Opportunities for digital monitoring of SDG impacts beyond carbon emission reductions in modern cooking

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Executive Summary

SDG impacts within carbon markets are becoming increasingly important, with carbon credits with certified SDG impacts fetching higher prices. Project interventions within the modern cooking sector have the potential for wide ranging and larger SDG impacts than many other types of carbon projects, as cooking is usually performed daily and has significant gender and health implications.

Measurement of these impacts has traditionally relied on simple metrics obtained through interviews, surveys, or observations, but these techniques introduce the potential for human input error, translation error, recall bias or the "Hawthorne effect" (the influence of an outsider in the home). Surveys can also be costly to implement, with time, wages, and travel costs all potentially significant.

Simple, reliable, and low-cost solutions for accurately monitoring these impacts are required, ideally in real-time. If digital data is already being collected, for example energy consumption data required for Gold Standard certification using MMMECD[1], SDG impacts can be derived from energy consumption data or can be monitored alongside with additional sensors, potentially at minimal installation, communication, and database cost.

This report reviews 17 SDG indicators defined in the Gold Standard SDG Tool that relate to modern cooking interventions, applying a standardised assessment framework to investigate the potential for using digital monitoring solutions. The matrix of data from applying a number of weighted assessment factors provides insight and comparison for project developers selecting SDG impacts to monitor, and when developing their monitoring plans for selected indicators.

Key findings:

Carbon credits with certified SDG impacts fetch higher prices, even though there is currently virtually no market for certified SDG benefits independently of carbon credits. SDG impacts in clean cooking activities are currently predominantly assessed through end user surveys with limited reliability. The overall trend to increased integrity in carbon markets requires more robust monitoring, which also drives an interest in more robust assessment of SDG impacts.

Frameworks governing the monitoring and reporting of SDG impacts exist under all the major carbon programmes relevant for clean cooking (Article 6.4, Gold Standard and Verra), however the Gold Standard SDG Tool represents a novelty in that it standardises SDG impact indicators and provides instructions for monitoring them. SDG impacts may also increasingly play a role in digital platforms used for managing and monitoring carbon projects in the clean cooking sector.

[1] https://globalgoals.goldstandard.org/news-methodology-for-metered-measured-energy-cooking-devices/

Eight indicators, mostly measuring contributions to SDG 7, have been found to be the most suitable for digital monitoring (see Figure 1) as they may be assessed using energy consumption monitors, which are relatively simple to install at the usage sites and collect data that relates to the impact indicator more directly than in other cases. Additionally, continuous energy consumption monitoring is a requirement for carbon projects applying MMMECD.

Impact indicators found least suitable for digital monitoring (see Figure 1) were SDG 5 indicators measuring reductions in time spent on cooking and SDG 1/SDG 7 indicators measuring improvements in household income and access to services. The most reliable and accessible way to monitor changes in cooking time is considered to be the deployment of stove usage monitors, but these are currently at a lower TRL than other sectors and less readily available. A proposed alternative approach for determining cooking time via electricity consumption monitoring removes the need for stove usage monitors and represents a more attractive opportunity for digital monitoring. Indicators measuring changes in household income rely on household income data in addition to cooking data, which can only be gathered through user surveys, thereby reducing the confidence level.

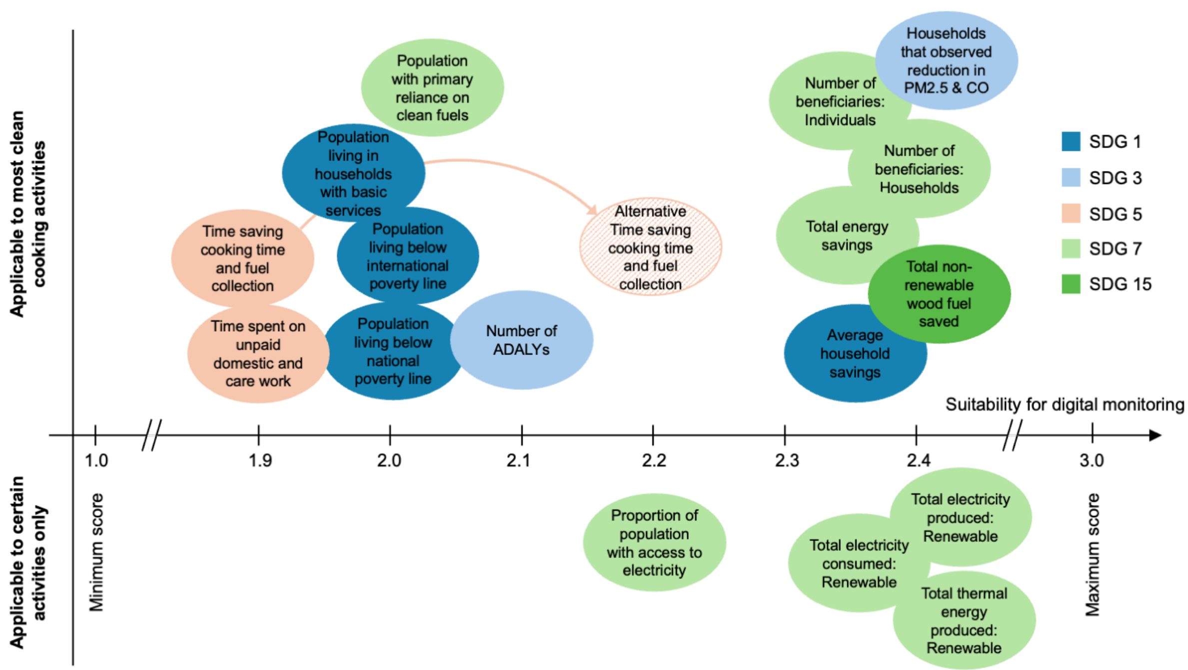

Figure 1. Schematic diagram summarising the result of the indicator assessment highlighting the suitability of indicators for digital monitoring; colours represent the SDGs that the indicators belong to using the official colours of SDGs 1, 3, 5, 7 and 15.

To calculate the SDG indicator value, many require additional data and factors alongside any digitally monitored values. This introduces challenges to the automated calculation of the indicator value and introduces more uncertainty and possibility for error and bias. Standardisation of factors should be further developed to ensure they rely upon the most recent academic research and best practice. Automation of conversion calculations, potentially via API calls, must be further developed to help streamline impact assessment.

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1. Introduction

The positive impacts of modern cooking on users and communities are manifold. A majority of modern cooking activities are partly funded through carbon finance, meaning that carbon emission reductions resulting from displacing less sustainable cooking fuels are carefully calculated based on standardised methodologies using standardised monitoring parameters. Carbon emission reductions contribute to climate action, hence to Sustainable Development Goal (SDG) 13. While contributions of modern cooking to other SDGs are typically considered as co-benefits under carbon crediting programmes, they are not usually assessed with the same diligence as carbon emission reductions.

Yet, the importance of SDG impacts in carbon markets is on the rise, with carbon credits with certified SDG impacts fetching 34% higher prices in 2023 according to Ecosystem Marketplace[2] and on average 31% higher prices between January 2021 and August 2024 according to BeZero[3]. This is of particular relevance to the modern cooking sector, boasting more diverse and larger SDG impacts than many other types of carbon projects. These importantly include:

- SDG 1 (No Poverty) - reducing household spending on cooking fuels and reducing time spent on cooking and collecting fuel
- SDG 3 (Improved Health and Well-being) - reducing indoor air pollution and improving respiratory health
- SDG 5 (Gender Equality) - freeing up time for women and girls, who are usually primarily responsible for cooking
- SDG 7 (Affordable and Clean Energy) - supporting the use of clean cooking fuels and energy-efficient appliances
- SDG 8 (Decent Work and Economic Growth) - reducing household spending on cooking fuels and freeing up time for other income generating activities
- SDG 15 (Life on Land) - reducing dependence on woody biomass and thereby forest degradation and deforestation

The most common way of monitoring SDG impacts is through user surveys on perceived changes since adopting the novel cooking technology. Such surveys, which are also used to determine carbon emission reductions, have often been found to yield unreliable results due to issues like recall or desirability bias[4]. They are also time-consuming for both the project developer and the user, and thereby costly, to implement.

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[2] Ecosystem Marketplace, State of the Voluntary Carbon Market, 2024.

[3] https://bezerocarbon.com/insights/buyers-pay-more-for-carbon-credits-with-sdg-claims, accessed October 2024

[4] Lewis, J. J., & Pattanayak, S. K. (2015). Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives*, 122(2), 102-111., Johnson, M., Edwards, R., & Masera, O. (2019). Measuring stove adoption and its impact on household air quality and greenhouse gas emissions. *Energy for Sustainable Development*, 46, 30-39., Adkins, E., Tyler, E., Wang, J., Siriri, D., & Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. *Energy for Sustainable Development*, 14(3), 172-185.

Carbon programmes provide frameworks for the assessment and quantification of SDG impacts. The new Paris Agreement Carbon Mechanism (PACM) enshrined in Article 6.4 of the Paris Agreement will require project developers to use a Sustainable Development (SD) Tool, the first version of which was recently adopted. This tool is expected to allow carbon project developers to define their own indicators and parameters to quantify SDG impacts. Carbon projects under Verra's Verified Carbon Standard (VCS) may seek additional certification under the Sustainable Development Verified Impact Standard (SD VISta) for SDG impacts. Gold Standard is the first major carbon programme to introduce an SDG Tool that streamlines and standardises assessment and reporting of SDG impacts. This is a development towards more rigorous SDG accounting and higher comparability between project activities.

Both Gold Standard and Verra allow for the certification of SDG impacts independently of the generation of carbon credits, however demand for this has been very limited to date. This highlights that for now the monetisation of certified SDG impacts is still only relevant in conjunction with carbon credits.

Figure 2 shows a project utilising MMMECD in the Gold Standard registry. Its contributions to SDGs 3, 5, and 7 are highlighted.

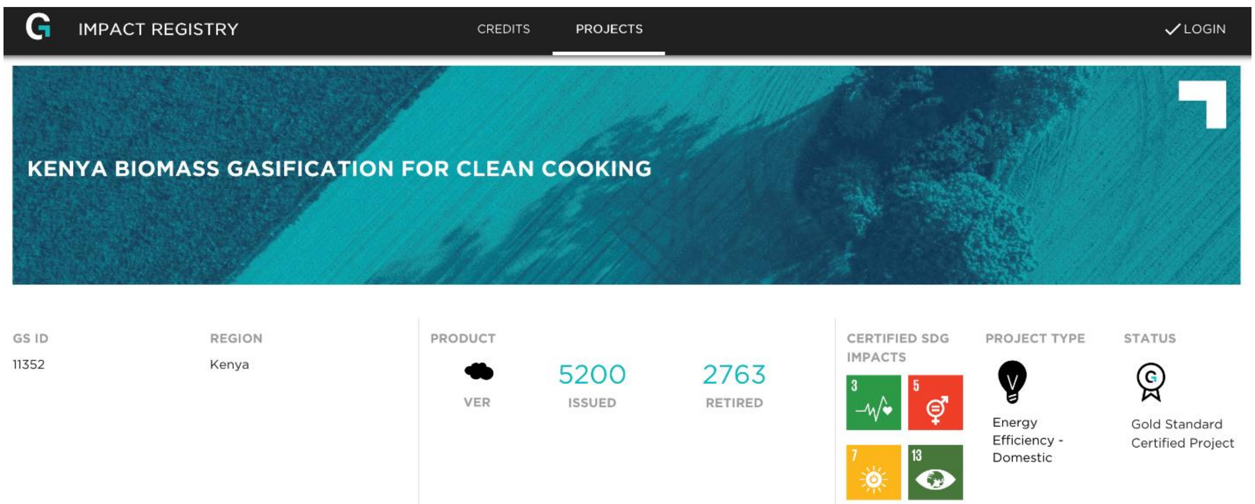

Figure 2. Screenshot from the Gold Standard Impact Registry showing a certified project applying MMMECD. The contributions to SDGs 3, 5 and 7 alongside SDG 13 are visually highlighted in the registry.

As digital monitoring of cooking appliances in carbon projects is becoming increasingly important, the question arises how digitalisation efforts can also be leveraged for SDG impacts. In order to answer this question for the modern cooking sector, in this work we carried out an in-depth analysis of 17 Gold Standard SDG Tool indicators relevant for modern cooking and opportunities for digitally monitoring key data. Digital monitoring in this context refers to real-time data collection by digital means that can be utilised to gather some, or all, of the data needed for the assessment of the SDG indicator. In many cases, energy consumption data collected with digital meters can be used for this assessment as well. Additionally, digital sensors to monitor stove usage, air pollution and human presence are relevant to some indicators. These were reviewed in detail with regard to their availability and associated costs.

For each indicator, an analysis was carried out to determine all required data and the corresponding data sources. The potential for digitisation was then assessed in accordance with a set of criteria taking into account the TRL and availability of sensors, costs, as well as the complexity and reliability of the monitoring system. Additional input to inform the analysis was sought from expert interviews with relevant stakeholders (listed in the appendix). This information was compiled into a matrix highlighting the challenges and overall digitisation potential for each of the considered indicators. This matrix, along with deep-dive tables on each indicator, can provide guidance to the modern cooking sector on where to focus scaling efforts in digitalisation and to project developers specifically to choose which SDGs to report and to easily identify indicators and robust monitoring methods for their activities.

Section 2 provides an overview of the Gold Standard SDG Tool, the selected indicators reviewed in this work, as well as other relevant tools, notably the Article 6.4 SD Tool and SD VISta.

Section 3 introduces and reviews all relevant digital sensing technologies, including Time-Activity Monitors, Household Air Pollution Monitors and Stove Usage Monitors.

Section 4 reviews all considered indicators and their data requirements in detail and provides the SDG indicator matrix combining the assessment of the individual indicators and the available sensing technologies.

Section 5 provides a discussion of the results and an outlook.

2. Frameworks and Tools Overview

2.1. GS SDG Impact Tool Overview

Gold Standard was the first carbon standard to develop a comprehensive SDG Impact Tool that streamlines the reporting, quantification, verification and certification of SDG contributions. The first excel-based version of the tool, which was developed with support from the Swedish Energy Agency and Thinking Machines Data Science, was published in 2021 and was made a mandatory part of project certification under Gold Standard's carbon standard Gold Standard for the Global Goals (GS4GG) 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 for monitoring them. Previously, project developers could freely choose how to monitor contributions to SDG targets, which meant that there was less consistency and comparability across projects. In order to propose new indicators, project developers now need to submit a standardised form[5]. Gold Standard is also in the process of working with a consultant to identify more indicators and expand the scope of the tool. This is not expected to yield major changes for the indicators eligible for clean cooking activities but rather to increase the tool's applicability to other types of activities.

The development principles for the SDG Impact Tool and its indicators are laid out in a guidance document[6] released by Gold Standard in 2019. In this guidance, principles for indicator selection and justification were defined, according to which indicators should be simple, limited in number, allow for high-frequency monitoring, constructed from well-established data sources, universally applicable, mainly outcome-focused, disaggregated and a proxy for broader issues. The SDG impact tool includes both official UN SDG indicators, as well as proxy indicators defined by Gold Standard. Since the UN SDG indicators were designed for national stocktaking rather than subnational or non-state projects, making accurate claims about progress towards the SDG targets on project level may be complicated. Proxy indicators are a way to address this challenge, as they are defined to capture impacts at project level.

According to Gold Standard, the tool has been designed and developed to fulfil the following four needs:

1. Making the existing Gold Standard for the Global Goals (GS4GG) SDG framework (matrix) quantifiable and verifiable.
2. Promoting uniformity in approach towards Monitoring, Reporting and Verification (MRV) of SDG impacts.
3. Upholding compliance with International Social & Environmental Accreditation & Labelling (ISEAL[7]) requirements for portfolio-level impact reporting.
4. Supporting GS4GG's alignment with the Paris Agreement.

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5 https://globalgoals.goldstandard.org/t-iq-proposal-template-for-monitoring-indicator-s-for-inclusion-in-the-sdg-impact-tool/

6 https://www.goldstandard.org/publications/sdg-tool-guidance

7 https://www.isealalliance.org/

The SDG Impact Tool also includes supporting resources for streamlined implementation, and reference values aiding auditors in efficient assessment and prevention of over-claiming. Benefits to users include streamlining the MRV process for increased efficiency and credibility, expanding contributions to multiple SDGs with minimal burden, enhancing transparent communication, standardising impact indicators for clear project comparison, and enabling portfolio-level SDG impact aggregation for sector comparability.

There are four distinct user groups of the SDG Tool, which are project developers, Validation and Verification Bodies (VVBs), host country representatives and reviewers. Project developers use the tool to define indicators, and report impacts under these indicators to the VVB. Any information that is reported in the SDG Tool no longer needs to be reported in other documents, like the PDD or Monitoring Reports. Upon submission of impact reports on the SDG Tool, a PDF summary is generated, which is then made publicly available in the Gold Standard impact registry. The VVBs have access to project data that they are validating or verifying, similarly reviewers have access to project data for performing the GS4GG design or performance review. Host country representatives may use the SDG tool to declare their nationally determined contribution (NDC). Gold Standard is also working on enhancing the tool further to enable monitoring against host country's SDG objectives in order to connect activity level data with national long-term targets for the SDGs.

Gold Standard plans to further develop the SDG Tool to gradually move all impact reporting onto the platform, including the calculation of carbon impacts. The vision is to have a flexible platform that can integrate data from various sources through Application Programming Interfaces (APIs) and allow for processing relevant data. Gold Standard also launched a new pilot programme for digital Monitoring, Reporting and Verification (dMRV) on 10th October 2024, "in order to test dMRV solutions as part of its plans for end-to-end digitisation of climate and sustainable development impact certification". Starting from 1 November 2024, interested project developers can apply to participate in the pilot programme.[8]

2.1.1 Relevant SDGs

This work focuses on those SDGs which are most relevant for clean cooking projects. These were determined using the Gold Standard Impact Dashboard[9] that shows how many registered GS4GG projects contribute to each SDG, disaggregated by project type. An overview of the number of GS-registered clean cooking projects contributing to each SDG is given in Table 1. Apart from SDG 13, which every GS4GG project needs to contribute to, six SDGs are found to be especially relevant, as they are used by several hundreds of projects. These are, in order of frequency, SDG 7, 3, 15, 8, 5 and 1.

[8] https://www.goldstandard.org/news/new-pilot-programme-for-digital-measurement-reporting-verification
[9] https://dashboard.goldstandard.org/

Table 1: Overview of SDGs and the number of Gold Standard-registered clean cooking projects that contribute to them, from Gold Standard SDG Impact Dashboard.

SDG		Number of GS projects contributing
13	Climate action	1125
7	Affordable and clean energy	882
3	Good health and well-being	853
15	Life on land	585
8	Decent work and economic growth	565
5	Gender equality	515
1	No poverty	481
4	Quality Education	141
12	Responsible consumption and production	141
6	Clean water and sanitation	78
2	Zero hunger	33
17	Partnership for the goals	30
9	Industry, innovation, and infrastructure	14
10	Reduced inequalities	5
11	Sustainable cities and economies	4
16	Peace, justice, and strong institutions	3
14	Life below water	0

2.1.2 Considered indicators

Under the six considered SDGs, the Gold Standard SDG Tool includes a total of 25 indicators that are relevant to clean cooking, which are listed in Table 2. Out of these, 18 are Gold Standard-defined proxy indicators (marked as GSDM), which are typically more relevant for activity-level impact monitoring. The others are SDG indicators, which were developed for national stocktaking and can be complicated to adapt to activity-level. Typically, an individual project's effect under these indicators will be very small and hence may be less meaningful to measure and communicate project impacts.

Most indicators relate to project impacts on the user side, such as improvements in air quality, time and money savings etc. Some indicators however relate more to the carbon project operations, concerning for example workplace equality and job creation.
Not all indicators lend themselves to real-time digital data collection, as in some cases the data is directly derived from the project operator's internal records (e.g. total number of jobs, number of women serving in managerial positions) or user surveys (number of visits to medical facilities). While staff records may be digitised and user surveys may be carried out using digital survey tools, these cases do not present compelling opportunities for digital monitoring. Hence, these indicators were not considered in the review. In total, 17 indicators were included in the review, highlighted in the 'Review' column of Table 2.

Table 2: List of all indicators included in the GS SDG Tool for clean cooking activities. Out of 25 indicators, 17 were considered relevant to this work and reviewed in detail.

SDG	Indicator		Review
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)	Yes
	GSDM-I1.1.1	Average household savings i.e., decrease in expenditure on basic service such as cooking, lighting, drinking	Yes
	GSDG-I1.2.1	Proportion of population living below the national poverty line, by sex and age	Yes
	GSDG-I1.4.1	Proportion of population living in households with access to basic services	Yes
3	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
	GSDM-I3.9.3	Number of households visited medical facilities/dispensary for treatment of respiratory issues etc. such as cough, shortness in breath, pneumonia, and other respiratory issues	No
5	GSDM-I5.1.1	Gender wage equity	No
	GSDG-I5.4.1	Proportion of time spent on unpaid domestic and care work, by sex, age and location	Yes
	GSDM-I5.4.1	Average time saving associated with cooking time and fuel collection	Yes
	GSDG-I5.5.2	Proportion of women in managerial positions	No
	GSDM-I5.5.1	Number of women serving in managerial/ leadership /ownership role	No
7	GSDG-I7.1.1	Proportion of population with access to electricity	Yes
	GSDM-I7.1.1	Number of beneficiaries: Households	Yes
	GSDM-I7.1.1	Number of beneficiaries: Individuals	Yes
	GSDG-I7.1.2	Proportion of population with primary reliance on clean fuels and technology	Yes
	GSDM-I7.2.1	Total electricity produced: Renewable	Yes
	GSDM-I7.2.2	Total thermal energy produced: Renewable	Yes
	GSDM-I7.2.3	Total electricity consumed: Renewable	Yes
	GSDM-I7.3.1	Total energy savings	Yes
8	GSDM-I8.5.1	Total number of jobs	No
	GSDM-I8.5.2	Total number of employees earning above local minimum wage	No
	GSDM-I8.5.3	Total number of employees paid living wage	No
15	GSDM-I15.1.1	Total non-renewable wood fuel saved	Yes
	GSDM-I115.2.1	Forest areas managed sustainably for forest products including sustainable produced fuelwood	No

2.2. Other SDG impact frameworks

2.2.1 Article 6.4 Sustainable Development Tool

Under the Paris Agreement Crediting Mechanism defined in Article 6.4 of the Paris Agreement, it will be a requirement for all activities to contribute to sustainable development in addition to reducing greenhouse gas (GHG) emissions. The Supervisory Body (SB) governing the mechanism adopted the Article 6.4 Sustainable Development Tool (SD Tool) on 9th October 2024 after first draft versions had been published in 2023. The tool is applicable to all future activities under Article 6.4, including Clean Development Mechanism (CDM) activities transitioning to this mechanism. It lays out the rules and provides guidance for identifying and managing social and environmental risks as well as determining contributions to sustainable development in line with the priorities of the host country and the SDGs.

Project developers need to demonstrate the direct impact of the project activity(ies) on 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.

The Supervisory Board has tasked the UNFCCC secretariat with developing the forms, which project developers will need to submit to report on sustainable development impacts and safeguards, which include the A6.4 Environmental and Social Safeguards Risk Assessment Form, the A6.4 Sustainable Development Tool Form, and the A6.4 Environmental and Social Management Plan Form. The A6.4 Sustainable Development form will include information such as:

- 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).

2.2.2 Verra SD VISta

The Sustainable Development Verified Impact Standard (SD VISta) by Verra is a standard designed to assess and verify the environmental, social, and economic impacts of projects that contribute to the SDGs. It is not exclusive to carbon or climate change mitigation projects, but currently certification under SD VISta is almost always sought in conjunction with certification under Verra's Verified Carbon Standard (VCS). By certifying SDG impacts under SD VISta in addition to carbon impacts under VCS, carbon projects issue SD VISta-labelled Voluntary Carbon Units (VCUs).

The SD VISta framework does not define standardised indicators but allows project developers to set out their sustainable development objectives, which need to contribute directly to at least one SDG target. Project developers must also use causal chains to map the cause-and-effect relationships of a project's activities and its impacts.

The standard also provides the option to generate SD VISta assets, which are standardised, transactable units quantified according to an SD VISta-approved methodology and verified by a VVB. These units represent certified SDG impacts generated independently of carbon credits. Currently there is only one approved methodology for SD VISta assets, which is the Methodology for Time Savings from Improved Cookstoves (ICS)[10]. This methodology is designed to estimate the time saved by households on cooking and fuel collection through the distribution of improved biomass cookstoves with a thermal efficiency of at least 25%. This indicator is aligned with SDG targets 5.4 (recognise and value unpaid [...] domestic work [...]) and 8.4 (improve global resource efficiency in consumption and [...] decouple economic growth from environmental degradation [...]). It is the same proxy indicator that is included in the GS SDG Tool as GSDM-I5.4.1. The methodology requires time savings to be determined through end user surveys and includes a non-binding example questionnaire. It does not mention any form of digital data collection.

To date, no SD VISta assets have been issued yet. On the other hand, more than 32 million SD VISta-labelled VCUs have been issued from 54 different projects[11], highlighting that demand for certified SDG impacts independently of carbon impacts is currently still limited.

[10] https://verra.org/methodologies/time-savings-from-improved-cookstoves-ics/
[11] https://registry.verra.org/app/search/SDVISTA/All%20Projects

2.3. SDG Impact Platforms

There are a range of platforms that offer tools to track, report, and improve SDG contributions, most of which cater to companies for sustainability reporting. The reporting provided by these platforms is often tailored to meet regulatory requirements for example under the EU's Corporate Sustainability Reporting Directive (CSRD) or the proposed Corporate Sustainability Due Diligence Directive (CSDDD). Most such platforms are not relevant for capturing or reporting project-level SDG impacts. Below is a selection of platforms that allow users to manage SDG data on the project level relevant for clean cooking activities, including data gathered from energy consumption meters and digital surveys. Some of these platforms are already managing data that is relevant to the considered GS indicators and they may offer useful tools for project developers to determine SDG impacts to be reported on the GS SDG Tool. API integrations with the GS SDG Tool in the future for automated data transfers are also a possibility.

Leonardo Impact

Leonardo Impact GmbH provides tools for measuring, verifying, and reporting social and environmental impact. Their platform helps organisations, including impact investors, NGOs, and businesses, collect high-quality ESG (Environmental, Social, and Governance) data, analyse it, and generate transparent, audit-proof reports. They focus on data from real people and affected communities, using AI to validate information and improve decision-making. Leonardo uses surveys as a key data source and has developed robust processes for science-based survey design, automated data quality and reliability analysis looking at outliers and suspicious data, as well as performing comparisons to benchmarks and on the ground validation. Their solutions are tailored to regulatory compliance, helping users meet sustainability goals and manage impact across portfolios efficiently. Leonardo's platform is being used for impact assessment and evaluation by The Solar-Electric Cooking Partnership for Displacement Contexts (SOLCO), an initiative under the Global eCooking Coalition (GeCCo) focused on providing solar electric cooking to displaced families and their host communities. Figure 3 shows the analysis dashboard of the platform that allows for visualisation and filtering of different SDG impacts.

Figure 3: Screenshot of the analysis dashboard of the Leonardo platform showing SDG 1 impact data.

Access to Energy Institute

The Access to Energy Institute (A2EI) has developed two open-source platforms, which can be used by projects developers to monitor their interventions: Prospect and the Appliance Demand Platform (ADP). The platforms both aggregate data, allow for customisable visualisations and facilitate remote analysis of technical and payment data. 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. ADP and Prospect are built on the same technology stack, with similar core functionality and features and A2EI expects the platforms to eventually merge into one. ADP is currently more focused on the appliance level and more relevant to monitoring the deployment and utilisation of modern cooking equipment. It already integrates and visualises household survey data that relates to SDG impacts, such as cooking time by gender or fuel costs by type. Calculation of SDG benefits from integrated real-time cooking data may also be available in the future. Figure 4 shows a screenshot of the platform ADP with figures and visualisations of gender-related impact data.

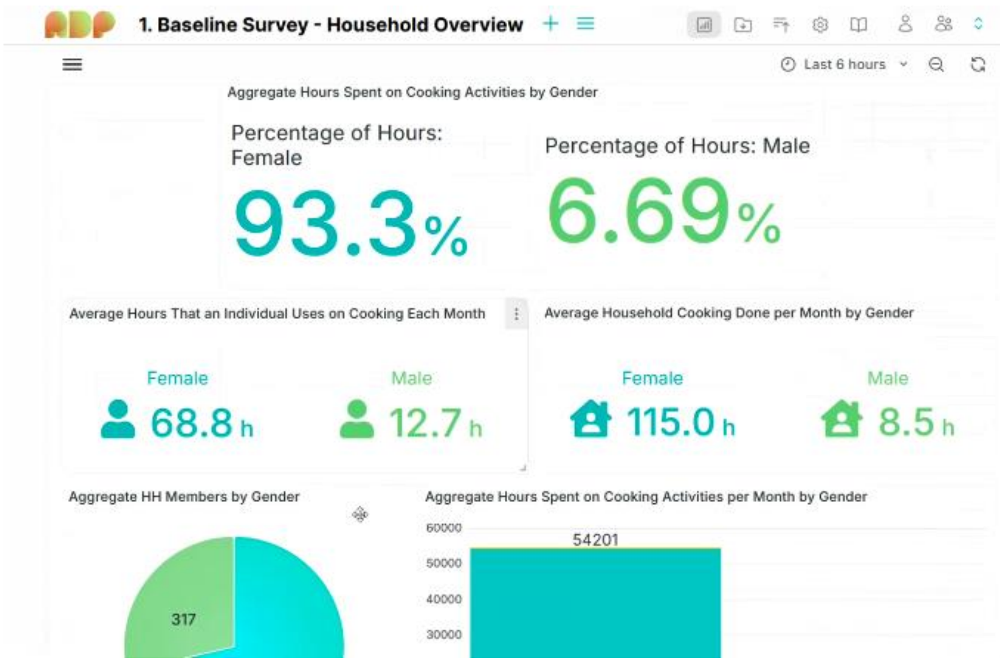

Figure 4: Screenshot of the dashboard of the Appliance Demand Platform (ADP) from A2EI.

CarbonHQ

CarbonHQ is a platform designed to simplify the management of carbon projects. It centralises project data, making it easier for project developers to access up-to-date information in real-time. It allows for the integration and processing of digitally monitored cookstove data from digital survey tools such as Kobo Collect and ODK to create forecasts of issuance volumes and manage sales. Imported data is checked for errors such as duplicates and data gaps. In the future, CarbonHQ envisions to allow for the integration of real-time digital data from monitoring units, include automated carbon credit calculation, automated system checks and direct data submission to VVBs and standards. The platform currently can import SDGs that a project activity contributes to from the relevant carbon standard registry. A future integration of digital SDG impact data and data processing to calculate SDG impacts on the platform is possible.

PowerSolve

PowerSolve provides a cloud-based platform to help carbon project developers manage and verify carbon offset projects, such as those distributing cookstoves and water filters. The platform centralises data collection, monitors device usage, and simplifies carbon credit verification through audit-ready reports. It also offers tools for project tracking, geo-mapping, and carbon credit forecasting. Currently the platform can import data from digital survey tools, which may include SDG impacts other than carbon as well.

3. Digital Monitoring Techniques

This section briefly describes the various digital monitoring techniques and equipment available at present[12]. It is assumed that the clean cooking project is following the Gold Standard MMMECD, for which energy consumption must already be monitored to provide data for carbon credits claimed.

3.1. Energy Consumption Monitor (ECM)

An Energy Consumption Monitor records the amount of energy consumed by a cooking device. If the cooking device uses electricity, then electrical power can be relatively easily measured alongside time to provide the energy consumed. Other monitors are available for monitoring gas supplied to cooking devices. These can be internal to the device, added externally or, potentially, calculated from smart meter data. As this is a requirement for the GS MMMECD, it is assumed this data is already available and if an SDG indicator can be calculated from the energy consumption data, then the calculation may not require any additional monitoring equipment.

Thirteen types of Energy Consumption Monitors were highlighted in a previous MECS report[12]. Since that report was published (Jan 2024) other products have become available, including the SimplePLUG from Geocene[13]. This is a dynamic field, and new solutions are being developed rapidly so it is advised to review the most up to date solutions before any project implementation. As this type of digital monitoring is required for projects using the Gold Standard MMMECD, if the SDG Indicator can be calculated from this data, then there is potentially no additional cost associated, but for comparison with the other digital monitoring techniques (shown in Table 4) the same assessment factors are applied to all digital monitoring techniques.

3.2. Time-Activity Monitor (TAM)

A Time-Activity Monitor is used to measure the amount of time individuals spend in various household micro-environments. These can either be static human presence detectors[12] which can detect when an individual is near to the detector, or they could utilise a ‘tag’ which the participant carries around which is detected within the different areas of the household. Real-Time Location System (RLTS) is a more general term for location monitoring used for many different applications including automotive, asset and healthcare tracking. The data from a RLTS could be utilised for Time-Activity Monitoring.
A tag system using small ultrasonic[14] tags for each participant was developed by the University of California Berkeley[15]. This was developed by EME Systems[16] in 2013, although it does not

[12] More detailed technical information is available here: https://mecs.org.uk/wp-content/uploads/2024/03/MECS-MMECD-Report-v7-FINAL.pdf
[13] https://carbon.geocene.com/simpleplug
[14] https://www.iotforall.com/indoor-positioning-ultrasonic-ultrasound
[15] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5579926/
[16] https://www.emesystems.com/index.html

appear they are still available from the company. Ultrasonic tags have the advantage that ultrasound does not pass through walls easily, so presence within a certain room can be detected.

Other tag systems for location monitoring use Bluetooth Low Energy (BLE)[17], typically from a person's mobile phone or from a BLE tag. Some tag systems use a mix of ultrasonic, BLE and Wi-Fi for more accurate location detection. Static human presence detectors, which are typically low cost and relatively simple to install, cannot distinguish between individuals, so they are prone to mis-readings. One such detector was used to monitor latrine use but, even in a relatively enclosed location, it was difficult to distinguish reliably and accurately a person entering and leaving the area[18].

TAMs which require participants to carry tags give high accuracy data but place a greater burden onto the participant. These systems are also relatively complex, with higher costs and hence would usually be used with a sample of households or for detailed research projects.

Some example Time Activity Monitoring systems include:

- Sonitor Real-Time Location Systems
    - Use ultrasonic sensing technology.
    - Focus on healthcare applications.
- Ubisense Dimension4 real-time location system
    - Uses ultra-wideband (UWB) radio frequency tags.
    - Focus on asset tracking and logistics.
    - Requires internet connection.
- CoreHW CoreTag CHW-TAG4001-2
    - Uses Bluetooth Angle of Arrival (AoA)
    - Focus on asset tracking and industrial applications.
    - Requires internet connection.
    - Evaluation kit: £600[19]. IC only (for use within a product): £5[20]
- Inpixon Location Tracking Tags
    - Uses ultra-wideband radio frequency tags.
    - Focus on safety, security, and productivity use cases.
    - Base station ("RLTS Anchor") cost: £880[21]. Tag Cost: £675[22]. Full Evaluation kit: £4600[23]
- Sewio UWB RTLS Tags
    - Uses ultra-wideband (UWB) radio frequency and BLE tags.
    - Focus on industry and retail applications.

[17] https://www.bluetooth.com/learn-about-bluetooth/tech-overview/

[18] Making Sanitation Count: Developing and Testing a Device for Assessing Latrine Use in Low-Income Settings, T. Clasen et al, Environ. Sci. Technol. 2012, 46, https://pubs.acs.org/doi/10.1021/es2036702

[19] https://www.digikey.co.uk/en/products/detail/corehw-semiconductor-ltd/CHW1010-EVKN4-1-0/16188334

[20] https://www.digikey.co.uk/en/products/detail/corehw-semiconductor-ltd/CHW1010-1-1-0/16123724

[21] https://www.digikey.co.uk/en/products/detail/nanotron-an-inpixon-company/BN01ANQEMPXER/13159746

[22] https://www.top-electronics.com/en/ruggedized-rtls-tag-chirp

[23] https://www.digikey.co.uk/en/products/detail/nanotron-an-inpixon-company/KNANQEV01CS/16365905

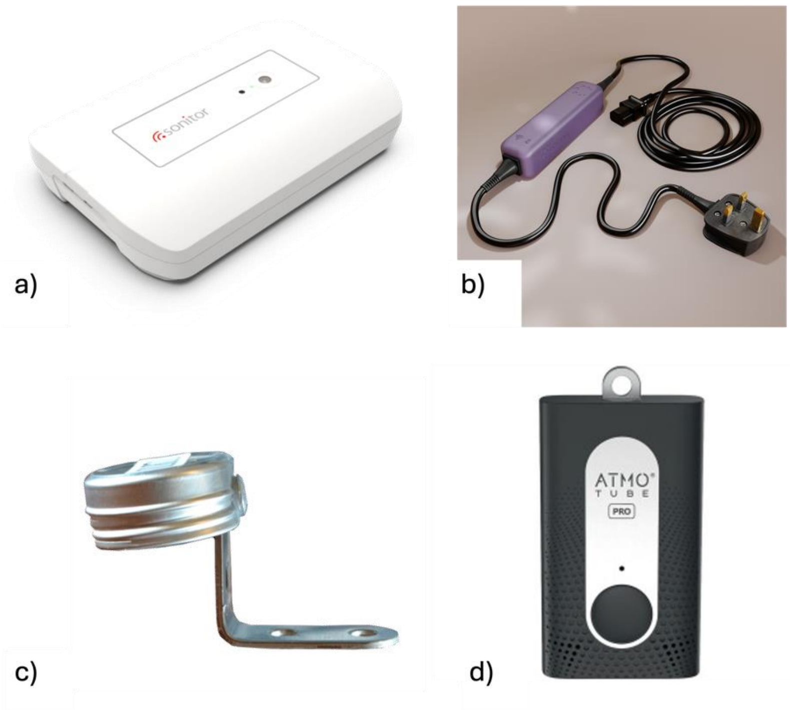

Figure 5: Selected photos of exemplary sensors, a) Time-Activity Monitor SonitorONE by Sonitor, b) Energy Consumption Monitor SimplePLUG by Geocen, c) Stove Usage Monitor Exact SUM by Climate Solutions, d) Household Air Pollution personal exposure monitor Atmotube PRO by Atmo.

3.3. Stove Usage Monitor (SUM)

Stove Usage Monitors[24] usually detect temperatures in order to observe if a cooking device is actively used or not. These can be attached to the cooking device or can be placed near to the cooking device with a probe or optical sensor to detect the cooking device temperature. They require algorithms to convert the temperature profiles into stove use events, as the temperature of the cooking device may fluctuate in normal operation. These algorithms are potentially quite complex to provide robust data on cooking events.

These units need to be physically robust to survive the high temperature ranges of some cooking devices. They provide time of use but cannot provide accurate data on the energy consumed by the cooking device and lack key information on meal types, quantity of food prepared, and fuels used. Pairing SUMS measurements with diaries or surveys can provide a more comprehensive picture of stove use patterns[25], but this requires greater participation and cost.

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[24] https://berkeleyair.com/sums

[25] "A glimpse into real-world kitchens: Improving our understanding of cookstove usage through in-field photo-observations and improved cooking event detection (CookED) analytics", Coffey et al., Development Engineering, 2021, Vol 6, https://doi.org/10.1016/j.deveng.2021.100065

Some examples include:

- iButtons
  - Simple coin-sized data loggers. Store up to 1 year of data internally. Battery life of around 1-5 years. Temperature ranges up to 145 °C, so can be prone to overheating. Cable download of data. Price range $20 - $140.
- EME Systems kSUMs
  - Accepts 3 to 6 k-type thermocouples. Logs to internal memory. USB download.
- Wellzion SSN-61 thermocouple loggers[26]
  - Uses k-type thermocouple. 32,000 readings internal storage. USB download. Around $30 per unit. Previously used in stove monitoring projects[27].
- Geocene Simple SUM
  - 5 year with typical usage. 1 year data memory. Bluetooth download via smartphone app. Lease for $36 per year.
  - Provide 'FireFinder' for cooking event analysis of raw data.
- Climate Solutions Exact SUM
  - Contactless infra-red thermal measurement. 5 years battery life. Bluetooth download. Around $30 per unit.
  - Also provide data-logging scales for accurate measurement of solid fuel use.

3.4. Household Air Pollution (HAP) Monitoring

Household air pollution can be generated through the use of inefficient and polluting fuels and technologies in and around the home, resulting in a range of potentially health-damaging pollutants, including small particles that penetrate deep into the lungs and enter the bloodstream. The measurement of these 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 adverse health effects, so SDG impacts focus mainly on the 'fine' particles with diameters 2.5µm or less, called '$PM_{2.5}$'.

The Gold Standard methodology uses "exposure to fine particulate matter ($PM_{2.5}$) as the best indicator of household air pollution"[28] but focuses on measurements of personal exposure of household members since measurements of pollution in particular places, such as the kitchen, are often poor indicators of overall daily exposure levels.

Exposure is the average concentration of a pollutant to which an individual or population is exposed over a specific period of time, accounting for their movement into and out of polluted

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[26] https://www.alibaba.com/product-detail/SSN-61-Support-K-type-Thermocouple_60589115282.html

[27] "A glimpse into real-world kitchens: Improving our understanding of cookstove usage through in-field photo-observations and improved cooking event detection (CookED) analytics", Coffey et al., Development Engineering, 2021, Vol 6, https://doi.org/10.1016/j.deveng.2021.100065

[28] https://globalgoals.goldstandard.org/411_hi_ics_methodology-to-estimate-and-verify-adalys-from-cleaner-household-air/

micro-environments (e.g. between rooms and outdoors). Because human activity and corresponding exposure follows a diurnal pattern that may differ on different days, exposure should be monitored for at least a 48-hour period. If longer periods are chosen for monitoring exposure, they should be done in multiples of 24 hours after the first 48 hours.

Emissions are the rate of release of a pollutant per unit time or per unit of fuel. Often measured 'directly' from the combustion source and can be measured in the laboratory or the field. Concentration is the mass of a pollutant in a volume of air. Concentrations are usually measured in households in a particular room, such as the kitchen or living room, for example by placing a monitor on the wall of the kitchen. Concentration measurements do not account for the presence of people[28]. A personal exposure level can be calculated from the concentration within different environments and the time spent by that person within those environments.

There are two main methods for quantifying PM exposure:

- **Gravimetric methods**, where sampled air is drawn 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 provides the PM concentration, which is used to calculate exposure within the time period the sensor is used (or between filter changes) for the location of the gravimetric sensor. 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. Gravimetric methods only provide the average concentration over the sample period between changes of the filter. Both portable/wearable and stationary gravimetric sensors are available.
- **Optical methods** allow the continuous monitoring of the PM concentration using indirect techniques, such as the reflection of infra-red (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 are 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. Studies[29] show that optical monitors usually report values for $PM_{2.5}$ that are biassed either too high or too low as compared with gravimetric monitors. Lower cost sensors utilising optical methods are generally not highly accurate in absolute terms but have high linearity which allows the accuracy to be calibrated[30]. Optical methods can show time varying concentrations, which may be useful to align with the presence of people within a location and the time-frame, necessary for exposure assessment. Both portable/wearable and stationary optical sensors are available.

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[29] "Comparison of Real-Time Instruments and Gravimetric Method When Measuring Particulate Matter in a Residential Building", Wang et al., Journal of the Air & Waste Management Association, 2016 Nov https://doi.org/10.1080%2F10962247.2016.1201022; "Comparative assessment of a real-time particle monitor against the reference gravimetric method for PM_{10} and $PM_{2.5}$ in indoor air", Tasić et al., Atmospheric Environment, Vol. 54,, 2012 Jul, https://doi.org/10.1016/j.atmosenv.2012.02.030;

[30] "Low-cost $PM_{2.5}$ Sensors: An Assessment of Their Suitability for Various Applications", Liu et al. Aerosol and Air Quality Research, 2020, https://doi.org/10.4209/aaqr.2018.10.0390

Personal exposure monitoring (PEM) usually requires a portable PM monitoring system. This is worn or carried by the subject and measures the PM concentration that individual is exposed to. Knowing the sample period allows a personal exposure value to be calculated. Other methods for calculating personal exposure could be stationary PM sensors designed only to take readings when the subject is within a particular location (e.g. a gravimetric sensor could be opened/closed or optical sensors switched on/off) or align the data with the presence of people within a location, requiring some form of timed-activity monitoring.

To claim health improvement impacts as project assets in the form of Averted Mortality and Disability Adjusted Life Years (ADALYs) using indicator GSDM-I 3.9.2, Gold Standard requires that personal exposure monitoring (PEM) of the main household cook within a sample of households in the target population is performed using either gravimetric monitoring alone or optical monitoring augmented by gravimetric monitoring.

Where optical monitoring is used to measure exposures, an adjustment factor shall be applied to the measurements to correct for bias and convert them to “gravimetrically equivalent” concentrations. The adjustment factor may vary by location, season, fuel type, and cooking practices, and thus shall be estimated in the relevant field setting. The adjustment factor is computed based on a set of at least 10 side-by-side 24 hour gravimetric and optical measurements. PEM shall be conducted every other year (i.e. every second year) at a minimum. PEM should be conducted in the season that is most representative of the full year, for example in a season that lasts longest in the year, with households experiencing other polluting sources that do not represent the conditions of the majority of the community (e.g. smokers or those using diesel generators) excluded from the sample. Project developers may also report on households seeing a reduction in pollutant concentration without following the ADALYs methodology, in which case monitoring using optical sensors, ideally laboratory calibrated, is sufficient. These health impacts are then issued as certified SDG impacts rather than ADALYs.

There are a wide (and growing) range of **$PM_{2.5}$ sensors** available on the market from a variety of manufacturers, including the following. Typically, these are optical sensors designed for continuous measurement:

- Sharp: GP2Y1040AU0F
  - Optical PM sensor with fan. Single quantity USD $10-15.
- Shinyei: 4 different sensors
  - Optical PM. Single quantity USD $10-15.
- Plantower: PMS5003
  - Optical PM. Single quantity USD $20-25.
- Sensirion: SPS30
  - Optical PM. Single quantity USD $30-50.
- Nova: SDS01
  - Optical PM. Single quantity USD $20-30.
- Winsen: ZH03B
  - Optical PM. Single quantity USD $10-15.
- Omron: B5W-LD0101-1
  - Optical PM. Single quantity USD $10-15.

- Bosch: BMV080
  - Optical PM. Very small size (<400 smaller than examples above). Fan-less.
  - Not yet commercially available but highlights future direction.

A small range of **household air pollution monitors**, which measure concentrations in specific micro-environments, are available, including:

- Shinyei
  - Ethernet connected continuous logging unit. Heater for updraft, so higher energy consumption.
- Climate Solutions Consulting HAPEx - $PM_{2.5}$ Data logger
  - Battery life has 5 years of real-time measuring. Provides calibrated real time $PM_{2.5}$ measurement.
  - $40 for 3 months rental (including pre and post calibration).

Portable **personal exposure monitors** available on the market include:

- Atmotube PRO
  - Wearable, portable air quality monitor and weather station. Internal battery with 10 days life. USB charged. Connects to mobile phone and data upload via app. Single quantity cost of $160.
- Aeroqual PM_{10} / $PM_{2.5}$ Portable Particulate Monitor
  - Handheld monitor. Stores data to internal memory. Download with USB.
- Prana Air $PM_{2.5}$ Monitor
  - WiFi enabled for data upload. Pocket sized. Single quantity USD $50.
- CurieJet P760
  - Wearable air quality monitor. Uses a small optical PM (laser). Data sent to mobile phone and web via user-installed app.
- SKC Personal Environmental Monitor
  - These are gravimetric sensor units. Designed for use with an air pump. The sample filter papers must be accurately weighed before/after for data.

Carbon Monoxide (CO) sensors may be required for projects involving charcoal-based interventions. CO levels above World Health Organization (WHO) air quality guidelines[31] could result in adverse health effects. For charcoal-based interventions only, room area monitoring of CO is required in all households undergoing $PM_{2.5}$ PEM. CO monitoring is required to run for 24 hours at a minimum in sample households. If the 24-hour average CO concentration exceeds the WHO 24hr CO concentration guideline in a fraction of monitored households, the same fraction of project households in the total project population will no longer be eligible for claiming SDG Impact.

Most CO sensors detect gas concentration through an electrochemical principle, with the electrochemical oxidation process of target gas on the working electrode within the sensor generating a proportional current. Some CO sensors use metal oxide sensors which detect changes in materials resistance, which is proportional to the detecting gas concentration, although these sensors require a heated sensor which can have relatively high power consumption.

[31] https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines

There are a wide (and growing) range of Carbon Monoxide (CO) sensors available for use within logging and monitoring products from a variety of manufacturers, including the following:

- SGS Sensortech
  - Produce a range of environmental monitoring sensors
  - Price: £10[32]
- SPEC Sensors
  - Price: £18[33]
- Winsen CO Sensors
  - Range of CO sensors and modules.
  - Example price: £2.60[34]

Most Carbon Monoxide (CO) monitors are produced for safety warnings in domestic and industrial environments. Fewer units which include data logging facilities are available, although some examples are given here:

- Lascar Electronics EL-USB-CO
  - Standalone USB CO data logger storing 32k readings.
  - Sensor life 4 years. Battery life is up to 3 months.
  - Cost: £96[35]
- Omega AQM-103
  - Logging up to 32k values. USB download.
  - Price: £230[36]
- PCE Instruments PCE-COG 10
  - Logging up to 5k values. USB download
  - Price: £308[37]
- MSL DL-1021
  - Measures PM and CO, along with other values.
  - Records 180k values with date/timestamp.
  - Ethernet connectivity - data can be viewed remotely.
  - Price: £680[38]
- Oksa CL-213-WF
  - Measures PM and CO along with other values.
  - Records 450k values with date/timestamp.
  - Wi-Fi and Ethernet connectivity - data can be viewed remotely.
  - Price: £560[39]

[32] https://uk.rs-online.com/web/p/environmental-sensor-ics/2541509
[33] https://www.digikey.co.uk/en/products/detail/spec-sensors-a-division-of-interlink-electronics/110-102/6136363
[34] https://shop.winsen-sensor.com/products/winsen-co-sensor-series?variant=43763345096896
[35] https://uk.rs-online.com/web/p/data-loggers/5363306
[36] https://www.omega.co.uk/pptst/AQM-103.html
[37] https://www.pce-instruments.com/english/measuring-instruments/test-meters/data-logger-data-logging-instrument-pce-instruments-humidity-temperature-co2-co-data-logger-pce-cog-10-det_6052908.htm
[38] https://www.measurementsystems.co.uk/sensors_and_meters/air_quality_and_gas_sensors/dl-1021--pm12510cotemperaturehumiditydew-point-data-logger-module
[39] https://www.oksa.co.uk/product/cl-213-wf-pm2-5-co-co2-temperature-humidity-dew-point-data-logger-module-rs-485-ethernet-poe-wi-fi/

3.5. Digital Survey Tools (DST)

Digital survey tools represent a modern and efficient approach to data collection, offering versatile solutions for various industries and 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. These have been summarised in a previous MECS report[12] with available solutions including:

- KoboCollect: https://www.kobotoolbox.org/
- Akvo Flow: https://www.akvoflow.org/
- ODK: https://getodk.org/index.html
- DigiESG: https://www.greendatalab.com/

4. SDG Impact Monitoring Matrix

The selected impact indicators from the Gold Standard SDG Tool as per Table 2 were assessed with regards to the suitability and applicability of digital monitoring techniques. The assessment that was carried out using ten different assessment factors is summarised in Table 3 in the form of a matrix. For each assessment factor a score was assigned that is represented by a colour (green = good, yellow = medium and red = bad). The assessment factors are explained in section 4.1. A detailed justification of the assignment of scores to the considered digital monitoring solutions is provided in section 4.2. The final score (suitability for digital monitoring) was derived as a combination of the individual assessment factors. The factors Cost of Digital Solution and SDG Indicator Confidence Level, which are considered particularly important, were weighted at 20% each, while the remaining factors together were weighted at 60% (or 7.5% each).

Each of the SDG indicators is reviewed individually in section 4.3 to highlight key information, relevant digital monitoring techniques, potential data sources for the calculation of the SDG indicator, applicability in the context of clean cooking activities and other relevant considerations.

Table 3: Matrix of SDG impact indicators with colour-coded scores of assessment factors; red = worst (e.g. highest cost or lowest confidence level), yellow medium, green = best (e.g. lowest cost or highest confidence level); the indicators highlighted in grey are only applicable to certain types of clean cooking activities

SDG	**1**				**3**		**5**			**7**							**15**
Assessment Factor	Population below international poverty line	Average household savings	Population below national poverty line	Population with access to basic services	Households with reductions in PM2.5 & CO	Number of ADALYS	Time spent on unpaid domestic work	Time saving: cooking time and fuel collection	Alternative time saving: cooking time and fuel collection	Population with access to electricity	Number of beneficiaries[40]	Population relying on clean fuels and technology	Renewable electricity produced	Renewable thermal energy produced	Renewable energy consumed	Total energy savings	Non-renewable wood fuel saved
Technical Readiness Level - Full System	Yellow	Yellow	Yellow	Yellow	Green	Green	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Availability of Digital Solution	Yellow	Yellow	Yellow	Yellow	Green	Green	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Cost of Digital Solution	Yellow	Yellow	Yellow	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Cost of Digital Logging System	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Digital Solution Data Communication Cost	Red	Yellow	Red	Yellow	Yellow	Red	Red	Red	Red	Red	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Complexity of Digital Monitoring System	Green	Green	Green	Green	Red	Red	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Digital Solution Local Installation Feasibility	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green
Digital Solution Data Resolution & Accuracy	Yellow	Green	Yellow	Yellow	Red	Red	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green	Green
Reliability of Digital Monitoring System	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
SDG Indicator Confidence Level	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Green	Green	Green	Green	Green
Suitability for Digital Monitoring	**2.0**	**2.4**	**2.0**	**2.0**	**2.4**	**2.1**	**1.9**	**1.9**	**2.2**	**2.2**	**2.4**	**2.0**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

[40] Note that while these are two separate indicators in the GS SDG Tool, in this assessment, “Number of beneficiaries: households” and “Number of beneficiaries: Individuals” were treated as one indicator

4.1. Explanation of Assessment Factors

The assessment factors used for the matrix investigating the suitability of digital monitoring, Table 3, are explained in more detail below. The assessment factors may only apply to sections of the full digital solution, for example: the resolution and accuracy only applies to any sensors used. To highlight which section(s) of the digital solution the assessment factor relates to, a very simplified model of a digital solution, broken into three sections, is used, shown in Figure 6.

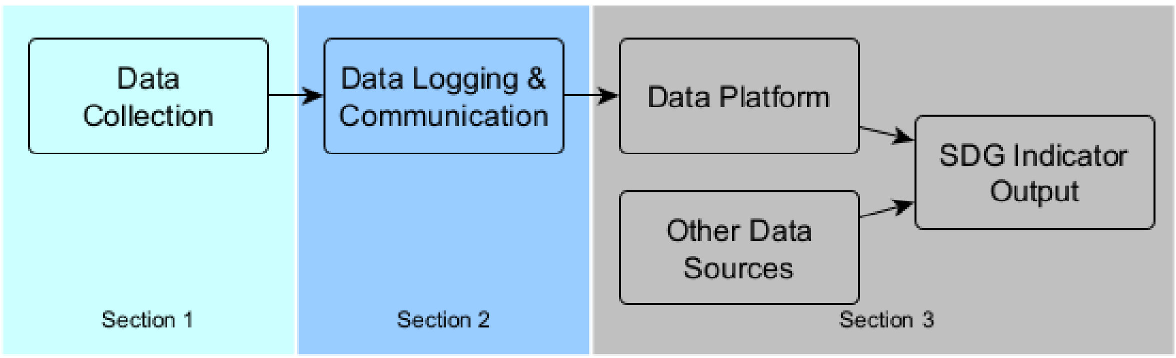


Figure 6: Simplified model indicating three sections of a digital monitoring solution.

Note that some of these assessment factors are subjective or qualitative - this report aims to provide a general overview and justification for the assessment factor used, but, with such a wide range of potential interventions from project developers, these assessment factors may have very different ratings for different projects.

Due to the complexity and potential wide range of interventions, the assessment factor used will be the lowest of the potential range of values, for example: if there is a range of sensors available from $5 up to $150, then a $5 lowest value will be used as consideration for the assessment factor.

Technical Readiness Level - Full System

This factor uses the standard definition of Technical Readiness Level (TRL)[41]. A TRL of less than 7 would relate to very early research or prototype solutions which would not yet be suitable for deployment, so all values 1 to 7 are low (red), 8 is medium (yellow) to 9 is high (green). This applies to all sections, 1-3.

Availability of Digital Solutions

If sensors are required to digitally monitor the parameter, this assessment factor looks at the range of different types of sensors available and the number of manufacturers of the sensors. Some SDG indicators may rely upon digital survey tools (sometimes alongside sensor-based data), so in those cases this factor reviews the range of digital survey tools available. This assessment factor only applies to section 1, “Data Collection”.

[41] https://www.ukri.org/councils/stfc/guidance-for-applicants/check-if-youre-eligible-for-funding/eligibility-of-technology-readiness-levels-trl/

Cost of Digital Solutions

The cost of digital solutions is reviewed to provide this assessment. Both for electronic sensors and digital survey tools this factor uses the lowest cost available for the assessment. The cost is assessed as low (<$10), medium ($10 to $35) and high (>$35). This assessment factor only applies to section 1, “Data Collection”.
Note that there may be additional costs for the data collection device, for example, lower cost sensors may require more laboratory-based calibration, or low-cost samples must be sent to laboratory facilities. If this is the case, then this additional cost is highlighted in the ‘Complexity of Digital Solution’ assessment factor.

Cost of Digital Logging System

This highlights the cost of any additional data logging system that might be required for digital monitoring. For example, remote logging may require use of the Global System for Mobile Communications (GSM) network which requires additional components and circuitry. The cost is assessed as low (<$35), medium ($35 to $100) and high (>$100). This assessment parameter only applies to section 2, “Data Logging and Communication”.

Digital Solution Data Communication Cost

This factor reviews the cost of sending the digital data or reading the data from the monitoring unit. For monitoring units with some form of wireless communication this cost depends on the time resolution of the data, the amount of data sent, and the communication system used. For monitoring units that record the data locally: the communication cost includes the cost for enumerators to visit the monitoring unit and download the data. This assessment factor applies to all sections, 1-3.

Complexity of Digital Solution

This factor highlights the complexity of the digital monitoring system, which may include the number of sensors to monitor, any sensor/equipment calibration requirements and costs, additional equipment that may be required (such as data-logging stations or additional networking infrastructure) and any specialised online resources that might be required.
For example, a household air pollution sensor may need calibration, local set-up, additional data-logging base-station system installation with high resolution data processing & communication, making such a system more complex. This assessment factor applies to all sections, 1-3.

Digital Solution Local Installation Feasibility

This factor reviews:

- How difficult is the installation of the digital solution?
- How often does the digital solution need to be physically checked or calibrated?
- Does the data need local download?
- If so, how easy is it to download the data and how often is this required?

- How intrusive is the digital solution to the end-user?

This assessment factor applies to sections 1 & 2.

Digital Solution Data Resolution & Accuracy

Data resolution is the smallest change that can be detected. Data accuracy is how close the data is to the actual value. Ideally a digital monitoring solution will have high resolution and high accuracy. Solutions with high resolution but low accuracy can be used to highlight trends, but not directly provide data for reporting any impact without further calibration. This assessment factor reviews the digital solutions available. This assessment factor only applies to section 1.

Reliability of Digital Solution

For this assessment the following factors have been reviewed:

- How robust are any digital solutions used?
  - E.g. Can the sensor survive the cooking environment including heat and steam?
- If applicable, what is the battery life?
- How durable is the solution?
  - E.g. Can the system be moved or relocated as may be required? What happens if the system is accidentally knocked?

This assessment factor applies to sections 1 & 2.

SDG Indicator Confidence Level

If the digitally monitored data is directly linked to the SDG indicator, then this gives a higher confidence level. If there are lots of assumptions, additional parameters or estimates required in order to calculate the SDG Indicator, then a low confidence level will be highlighted.
To assess this confidence level the following questions are reviewed for the SDG indicator:

- What other parameters, assumptions or estimates are required to convert the sensor data into the SDG indicator value to be reported?
- Where does any additional data that may be required come from?
- How reliable are the sources of additional data that may be required?
- How automatic is the conversion process (e.g. are Application Programming Interfaces (APIs) available to automatically convert data)?
- What conversion algorithms are required and how complex are they?
- Any data processing and conversion algorithms must be available for the VVB to analyse and validate - is this possible?

This assessment factor only applies to section 3.

Suitability for Digital Monitoring

Suitability is the ‘total’ of all the above assessment factors. This has been calculated by assigning a value of 1 to red and 3 to green. Some assessment factors have been highlighted as being more important to their impact on the suitability, for example the cost of a digital solution is typically a highly important factor. To incorporate the importance of different assessment factors, a weighting factor has been applied to each factor. The suitability is then the weighted average of all the assessment factors. This average value is given in the total box, along with the colour code.

4.2. Justification of Assessment Factors for Digital Monitoring Techniques

In order to obtain a score for each assessment factor for the considered indicators, first a scoring of all considered digital monitoring techniques was carried out. Table 4 shows the scoring and justification of each assessment factor for all digital monitoring solutions. In the case of several indicators, a combination of a sensor and digital survey tools is necessary to obtain all required data to calculate the SDG indicator. In these cases, the score was derived as a weighted average of the sensor and the digital survey tools. Three different weighting factors for the digital survey tools were applied based on how relevant the gathered data is for the determination of the indicator:

- 50%: digital survey tools are used to determine a key parameter in the impact calculation for the indicator
- 30%: digital survey tools are used to for contextual data that is required by Gold Standard
- 10%: digital survey tools are only used for the disaggregation of relevant data by categories such as sex, location, etc.

This method was used for scoring all but one assessment factor: the SDG Indicator Confidence Level was determined on an indicator system level, considering the combination of required monitoring techniques.

Table 4: Scoring and justification of assessment factors for the different digital monitoring solutions considered.

	Energy Consumption Monitor	Time Activity Monitor	Stove Usage Monitor	Household Air Pollution	Digital Survey Tool
Technical Readiness Level - Full System	Medium - TRL 8: energy consumption meters exist and are being used to monitor modern cooking	Worse - TRL 5: technology basic validation in a relevant environment Off the shelf solutions are typically for different applications.	Worse - TRL 7: technology prototype demonstration in an operational environment.	Good - TRL 9: actual technology qualified through successful mission operations.	Good - TRL 9: actual technology qualified through successful mission operations.
Availability of Digital Solution	Medium - Energy consumption monitors are abundant but not for the application in modern cooking devices.	Medium - Solutions used for different applications are available.	Worse - While temperature sensors are readily available, temperature sensors designed for stove monitoring are limited.	Good - A wide, and growing, selection of sensors available.	Good - Many different tools exist.
Cost of Digital Solution	Medium - Logging units in the region of $35-$50 are available at present[12], with potential future costs <$35.	Good - Tags are relatively low cost.	Medium - While the sensors used are widely available temperature sensing techniques, such as thermocouples or infra-red sensors, sensors designed for use on cookstoves are harder to find, requiring higher temperature ranges.	Good - Cost is low for optical PM sensors. Cost is being driven down by competition for domestic air quality applications. Potential for lower costs in future.	Good - Free and low-cost tools exist.
Cost of Digital Logging System	Medium - Logging systems have a wide range of costs.	Worse - Full system requires a data logging base unit and Wi-Fi connection.	Medium - Logging systems have a wide range of costs.	Medium - Wide range of costs and services. Potential for lower costs in the future.	Good - Data is collected using free or low-cost smartphone applications

	Energy Consumption Monitor	Time Activity Monitor	Stove Usage Monitor	Household Air Pollution	Digital Survey Tool
Digital Solution Data Communication Cost	Medium - Communication systems have a wide range of costs (see SUM).	Medium - Probably will require Wi-Fi connection for available solutions. Data amounts depend upon location resolution requirements.	Medium - All the SUMs listed here use a cable or Bluetooth download, requiring local access to the device, potentially requiring enumerators visiting each household. This has a high cost and is logistically challenging. Some SUM units allow smart phone download via Bluetooth then upload via Wi-Fi, but this requires participants to have smart phones and data contracts. Some SUMs units have additional Bluetooth download and GSM upload communication units which can service a number of SUMs, but this adds equipment and data costs to these systems.	Medium - GSM based data then costs will be relatively high. For an accurate picture of air quality, relatively high time-resolution data is required, in the region of mins-hourly.	Worse - Requires visits and interviews with users by an enumerator. Data can be locally stored on phone and uploaded later on Wi-Fi.
Complexity of Digital Solution	Good - These units are relatively simple and self-contained.	Worse - Systems require base stations with a power supply in each monitored household, multiple tags per household and (potentially) a Wi-Fi- connection for data. Participants must remember to carry tags. Cooking activities may occur in different areas from the baseline, for example if no electrical socket is available in the kitchen, which must be taken into account.	Good - These units are relatively simple and self-contained.	Worse - HAP sensor systems are highly complex as baseline and project surveys are required alongside sensor data. Optical sensors will require calibration alongside gravimetric methods to comply with GS methodology. Ideally: need to use PEM which are more expensive and require active participation. Static PM concentration monitors are cheaper and easier to install, but do not give good indication of actual individual exposure.	Good - DST is usually an app on a smartphone, so does not require additional equipment installation or calibration.

	Energy Consumption Monitor	Time Activity Monitor	Stove Usage Monitor	Household Air Pollution	Digital Survey Tool
Digital Solution Local Installation Feasibility	Good - Needs to be connected to the stove in a way that it cannot be easily removed or connected to other devices, but this can typically be prepared before distribution.	Worse - Will require monitoring base stations set up in each monitored household. Requires participation.	Good - Need to be added to the stove or near to the stove. With Bluetooth data transfer then relatively easy to download the data, although this does require a site visit.	Medium - the placement of the PM sensors requires careful consideration. Ideally a PEM is used. If not, then the position of any static PM concentration monitor must be similar for the sample households. There is a high risk that the sensors will be covered or moved in relatively dynamic cooking environments.	Medium - Household visits can be time-intensive and intrusive for users.
Digital Solution Data Resolution & Accuracy	Good - Under GS MMMECD[42] calibrated monitoring equipment, with evidence, is required. For electrical cooking, measurement of energy there are high accuracy sensors and techniques available.	Medium - Potential for highly accurate location/time data, but cooking environments are complex with multiple activities occurring in the same space. Separating cooking data from other activities could be difficult. Also tags rely upon participation, which could affect accuracy.	Good - The temperature sensors can have very high accuracy and reasonable resolution. The main issue is the placement of the sensor to measure the stove temperature. Typically, these sensors provide a 'stove on' and 'stove off' data, although this does need post-processing.	Worse - If calibrated, then PM sensors can have high resolution and accuracy. If uncalibrated then accuracy is affected and only trends can be measured. Data from PM sensors is also highly dependent upon sensor placement[43].	Worse - Reliability of data is low due to biases and human error.
Reliability of Digital Solution	Medium - if meters are not adequately connected to stoves, users may remove them. Bad network coverage may result in data losses.	Medium - Tags are highly reliable and with good battery life (2-5 years), but the systems require additional base stations for each monitored household, which increases complexity and hence lowers reliability.	Medium - Difficult to maintain sensors due to the environment of these sensors (near to high temperatures and with exposure to water).[44]	Medium - PM sensors can easily be affected by steam, which may affect readings in cooking environments. Sensor power consumption needs to be investigated - some sensors have high power requirements and are only suitable if grid-power is available.	Medium - coordination issues with households may arise, visits may be interrupted due to weather conditions, illness, vehicle failure etc.

[42] https://globalgoals.goldstandard.org/news-methodology-for-metered-measured-energy-cooking-devices/

[43] "HAPIT, the Household Air Pollution Intervention Tool, to Evaluate the Health Benefits and Cost-Effectiveness of Clean Cooking Interventions", Pillarisetti et al. Book: Broken Pumps and Promises, 2016, http://dx.doi.org/10.1007/978-3-319-28643-3_10

[44] https://pubs.acs.org/doi/10.1021/es504624c

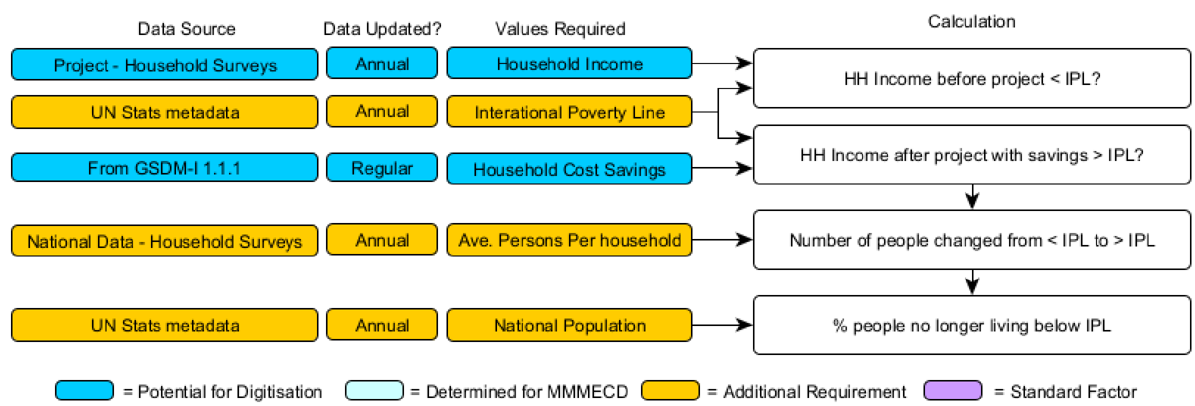
4.3. Assessment of Suitability of SDG Indicators for Digital Monitoring

This section reviews the relevant SDG Indicators from the Gold Standard SDG Indicator Tool. The confidence level for using digital monitoring to calculate the SDG indicator is highlighted, along with other factors or values which may be required to calculate the impact of the project on the indicator. If applicable, indicator data units, definitions and guidance are provided, along with options available for digital monitoring solutions. The "Data Updated?" value highlights if this parameter needs to be reassessed after initial indicator calculation. Potential data sources for the various values required are also shown.

SDG 1: No Poverty

GSDG-I 1.1.1	**Proportion of the population living below the international poverty line[45] by sex, age, employment status and geographic location (urban/rural)**		
Data unit	Custom	**Defined by UN/GS**	UN
GS Guidance	Not available		
Digital Monitor(s)	From GSDM-I 1.1.1 value (Energy Consumption Monitor) Digital Survey Tools		

Parameters required to determine indicator:



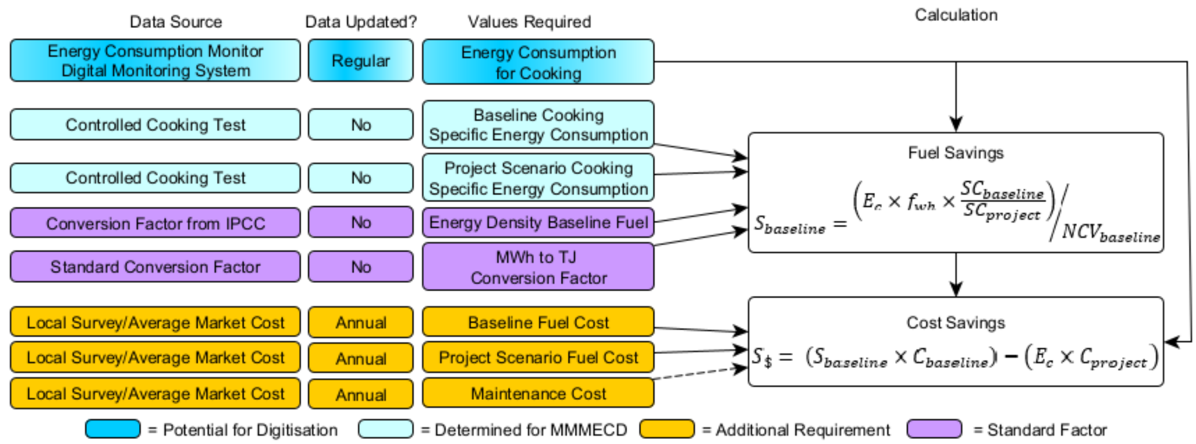
UN Stats metadata (https://unstats.un.org/sdgs/metadata/) and data portal (https://unstats.un.org/sdgs/dataportal) can be used as data sources.

Applicability	Applicable to any cooking equipment that reduces spending on cooking
Considerations	• Data quality issues as surveys must be carefully recorded by trained personnel. • Income is difficult to measure accurately. • Similar surveys might not be strictly compatible. • Potentially very small change from a single project.
Weighting factor of digital tools	Energy consumption monitor: 50% Digital survey tool: 50% Digital survey tool needs to be used to determine income level, which is a critical parameter for indicator assessment.
SDG Indicator Confidence Level	Medium - The ECM provides data relating to fuel savings, but additional data required, especially relating to income, is difficult to measure accurately and requires additional surveys alongside national data.

[45] International poverty line is the percentage of the population living on less than $2.15 a day at 2017 international prices.

GSDM-I 1.1.1	**Average household savings i.e., decrease in expenditure on basic service such as cooking, lighting, drinking**		
Data unit	USD or local currency	**Defined by UN/GS**	GS
GS Guidance	• Should be estimated through household savings determined by surveys in representative households or using fuel cost savings as proxy. • If using fuel costs, usage rate of devices, fuel cost variations and device maintenance costs shall be considered.		
Digital Monitor(s)	Energy Consumption Monitor (Digital Survey Tools)		

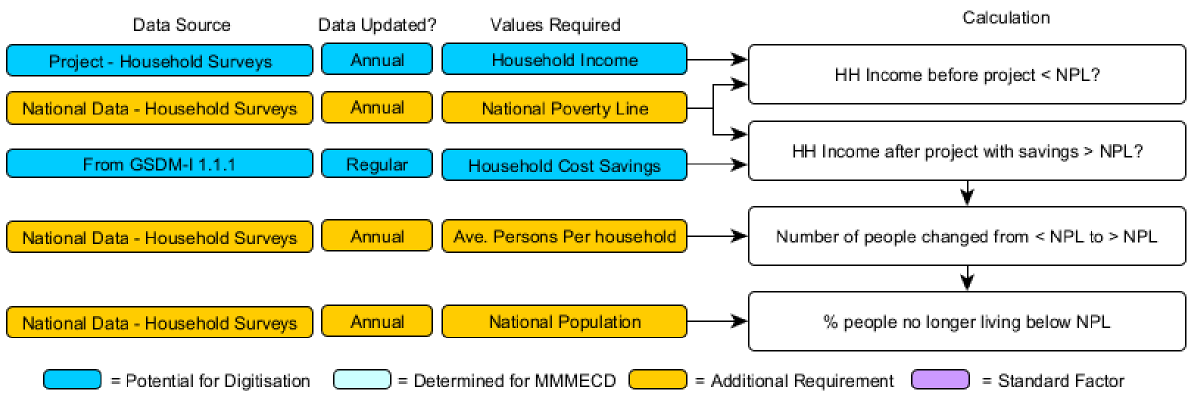
Parameters required to determine indicator:



Applicability	Applicable to any cooking equipment that reduces spending on cooking
Considerations	• Potentially requires local survey - actual savings may be highly variable. • Fuel cost(s) may vary through the year and are difficult to track. • Maintenance cost could potentially be higher for clean cookstoves and may need to be factored in.
Weighting factor of digital tools	While digital survey tools may be used, they are not strictly necessary and were hence disregarded in this assessment.
SDG Indicator Confidence Level	High - Data from ECM is highly proportional to the reduced expenditure on fuel.

GSDG-I 1.2.1	**Proportion of population living below the national poverty line[46], by sex and age**		
Data unit	Custom	**Defined by UN/GS**	UN
GS Guidance	Not available		
Digital Monitor(s)	From GSDM-I 1.1.1 value (Energy Consumption Monitor) Digital Survey Tools		

Parameters required to determine indicator:



Applicability	Applicable to any cooking equipment that reduces spending on cooking
Considerations	• Data quality issues as surveys must be carefully recorded by trained personnel. • Income is difficult to measure accurately. • Similar surveys might not be strictly compatible. • Potentially very small change from a single project.
Weighting factor of digital tools	Energy consumption monitor: 50% Digital survey tool: 50% Digital survey tool needs to be used to determine income level, which is a critical parameter for indicator assessment.
SDG Indicator Confidence Level	Medium - The ECM provides data on fuel savings, but additional data required, especially relating to income, is difficult to measure accurately and requires additional surveys alongside national data.

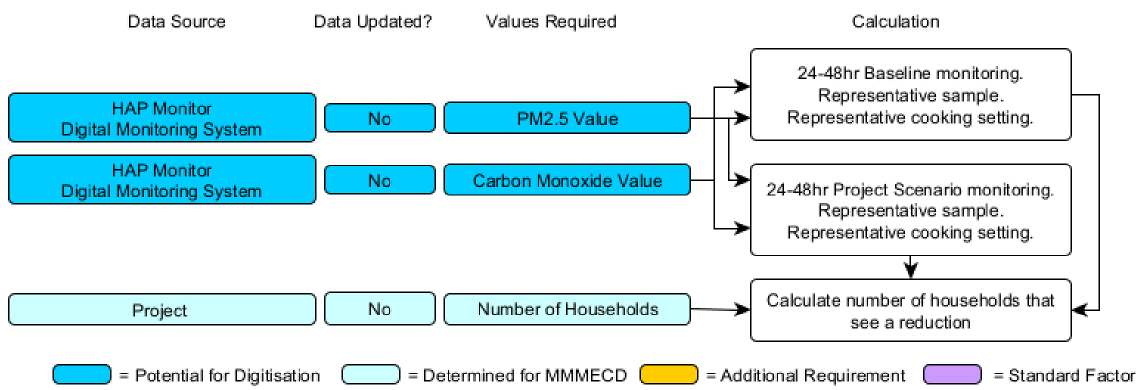
[46] National poverty estimates are typically produced and owned by country governments

<table>
<tr><td>GSDG-I 1.4.1</td><td colspan="3">Proportion of population living in households with access to basic services</td></tr>
<tr><td>Data unit</td><td>%</td><td>Defined by UN/GS</td><td>UN</td></tr>
<tr><td>GS Guidance</td><td colspan="3">● Indicator is dependent on many other existing SDG indicators, which need to be estimated to determine it.</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">From GSDG-I 7.1.2</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:
This indicator is based upon 9 components, including energy services. This indicator is presented as a dashboard of the 9 components, with data about each service from individual and specific SDG indicators. The energy services component will be captured through GSDG-I 7.1.2 “Percentage of population with primary reliance on clean fuels and technology”.</td></tr>
<tr><td>Applicability</td><td colspan="3">See GSDG-I 7.1.2</td></tr>
<tr><td>Considerations</td><td colspan="3">See GSDG-I 7.1.2</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">See GSDG-I 7.1.2</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">Medium - The component of energy services for this indicator comes directly from GSDG-I 7.1.2, so has the same confidence level.</td></tr>
</table>

SDG 3: Good Health and Well-being

GSDM-I 3.9.1	**Number of households that observed reduction in PM2.5 & carbon monoxide (CO) concentration reductions**		
Data unit	Number of households	**Defined by UN/GS**	GS
GS Guidance	• The project should conduct 24h or 48h monitoring in a sample of households for both the baseline and project scenario.		
Digital Monitor(s)	HAP Monitor		

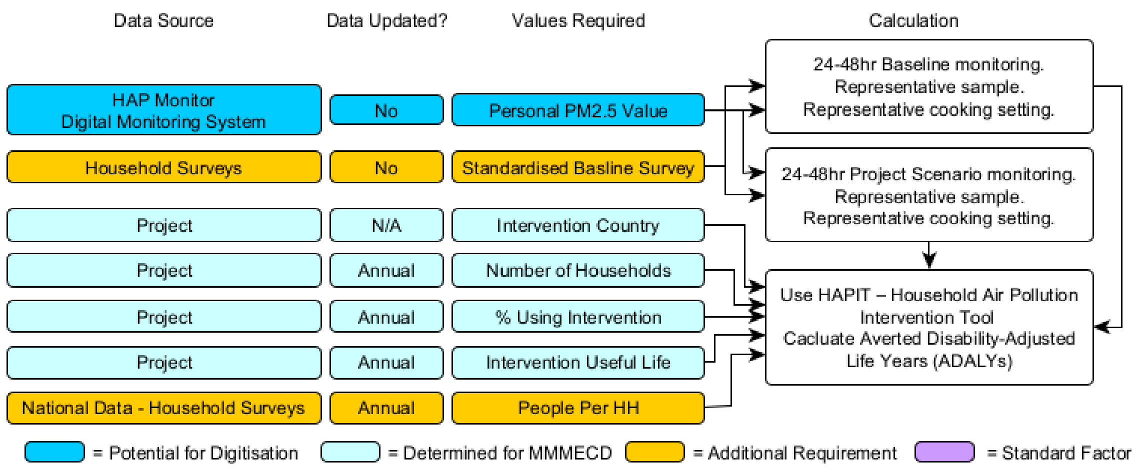
Parameters required to determine indicator:



Applicability	Applicable to all cooking equipment reducing indoor air pollution
Considerations	• Regular data collection not strictly required, but could increase integrity of impact monitoring • Data highly sensitive to sensor installation locations. • Representative cooking setting is required.
Weighting factor of digital tools	n/a
SDG Indicator Confidence Level	High - Laboratory calibrated HAP monitoring units are used for both baseline and project scenarios. This data is directly proportional to the indicator.

GSDM-I 3.9.2	**Number of Averted Mortality and Disability Adjusted Life Years (ADALYs)**		
Data unit	ADALYs	**Defined by UN/GS**	GS
GS Guidance	• Apply the ADALYs quantification methodology. [28]		
Digital Monitor(s)	HAP Monitor Digital Survey Tools		

Parameters required to determine indicator:

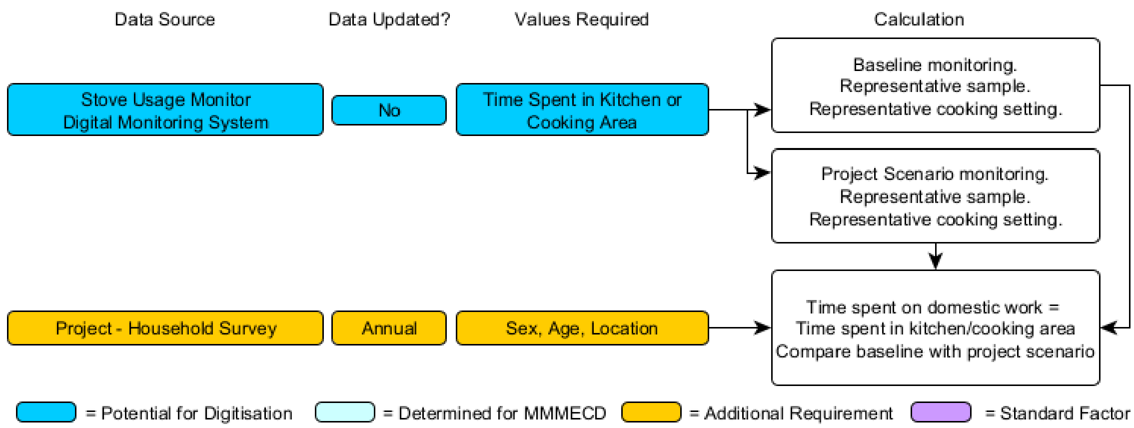


Use HAPIT[47] for estimates of health changes due to interventions designed to lower exposures to household air pollution.

Applicability	Applicable to all cooking equipment reducing indoor air pollution
Considerations	• HAPIT has (at present) no API to call data automatically. • Need to account for movement into and out of polluted micro-environments. • If optical monitoring, need to calculate adjustment factor (ratio of mean gravimetric to mean optical). • HAP PEM is only required for the primary cook of the household.
Weighting factor of digital tools	HAP Monitor: 70% Digital Survey Tools: 30% The methodology requires a household survey, but this is not used to determine parameters that influence the indicator.
SDG Indicator Confidence Level	Medium - Laboratory calibrated HAP monitoring units are used for both baseline and project scenarios, but additional survey data is also required. Data must then be (at present) manually entered into HAPIT, increasing the chance of error. A number of uncertainties remain within HAPIT, although it represents the 'state of the science' and relies on the best available knowledge.

[47] https://householdenergy.shinyapps.io/hapit3/

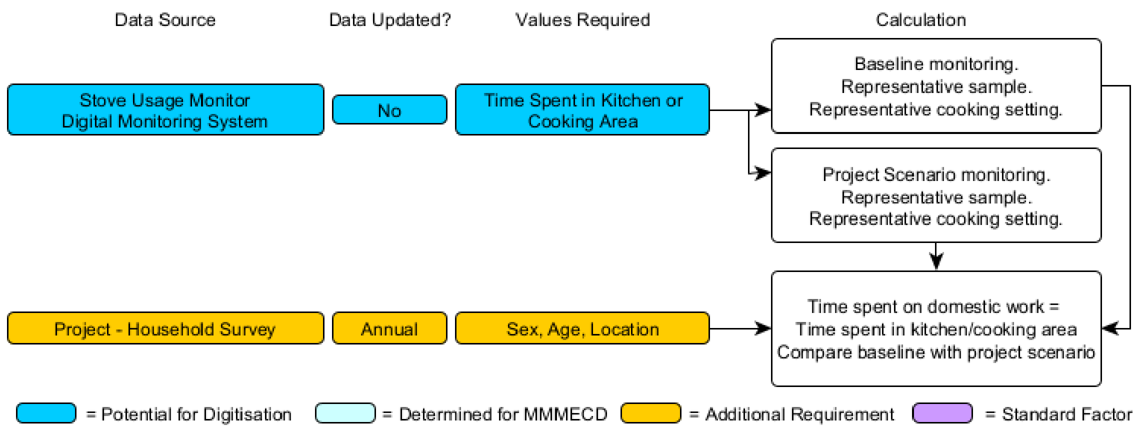
SDG 5: Gender Equality

<table>
<tr><td>GSDG-I 5.4.1</td><td colspan="3">Proportion of time spent on unpaid domestic and care work, by sex, age and location</td></tr>
<tr><td>Data unit</td><td>%</td><td>Defined by UN/GS</td><td>UN</td></tr>
<tr><td>GS Guidance</td><td colspan="3">Not available, refer to GSDM-I 5.4.1</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">Stove Usage Monitor[48]
Digital Survey Tools
(Time-Activity Monitor, Energy Consumption Monitor)</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:
Time savings from cooking time[49] (same as GSDM-I 5.4.1, below).

</td></tr>
<tr><td>Applicability</td><td colspan="3">Applicable to all cooking equipment reducing cooking time</td></tr>
<tr><td>Considerations</td><td colspan="3">• This indicator should be disaggregated by the following dimensions: sex, age and location.
• Different sensors or surveys could be used for monitoring this indicator; this assessment considers monitoring of cooking time with stove usage monitors which are considered the most available and relevant sensors
• The project should establish the link between project technology / implemented measures and its impact on this indicator.
• Gender dimensions must be considered within complex interconnected domains[50].</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">Stove Usage Monitor: 90%
Digital Survey Tools: 10%
The digital survey tool is only used to disaggregate data by sex, location etc. but is not used to determine parameters required for quantitative assessment of the indicator.</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">Medium – Cooking events measured with SUM require careful data processing to ensure reasonable accuracy. Stove usage data does not necessarily directly relate to time spent actively cooking (e.g. in the case of EPCs).</td></tr>
</table>

[48] Time-Activity Monitors are, at present, not deemed suitable here due to cost and accuracy issues, for example multiple activities may happen within the cooking location.
[49] Fuel collection time is, at present, very difficult to digitally monitor without wide area location tracking systems.
[50] https://mecs.org.uk/resources/mecs-gender-framework/

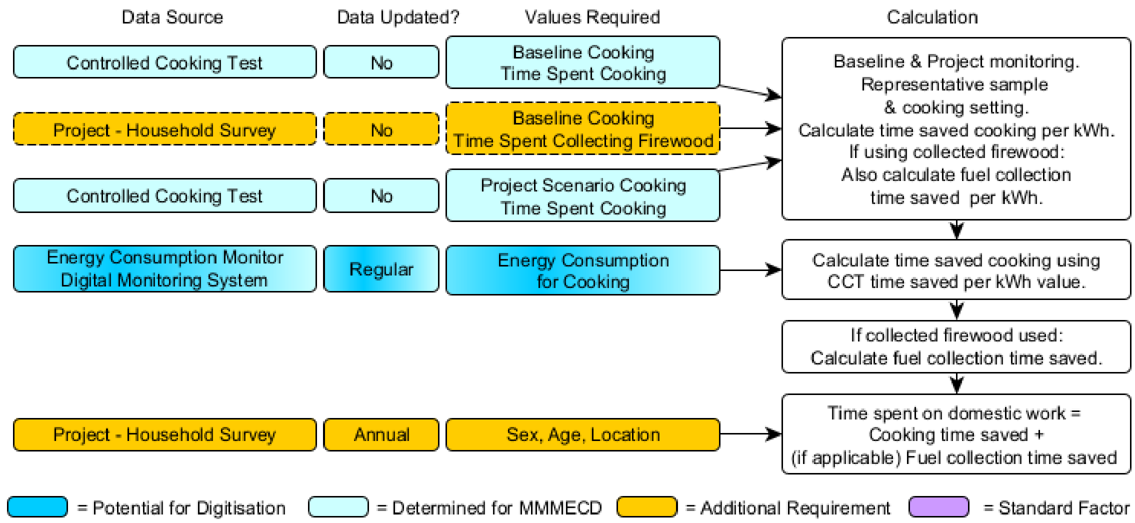
GSDM-I 5.4.1	**Average time saving associated with cooking time and fuel collection**		
Data unit	minutes/hr per household	**Defined by UN/GS**	GS
GS Guidance	• Refer to Gold Standard Gender Equality Requirements & Guidelines.[51] • Project should conduct surveys in representative households. • Project should report on primary ways that households are using time saved on fuel collection.		
Digital Monitor(s)	Stove Usage Monitor Digital Survey Tools (Time-Activity Monitor, Energy Consumption Monitor)		

Parameters required to determine indicator:



Applicability	Applicable to all cooking equipment reducing cooking time
Considerations	• Different sensors or surveys could be used for monitoring this indicator; this assessment considers monitoring of cooking time with stove usage monitors which are considered the most available and relevant sensors • Fuel collection is disregarded, as digital monitoring is not considered feasible. • Gender dimensions must be considered within complex interconnected domains[50].
Weighting factor of digital tools	Stove Usage Monitor: 90% Digital Survey Tools: 10% The digital survey tool is only used to disaggregate data by sex, location etc. but is not used to determine parameters required for quantitative assessment of the indicator.
SDG Indicator Confidence Level	Medium - Cooking events measured with SUM require careful data processing to ensure reasonable accuracy. Stove usage data does not necessarily directly relate to time spent actively cooking (e.g. in the case of EPCs).

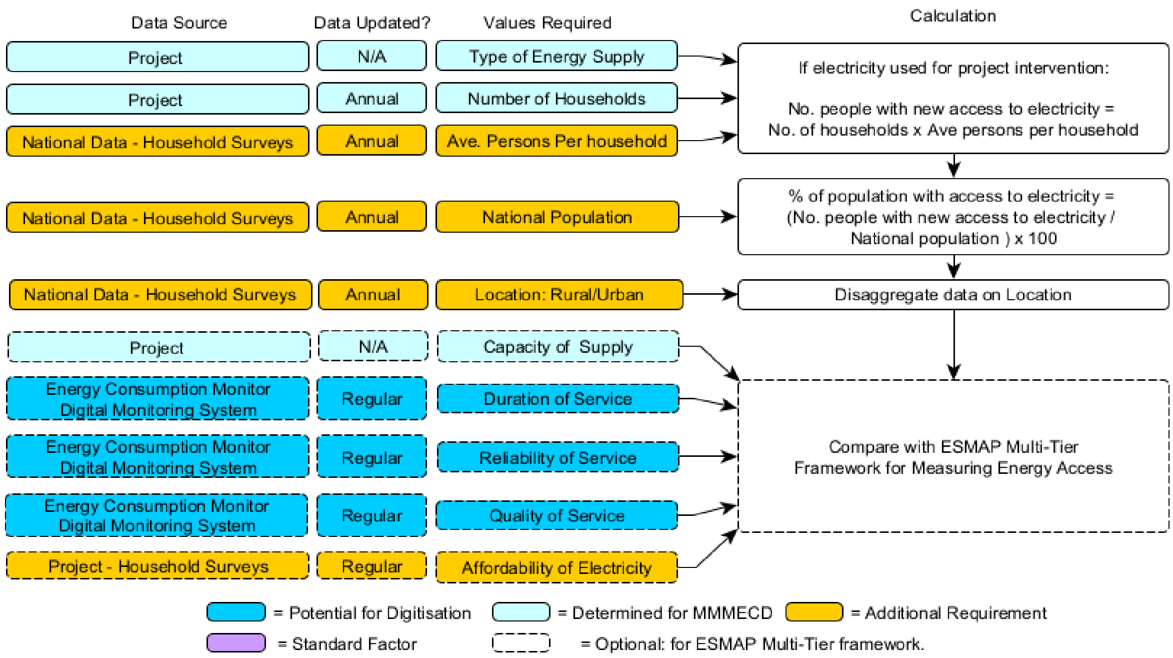
[51] https://globalgoals.goldstandard.org/104-par-gender-equality-requirements-and-guidelines/

<table>
<tr><th>Alternative
GSDM-I 5.4.1</th><th colspan="3">Average time saving associated with cooking time and fuel collection</th></tr>
<tr><td>Data unit</td><td>minutes/hr per household</td><td>Defined by UN/GS</td><td>Proposed alternative</td></tr>
<tr><td>GS Guidance</td><td colspan="3">Not available</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">Energy Consumption Monitor
Digital Survey Tools</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:

</td></tr>
<tr><td>Applicability</td><td colspan="3">Applicable to all cooking equipment reducing cooking time / firewood collection</td></tr>
<tr><td>Considerations</td><td colspan="3">• The Controlled Cooking Test needs to ensure accurate time monitoring of cooking activity
• Baseline fuel stack needs to be considered when determining time savings</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">Energy Consumption Monitor: 90%
Digital Survey Tools: 10%
The digital survey tool is used to baseline time spent collecting firewood (if applicable) and to disaggregate data by sex, location etc.</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">High - ECM can provide accurate data, which is directly linked to the indicator value, although disaggregation data will require surveys.</td></tr>
</table>

SDG 7: Affordable and Clean Energy

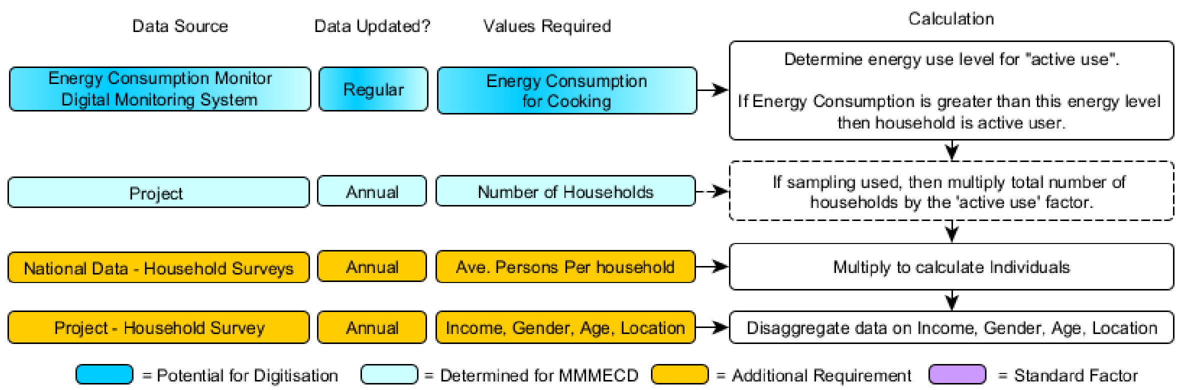
GSDG-I 7.1.1	**Proportion of population with access to electricity**		
Data unit	%	**Defined by UN/GS**	UN
GS Guidance	• Data shall be disaggregated by type of electricity supply, capacity, availability, reliability, quality, affordability and legality of service.		
Digital Monitor(s)	Energy Consumption Monitor Digital Survey Tools		

Parameters required to determine indicator:



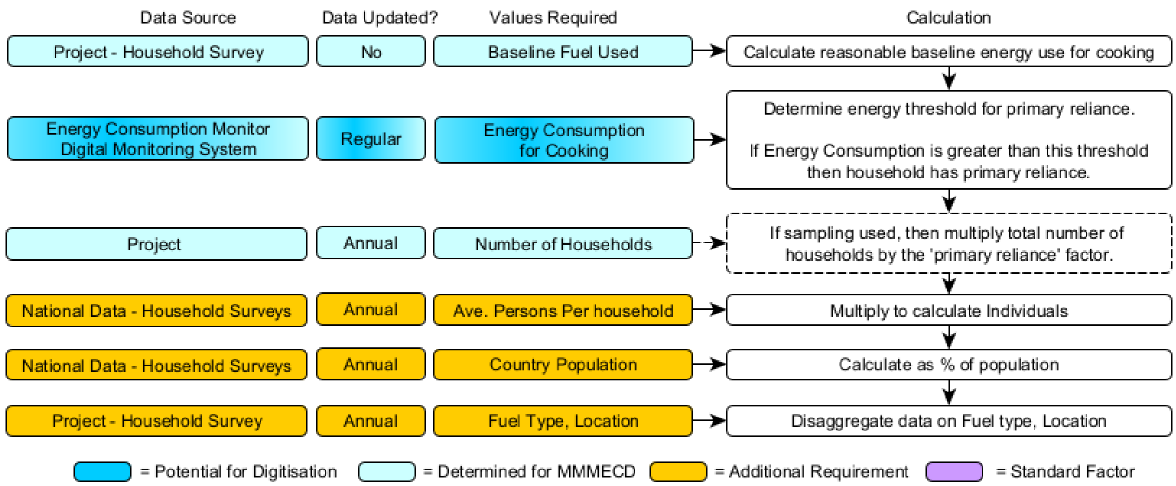
Applicability	Only applicable to activities that increase electricity access, i.e. provide electricity source or connection alongside cooking equipment
Considerations	• Access to electricity is not binary, for more granular data follow ESMAP Multi-Tier Framework for Measuring Energy Access[52]. • Disaggregated by total, urban and rural access rates.
Weighting factor of digital tools	Energy Consumption Monitor: 90% Digital Survey Tools: 10% The digital survey tool is only used for disaggregation to determine the affordability of electricity but is not used to determine parameters required for quantitative assessment of the indicator.
SDG Indicator Confidence Level	High - This factor can be calculated directly from project implementation data. ECM, alongside surveys, can provide disaggregation to help improve granularity. ECM can also provide data on active users, improving confidence in the impact.

[52] https://www.esmap.org/mtf-multi-tier-framework-website

<table>
<tr><td>GSDM-I 7.1.1</td><td colspan="3">Number of beneficiaries: Households
Number of beneficiaries: Individuals</td></tr>
<tr><td>Data unit</td><td>No. of HH
No. of users</td><td>Defined by UN/GS</td><td>GS</td></tr>
<tr><td>GS Guidance</td><td colspan="3">• Recommended to disaggregate data by residence settings (i.e. rural, urban, peri-urban), gender, income level.
• For individuals: only account for users actively using the clean cooking device.</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">Energy Consumption Monitor</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:
Refers to the number of unique households that were provided access to clean fuels and technologies for domestic cooking.


</td></tr>
<tr><td>Applicability</td><td colspan="3">Applicable to any activity</td></tr>
<tr><td>Considerations</td><td colspan="3">• Use a conservative approach for such estimation and provide details of the assumptions made.
• Data disaggregation as per end-user's residence settings, gender and income level may provide more insight into the beneficiaries targeted by the projects.
• Project should provide details of all assumptions used for calculation.</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">n/a</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">High - ECM can provide accurate data, which is directly linked to the indicator value, although disaggregation data will require surveys.</td></tr>
</table>

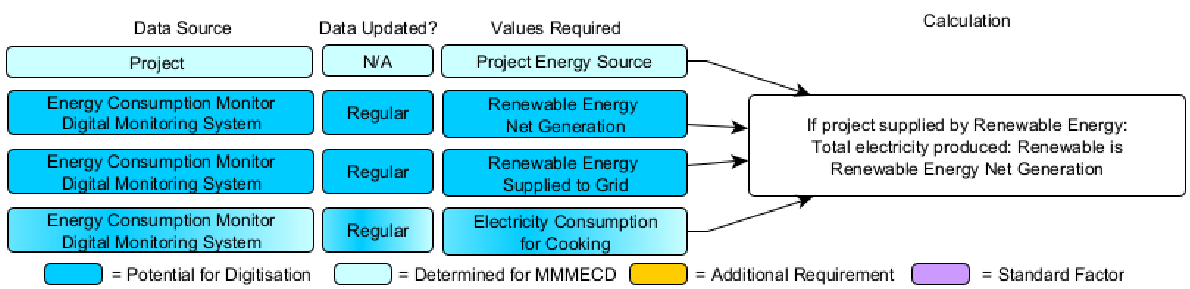
<table>
<tr><td>GSDG-I 7.1.2</td><td colspan="3">Proportion of population with primary reliance on clean fuels and technology</td></tr>
<tr><td>Data unit</td><td>% or number</td><td>Defined by UN/GS</td><td>GS</td></tr>
<tr><td>GS Guidance</td><td colspan="3">• Can be disaggregated by urban/rural place of residence, fuel types and estimates for different end-uses.</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">Energy Consumption Monitor
Digital Survey Tools</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:



Note: This calculation and factors used must be approved by VVB</td></tr>
<tr><td>Applicability</td><td colspan="3">Applicable to any activity where cooking equipment becomes primary cooking technology for a relevant number of users</td></tr>
<tr><td>Considerations</td><td colspan="3">• Disaggregate by urban/rural place of residence, by estimates for different end-uses, and by fuel types.
• Potentially very small change from a single project.</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">Energy Consumption Monitor: 90%
Digital Survey Tools: 10%
The digital survey tool is only used to disaggregate data by sex, location etc. but is not used to determine parameters required for quantitative assessment of the indicator.</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">Medium - ECM data must be processed using project survey and national survey data, reducing the confidence level of digital data relating to the SDG indicator. Disaggregation data will require surveys.</td></tr>
</table>

GSDM-I 7.2.1	**Total electricity produced: Renewable**		
Data unit	MWh	**Defined by UN/GS**	GS
GS Guidance	• Provide details of quantity of net electricity generation that is produced and fed into the grid and/or consumed internally as a result of the implementation of the project activity • Disaggregation of data on consumption of renewable energy by resource and end-use sector could provide insights into other dimensions of the goal, such as affordability and reliability		
Digital Monitor(s)	Energy Consumption Monitor		

Parameters required to determine indicator:

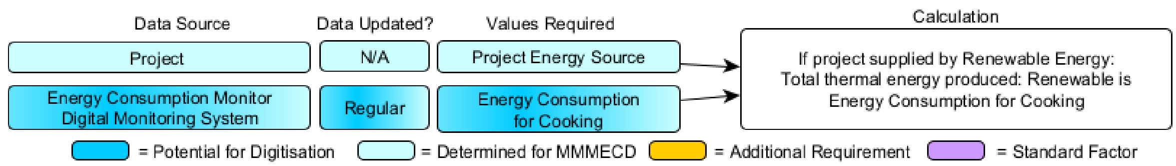


Note: Some solar off-grid cooking systems may not use all the energy for cooking. Actual energy used for cooking should be measured.

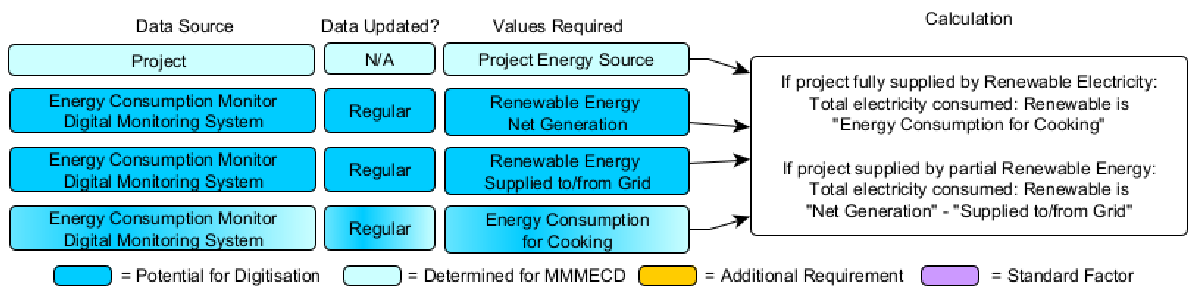
Applicability	Only applicable to activities producing renewable energy
Considerations	• Disaggregating renewable electricity production by resource and end-use provides more insights. • Disaggregate between grid and off-grid capacity.
Weighting factor of digital tools	n/a
SDG Indicator Confidence Level	High - ECM can provide accurate data which is directly linked to the indicator value.

GSDM-I 7.2.2	**Total thermal energy produced: Renewable**		
Data unit	GJ	**Defined by UN/GS**	GS
GS Guidance	• Users may include residential, commercial and institutional settings		
Digital Monitor(s)	Energy Consumption Monitor		

Parameters required to determine indicator:

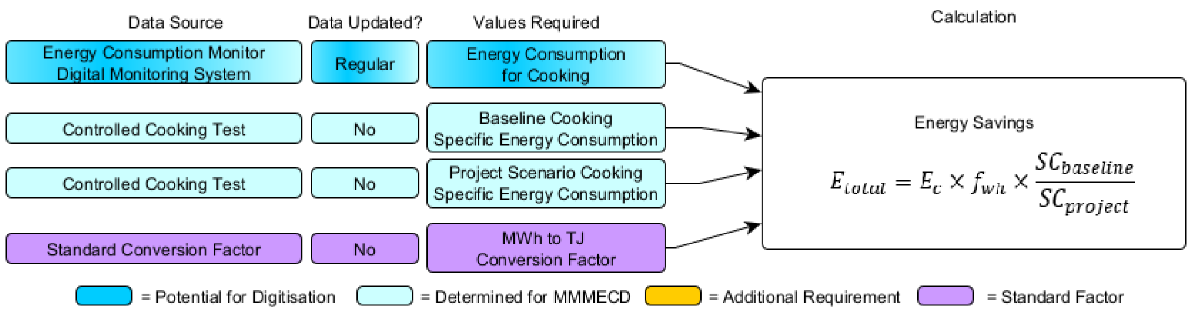


Applicability	Only applicable to cooking equipment relying on renewable fuel
Considerations	n/a
Weighting factor of digital tools	n/a
SDG Indicator Confidence Level	High - ECM can provide accurate data which is directly linked to the indicator value.

<table>
<tr><td>GSDM-I 7.2.3</td><td colspan="3">Total electricity consumed: Renewable</td></tr>
<tr><td>Data unit</td><td>MWh</td><td>Defined by UN/GS</td><td>GS</td></tr>
<tr><td>GS Guidance</td><td colspan="3">• Users may include households, rural health centres, rural schools, grain milling, water pumping, irrigation, etc.
• Where possible, electricity consumption data should be disaggregated by user category.</td></tr>
<tr><td>Digital Monitor(s)</td><td colspan="3">Energy Consumption Monitor</td></tr>
<tr><td colspan="4">Parameters required to determine indicator:

</td></tr>
<tr><td>Applicability</td><td colspan="3">Only applicable to cooking equipment relying on renewable electricity</td></tr>
<tr><td>Considerations</td><td colspan="3">• If cooking intervention is not fully renewable, then this factor is probably not suitable.
• Disaggregating renewable electricity consumption by resource and end-use provides more insights.
• Disaggregate between grid and off-grid capacity.</td></tr>
<tr><td>Weighting factor of digital tools</td><td colspan="3">n/a</td></tr>
<tr><td>SDG Indicator Confidence Level</td><td colspan="3">High - ECM can provide accurate data which is directly linked to the indicator value.</td></tr>
</table>

GSDM-I 7.3.1	**Total energy savings**		
Data unit	TJ or other units	**Defined by UN/GS**	GS
GS Guidance	• Report the total energy savings values based on project performance data. • Where project units are of different type/age; weighted average energy consumption per unit should be applied. For ex-ante estimation, the project may use the manufacturer's specifications. Project should provide details of all assumptions used for calculation.		
Digital Monitor(s)	Energy Consumption Monitor		

Parameters required to determine indicator:

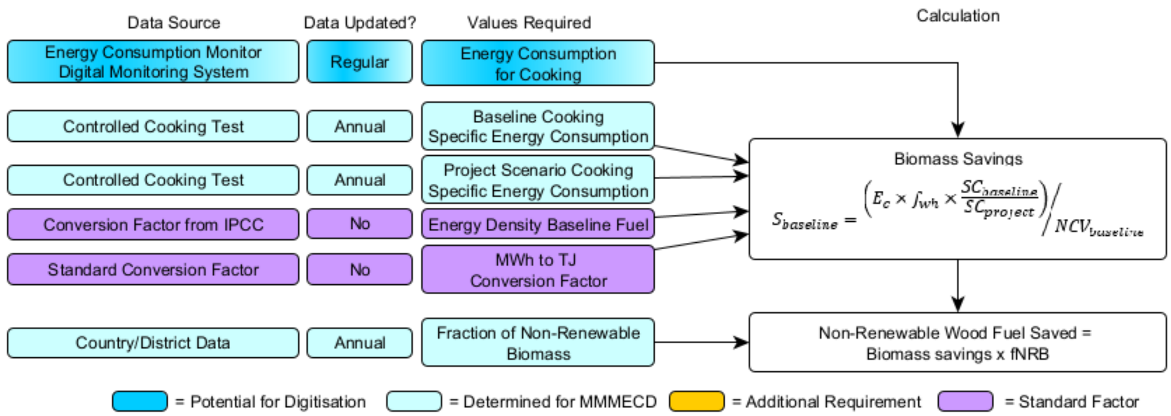


Applicability	Applicable to any activity generating energy savings
Considerations	• Either use averages or, with digital monitoring, use real time data from each unit.
Weighting factor of digital tools	n/a
SDG Indicator Confidence Level	High - ECM can provide accurate data which is directly linked to the indicator value.

SDG 15: Life on Land

GSDM-I 15.1.1	**Total non-renewable wood fuel saved**		
Data unit	tonnes/year	**Defined by UN/GS**	GS
GS Guidance	• Fuel savings shall be adjusted for the fraction of biomass that can be established as non-renewable (fNRB) • The measurement method (sample survey or direct measurement at end user locations) shall be disclosed • Projects shall transparently disclose if a suppressed demand scenario exists • For charcoal or other processed fuel derived from wood, woody biomass can be estimated from charcoal using a default conversion factor		
Digital Monitor(s)	Energy Consumption Monitor		

Parameters required to determine indicator:
Tools available for fraction non-renewable biomass include Mofuss[53] and CDM tool 30[54].



Applicability	Applicable to any cooking equipment displacing non-renewable woody biomass
Considerations	• Measurement method must be disclosed. • Disclose if a suppressed demand situation exists. • Wood biomass can be estimated from charcoal using a default conversion factor. • Some concerns around fNRB value which directly affects this indicator.
Weighting factor of digital tools	n/a
SDG Indicator Confidence Level	High - ECM can provide accurate data which is directly linked to the indicator value.

[53] https://www.mofuss.unam.mx/mofuss-ds/
[54] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-30-v1.pdf/history_view

5. Discussion and Outlook

As the importance of certified SDG impacts in carbon markets is growing, the frameworks for monitoring and reporting them are becoming increasingly robust. The Gold Standard SDG Tool represents a significant milestone in streamlining and standardising SDG impact reporting for carbon projects. This standardisation will contribute to increased comparability and reliability of reported impacts. Currently the tool represents a user-input data repository for data collected by the project developer, which means any data collected by digital means still needs to be manually transferred to the tool. Gold Standard's vision includes the integration of real-time sensor data with automated data collection, as well as data processing to derive SDG impacts, but the timeline for this is unclear and given the complexity of this undertaking it is not expected to be realised in the short-term. The reporting and verification of impacts on the tool has already partly been implemented.

This report has highlighted and reviewed 17 SDG indicators from the Gold Standard SDG Tool relating to modern cooking interventions, which were analysed with regards to their suitability for digital monitoring using a standardised assessment framework. This assessment framework considered factors such as costs, availability, TRL, and reliability of existing digital solutions relevant to the respective indicators. In cases where indicators rely on more than one digital monitoring solution, a combined score was derived based on individual weighting factors. As a result, a matrix of data was created that allows for insight and comparison of the considered SDG impact indicators with regards to digital monitoring.

A number of digital monitoring techniques for measuring metrics relating to the SDG indicators were reviewed and analysed with regard to the assessment framework:

Digital survey tools are seen as the most developed of the digital monitoring techniques available. They are low-cost and, as they are typically software systems, can be easily installed onto personal smartphones, with virtually no hardware cost nor local installation or calibration requirement. The data from the digital survey tools must be carefully and securely managed and must still be processed to provide information relating to the SDG indicator. Digital survey tools only help reduce human input error and streamline data collection - there is still the potential for recall bias and the Hawthorne effect. Most surveys also require site visits, with associated time costs and wages.

Energy consumption meters are a requirement for carbon projects applying MMMECD, which is the focus methodology for this report, so indicators relating to energy consumption data are shown to be relatively easy to calculate at low additional cost. There is a growing range of solutions available to measure energy consumption and, while these solutions are relatively expensive at present, it is expected that the cost of implementing energy consumption monitoring will fall rapidly with economies of scale and standardisation. Additional digital monitoring techniques (HAP, SUM and TAM) will all add additional cost to the project implementation.

A small range of **stove usage monitors** is available and the data from these devices can help highlight cooking events, improving the integrity of SDG impact claims. Stove usage monitors are a niche product and so there is less competitive drive to reduce prices and introduce more models.

Air quality monitoring for health benefits is a highly competitive market with numerous manufacturers producing low-cost sensors and monitoring equipment. Due to the very large market for such devices, there has been a large reduction in sensor prices, with solutions still reducing in both size and cost and it is predicted that sensors will become smaller, cheaper, require less power and be more accurate in the short to medium term. There is a smaller market for household air pollution sensors for personal exposure monitoring, especially in remote rural environments typically without Wi-Fi. At present Gold Standard requires laboratory calibration of any HAP sensor used for baseline and scenario monitoring, although these can be rented from specialist companies for the 24 or 48 hours required for the indicator assessment. Adding HAP sensing equipment to a cooking project intervention may become more common in the medium term, as calibrated sensors are utilised in monitoring products.

Monitoring HAP to measure any potential reduction in of $PM_{2.5}$ and CO as a co-benefit is less onerous than direct health benefit claims and can be performed with lower cost optical sensor-based logging systems.

The main aspect with monitoring HAP for health benefit claims is the conversion of sensor data into health effects. Sensor placement, air flow, and installation location environment will all affect the data recorded. It has been anecdotally highlighted that long-term data from HAP measurement with cooking interventions did not provide useful insight and other external environmental factors, such as windows opening, neighbours' activities, nearby generators etc, had a much larger effect. As more HAP real-time data becomes available, most probably from air quality measurement programs not related to cooking, the algorithms and conversion from sensor data to health effects will become better understood and more accurate. HAPIT[47] is a very welcome implementation of applying the best and most up to date metrics to relate air quality measurements with health effects. As more research is performed into this area and more data available for analysis, this tool will become even more accurate and useful. Ideally this tool will become available via an API function call, although the timeline for adding this functionality is not known.

Time-activity monitoring is seen as one of the hardest techniques to accurately implement at reasonable cost. Only a few solutions suitable for the project implementation areas are available and the specific activity data is difficult to disaggregate from other activities that may happen within the same location. As smartphone use becomes more ubiquitous there is greater potential for very low-cost location tracking using GPS, but this will be in the longer-term and potentially has security and data privacy implications.

The impact indicator assessment showed that nine out of the 17 indicators are equally and well suited for digital monitoring, with most of these indicators relating to SDG 7. All but one of these can be determined quite reliably utilising energy consumption data, with few or no additional data needed for indicator assessment. One indicator utilises a HAP monitor, which represents an additional sensor that needs to be installed as part of the baseline study and project operations.

Although the range of assessment values is small, indicating relatively small differences in suitability for digital monitoring, the lowest ranking indicators are the SDG 5 indicators that relate to time savings for cooking. In the assessment stove usage monitors were considered as the best available monitoring solution for these indicators, yet their limited availability, high data communication costs and low TRL means that indicators that can be measured with other sensors are considered more suitable for digital monitoring. Similarly, several indicators (including most SDG 1 indicators) rely in part on data that can only be obtained via user surveys, reducing their suitability for digital monitoring.

An alternative approach to determining cooking time savings was proposed, whereby cooking time savings are derived from time measurements performed in the baseline studies required by MMMECD, such as the Controlled Cooking Test. Where this test currently establishes the ratio in energy consumption between baseline and project cooking equipment, it could at the same time establish the ratio in cooking time, which then allows for monitoring time savings based on the energy consumption of the project device. Given the higher TRL and availability of energy consumption meters, this approach is assessed as more suitable for digital monitoring. If permitted by Gold Standard, it could enable SDG 5 impact monitoring that is comparable, reliable (provided that relevant guidance and safeguards are established) and cost-efficient.

Reviewing each SDG indicator in detail and highlighting any additional data required alongside the digital monitoring techniques to calculate the actual value has shown how complex some of the indicators are:

- The translation of digital data into real events (for example, calculating a cooking event from stove temperature) requires potentially complex data processing algorithms which need standardisation and rigorous assessment to ensure their validity. This is especially true of air pollution data.
- Some SDG indicators have additional factors which require additional data sources. Even if high-accuracy real-time digital data is collected, if survey or national-level data is also required then problematic biases and data errors can occur, lowering the confidence in the final calculated SDG indicator value.
- It has been highlighted that many impacts require far more qualitative factors than just single quantitative values from digital sensors. This is especially true for gender-based indicators.

Even though potential detail may be lost when using practical SDG indicators, the indicators have been designed to be as robust as possible, while still being suitable for project developers to monitor. Having standardised indicators allows project developers to monitor the impact from their interventions.

Having efficient and rigorous databases of relevant data sources and conversion algorithms would help the simplification of SDG indicator measurement. HAPIT is a very good example of what can be done to provide best practice based upon the latest data and academic literature to help calculate impact. Ideally this type of standardised online database would be available for many of the relevant factors used to calculate indicators, such as national level information.

It is hoped that in the short to medium term there is a push towards automating the conversion process using APIs and online databases. This will not happen naturally and will require strategy and input from the standards setting organisations and other stakeholders. Platforms to pull together data from multiple sources to report SDG impact are available and, as the market for highly credible SDG impacts improves, it is expected that there will be more solutions available. Ensuring these platforms work towards a common standard would greatly help with the interoperability of these platforms with monitoring devices and data sources.

This report assesses the suitability of SDG indicators within the Gold Standard SDG Impact Tool for digital monitoring, but it should be noted that this is a snapshot of the situation at present. There are many additional drivers which could change or disrupt the suitability rating provided here.

It is expected that the cost for sensors and digital monitoring devices will be driven down through economies of scale and technology improvements coming from academic research or by alternative applications. For example, it is expected that air quality monitoring devices will become smaller in size and lower in cost as the sensor technology is integrated within consumer electronics, such as smart phones and watches. This is already happening (for example: a new Bosch[55] sensor is 400 times smaller than other comparable air quality sensors). This will also lead to greater amounts of data, more confidence in any data analysis applied to the sensor readings and eventually into more robust monitoring solutions for all applications.

The perceived value of the different SDG impacts will be driven by market forces and certain SDG impacts and indicators may be considered more meaningful and more valuable by the market than others. A notable development was the launch of the Clean Impact Bond by Cardano Development, IFC, and partners, which is a results-based financing instrument that aims to mobilise finance for SMEs based on the sales of health and gender benefits certified under Gold Standard.[56] It highlights a particular interest in health and gender impacts, which may motivate extra efforts in improving monitoring methods for the relevant indicators.

For markets to have confidence in SDG indicators using digital data, there needs to be a much larger number of projects performing both traditional SDG impact monitoring alongside the collection of digital data. These data sets can then be used for academically rigorous analysis to

[55] https://www.bosch-sensortec.com/news/worlds-smallest-particulate-matter-sensor-bmv080.html
[56] https://mecs.org.uk/clean-impact-bond-profiled-by-ifc-at-the-innovate4climate-forum-2023/

ensure digital data collected is meaningful and provides accurate information relating to SDG impact. As more data is collected from projects implementing the GS MMMECD and, potentially, from consumer smart meter data or other sources, more robust conversion algorithms can be trained, tested and demonstrated for suitability.

It is worth highlighting that standard setting organisations and platform developers have very high ambition to incorporate digital monitoring techniques, but usually with limited technical resources to work on implementing many features and services. Their focus needs to be driven by the most relevant and economic needs of the market and the project developer.
Open-source platforms (such as ADP and Prospect from A2EI) may also help interested developers quickly onboard data and develop these robust algorithms to automatically calculate SDG impacts. These can be developed and tested quickly and compared alongside the traditional approaches for calculating SDG indicators, to ensure that digital techniques can be more robust and reliable and to highlight when other, potentially more qualitative, data may be required.

Appendix

Stakeholder Interview List

Name	***Organisation***	***Date interviewed***
Elliot Avila	A2EI (Access to Energy Institute)	13/9/2024
Anshika Gupta	Gold Standard	25/9/2024
Yesmeen Khalifa	MECS	26/9/2024
Jan Moellmann	Leonardo Impact	21/10/2024

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