	Proportion of population living below the national poverty line, by sex and age	no			
	1.4.1 / GSDG-I1.4.1	Proportion of population living in households with access to basic services	yes	https://unstats.un.org/sdgs/metadata/		
	GSDM-I3.9.1	Number of households that observed reduction in PM2.5 & carbon monoxide (CO) concentration reductions	yes			
	GSDM-I3.9.2	Number of Averted Mortality and Disability Adjusted Life Years (ADALYs)	yes	GS Methodology to Estimate and Verify ADALYs from Cleaner Household Air	yes	
	GSDM-I3.9.3	Number of household visited medical facilities/dispensary for treatment of respiratory issues etc. such as cough, shortness in breath, pneumonia and other respiratory issues	yes			
	GSDM-I4.4.1	Number of employees provided skill development training	yes			
	GSDM-I4.4.2	Number of training hours provided for employees (full-time, part-time, or temporary), disaggregated per gender	yes			
	4.a.1 / GSDG-I4.a.1	Proportion of schools with access to: (a) electricity; (b) the Internet for pedagogical purposes; (c) computers for pedagogical purposes; (d) adapted infrastructure and materials for students with disabilities; (e) basic drinking water; (f) single-sex basic sanitation facilities; and (g) basic handwashing facilities (as per the WASH indicator definitions)	no			

85 Note that some but not all Gold Standard indicators coincide with official UN indicators for the SDGs. Indicators starting with "GSD-" are Gold Standard-defined indicators, while the others are UN indicators.
86 For exemplary detailed calculation methods for some of the indicators see Appendix 8.2

Table 16: Co-Benefits of clean cooking and links to SDGs (cont.).

5 GENDER EQUALITY	GSDM-I5.1.1	Gender wage equity	yes			
	5.4.1 / GSDG-I5.4.1	Proportion of time spent on unpaid domestic and care work, by sex, age and location	yes		yes	
	GSDM-I5.4.1	Average time saving associated with cooking time and fuel collection	yes	GS Gender Equality Requirements & Guidelines SD VISta Methodology for Time Savings from Improved Cookstoves (ICS)		
	5.5.2 / GSDG-I5.5.2	Proportion of women in managerial positions	no			
	GSDM-I5.5.1	Number of women serving in managerial/ leadership /ownership role	yes			
7 AFFORDABLE AND CLEAN ENERGY	7.1.2 / GSDG-I7.1.2	Proportion of population with primary reliance on clean fuels and technology	yes			
	7.1.1 / GSDG-I7.1.1	Proportion of population with access to electricity	yes	ESMAP Multi-Tier Framework for Measuring Energy Access		
	GSDM-I7.1.1	Number of beneficiaries: Households	yes			
	GSDM-I7.1.1	Number of beneficiaries: Individuals	yes			
	GSDM-I7.2.3	Total electricity consumed: Renewable	yes		yes	
	GSDM-I7.2.1	Total electricity produced: Renewable	yes			
	GSDM-I7.2.2	Total thermal energy produced: Renewable	yes		yes	
	GSDM-I7.3.1	Total energy savings	yes		yes	
8 DECENT WORK AND ECONOMIC GROWTH	GSDM-I8.5.2	Total number of employees earning above local minimum wage	yes	WageIndicator		
	GSDM-I8.5.3	Total Number of employees paid living wage	yes	The Anker Methodology for Estimating a Living Wage		
	GSDM-I8.5.1	Total number of jobs	yes			
	8.4.1	Material footprint, material footprint per capita, and material footprint per GDP			yes	

Table 16: Co-Benefits of clean cooking and links to SDGs (cont.).

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	9.4.1	CO2 emission per unit of value added (Note: Only applicable for institutional cooking, e.g. schools as part of the countries infrastructure)			yes	
11 SUSTAINABLE CITIES AND COMMUNITIES	11.6.2	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) (Note: Only applicable for projects in cities)			yes	
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	12.2.1	Material footprint, material footprint per capita, and material footprint per GDP			yes	
13 CLIMATE ACTION	GSDM-I13.2.2	BCe emissions reduced per year and amount of net CO2eq	yes	GS Quantification of climate related emission reductions of Black Carbon and Co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves	yes	
14 LIFE BELOW WATER	14.3.1	Average marine acidity (pH) measured at agreed suite of representative sampling stations			yes	
15 LIFE ON LAND	GSDM-I15.1.1	Total non-renewable wood fuel saved	yes		yes	
	GSDM-I115.2.1	Forest areas managed sustainably for forest products including sustainable produced fuelwood	no			
	15.3.1	Proportion of land that is degraded over total land area			yes	

5.3. Opportunities for digitised monitoring of co-benefits

There are a wide range of opportunities for improving the monitoring of co-benefits through the use of digital technologies and hardware. These opportunities are reviewed in this section.

5.3.1. Improvement of survey techniques

Surveys can be improved through the use of integrated digital surveying tools, as have been described in Section 3.2: Digital Survey Tools. These utilise smartphone apps with guided forms to collect a large amount of data relating to a range of different SDGs (e.g. gender or age of the cook, perceived health improvements, financial savings etc.). Data is automatically stored to an online platform when the smartphone is in a reception area. While these are little different from traditional user interviews in terms of introducing human error, they can still provide significant time savings and more accurate data due to an increased number of data points.

5.3.2. Indirect monitoring through energy usage data

Having reliable cooking energy consumption data from cooking appliances opens up the opportunity for the project developer to derive estimates of up to 11 additional SDG impacts (SDG 1, 3, 5, 6, 7, 8, 9, 11, 12, 14, 15) with appropriate additional ex-ante values that are to be validated at project start and crediting period renewal.

Table 16 shows an overview of the SDG impacts and if they can be derived from the metered cooking energy consumption for the exemplary case of firewood as baseline and electricity as project fuel. These SDG impacts include SDG 3 (Health) via ADALYs due to the improved air quality, SDG 5 (Gender) through the time saved from collecting firewood, SDG 15 (Life on Land) through the amount of biomass (trees) remaining in forests due to the reduced firewood consumption. The calculations and ex-ante values required are provided in Appendix 8.2. This can represent a cost-efficient method to obtain quantifiable impact estimations for co-benefits of clean cooking activities that are more comparable across projects. This data could be made even more accurate if additional information is included, such as regarding the cooking technology and the amount of stacked fuel used, through digital monitoring and analysis. Standardised digital tools that define eligible calculation methods for co-benefits from metered energy usage alongside default values for the necessary ex-ante values could provide more legitimacy to this approach and enhance integrity of co-benefit claims.

For many co-benefits indirect measurement through energy usage data and direct measurement of the co-benefits through additional sensors as discussed in the following are alternative approaches. While there may be some additional benefits from direct measurement, the indirect measurement of the co-benefits has the significant advantage that it relies on just the already metered energy data plus some ex-ante values that are fixed at the start of the crediting period. This would incur minimal additional costs to the project developer while providing significantly more reliable, quantifiable and comparable estimates on the co-benefits compared to the current practice of using surveys - especially if standardised tools that define the calculation methods and provide default ex-ante values are developed and used as mentioned above.

5.3.3. Direct monitoring through additional sensors

To increase monitoring accuracy and the scope of measurable impacts, additional data can be gathered using the same measuring device that captures the energy consumption data needed for CO_2e emission reduction reporting. Upgrading the measuring device with additional functionalities or sensors further expands the possibilities of impact monitoring.

Human Presence Detection

Detecting if a person is present at a cookstove can help to inform any time saving associated with cooking time (SDG 5). This could be inferred from the cooking event power and time data, with the assumption that a person is at the cookstove for the entire duration of the cooking event, but this may not be accurate, as pots may be left simmering or boiling without anyone present. If an accurate detection system could be implemented, then more accurate data for length of time at the cookstove can be used. There are several methods for electronic human presence detection[87] including:

- **Ambient light sensors** to measure the light reflecting from an approaching user to detect human presence from a distance. Issues include: inaccurate readings.
- **Ultrasonic proximity sensors** use ultrasonic waves and analyse the time it takes to return to determine distance to the sensor. Issues include: limited detection ranges.
- **IR proximity sensors** use infrared (IR) light reflection to determine distance and detect figures. Issues include: limited detection ranges.
- **Passive IR sensors** are used to detect motion of IR light-emitting sources (typically human bodies). Issues include: false positives due to other IR heat sources, especially from cookstoves.
- **Capacitive proximity sensors** create their own electrostatic field but when an object approaches the sensor, it changes the sensor's capacitance, resulting in an amplitude change. These can be low cost, but have potential for false positives, especially with pots and water used on cookstoves.
- **Time-of-flight sensors** emit a signal that reflects off a surface and measures the time it takes to return to the sensor. Time-of-flight sensors use an array of light-sensing pixels to determine relative distances from the object, creating a range map. They can be more complex to implement but can be designed for low power consumption.
- **Visual sensors**, using image processing and recognition, can detect human shapes. While complex and potentially expensive to implement, they can give accurate detection data.

Temperature sensing

Temperature sensing can be used to add information relating to the cooking technique, stove usage and efficiency, meteorological data for renewable energy systems, and human comfort amongst other parameters.

Some techniques to convert temperature into an electronic signal which can be integrated into a monitoring system include:

87 https://www.electronicdesign.com/markets/automation/article/21140143/powering-human-presence-detection-with-sensors

- **Thermo-couples** consist of two different conductors which, when subjected to a temperature gradient, will produce a voltage proportional to the temperature difference. They are low cost, have high temperature ranges, and have very small thermal mass so they can respond quickly to changes in temperature. Disadvantages include the very small output voltage, the need for cold-junction calibration, they require direct contact with the monitored device, and some have relatively low accuracy.
- **Resistive temperature sensors**, which include Resistance Temperature Detectors (RTD) and thermistors, are resistors whose resistance value varies with temperature. These can be used to give a varying output voltage, by wiring them in a potential divider circuit. They are low cost and readily available, but they typically have lower temperature sensor ranges, require direct contact, and may require calibration.
- **Infra-Red sensors** focus infrared light at an object to detect and then measure energy or radiation coming from its surface. The detector then translates the amount of electricity generated into a temperature reading. These are non-contact which allows remote sensing and can measure wide temperature ranges but require additional circuitry and hence cost.
- **Analogue output devices** contain integrated circuitry which reads an integrated temperature sensor and outputs a linear voltage which is proportional to the temperature. These are factory calibrated but can be more expensive and require direct contact.
- **Digital output devices** have an in-built analogue to digital converter. The temperature is measured and then converted into a digital signal. This digital signal can then be read by the monitoring device. Some have unique IDs which allows a number of sensors to be added to just the data lines. They are factory calibrated, but are typically for measuring lower temperature ranges, require direct contact, and have higher complexity and hence cost. Some digital units measure a range of parameters, including temperature, humidity and pressure, in one integrated package.

Particulate Matter sensing

The measurement of the small particles, called particulate matter (PM) is important for assessing health impacts of clean cookstove projects. PM are aerosols composed of solids (dust, soot) and liquid droplets of tars and other combustion products (excluding water vapour). They occur in a wide range of sizes (between 0,005µm and 100µm in diameter) and with very diverse chemical compositions. The smaller respirable particles have more adverse effects on health as they can penetrate the lungs more deeply, with health impacts focusing mainly on the ‘fine’ particles with diameters below 2.5 µm, called ‘$PM_{2.5}$’, or below 1µm, called ‘$PM_{1.0}$’.

There are two main methods for quantifying PM exposure:

- **Gravimetric methods**, where sampled air is sucked through a filter for a specific time period and then the filter is weighed to measure the deposited particles on a high-precision scale. This method provides accurate absolute measurements, if performed in controlled laboratory conditions, but is labour-intensive, slow, and hence expensive and is also prone to uncertainties from filter handling, transport, conditioning and weighing. This method is approved for Gold Standard quantification of climate related emission reductions of black carbon and co-emitted species[88].

- **Reflection of light methods** allow the continuous monitoring of the PM concentration using indirect techniques, such as the reflection of IR or laser light by the aerosols. Sampled air is drawn through a chamber either with a fan or a heated element. The IR or laser light will reflect off particles which is detected by a high gain light detector. Due to the different wavelengths, laser light can detect smaller particles. Typically, reflection of light sensors require accurate calibration if absolute values are required, but they can be used to highlight relative changes.

  For remote monitoring systems, the reflection of light PM method is potentially the most appropriate, but is not, at present, approved for the Gold Standard quantification of climate related emission reductions of black carbon and co-emitted species[89]. The sensors can have relatively high-power consumption requirements, due to internal fans or heaters. Typically, they are powered on and allowed to settle for minutes, then a reading taken and then shut down to conserve power until the next reading is required. Many manufactures of PM sensors exist, outlined in Table 17.

Table 17: Current manufacturers of PM sensors.

Manufacturer	Link
Winsen	https://www.winsen-sensor.com/dust-sensor/
Bosch	https://www.bosch-sensortec.com/products/environmental-sensors/particulate-matter-sensor/bmv080/
Omron	https://www.ia.omron.com/products/category/energy-conservation-support_environment-measure-equipment/equo-environment-sensor/air-particle-sensor/
Sensirion	https://sensirion.com/products/catalog/SPS30/

Air quality sensors

There are a wide, and ever-expanding, range of lower cost sensors for measuring various aspects of air quality. These include sensors for carbon dioxide (CO_2), carbon monoxide CO), nitrous Oxides (NO_x), methane (CH_4) and Volatile Organic Compounds (VOCs), amongst others. They are typically electro-chemical devices with integrated circuitry. The range is too large to go into detail within this report but include devices from manufacturers outlined in Table 18.

Table 18: Current manufacturers of air quality sensors.

Manufacturer	Link
Bosch	https://www.bosch-sensortec.com/products/environmental-sensors/
Murata	https://www.murata.com/en-eu/products/sensor
Renesas	https://www.renesas.com/us/en/products/sensor-products
Amphenol	https://www.amphenol-sensors.com/en/telaire

88 *https://globalgoals.goldstandard.org/standards/412_V1.1_ICS_SLCP_Black-Carbon-and-Co-emitted-Species-due-to-the-replacement-of-less-efficient-cookstoves-with-improved-efficiency-cookstoves.pdf*
89 *https://globalgoals.goldstandard.org/standards/412_V1.1_ICS_SLCP_Black-Carbon-and-Co-emitted-Species-due-to-the-replacement-of-less-efficient-cookstoves-with-improved-efficiency-cookstoves.pdf*

There are also a wide variety of fully integrated particulate/air quality sensor units, typically aimed at the consumer market, with a small selection highlighted in Table 19. These usually have multiple integrated sensors, local data storage and Wi-Fi connection to upload data for real time viewing, either online or through a dedicated smart phone app. They are relatively high cost, although some have lower-priced DIY versions and open designs.

Table 19: Fully integrated particulate/air quality sensor units.

Company	Link
PurpleAir	https://www2.purpleair.com/
Sensor.Community	https://sensor.community/en/
Air Quality Egg	https://airqualityegg.com/home
Clarity	https://www.clarity.io/
Airly	https://airly.org/en/
IQAir	https://www.iqair.com/air-quality-monitors

5.4. Considerations on black carbon

Black carbon (BC), commonly known as soot, is a component of fine particulate air pollution (≤ $PM_{2.5}$) formed by the incomplete combustion of wood and fossil fuels. Black carbon is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths. It has an atmospheric lifetime of days to weeks and is therefore considered a short-lived climate pollutant (SLCP). Cookstoves fuelled by solid fuels are one of the key contributors to SLCPs such as BC, CH4 and ozone (O_3) precursors like carbon monoxide (CO) and volatile organic compounds (VOCs). Biofuel cooking accounts for around 15% of global black carbon emissions[90]. Black carbon has negative effects on health when inhaled and effects on climate by increasing the absorption of sunlight. In order to determine the net climate effect of BC, co-emission of other aerosols like sulphur dioxide (SO_2) with a negative radiative forcing index, i.e. a climate cooling effect, have to be considered[91]. The reduction of activities with a high ratio of warming (e.g. BC) to cooling (e.g. SO_2) pollutants, like biomass burning, therefore has the highest mitigating impact on climate (compared, for example, with the burning of fossil fuels)[92]. The short atmospheric lifetime of BC means that reducing BC emissions would result in a faster climate response than mitigating CO_2 and other long-lived greenhouse gases, and BC is estimated to be second only to CO_2 in its warming impact[93].

The Gold Standard provide a methodology for the "Quantification of climate related emission reductions of Black Carbon and Co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves"[94]. This methodology only accounts for BC and co-emitted species from fuel consumption, but these emissions can also occur during fuel production and fuel transportation. In order to quantify the reduction in BC, this methodology

90 Bond, T. C., et al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res. Atmos., 118, 5380–5552, DOI:10.1002/jgrd.50171
91 Akemura, t. et al (2019), Weak global warming mitigation by reducing black carbon emissions, Nature, DOI:10.1038/s41598-019-41181-6
92 https://www.ccacoalition.org/short-lived-climate-pollutants/black-carbon
93 Black carbon cookstove emissions: A field assessment of 19 stove/fuel combinations by Charity Garland, Samantha Delapena, Rajendra Prasad, Christian L'Orange, Donee Alexander, Michael Johnson. DOI: 10.1016/j.atmosenv.2017.08.040
94 https://globalgoals.goldstandard.org/standards/412_V1.1_ICS_SLCP_Black-Carbon-and-Co-emitted-Species-due-to-the-replacement-of-less-efficient-cookstoves-with-improved-efficiency-cookstoves.pdf

requires a baseline survey of target population characteristics and a baseline performance test of fuel consumption and use (such as a kitchen performance test). The emissions reduction for BC and co-emitted species requires the calculation of the BC and co-emitted species reduction for an individual technology compared to the individual technology baseline. Adjustment factors can also be used to account for any bias in laboratory versus field testing. The BC equivalent conversion factor is the ratio of the global warming potential (GWP) of the emitted co-species to the GWP of BC for a 20-year horizon. The 20-year GWP of BC and emitted co-species values are provided by the IPCC[95], or credible published regional values could also be used. Laboratory testing of the improved biomass cookstove is performed to measure the emission factor in terms of grams per kg fuel consumed, which must be performed every 2 years as part of the GS methodology. With modern energy cooking devices, such as electricity, there may be no direct stove emissions, so assessment of the fuel used to provide the electricity and the BC and co-species emitted is required.

BC emissions sampling is relatively intensive and costly compared to other types of stove performance tests, requiring gravimetric methods (as discussed in the particulate matter sensing section) with mass deposition onto filters and then further analysis to determine black-body optical parameters. But monitoring $PM_{2.5}$ can be used as a proxy monitoring parameter for BC, as $PM_{2.5}$ values agree well with the sum of organic matter and Black Carbon[96]. As previously discussed, $PM_{2.5}$ monitoring can be performed using light-scattering techniques with relatively low-cost sensors.

A protocol for black carbon emissions has been developed by Nordic test and research institutes[97] aiming to standardise the procedure for measurement of BC in terms of both elemental and organic carbon. Laboratory testing facilities for measurement of black carbon and other emissions from cookstoves can be provided by specialist companies, such as Climate Solutions Consulting[98].

Field-based monitoring of black carbon has highlighted a large difference between estimated BC emission factors and measured BC emissions[99], with measured values over eight times higher. The application of field-based measurements could demonstrate more substantive impacts of clean cooking on short-lived climate pollutants for both climate impact and health-based co-benefits.

5.5. Challenges for monitoring co-benefits

While co-benefit monitoring and reporting is seen to be increasingly important, procedures need to be simple and cost-effective in order to be useful to project developers in real world applications.

The main challenge for digital monitoring of co-benefits is the cost, with many developers reviewing solutions but finding them too expensive to implement at present. The additional cost of sensors and associated hardware along with data costs for communicating these parameters must be covered by additional value from the data. But if the co-benefits are

95 https://www.ipcc.ch/report/ar6/wg1/
96 https://globalgoals.goldstandard.org/standards/412_V1.1_ICS_SLCP_Black-Carbon-and-Co-emitted-Species-due-to-the-replacement-of-less-efficient-cookstoves-with-improved-efficiency-cookstoves.pdf
97 https://www.ccacoalition.org/projects/developing-and-conducting-black-carbon-emissions-testing-and-protocols-heat-stoves
98 https://www.climate-solutions.net/services/stove-field-emission-testing
99 https://documents1.worldbank.org/curated/en/099051123130561434/pdf/P17423201c1bc105d0a4da0803634916bb0.pdf

derived from the energy consumption value already being monitored then there should be little to no additional cost.

These sensors may also require accurate installation. For example, a PM sensor may need to be installed at a specific height and distance from any cooking equipment. Potentially end-users or other actors may adjust or move the sensors which may invalidate the data.

Data from the sensors may not be useful if it is not calibrated initially or at regular intervals, which may require site visits and associated time and cost.

There is also the potential for damage, theft or repurposing of sensing equipment, especially if it includes parts useful for other applications, such as batteries or memory cards. The end user must be involved in the monitoring process and the benefits must be clear to them.

The data produced from any co-benefit monitoring must have economic value, either from higher emission reduction credit prices or from monetising the data for other purposes, such as for appliance manufacturers to improve their devices, operation & maintenance reasons or for academic studies. Markets for co-benefits are emerging and more stringent requirements from the standard-setting bodies are driving progress in this area.

Another potential challenge is that higher accuracy and more reliable data may highlight that the impacts are not as great as expected, which may affect the price obtained for claimed impacts, potentially reducing the price in the short term. But in the longer-term higher accuracy data should lead to greater confidence in any claimed impacts and reduced perceived risk by potential buyers.

5.6. Relevant Initiatives

Climate Solutions Consulting

https://www.climate-solutions.net/

Climate Solutions design and manufacture sensors to enable the digital monitoring of all types of clean cooking programs, including adoption & usage, stove stacking, emissions, time, fuel consumption and aDALYs. They can provide a modular suite of sensors including:

- Infra-red stove use temperature monitor
- Thermocouple stove temperature monitor
- $PM_{2.5}$ air quality monitor
- Data-logging fuel scales

Their equipment has internal batteries and log data internally, with up to 90 days of data stored at 1 min sampling rate. This can be downloaded via Bluetooth Low Energy using either a dedicated 'launcher' device or using a smartphone app. There are also options being developed for automatic cellular or LoRaWAN reporting of data from the field. (Image source[100])

100 https://www.climate-solutions.net/products

Geocene

https://www.geocene.com/

Geocene provides hardware and firmware engineering services for low power devices. They have developed a low cost cookstove usage monitor called 'The Dot', designed for improved cookstoves and, through the Clean Cooking Alliance, have deployed over 10,000 of these devices with over 1 billion data points collected. They use a high temperature thermocouple probe with data stored locally before being uploaded via the Geocene mobile app using Bluetooth Low Energy. They have also developed open-source algorithms for detecting cooking events within their data sets. (Image source[101])

OpenHAP

https://climateledger.org/en/Use-Cases/OpenHAP.66.html

The open Household Air Pollution (openHAP) project was implemented by EED Advisory and its local partners to design, demonstrate and implement low cost indoor air pollution monitoring systems. This included a pre-study covering 20 households to review the best performing air pollution sensors with data collected alongside thermal imaging equipment.

A low-cost Wi-Fi based $PM_{2.5}$ unit was then developed and over 2.5 million data points were collected from 100 households in two low-income areas. The SDS011 $PM_{2.5}$ sensor was used in this project. A report: "Use of Low-Cost Technology in Monitoring Indoor Air Pollution"[102] provides the findings and outputs from this project. (Image source[103])

5.7. Future developments

There is an increasing range of hardware and technology for measuring, recording, and reporting parameters that help to measure co-benefits. This is being driven by many different stakeholders, including wide ranging national and global[104] initiatives for improved air quality, and the increasing prevalence of portable smart technology for tracking health metrics. As the economies of scale and competition drive the price point down, these sensors may become economical for use within digital monitoring systems for clean cooking activities.

The main development required for greater uptake of digital co-benefit monitoring is either regulation requiring this data be collected or the ability to monetise the data. Initially the use of energy consumption data, requiring no additional sensing equipment, can be used to improve SDG impact monitoring. In the longer term it is expected that the cost of equipment will be driven down, alongside markets emerging for sale of this data. This may be driven by

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101 https://www.geocene.com/projects-detail#temp-dot-div
102 https://www.climateledger.org/resources/220609-OpenHAP-final-report.pdf
103 https://climateledger.org/en/Use-Cases/OpenHAP.66.html
104 https://www.ccacoalition.org/content/global-initiatives

requirements from the standard-setting bodies, which are increasingly focused on robust quantification of SDG impacts, or host countries. Real, accurate and verified data will help improve integrity and trust in reported emission reductions and hence the price paid for the carbon credits. Also, markets for the sale of SDG impacts are already emerging (such as the Clean Impact Bond) and may provide additional revenue streams for project developers.

The use of monitoring systems for co-benefits will also provide useful datasets for academia, helping to improve knowledge of climate change and sustainable development. Alongside the energy consumption data, these data sets may also be useful for appliance manufacturers to help them design more efficient equipment or to help highlight operational and maintenance issues.

5.8. Selected Resources

Gold Standard Methodology: Quantification of climate related emission reductions of Black Carbon and Co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves
By: Gold Standard Published: 2017
https://globalgoals.goldstandard.org/standards/412_V1.1_ICS_SLCP_Black-Carbon-and-Co-emitted-Species-due-to-the-replacement-of-less-efficient-cookstoves-with-improved-efficiency-cookstoves.pdf

Use of Low-Cost Technology in Monitoring Indoor Air Pollution
By: Climate Ledger Initiative Published: 2022
https://www.climateledger.org/resources/220609-OpenHAP-final-report.pdf

8th meeting of the Article 6.4 Supervisory Body
By: UNFCCC Published: 2023
https://unfccc.int/event/Supervisory-Body-8

Draft Article 6.4 sustainable development tool, Version 2.0
By: UNFCCC Published: 2023
https://unfccc.int/sites/default/files/resource/a64-sb008-aa-a10.pdf

Concept Note Development of a sustainable development tool for Article 6.4 of the Paris Agreement, Version 2.0
By: UNFCCC Published: 2023
https://unfccc.int/sites/default/files/resource/a64-sb007-aa-a07.pdf

Sustainable Development Verified Impact Standard, Version 1.0
By: Verra Published: 2019
https://verra.org/wp-content/uploads/2019/01/Sustainable-Development-Verified-Impact-Standard-v1.0.pdf

6. Case Studies

Project location(s)	Bangladesh & Cambodia (with pilots in Zambia and Rwanda)
Cooking technology	Induction hob (single 2000W or double 1,000W hob/ 1500W with Booster)
Carbon standard and methodology	Gold Standard Methodology for Metered and Measured Energy Cooking Devices
Start of project operations	Jan 2022
Number of installed appliances so far	10,000 in Bangladesh & Cambodia 500 in Zambia and 100 in Rwanda
Innovative dMRV solution	ATEC, working with FairClimateFund & MECS, have developed a pilot scheme providing IoT enabled PAYGo induction cooking hobs with a “earn-as-you-cook” finance model, with 70% of carbon finance being returned to the end user via micro-payments. Their eCook induction hob is grid-connected with GSM (2G with 4G LTE module available in 2024) enabled energy metering. Energy use data is calculated from the device power setting and the length of time the unit is used. Data is sent multiple times a day to the proprietary ATEC dMRV data platform. 

	Share of monitored users	100%
Challenges met	At present ATEC is ready for data integration into SustainCERT dMRV but this is not yet enabled. Micro-payments to end users is complex and end users must have some form of mobile money account for this solution. This solution is still being developed. Customers do not yet understand the “cook-to-earn” concept fully. Need to justify the additional cost of this stove when compared to others on the market. Non usage of stoves may lead to connectivity issues to the device.	
Quote	“Focus on credibility and accountability of devices”	

Project location(s)	Kenya
Cooking technology	LPG
Carbon standard and methodology	Gold Standard Methodology for Metered and Measured Energy Cooking Devices
Start of project operations	Jan, 2023
Number of installed appliances so far	10,000 cylinder smart meter units supplied.
Innovative dMRV solution	Cylinder Smart Meter (CSM) contains a low-pressure LPG regulator, metering capabilities and a communications system and utilises patent pending gas flow sensing technology to provide safe, high-precision metering of customer consumption. CSM designed for control of gas for pay-as-you-go finance. Data for carbon credits was already being collected for sales reasons on their proprietary platform. PayGo also implements Tag & Trace via a QR code on their cylinders for additional monitoring of inventory levels & cylinder locations for supply logistics. Selling carbon credits through Carbon Clear.

Costs of dMRV solution	$40 (target price)

	Share of monitored users	100%
Challenges met	Time taken for the project validation process has been over two years. Information from standard-setting bodies being updated without informing project developers. SustainCERT dMRV platform only suitable for grid-connected projects. Costs of monitoring must include both hardware and ongoing data costs, so cannot rely purely on carbon finance for this.	
Quote	“Validation has been a long and needlessly confusing process. It feels like the process is designed to be frustrating for new players in the sector”	

<table>
<tr><th colspan="3">UpEnergy</th></tr>
<tr><td>Project location(s)</td><td colspan="2">Uganda, Tanzania
(with pilot projects underway in Zambia and Ghana)</td></tr>
<tr><td>Cooking technology</td><td colspan="2">Electric Pressure Cookers</td></tr>
<tr><td>Carbon standard and methodology</td><td colspan="2">Gold Standard Technologies And Practices To Displace Decentralized Thermal Energy Consumption,
Gold Standard Methodology for Metered & Measured Energy Cooking Devices</td></tr>
<tr><td>Start of project operations</td><td colspan="2">April 2021</td></tr>
<tr><td>Number of installed appliances so far</td><td colspan="2">5,000+</td></tr>
<tr><td rowspan="3">Innovative dMRV solution</td><td colspan="2">UpEnergy in collaboration with PowerUp distributes an Electric Pressure Cooker by PowerUp with an integrated sensor continuously measuring electricity consumption. The consumption data is stored internally and can be retrieved using a pen drive. It is then uploaded and managed using a third-party data application. PowerUP is also developing a version of these cookers with an integrated GSM module to enable remote monitoring. Additionally, UpEnergy uses SalesForce for digital user surveys to gather feedback and data on the use and impact of these e-cookers.
 </td></tr>
<tr><td>Costs of dMRV solution</td><td>18-25% of product cost</td></tr>
<tr><td>Share of monitored users</td><td>Target to reach 100%</td></tr>
</table>

Challenges met	The battery of the sensor needs replacement every 2-3 years. They plan to mobilize key service staff in regional hubs to handle service/warranty needs. Many perceive modern electric cooking as expensive, luxurious, and unsafe. UpEnergy, collaborating with sector stakeholders, has initiated experiential campaigns to demystify and promote e-cooking. There is challenge of product misuse leading to high failure rates, which UpEnergy addresses through dedicated relationship officers, a customer care team and various regional hubs that disseminate knowledge on product use and by building closer relationships with end-users to track and support usage. The initial product cost is high, but carbon finance makes it more accessible.
Quote	“With our e-cookers' digital monitoring capabilities, we balance high-tech oversight with essential on-the-ground kitchen observations, ensuring a comprehensive and accurate impact assessment.” *Andrew Wanyaka, Carbon Operations Lead*

7. Outlook

“Carbon markets are data”[105]

Digital monitoring, reporting and verification for modern cooking systems, while an emerging field at a nascent stage, has huge potential for both sustainable development impact and emissions reduction. Accurate and real-time digital data improves trust and transparency and hence increases the integrity of emission reductions. This, in turn, should help drive up the value of carbon credits and, potentially, other SDG impacts, providing higher revenue streams for project developers.

A key finding from stakeholder engagement is that, while significant strategic development is underway on the topic of digital monitoring, reporting and verification, much has yet to be translated into the field or the carbon certification standards. The requirements put on project developers by standard-setting bodies are limited, as they are still developing the principles and guidelines that should govern dMRV. Project developers and impact verifying bodies in many instances seem to be ahead of standard setting bodies in driving innovative solutions, but do so in a largely unregulated playing field. This bears a risk for early-moving project developers having to adapt their solutions later on to new regulation from standards.

At present there are only a handful of measuring devices or monitored appliances, utilising a range of measurement techniques and different communication systems. It is expected that a much larger range of metered appliances or external energy consumption monitoring systems will be available over the coming few years, as early adopter schemes increase the knowledgebase for practical implementation and larger projects drive economies of scale. Standardisation and interoperability of equipment, data formats and communications systems is key to increasing the equipment ecosystem.

Data management platforms for recording and reporting data from monitoring systems are typically built by project developers and therefore bespoke and proprietary. This creates a high barrier to entry for project developers without the capital or capacity to develop these systems. It is expected that a wider range of companies will provide these platforms, as the potential economic benefits are realised. Key to this will be multi-stakeholder standardisation initiatives.

Data from dMRV systems may also be used to improve the accuracy of other key parameters used for impact assessment, some of which have been the subject of debate and controversy due to reliability concerns. Although this may highlight a lower level of emission reductions from clean cooking projects, those emission reductions will be more accurate, trust in the market will be increased and hopefully will drive more action on impacts to reduce climate change.

105 https://www.carbonclear.earth/team

8. Appendix

8.1. Stakeholder List

Thanks are given to the following people and organisations for providing expert interviews and up-to-date insight for this document.

Organisation	Name	Website
A2EI	Elliot Avila	https://a2ei.org/
ATEC	Wilm Romf	https://www.atecglobal.io/
atmosfair	Annika Richter Zoltán Müller-Karpe	https://www.atmosfair.de/en/
BBOXX	Norio Suzuki	https://www.bboxx.com/
BURN Manufacturing	Molly Brown, Nathan Gachugi	https://www.burnstoves.com/
Carbon Check	Anubhav Dimri	https://www.carboncheck.co.in/
Climate Impact Partners	Tom Owino	https://www.climateimpact.com/
Climate Solutions Consulting	Olivier Lefebvre	https://www.climate-solutions.net/
CO2Balance	George Syder	https://www.co2balance.com/
Earthhood	Archit Srivastava	https://www.earthood.in/
Ener-Grow	Aaron Lepold	https://ener-grow.com/
Fair Climate Fund	Harry Clemens	https://www.fairclimatefund.nl/en
Gamos East Africa	Jon Leary	http://gamos.org/
Geocene	Danny Wilson	https://www.geocene.com/
Gold Standard	Claire Willers	https://www.goldstandard.org/
GSMA	Zach White	https://www.gsma.com/
Inclusive Energy	Vijay Bhopal	https://inclusive.energy/
INFRAS	Jürg Füssler	https://www.infras.ch/en/
K-PayAsYouGo	Mahesh Badgujar	https://kpayasyougo.com/
PayGo Energy (Sun King)	Mark O'Keefe	https://www.paygoenergy.co/
Powerpay	Geoffrey, Kimiti	https://www.powerpayafrica.com/
SteamaCo	Warren Scott-White	https://steama.co/
SustainCERT	Nadine Planzer	https://www.sustain-cert.com/
TASC	Edwin Cogho, Bianca Stead	https://tasc.je/
UNFCCC Secretariat	Gajanana Hegde	https://unfccc.int/
UpEnergy	Anantha Karthik	https://www.upenergygroup.com/

	Rajagopalan	
VCS Verra	Kranav Sharma	https://verra.org/programs/verified-carbon-standard/
Verst Carbon	Ian Mutai, Evans Kayo, Charles Waweru	https://verst.earth/

8.2. Equations for calculation of co-benefits from energy data

1 NO POVERTY

Target 1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day

Indicator 1.1.1 Proportion of the population living below the international poverty line by sex, age, employment status and geographic location (urban/rural)

Ex-ante values required for this calculation:

- firewood costs C_f [$/t]
- electricity costs C_e [$/MWh]
- Energy density wood $NCV_{b,wood}$ [TJ/t]
- MWh to TJ conversion factor $f_{MWh\text{-}TJ}$ [TJ/MWh]
- Firewood cooking specific energy consumption SC_b [TJ/person/year]
- Electric cooking specific energy consumption SC_p [TJ/person/year]

$$Cost\ savings\ [\$/year] = B_y(E_c) \cdot C_f - E_c \cdot C_e$$

with

- Biomass savings due to electric cooking $B_y(E_c)\ [t/year] = E_c \cdot f_{MWh-TJ} \cdot \frac{SC_b}{SC_p} \div NCV_{b,wood}$
- Electricity consumption for cooking E_c [MWh/year]

3 GOOD HEALTH AND WELL-BEING	**Target 3.9** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
	Indicator 3.9.1 Mortality rate attributed to household and ambient air pollution)
	Ex-ante values required for this calculation: • total global/national disability adjusted life years lost due to air pollution from cooking with biomass $DALYS_{tot}$ [DALYs/year] • total global/national biomass consumption for cooking B_{tot} [t/year] $adverted\ DALYs\ (ADALYs) = \frac{DALYs_{tot}}{B_{tot}} \cdot B_y(E_c)$
5 GENDER EQUALITY	**Target 5.4** Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate
	Indicator 5.4.1 Proportion of time spent on unpaid domestic and care work, by sex, age and location
	Ex-ante values required for this calculation: • average time spend collecting firewood when household is collecting firewood $t_{firewood}$ [h/year/household] • baseline firewood consumption B_{old} [t/year/household] • percentage of households collecting firewood $f_{collect}$ [1] $Time\ \ savings\ [h/year] = \frac{t_{firewood}}{B_{old}} \cdot f_{collect} \cdot B_y(E_c)$

	Target 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
	Indicator 6.6.1 Change in the extent of water-related ecosystems over time
	Ex-ante values required for this calculation: • Fraction of non-renewable biomass fnrb [1] $Net\ biomass\ remaining\ in\ forests\ [t/year] = fnrb \cdot B_y(E_c)$
	Target 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
	Indicator 7.2.1 Renewable energy share in the total final energy consumption
	$Electricity\ consumption\ for\ cooking\ [MWh/year] = E_c$
	Target 8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead
	Indicator 8.4.1 Material footprint, material footprint per capita, and material footprint per GDP
	$Reduction\ of\ primary\ energy\ used\ for\ cooking\ [TJ/year] = NCV_{b,wood} \cdot B_y(E_c) - f_{MWh-TJ} \cdot E_c$
	Target 9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
	Indicator 9.4.1 CO2 emission per unit of value added Note: Only applicable for institutional cooking (e.g. schools as part of the countries infrastructure)

	Ex-ante values required for this calculation: ● Firewood emission factor $EF_{b,input}$ [t_CO_2/TJ] CO_2 emission reductions* ER [t/year] = $E_c \cdot f_{MWh-TJ} \cdot \frac{SC_b}{SC_p} \cdot EF_{b,input}$ *while providing same cooking service / value added
	Target 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
	Indicator 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) Note: Only applicable if project activity is taking place in cities
	Ex-ante values required for this calculation: ● Air pollution from firewood burning $EF_{b,PM2.5}$ [t_PM2.5/t_firewood] $Reduction\ of\ PM2.5\ emissions\ in\ cities\ = B_y \cdot EF_{b,PM2.5}$
	Target 12.2 By 2030, achieve the sustainable management and efficient use of natural resources
	Indicator 12.2.1 Material footprint, material footprint per capita, and material footprint per GDP
	$Reduction\ of\ primary\ energy\ used\ for\ cooking\ [TJ/year] = NCV_{b,wood} \cdot B_y(E_c) - f_{MWh-TJ} \cdot E_c$

	Target 14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
	14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations
	Ex-ante values required for this calculation: ● Total anthropogenic CO_2 emissions since 1850 E_{tot} [t_CO_2] ● Total ocean ph reduction since 1850 ph_{tot} [1] $Reduction\ of\ ocean\ acidification = \frac{ph_{tot}}{E_{tot}} \cdot ER(E_c)$
	Target 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world
	Indicator 15.3.1 Proportion of land that is degraded over total land area
	$Net\ biomass\ remaining\ in\ forests\ [t/year] = fnrb \cdot B_y(E_c)$

9. List of Tables

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11. List of Acronyms

Acronym	
ADALYs	Averted Disability-Adjusted Life Years
API	Application Programming Interface
BFT	Baseline Field Test
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
CME	Coordination / Management Entity
DLT	Distributed Ledger Technology
DNA	Designated National Authority
DOE	Designated Operational Entity
dMRV	Digital Monitoring Reporting and Verification
ER	Emission Reduction
GHG	Greenhouse Gas
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
GWP	Global Warming Potential
ICVCM	Integrity Council for Voluntary Carbon Market
IoT	Internet of Things
LDC	Least Developed Countries
LMIC	Low and Middle Income Countries
LoRaWAN	Long Range Wide Area Network
LPG	Liquified Petroleum Gas
LTE-M	Long-Term Evolution Machine Type Communication
M2M	Machine to Machine
MECD	Modern Energy Cooking Device
MMECD	Metered and Measured Energy Cooking Devices
MQTT	Message Queuing Telemetry Transport
MVNOs	Mobile Virtual Network Operators
NB-IoT	Narrowband Internet of Things
NDC	Nationally Determined Contributions
PaaS	Platform as a Service
PAYGo	Pay As You Go
PDD	Project Design Document
PFT	Project Field Test
PO	Project Owner
PoA	Programme of Activities
SaaS	Software as a Service
SB	Supervisory Body
SDG	Sustainable Development Goals
SD VISta	Sustainable Development Verified Impact Standard
SFTP	Secure File Transfer Protocol
SMEC	Simplified Methodology for Clean and Efficient Cookstoves
SSA	Sub-Saharan Africa

SB	Supervisory Body
tCO2e	Tonne of carbon dioxide equivalent
TPDDTEC	Technologies and Practices to Displace Decentralised Thermal Energy Consumption
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
VCU	Verified Carbon Units
VER	Verified Emission Reduction
VPA	Voluntary Project Activity
VVB	Validation and Verification Body