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Ref. Ares(2023)5455011 - 07/08/2023

Development of best transition pathways for Local Energy Communities (LEC) through impact assessment

Deliverable 3.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 957843 (MAESHA). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Deliverable D3.3
Development of best transition pathways for Local Energy Communities (LEC) through impact assessment

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Date (01/08/2023)

DELIVERABLE 3.3 – VERSION 1
WORK PACKAGE N° 3

Nature of the deliverable		
R	Document, report (excluding the periodic and final reports)	X
DEC	Demonstrator, pilot, prototype, plan designs	
DEM	Websites, patents filing, press & media actions, videos, etc.	
O	Software, technical diagram, etc.	

Dissemination level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Quality procedure

Revision	Date	Created by	Short Description of Changes

Document Approver(s) and Reviewer(s):
NOTE: All Approvers are required. Records of each approver must be maintained. All Reviewers in the list are considered required unless explicitly listed as Optional.

Name	Role	Action	Date
		<Approve / Review>	

ACKNOWLEDGEMENT

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More information on the project can be found at https://www.maesha.eu

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EXECUTIVE SUMMARY

Under the agenda 2030, countries joining the United Nations (UN) join efforts to combat overarching challenges of the global society. Stipulated in distinct Sustainable Development Goals (SDGs), the agenda specifies seventeen areas of development, in which significant improvements must be achieved by 2030 to ensure the ongoing development of economies, and societies in a sustainable manner. Committing to the agenda 2030, countries are obliged to streamline their efforts under the SDGs and adopt overarching strategies and goals. As one distinct goal, SDG 7 aims to provide affordable and clean energy to all people. As of the multidisciplinary interlinkages of energy to economic, social, societal, and finally human development as a collective term, SDG 7 has numerous synergies and trade-offs with many other SDGs. Efforts taken under SDG 7, including energy interventions and projects impact other dimensions of development – reflected in other SDGs. Hence, the holistic impact of an energy intervention and its alignment in global development efforts can be assessed by evaluating the impact of the intervention in other SDGs.

In this report, we propose how to assess the impact of selected energy interventions supporting the energy transition of geographical islands against the holistic SDG framework. In striving for a decarbonized energy transformation in alignment with SDG 7, European islands and their inhabitants take a special seat at the discussion table—being both most vulnerable in terms of energy access at reasonable costs, but simultaneously recognized as a favorable place for innovation due to high costs of energy and a strong sense of community/collective action. With most islands having access to great potential of various renewable energy sources, island energy systems and their communities are intrinsically developing emerging decentralized and community-centered energy delivery approaches – contrasting historic centralized top-down energy supply. Hence, the selected subsystems of the energy transition assessed in this report include innovative decentralized energy supply and delivery structures.

The methodological approach can be structured into two parts. In the first part, a tailored SDG-based assessment framework is developed. SDGs relevant to reflect the impact of the energy interventions undertaken during island energy transition, and especially the MAESHA project, as well as suitable metrics are identified. In the second part, the developed assessment framework is systematically applied, using qualitative and/or quantitative data from the demonstration island Mayotte. We compare empirical evidence with community perceptions to further enrich the framework and explore hot-spots and elaborate normative scenarios. The output of the work will include a comprehensive SDG-based assessment of selected project activities and a project tailored framework, which can easily be applied in the follower contexts. The framework and overall approach will be applied in the MAESHA project after demonstration of the various energy interventions.

LIST OF FIGURES

LIST OF ABBREVIATIONS

BES - Battery Energy Storage
CAS - Compressed Air Storage
CEA - Clean Energy Access
CO_2 – Carbon Dioxide
DR - Demand Response
DRE - Distributed Renewable Energy
DSM - Demand-Side Management
EDM - Electricité de Mayotte
EU – European Union
FES - Flywheel Energy Storage
GDP - Gross Domestic Product
GREIN - Global Renewable Energy Island Network
HES - Hydrogen Energy Storage
kWh – Kilowatt Hour
LCA - Life-Cycle Assessment
MDG - Millenium Development Goal
MWp – Megawatt Peak
PHS - Pumped Hydro Storage
PV - Photovoltaic
SCS - Super Capacitors Storage
SDG – Sustainable Development Goal
SEP - SDG Evaluation of Products
SG – Smart Grid
SPC - Sustainable Production and Consumption
TUB – Technical University Berlin
UN - United Nations
USD – US Dollars

1. INTRODUCTION

This report results from the MAESHA project, which aims to decarbonize energy systems of geographical island. The following chapter provides an overview of the MAESHA project (section 1.1) and places the present analysis and report in the project activities (section 1.2).

1.1. ABOUT MAESHA

There are more than 2200 inhabited islands in the European Union, many of which depend on expensive fossil fuel imports for their energy supply. The large-scale deployment of local renewable energy sources and storage systems on these islands would contribute to decarbonizing the energy system. However, this endeavor requires flexible solutions, new tools and efficient frameworks that can be adapted to local needs. The EU-funded MAESHA project develops smart and flexible methods of storage and energy management as well as modelling tools and technical systems with the aim of promoting the transition towards sustainable energy. Designed with respect to the interests of the local communities, adapted to the market and ready to be disseminated, the new approaches serve as a demonstration for the future decarbonization of Mayotte and other European islands.

1.2. SCOPE OF THIS DOCUMENT

Energy is crucial for any kind of economic, social, societal, and finally human development [1]. With increasing knowledge about interlinkages of energy and it´s surroundings, it became evident that energy interventions impact the economic, technical, environmental and social system embedded in [2]. As countries streamline their development efforts under the Sustainable Development Goals (SDGs) agenda, the impact of interventions aiming to provide affordable and clean energy to all people – stipulated in the distinct SDG 7 – on various other dimensions of development reflected under distinct SDGs, has been explored. Evidently, efforts taken under SDG 7, including energy interventions and projects impact other SDGs – and may provoke synergies or trade-offs. With the ambition of the SDGs to cover all dimensions of development, tracing the impact of energy interventions via impacted other SDGs provides a holistic impact assessment. This report develops the foundation how to investigate the holistic impact of energy interventions and related energy subsystems within the energy transition of Mayotte. Based on previous related research, the approach to develop a suitable SDG assessment framework and metrics that enable to assess the sustainability of energy interventions qualitatively and quantitatively is established. The framework will be applied to selected energy interventions in Mayotte, representing interventions relevant for decarbonizing energy systems of islands. With island energy systems and their communities intrinsically developing emerging decentralized and community-centered energy delivery approaches – contrasting historic centralized top-down energy supply – the selected energy interventions shed light on the sustainability of innovative decentralized energy interventions. Further, the results of the assessment will be extended by feeding-in the perceptions of local stakeholders. Hence, the analysis holds the ambition to i) generate a transferable routine for assessing energy interventions using a holistic SDG-based framework and ii) apply the framework to a set of island energy interventions, developing best-practices of transitions, identifying hot-spots of distinct solutions and their perceived value in the community.

2. BACKGROUND AND RELEVANT RESEARCH

The following chapter develops the relevance and rationale for the research conducted in this report. Section 2.1 provides the context of energy transition on islands, with special focus on decentralized energy delivery models and the role of community energy. The section will be used to define relevant energy interventions to be assessed within this task in later stage. Section 2.2 reviews the relationship of energy interventions and other dimensions of development reflected in the SDGs. Section 2.3 briefly introduces the island of Mayotte, which serves as a demonstration for the MAESHA project and the subsequent analysis.

2.1 ENERGY TRANSITION ON ISLANDS AND THE ROLE OF DECENTRALIZATION

The European Union's (EU) pursuit of carbon emission neutrality by 2050 [3] puts European islands and their inhabitants in a unique position during discussions. They are highly vulnerable in terms of accessing affordable energy [4], but are also recognized as favorable hubs for innovation [5] due to their high energy costs and strong sense of community and collective action [6]. Nowhere Is the energy trilemma – formed by security, carbon neutrality and affordability, higher than on energy islands [7]. Geographical isolation, limited space, and lack of fossil resources traditionally force islands to rely on fuel imports for their power supply [8]. This dependence on a few dominant fuel suppliers can lead to a lock-in of low energy market liquidity and carbon-intensive power supply, posing risks to the overall island economy [7]. A comprehensive study involving 44 global islands by Ioannidis et al. highlights the specific vulnerabilities of island energy systems concerning the (1) availability, (2) accessibility, (3) affordability, and (4) acceptability of energy supply [7]. Ironically, despite facing these challenges, most islands possess abundant renewable energy sources, including solar power, hydropower, wind power, and biomass [9]. However, most island systems cannot exploit their renewable energy potential, due to their poor grid infrastructure [8]. Confronted with these factors, many European islands still face challenges in their energy transition efforts, which are more significant compared to their inland counterparts [7].

However, European islands gain increased attention by European funding schemes, research, and energy interventions. Furthermore, the International Renewable Energy Agency (IRENA) has established the Global Renewable Energy Island Network (GREIN) as a platform for exchanging ideas and fostering cooperation in the development of renewable energy projects on islands. Over 60 European islands have signed the "Pact of Islands," committing to achieving sustainability targets set by the European Union (EU) for the year 2020 [9]. Additionally, several islands around the world, including Samsoe in the Baltic Sea, Canary Island in the North Atlantic, Reunion in the Indian Ocean, Hawaiian Island in the Pacific, and Guadeloupe Island in the Caribbean, have successfully implemented extensive renewable energy initiatives. The small energy system scales offer prompt response towards energy interventions, making energy island systems suitable real-world labs for testing technologies. The strong sense of community on islands have shown energy interventions involving the local inhabitants to be more promising compared to the mainland counterpart [6,10]. With increasing research and technology development, the prospects of integrating the vast abundant renewable energies in islands power grids are becoming more promising. According to Kuang et al. [9], strategies to increase the share of renewable energy consumption in islands follow the development of grid-integration technologies ensuring a balance between energy supply and demand required for continuous power supply including storage, smart grid technologies, and demand-side management, hybridization of supply, and decentralized supply and consumption approaches.

- Energy storage: Renewable energy sources exhibit inherent volatility and unpredictability, while island power grids require real-time balancing of supply and demand. To address the stochastic and fluctuating nature of renewable energy generation, energy storage techniques have proven to be effective solutions. Excess renewable energy can be converted into mechanical, electromagnetic, or chemical energy through various energy storage systems. These stored energy reserves can be tapped into during periods of insufficient electricity generation from renewable sources, providing essential buffering capacity to accommodate output variations. A variety of energy storage technologies have been demonstrated on islands, including Pumped Hydro Storage (PHS), Battery Energy Storage (BES), Compressed Air Storage (CAS), Flywheel Energy Storage (FES), Hydrogen Energy Storage (HES), Super Capacitors Storage (SCS), and more. Among these, BES stands out as one of the most popular and widely adopted energy storage methods in the market. The main types of BES include lead-acid batteries, lithium-ion batteries, vanadium redox batteries, nickel-cadmium batteries, and sodium-sulfur batteries. As a special case of battery storage, utilizing electric vehicles to buffer surplus electricity and feeding back into the grid via bilateral charging is becoming increasingly relevant in urban areas.

- Smart Grid technologies: The emergence of smart grids has revolutionized the balance between electricity supply and demand, thanks to advanced information and communications technology. With the help of sophisticated metering technology, real-time information on renewable energy generation can be relayed to customers, and their electricity demands can be communicated back to the renewable generation units, creating a bidirectional flow of communication. As a result, renewable energy generation can be automatically adjusted to match electricity demand efficiently, achieving operational objectives with minimal environmental impact while maximizing system reliability and stability. The implementation of smart grids is a crucial strategy for many islands seeking to develop renewable energy sources.
- Demand-side management and demand response: In islands, electricity generation primarily caters to commercial and residential needs. With the advancement of communication and information infrastructures, responsive demand-side management (DSM) can be employed to synchronize residential energy consumption with the varying power generation from renewable sources. DSM involves coordinating power supply and demand through end-user appliance management. Early DSM schemes, developed in the 1970s to address peak and load shedding for reducing peak capacity requirements, were relatively low in automation. However, the latest programs of the third generation leverage the capabilities of Smart Grids (SGs), incorporating two-way communications and intelligent load management. This enables the exchange of real-time grid status and market signals with end-users, leading to more efficient management [11]. Such programs, focusing on short-term effects with timescales close to power and load reduction delivery, are commonly known as demand response (DR) schemes [11]. For a comprehensive overview of different DR schemes, you may refer to Albadi and El-Saadany [12].
- Hybridization of supply: Renewable energy sources, such as solar, wind, geothermal, and hydropower, possess inherent seasonality, variability, periodicity, and other characteristics that make it challenging to always provide a continuous and stable power supply [9]. To address this issue, hybrid energy systems combine multiple renewable energy generation sources, thereby reducing the likelihood of all available resources being unavailable at a specific point in time. Hybrid systems offer various configurations, such as wind/photovoltaic (PV), PV/biomass, wind/hydropower, wind/PV/biomass, and others.
- Decentralized supply and consumption: decentralized energy generation utilizes dispersed available energy sources for electricity generation that can be directly connected to the distribution network or feed the local customer. This approach offers several advantages over conventional centralized generation patterns, see [13]. Hence, distributed generation can reduce transmission losses and costs, simplify transmission and distribution configurations, and decrease transmission congestion. With a flexible sizing of distributed generation, ranging from a few kilowatts to hundreds of megawatts, it is well-suited for islands with isolated locations and smaller populations. As a specific case, a microgrid is a small-scale localized energy system that includes various distributed generators, energy storage devices, and local loads [14]. Microgrids can operate both in islanded mode and grid-connected mode, and the distributed renewable generators can be installed at various locations within the microgrid. With coordinated control, microgrids can partially dispatch the variability and intermittency of renewable energy. Yet again differing from decentralized energy systems, distributed energy systems are small-scale energy generation units (structure), at or near the point of use, where the users are the producers whether individuals, small businesses and/or local communities [15]. For a graphical illustration comparing structure and system configuration of distributed and decentralized energy systems according to Vezzoli et al. [15] , see Figure 1

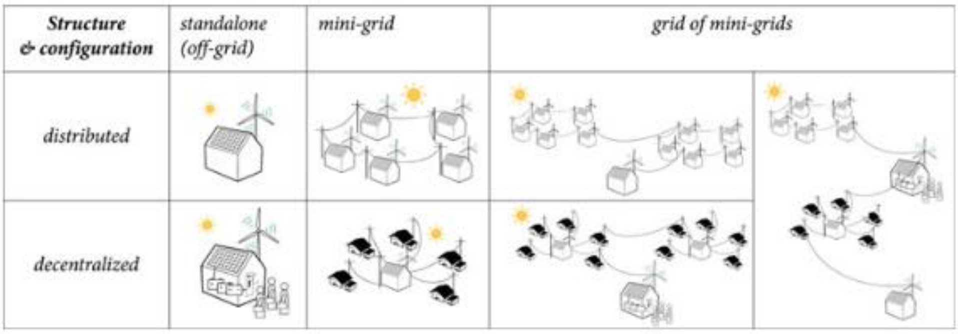


Figure 1: Distributed/decentralised energy. System structure and configurations. Reprinted from [15].

Distributed and decentralized renewable energy supply is thought to have various advantages against centralized approaches. Centralized energy systems, historically relying on fossil fuels, i.e., coal and diesel power plants, are environmentally unsustainable, leading to rapid resource depletion. Additionally, these energy sources contribute to high greenhouse gas emissions (CO_2 emissions) throughout their life cycle, exacerbating global warming. Furthermore, the extraction and transportation processes of these exhaustible resources result in various pollution problems. In contrast, renewable and distributed resources, such as small-scale solar or wind generation units, offer greater environmental sustainability by utilizing locally available and renewable energy sources. This leads to reduced environmental impact compared to the extraction, transformation, and distribution processes involved in using fossil fuels. Moreover, renewable resources exhibit much lower greenhouse gas emissions during their utilization. Additionally, decentralized energy production and distribution, in comparison to centralized systems, require less distribution infrastructure, and reduce distribution losses [15]. From a rudimentary technical perspective, decentralized and distributed energy systems offer greater reliability and resilience than centralized schemes. The distributed nature enables to serve energy loads via multiple energy supply options – hence, a fault may be coped with switching the supply unit. From a socio-economic perspective, decentralized and distributed energy systems offer wider possibilities to equally distribute wealth. Small energy generation units can be managed by small economic entities, allowing users to become 'prosumers' (producers + consumers). These generation units can be interconnected within a micro energy network, which may be linked to a larger global network. In this context, Distributed Renewable Energy (DRE) systems have the potential to democratize energy access, thereby promoting a reduction in inequality, enhancing community self-sufficiency, and enabling self-governance. Quoting Vezzoli et al. [15], it “is clear […] that only those who have the control of the energy system have the possibility to increase their development.” [p. 4]

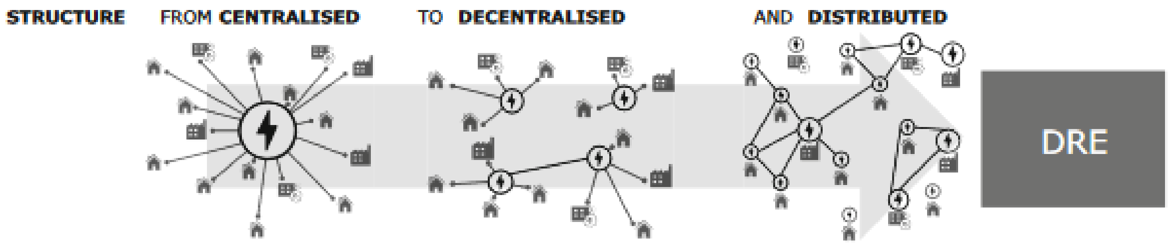


Figure 2: Paradigm shift from non-renewable/centralised energy generation systems to renewable/ distributed ones. DRE = Distributed Renewable Energy. Reprinted from [15].

The potential participation in energy production, distribution, and managed consumption lifts communities into an empowered role of becoming active players within the energy landscape. With increasing decentralization of the energy system, the role of households and local communities is changing from passive consumers to active prosumers [16]. As an essential socio-economic phenomenon, consumers have self-organized and co-operated to form a community energy system. In 2017, more than 2800 such initiatives in the form of energy co-operatives have established in Europe alone [17] (for a detailed overview of Local Energy Communities (LECs) and their implementation in the MAESHA project, we refer to Deliverable 3.2). Because of the deep embeddedness in the local community, thereby awareness of the local needs, and proximity to the local users, the activities undertaken by energy communities and cooperatives in decentralized energy systems – including generation, supply, consumption and sharing, energy services, distribution, electro-mobility [18] – may have additional impact on local development, compared to top-down centralized energy interventions.

In line with this argument, the literature recognizes the role of LECs in promoting social innovation and local development [19]. Otamendi-Irizar et al. [20] further investigate the potential of LECs to contribute to (local) sustainable development, examining their organizational structure, aims, scope, and determinants of successful impact. Assessing 16 LEC projects from eight European countries, they find positive impacts for most SDGs, pointing to strong sustainability outcomes beyond SDG 7 alone. Arguably, LEC’s contribution to the SDGs may be even stronger in contexts beyond the European mainland, for example where poverty and resource scarcity pose additional challenges.

2.2 ENERGY AND THE SUSTAINABLE DEVELOPMENT GOALS

As a successor to the Millenium Development Goals (MDGs), the United Nations (UN) stipulated the SDGs as a part of the UNs 2030 Agenda for Sustainable Development. The SDGs aim to streamline efforts in sustainable development, broadly defined and all-encompassing, in international and the UN partner´s national policies and ambitions. Organized in a Goal > Target > Indicator hierarchy, the SDGs comprise 17 goals and 169 targets, and aim at tackling multiple and complex challenges faced by humankind. As one essential distinct SDG, ensuring ‘access to affordable, reliable, sustainable and modern energy for all’, SDG 7 is dedicated to streamline efforts in global energy related interventions. Targets within SDG 7 are:

- 7.1: By 2030, ensure universal access to affordable, reliable, and modern energy services
- 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix
- 7.3: By 2030, double the global rate of improvement in energy efficiency

Figure 3: The 17 Sustainable Development Goals.

With the complexity of all SDGs (listed in Figure 3), it is obvious that the distinct SDGs are implicitly interdependent. In fact, governments throughout the world have already declared the 17 SDGs and their 169 targets to be “integrated and indivisible” [21]. Energy, being “at the heart of most critical economic, environmental and developmental issues facing the world today” [22] certainly stands out as a prominent SDG being mutually interlinked with many other SDGs reflecting fields of development.

The interconnections among the Sustainable Development Goals (SDGs) have been thoroughly reviewed in the preparation of this manuscript to identify those SDGs that, due to their relevance to energy, are considered in the proposed framework for assessing energy interventions and energy subsystems in energy transitions. The review is based on previous work conducted by TUB, as documented in a scientific publication [23].

In 2015, Le Blanc [24] applied network analysis techniques to map the links between different SDGs, aiming to facilitate deeper integration of policies across various thematic areas of sustainable development. The paper primarily focused on a qualitative assessment at the policy level, based on the interpretation of wording, rather than examining individual "biophysical, social and economic systems" [24]. While Le Blanc's mapping identified relatively few interlinkages for SDG 7, it highlighted that the core thematic areas with the most interlinkages included inequality, sustainable production and consumption (SPC), poverty, hunger, and education. Moreover, the interconnection between energy and industrialization was identified as one of several gaps not fully covered by the SDGs [24].

Nilsson et al. [25] further developed the concept of synergies and trade-offs between SDGs, building on Le Blanc's work [24]. They contributed a detailed framework describing various types of interactions between the goals. To enable prioritization of policy options based on up-to-date empirical evidence, the authors presented a scoring system to assess the interdependency between two specific SDGs, ranging from -3 for a strong negative relationship to +3 indicating the strongest synergy. Besides the strength of the interaction, three additional criteria were suggested for assessment: whether the impact is reversible or irreversible, whether it is unidirectional or bidirectional, and the level of certainty based on available evidence. Unlike the previous work, Nilsson et al. [25] analyzed interlinkages at the goal level and did not delve into corresponding targets. They emphasized the importance of the local context, available technologies, and time and space aspects. They encouraged attention to specific local root causes and warned against abstract generalizations [25].

More recently, specific correlations between SDG 7 (Clean Energy for All) and the remaining 16 SDGs have piqued the interest of the scientific community, leading to the following research articles. Fuso-Nerini et al. [26] identified and examined the links between energy and other SDGs that could be addressed by changes in the energy system topology. Their research extended beyond the initial provision of energy (Target 7.1) to encompass all energy-related aspects and impacts, considering the point when energy is converted into energy services. Unlike the previous two articles, this analysis dealt with a detailed SDG target level, using qualitative evidence obtained from experts in relevant thematic fields and referring to previous studies. The interlinkages were described using a plain synergy-trade-off classification. Similar to Nilsson et al. [25], the authors emphasized the manifold and highly context-specific nature of interdependencies on the level of individual SDG targets [26].

The most comprehensive study on the interlinkages between SDG 7 and other SDGs was conducted by McCollum et al. [27]. In 2017, the authors reported on a large-scale assessment of relevant energy literature to identify interactions of SDG 7 with other SDGs, considering governance, time, geography, technology, and directionality as context-dependencies. They evaluated the nature and strength of identified interactions and the robustness of the literature evidence. The study built upon the scoring framework by Nilsson et al. [25] and the general description of interdependencies among goals provided by Nerini et al. [26]. The interdependencies with SDG 7 were calibrated on the level of individual SDG targets or groups of two or more closely related targets. Based on evidence from literature and expert inputs, the authors make a first approach to i) test the robustness of interlinkages and ii) quantifying the scale of interlinkages: +3 (indivisible), over 0 (consistent), to -3 (cancelling). Figure 4 shows the nature of the interactions between SDG7 (Energy) and the non-energy SDGs. The relationships may be either positive (left panel) or negative (right panel) to differing degrees, indicated by distance to the center.

Figure 4: nature of the interactions between SDG7 (Energy) and the non-energy SDGs according to McCollum et al [27].

Notably, the authors found that positive interactions, including indivisible, reinforcing, or enabling aspects, outweighed negative interactions (constraining, counteracting, or cancelling) in both number and magnitude, among all SDGs (except SDG 17 "means of implementation," which was not considered) [27]. The strongest reinforcing interrelation of SDG 7 to other SDGs is in sustainable cities and communities. Here, energy ensures access to basic housing services (implies that households have access to modern energy forms), facilitates efficient, renewable-based transportation, urban infrastructure solutions, reducing noise. Other strong reinforcing impacts exist amongst others to reducing poverty, hunger, promoting well-being, facilitating clean water and sanitation access, promotion of peace and climate action. In contrast, the highest counteracting impact of SDG 7 to other SDGs can be identified when the energy production and delivery competes with other resources. For example, large-scale bioenergy and food production may compete for scarce land and other inputs (e.g., water, fertilizers), depending on how and where biomass supplies are grown and the indirect land use change impacts that result. However, in any of the potential interlinkages McCollum et al. highlight that both the direction of interlinkage, and strength is highly contextual.

In 2017, Pradhan et al. [28] quantified the interactions of the SDGs, both in the direction of positive correlations (synergies) and negative correlations (trade-offs). They adopted a novel approach, considering statistical correlations at the most detailed level of the SDGs, using actual data collected from 227 countries for the SDG indicators used to track progress in respective targets. For SDG 7, the authors found a surprisingly balanced ratio of positive and negative correlations with 14 other SDGs, see the reprinted Figure 5. They also demonstrated that even the indicators within SDG 7 can correlate negatively in certain geographical contexts [28]. For example, "proportion of population with access to electricity,", an SDG 7 indicator, has increased in some countries by expansion of nonrenewable energy sources, which jeopardizes progress in the SDG 7.2 indicator ""renewable energy share in the total final energy consumption".

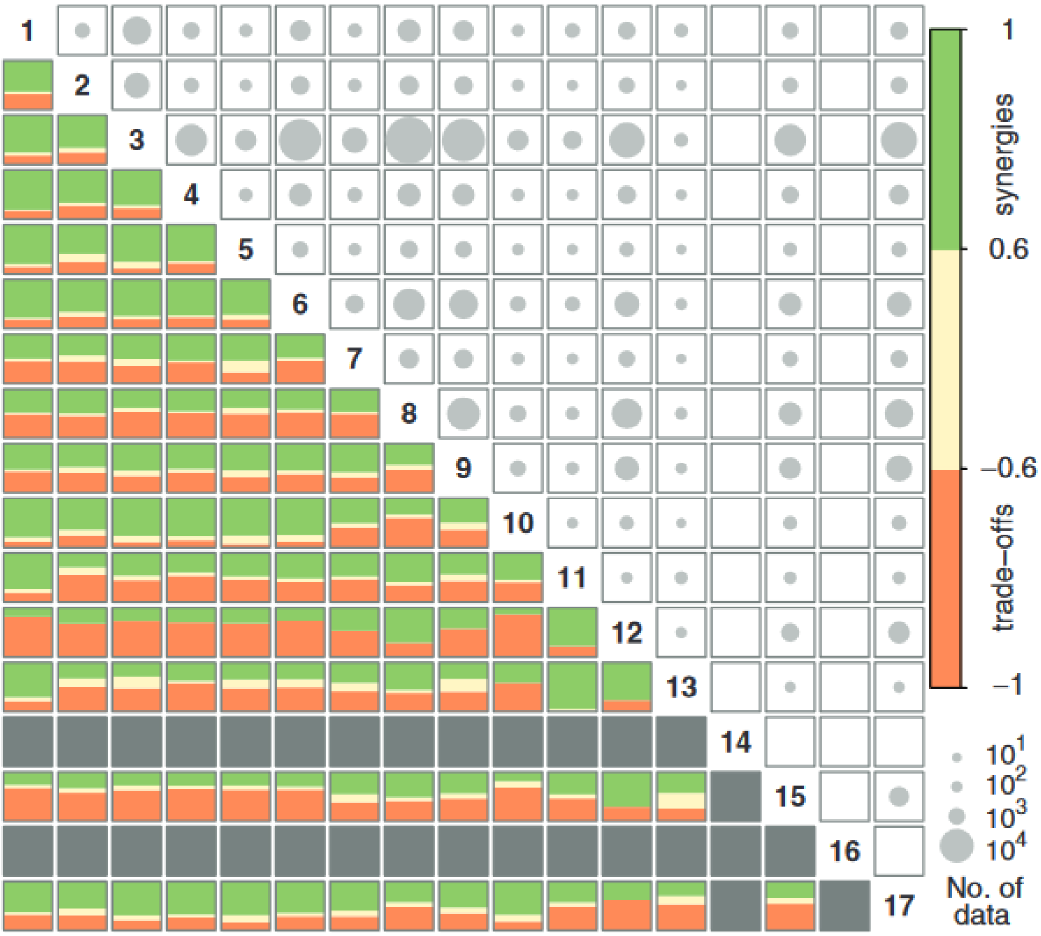


Figure 5: Observed synergies and trade-offs between the SDGs, reprinted from Pradhan et al. [28]. The color bars represent the shares of synergies (green), non-classifieds (yellow), and trade-offs (orange) observed between the SDG pairs for the entire dataset. The grey bar depicts insufficient data. The area of the circle in the boxes indicates the number of data pairs (see the legend for comparison). The SDGs are represented by the numbers in the diagonal.

Interestingly, the empirical evidence of Pradhan conflicts with assumptions of previous, theoretical literature. While theoretical literature suggested SDG 7 to be amongst the SDG with most interlinkages to other SDGs, the analysis of Pradhan et al. shows SDG 7 to not be included amongst the top 10 synergy or trade-off pairs [28]. The reasons behind this mismatch may be rooted in the i) complexity of energy interventions and ii) missing direct link of energy contributing to a specific SDG, but rather being rooted at the starting point of a causal chain.

Subsequently, Schöne et al. [23] attempted to use the SDGs to bridge from a macro-level to a micro-level. The authors tested the applicability of the SDG indicators as a basis for an impact assessment of access-to-energy projects. Based on the SMART framework for indicators, the authors tested the SDG indicators for their attributes – Specific, Measurable, Achievable, Relevant and Time-bound – to be directly applicable to assess access-to-energy projects. Hence, the study differs from the previous literature in not aiming to identify potential interlinkages, but questioning the appropriateness of the SDG framework to measure impact in case that interlinkages exist, on the level of the energy intervention. In total, the authors find 58 indicators to be directly applicable to assess the impact of access to energy interventions, i.e., in education, economic growth, and hunger eradication, see Figure 6.

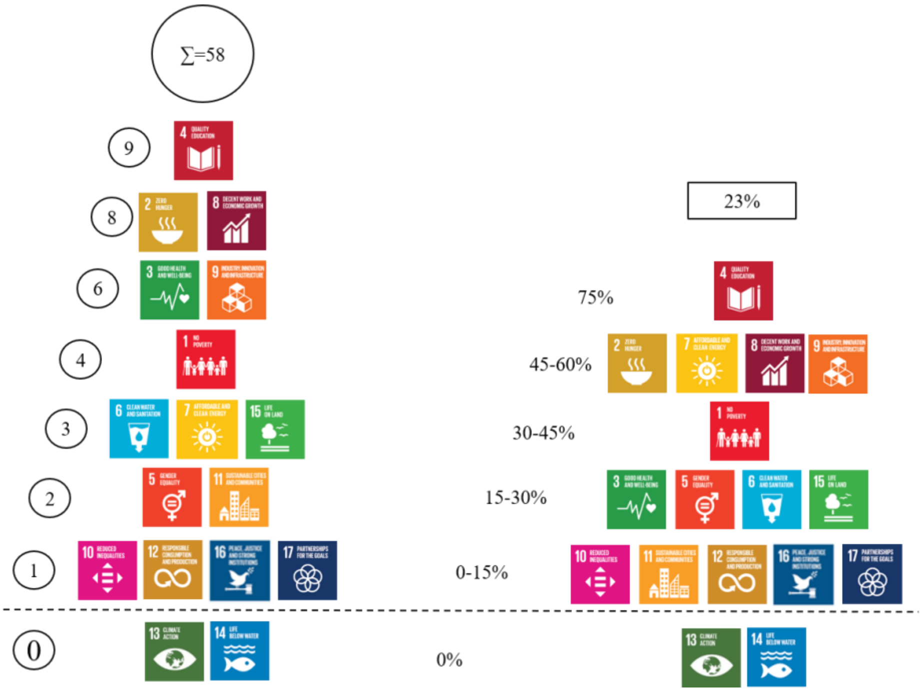


Figure 6: Number of relevant indicators along the SDGs (left) and share of respective eligible indicators within the certain SDGs (right). Reprinted from [23].

Additionally, the authors provide positive examples on how energy can stimulate development in other SDGs on a micro-level. However, the review points out that the potential impact substantially depends on the local context and project characteristics. In fact, observing the impact of energy on other fields of development on a micro-level adds a critical note to macro-level studies that suggest that energy provision inevitably leads to development because it *can.* To cite Kooijman van Dike "it is at micro level that a more critical note is added. Here, studying the actual lived changes of people in interaction with energy, a consensus exists, that energy can, in best case improve opportunities for development" [29].

Most recently (2023), a novel interesting approach investigating interrelations between SDG 7 and other SDGs was taken by Casati et al. [30]. Instead of attempting to test for evidential changes SDG 7 caused in other SDGs, the authors assessed the perceived relations within the society. tested stakeholders' perceptions, i.e., the private sector, public institutions, and civil society organizations, through a structured survey, about the interconnections between access to clean electricity and selected social-related SDGs. A strong positive impact was perceived, especially for SDG 3, SDG 8, SDG 6 (Clean water and sanitation), SDG 4, SDG 1 (top five in descending order). Figure 7 illustrates the stakeholders' perception of synergies between access to clean electricity and other SDGs.

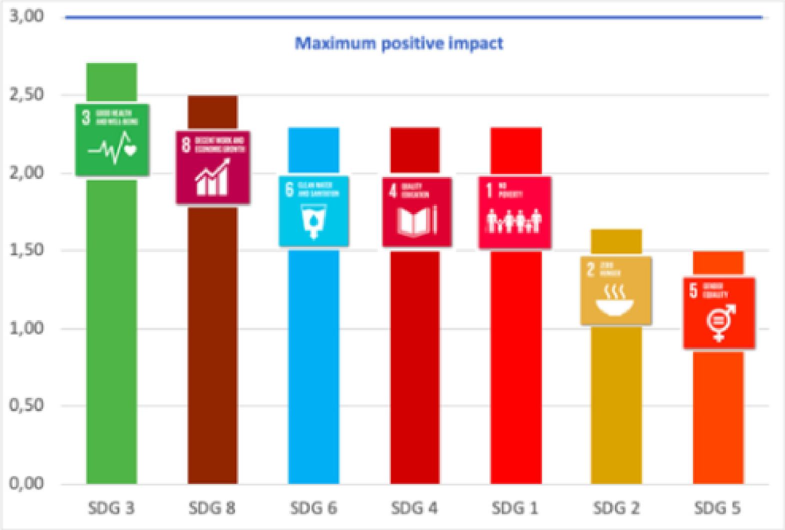
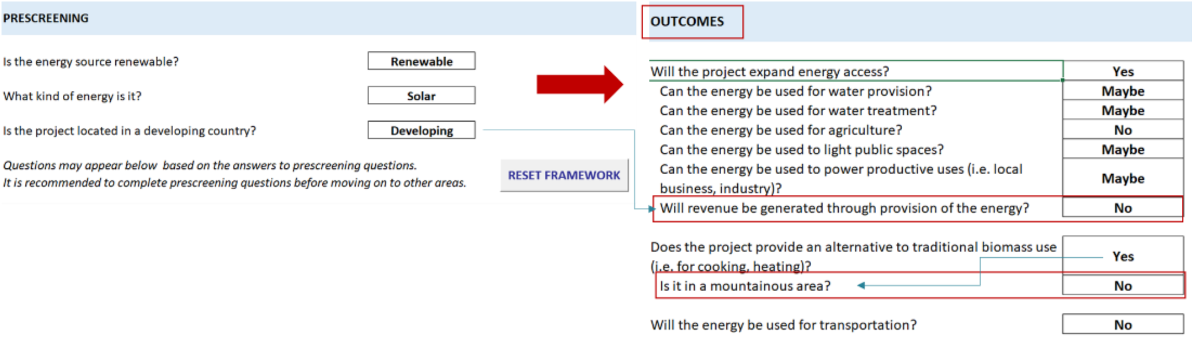


Figure 7: Stakeholder's perception of synergies between access to clean electricity and other SDGs. Reprinted from [30].

Finally, the authors develop a composite Social Clean Energy Access (Social CEA) Index, capturing the status of social factors on health, education, economic development, gender equality, and quality of life related to electricity access.

With increasing recognition and popularity of the SDGs, some scientists and practitioners aimed to develop tools that rely on the SDGs to investigate a specific project´s impact. For example, with a similar motivation to Schöne et al. [23], Castor et al. [31] aimed to assess energy interventions and projects by directly using the SDGs. Based on the investigations by Fuso-Nerini et al. [26], who investigated (a) if an interaction between an SDG target and any type of energy project exists, (b) if this interaction consists of synergies, trade-offs, or both, and (c) how this interaction can be influenced by the context of the energy project, the authors developed a series of 'yes' or 'no' questions reflecting targets (notably not indicators) of the SDGs and supporting in determining the nature of an interaction between an energy project and the SDG targets. Following the 'yes' or 'no' questions finally evolved in a decision tree with organized questions, follow-ups, and outcomes. As a final output, the authors developed an Excel-based "Sustainable Development Goals Impact Assessment Framework for Energy Projects" (SDGs-IAE) tool, which includes the decision tree and thereby allows for a qualitative assessment of SDG target synergies and trade-offs within the context of a given energy project (see Figure 8 for a visual representation of the assessment procedure in the Excel tool).



PRESCREENING

Is the energy source renewable?	Renewable
What kind of energy is it?	Solar
Is the project located in a developing country?	Developing

Questions may appear below based on the answers to prescreening questions.
It is recommended to complete prescreening questions before moving on to other areas.

OUTCOMES

Will the project expand energy access?	Yes
Can the energy be used for water provision?	Maybe
Can the energy be used for water treatment?	Maybe
Can the energy be used for agriculture?	No
Can the energy be used to light public spaces?	Maybe
Can the energy be used to power productive uses (i.e. local business, industry)?	Maybe
Will revenue be generated through provision of the energy?	No
Does the project provide an alternative to traditional biomass use (i.e. for cooking, heating)?	Yes
Is it in a mountainous area?	No
Will the energy be used for transportation?	No

Figure 8: Visual representation of the assessment procedure using the Excel interface of the SDGs-IAE tool developed by [31].

The framework utilizes guiding questions in the categories prescreening, governance, project, outcomes and action, with customized follow-up questions and categories according to the provided answers (for example, the questionnaire differs according to the project being implemented in a "developed" or "developing" country). In total, the tool includes a maximum of 94 questions for energy project developers and decision-makers to answer for a given project. The Excel-based tool is publicly available and has been successfully applied to energy projects before, including for large hydropower projects and nuclear power plants [31], biomass/biofuels and waste to energy [32]. Also, other authors have suggested the integration of additional dimensions in the tool [32]. Overall, SDG-IAE provides a useful approach for assessing the SDG impacts of energy-related projects.

In a similar approach, an SDG impact assessment tool has been developed by a cluster of researchers and practitioners around the University of Gothenburg to visualize the results from a self-assessment of how an activity, organization, or innovation affects the SDGs [33]. Primary aim of the tool is the usage in planning of any – not necessarily energy-specific – intervention rather than assessing retrospectively. Hence, the tool guides the user through the distinct SDGs by asking the user to indicate if the assessment object (innovation, research activity, organization, project, and other initiative) has an impact on each of the 17 SDGs as either direct positive, indirect positive, no impact, indirect negative, direct negative, or more knowledge. The tool is suitable when collaboratively planning interventions ahead and supports in self-defining strategies how to move forward (see example of the assessment process in Figure 9).

MAESHA LEC Test Assessment

Perform the impact assessment by clicking on any SDG

INTRODUCTION

Renewable energy solutions are becoming cheaper, more reliable and more efficient every day. Our current reliance on fossil fuels is unsustainable and harmful to the planet, which is why we have to change the way we produce and consume energy. Implementing these new energy solutions as fast as possible is essential to counter climate change, one of the biggest threats to our own survival.

TARGETS

For a complete description of the targets, please visit https://sustainabledevelopment.un.org/sdg7

Universal access to modern energy
By 2030, ensure universal access to affordable, reliable and modern energy services.

Increase global percentage of renewable energy
By 2030, increase substantially the share of renewable energy in the global energy mix.

Double the improvement in energy efficiency
By 2030, double the global rate of improvement in energy efficiency.

Promote access to research, technology and investments in clean energy
By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

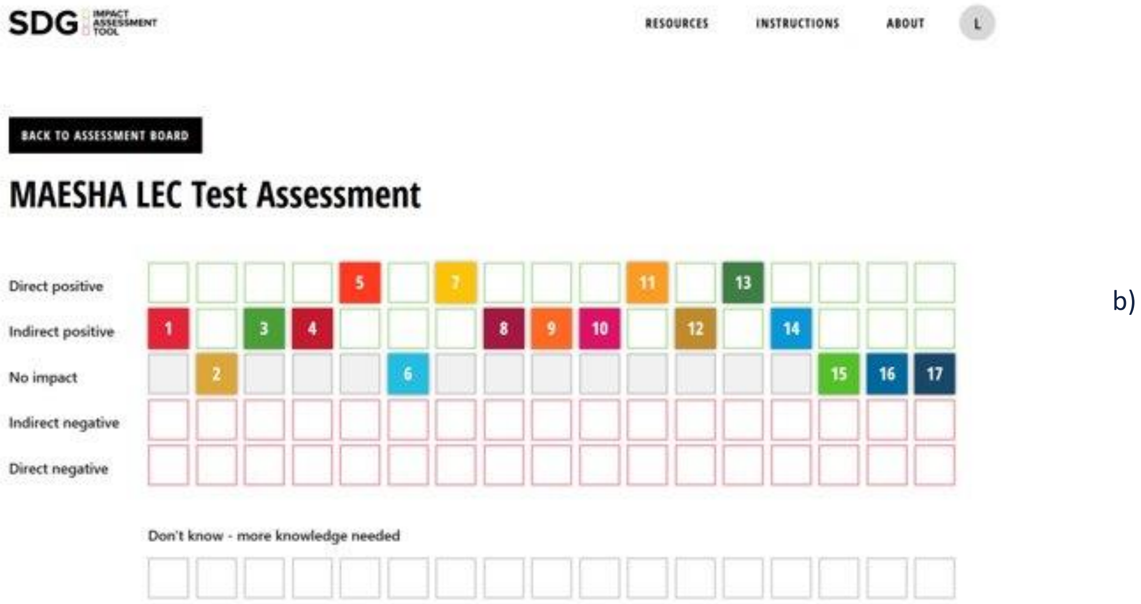
Expand and upgrade energy services for developing countries
By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support.

How does your case impact SDG 7?

Motivate why

deployment of solar PV/RE, access to energy

a)



MAESHA LEC Test Assessment

Direct positive					5		7				11		13				
Indirect positive	1		3	4				8	9	10		12		14			
No impact		2				6									15	16	17
Indirect negative																	
Direct negative																	
Don't know - more knowledge needed																	

Figure 9: Example of the SDG-IAT a) assessment process and b)depiction of results (example) developed by [33].

A group of researchers around the Centre for Sustainable Leadership at the University of Witten/ Herdecke (ZNU) and Öko-Institut e.V. developed SDG Evaluation of Products (SEP), a life-cycle assessment (LCA) based tool for the assessment of the SDG impact of products and services [34]. The authors identify 61 of 169 SDG targets from all 17 goals as being product-related, and compile indicators for the quantification of impacts. These indicators comprise of (adapted) indicators from the Global Indicator Framework, and additional indicators from other frameworks and sources. The resulting tool is compatible with ISO 14040/44 for LCAs and reports a total of 45 SDG-related indicators (22 mandatory, 23 complementary). While SEP does not focus on energy projects specifically, it provides a valuable attempt of linking methodologies and further developing existing assessment approaches.

As outlined in this section, multiple interactions exist between energy, (partially) captured in SDG 7, and the other 16 SDGs. Several frameworks for the assessment of SDG impacts and their interlinkages have been developed over time, each with a different scope and approach, resulting in distinct strengths and shortcomings of each tool. For the purposes of the analysis in the MAESHA projects, these tools will be further reviewed and combined, adapted or altered to best fit the purposes of the study.

2.3 CASE STUDY OF MAYOTTE

Mayotte, a French overseas department situated in the Indian Ocean between Madagascar and the coast of Mozambique, comprises two inhabited islands, Grande Terre and Petite Terre. Officially, the population of Mayotte is recorded at 300,000 people, but an additional 200,000 individuals are estimated to live on the island without official registration. Within the registered population, the unemployment rate stands at 35%, in stark contrast to the approximately 9% average in France during the same period. Astonishingly, 70–84% of the people live below the poverty line, and the overall gross domestic product (GDP) per capita is USD 13,000, which is half that of the neighboring island of La Réunion. The island's young population—where roughly half is under 18 years old—faces significant economic challenges in the near future.

Despite these challenges, Mayotte's geographical location offers great potential for renewable energies, especially solar photovoltaic (PV) with a high global horizontal irradiation of 1850 kWh/m2 [35]. While land availability poses constraints on wind energy, offshore wind and ocean energy remain as realistic exploitable resources. However, the current electricity production relies heavily on diesel generators, with 95% supplied by two power plants (Longoni and Badamiers), both owned by Electricité de Mayotte (EDM), the vertically operating supply and distribution company. A mere 5% of electricity supply comes from PV plants (23 MWp with a 4% annual growth rate). Unfortunately, Mayotte's power grid does not yet conform to European standards, offering low redundancy and limited visibility on grid status, leading to frequent supply interruptions in various feeder sections. In 2020, the local grid operator reported a total of 1943 minutes of "criterion B" interruptions, defined as interruptions lasting longer than three minutes in medium voltage for any reason, including maintenance.

As envisioned in the Progammation Pluriannuelle de l'Energie, which outlines Mayotte's medium- and long-term energy strategy, large-scale integration of renewable energies faces significant challenges. To address the volatile nature of renewable energies and reduce bottlenecks, flexibility services are crucial for the island's future energy system development. The MAESHA project aims to establish a flexibility management trading platform capable of coordinating various flexibility services within a market scheme. These flexibility services differ in their nature, and include newly developed storage assets, as well as organizing existing infrastructures to offer flexibility, i.e., via residential and industrial demand response.

3. APPROACH AND METHODOLOGY

This section outlines the methodology of developing and applying the SDG assessment in the MAESHA project. To do so, we first reflect on the previous related research reviewed in section 2.2, establishing the status quo and shortcomings. This allows us to subsequently establish the ambition of the approach taken in the project.

We conclude on the review of research that has been conducted to analyze the potential interlinkages of energy interventions and other SDGs, and additional outputs, i.e., free available tools:

- SDG 7 (clean and affordable energy) is interlinked with many other SDGs. The interlinkages include both synergies and trade-offs, depending on the specific context. On a micro-level, considering the specific context, evidence on the impact of SDG 7 on other SDGs is scarce. Essentially, the causalities – hence, success factors or threats – between energy interventions and their impact on other SDGs is not well understood.
- The impact of energy interventions on SDGs have predominantly been assessed qualitatively on a goal or target level. However, some approaches show a) quantitative correlations or b) propose using some quantitative indicators of the SDGs directly.
- As an extension to objective observations of the impact of energy interventions, an attempt has been made to assess the perceptions of the population affected by the intervention towards its effect on certain fields of development captured by the SDGs.

Hence, as a useful contribution advancing the status-quo in SDG impact assessments, our analysis holds the ambition to

i) Study the impact of energy interventions – understood as activities, energy systems or subsystems, or other initiatives – on other SDGs on the most suitable local level.
ii) Include both qualitative and quantitative results, while both are linked in a meaningful way providing either explanations or useful additional explorations.
iii) Include the local community as feedback for calibrating and extending the assessment framework.
iv) Study islands and their communities as a hub for energy transition innovation.

To reach this ambition, our work follows the workflow and approach drafted in Figure 10.

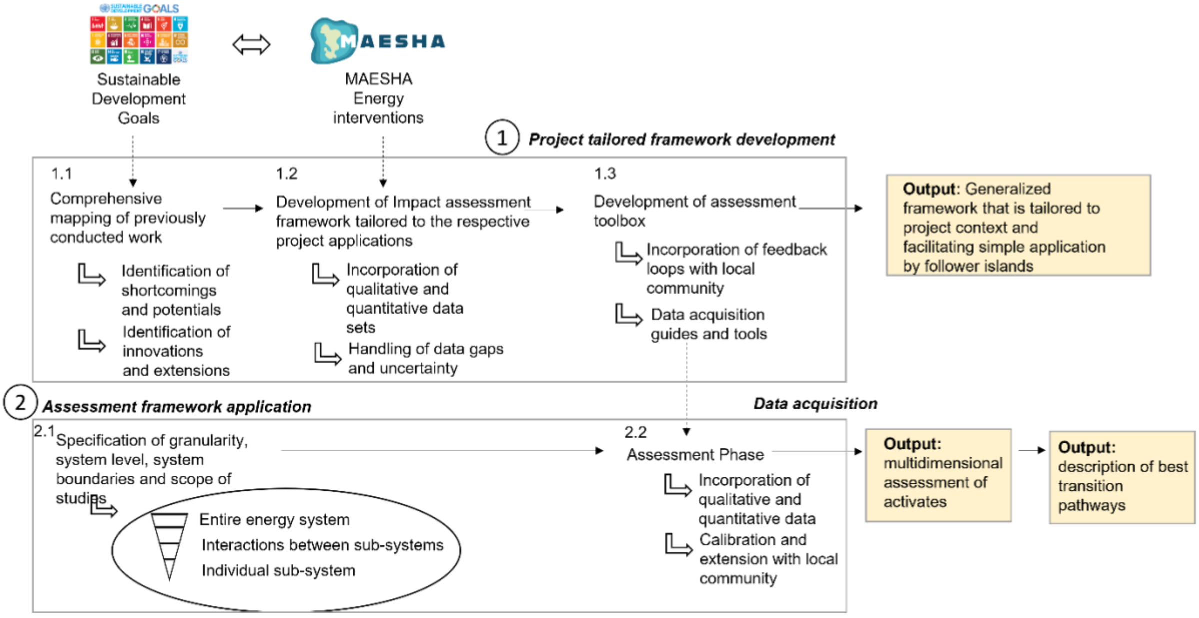


Figure 10: Overall approach including the development and tailoring an assessment framework, its application and the activities' outputs.

The proposed workflow will be conducted based on the project's progress regarding the implementation of LECs and selected technical solutions. Relevant energy interventions will be defined based on the status of the solutions deployed in the project, including the LEC formation. To maximize the task´s efficiency, the developments in respective tasks and interaction with local stakeholder will closely be followed to iteratively organize the data mapping.

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