On behalf of:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

Implemented by

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

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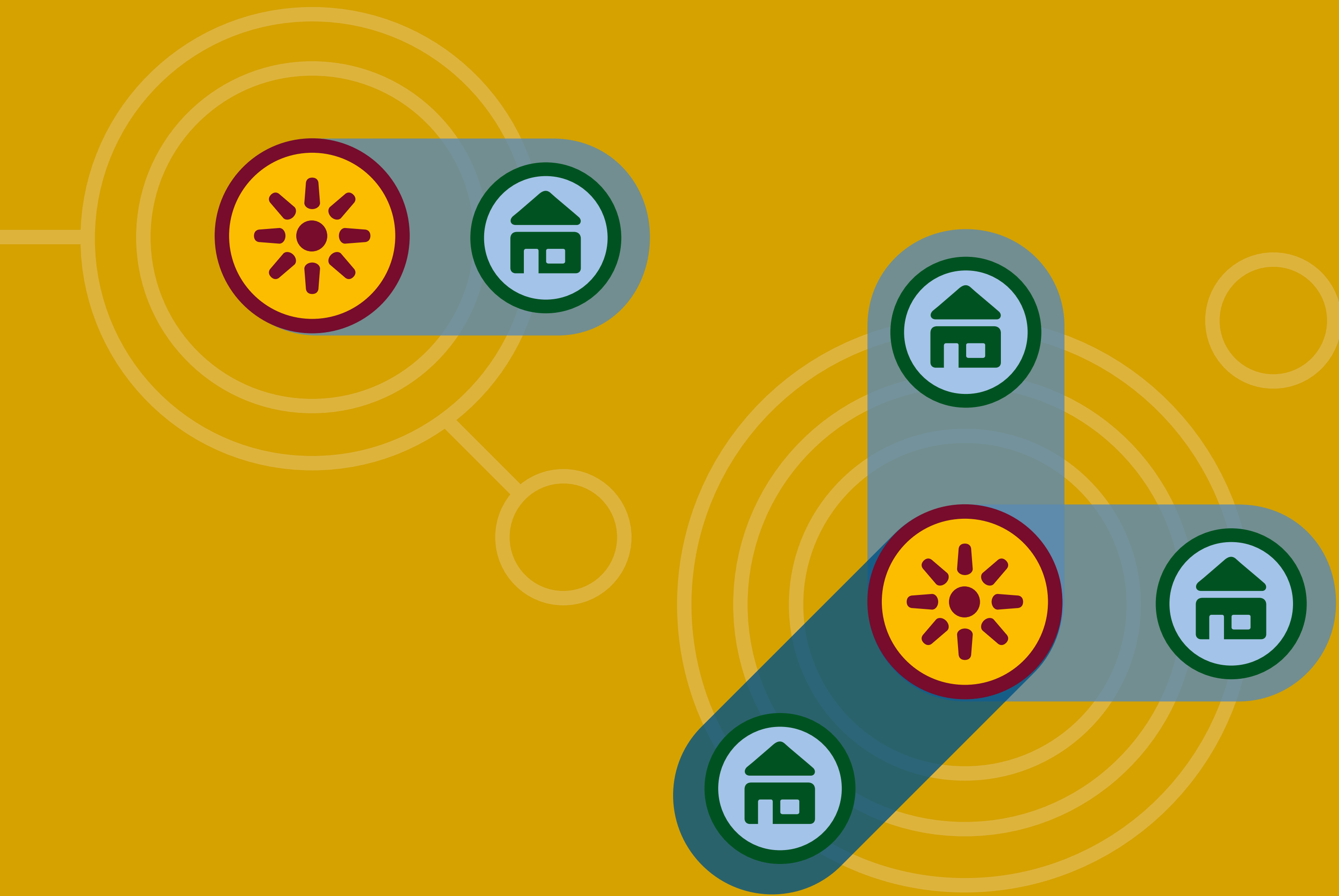
better climate

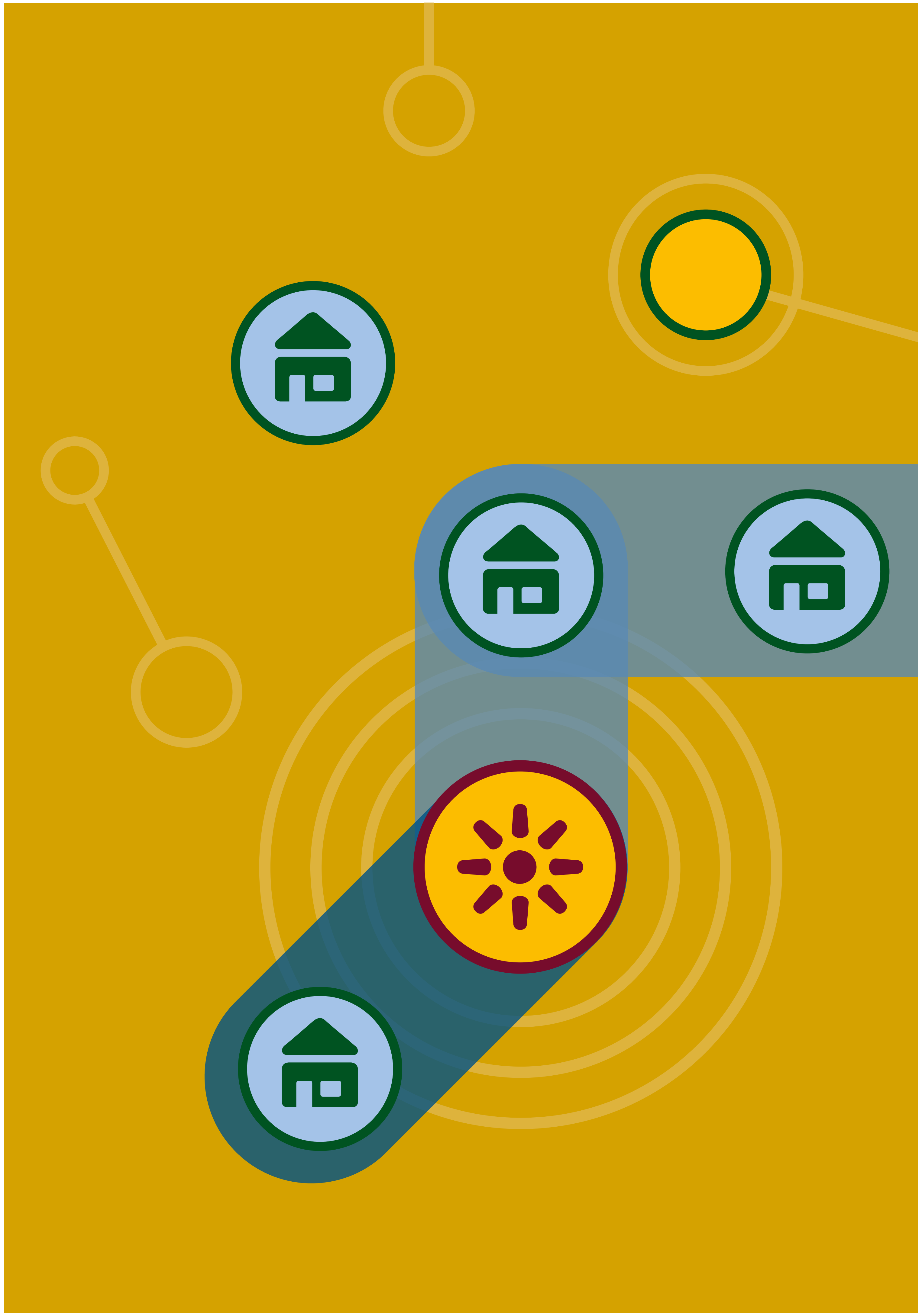
REINER LEMOINE INSTITUT

*cheaper – cleaner – smarter*

# Off-Grid Renewable Energy for Climate Action

*Pathways for change*





# Content


Foreword 5

Executive Summary 7

## Challenges

Electricity Access, Off-Grid Systems, and Climate Action 11

How to achieve SDG7: Global Electrification Scenarios 17

## Cheaper, Cleaner, Smarter

Cheaper – Off-Grid reduces Investment Needs 25

Cleaner – Off-Grid reduces GHG Emissions 33

Smarter – Off-Grid Electrification Benefits 39

## Solutions

Key Barriers and Solutions for Off-Grid Electrification 47

Implementing Solutions – International Support and the Role of NDCs 53

Conclusion and Recommendations 59

## References and Methodology

References 63

Methodology for scenario development and electrification solutions 67

Methodology for demand estimation 71

Methodology for assessment of investment needs 72

Methodology for estimation of the GHG reduction potential 72

# Foreword

We agreed in Paris to limit the global temperature increase to well below 2 °C, if possible to 1.5 °C, compared to pre-industrial levels. However, the IPCC has provided solid scientific evidence that more ambition is necessary in order to reach this goal. We need a continuous reinforcement of climate action worldwide. The measures taken to combat climate change will not be the same for everyone. On the contrary, it is our collective duty to find adequate solutions for the individual context of each country.

The decarbonization of our energy systems is central to this endeavour. This is true for Germany as well as for a whole range of other countries. For many of them, however, the prospect of a comprehensive energy transition goes far beyond the substitution of fossil fuel-based generation. Almost 1 billion people worldwide still have no access to modern forms of energy or centralized electricity grids in 2019. In those circumstances, decentralized off-grid renewable energy solutions can constitute an important part of the solution. They represent a paradigm shift as they can establish access to clean energy in remote settings and empower those that have so far been left behind. This is true for cost-effective stand-alone systems as well as for clean mini-grids.

The climate relevance of these innovative decentralized electrification approaches is tremendous. This study shows that the deployment of renewable energy technologies in remote areas carries significant potential for mitigating $CO_2$ emissions. Most importantly, the provision of energy access directly targets the development needs of those most vulnerable to the impacts of climate change. Off-grid renewable energy can also help bolster adaptive capacities and ensure the resilience of livelihoods for adversely affected populations.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety has assessed *Off-Grid Renewable Energy for Climate Action* in a commitment to support energy transitions that are just and inclusive. The study reveals that universal access to affordable, reliable, sustainable and modern energy must be a priority; also, and especially, in the context of climate action.

**Svenja Schulze**

*Federal Minister for the Environment, Nature Conservation and Nuclear Safety*

# Executive Summary

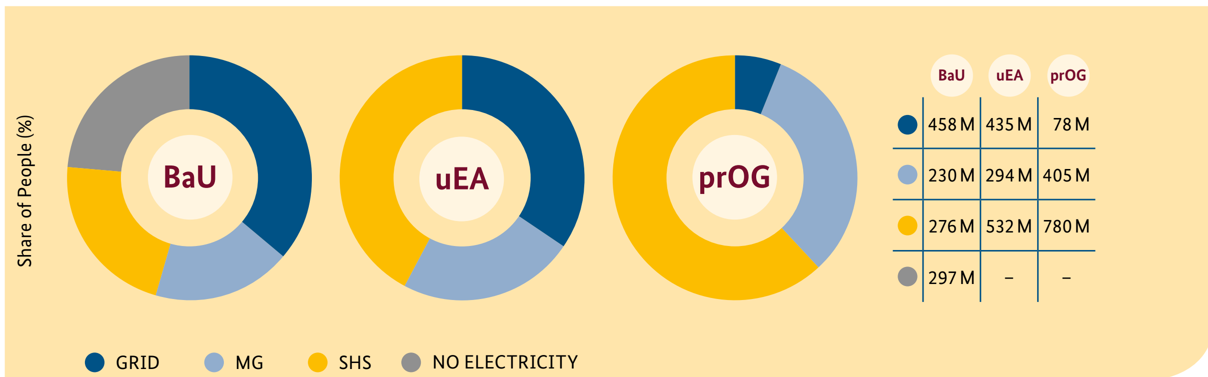
Achieving universal electrification by 2030 (SDG7) implies the provision of electricity access to more than 1.2 billion people cumulatively, of which the majority characterizes as highly climate vulnerable.
In this global study, we assessed off-grid systems (mini-grids and solar-home-systems) regarding their importance for electrification and climate action. Particularly the impact of off-grid technologies for providing electricity access in 52 target countries with low electrification rates was quantified. Furthermore, market potential, related greenhouse gas (GHG) emission mitigation and the respective socio-economic benefits were analysed.

Based on the findings of our study off-grid renewable energy technology has significant practical and economic merits over grid expansion in most cases.
In addition, off-grid solutions bear significant relevance for climate change mitigation and adaptation, having the potential to reduce GHG emissions, to build resilience towards adverse consequences of climate change on human and environmental systems, and to provide pathways for green growth and development.

In many regions of the world, SDG7 can be reached ***cheaper***, ***cleaner*** and ***smarter*** with off-grid solutions compared to a grid extension scenario.
We created three main scenarios to derive concrete numbers on electrification pathways, investment needs and GHG emissions:

- **BaU** Business-as-Usual (BaU), relative values applied for people to be electrified based on New Policy scenario of IEA;
- **uEA** Universal-Electricity-Access (uEA), based on GIS analysis of current grid infrastructure and settlement patterns combined with current policy frameworks; and
- **prOG** Progressive Off-Grid (prOG), based on uEA with most progressive policy frameworks for off-grid.

Share of people gaining electricity access until 2030: different scenarios all countries



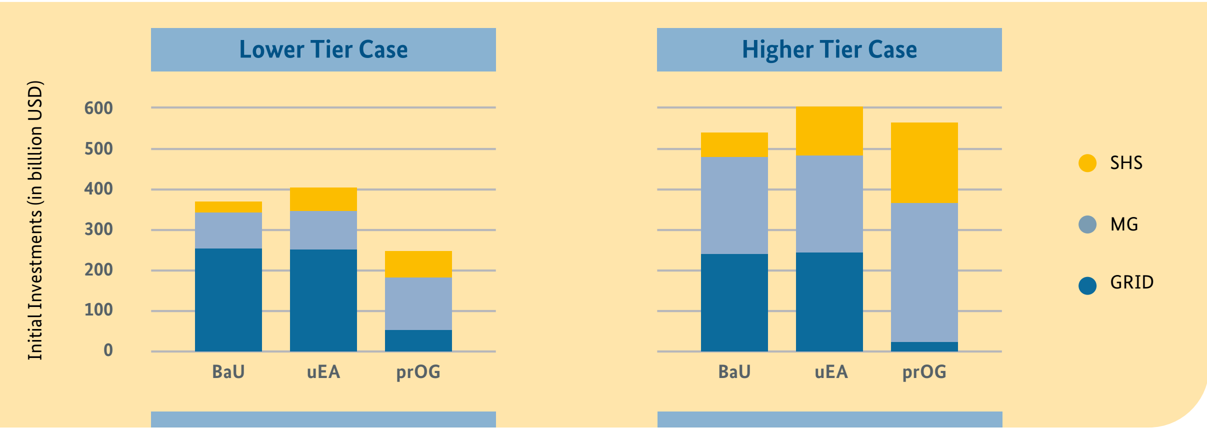

| | BaU | uEA | prOG |
|---|---|---|---|
| GRID | 458 M | 435 M | 78 M |
| MG | 230 M | 294 M | 405 M |
| SHS | 276 M | 532 M | 780 M |
| NO ELECTRICITY | 297 M | – | – |

# Main findings

## Cheaper

We find that initial investments of approximately 400 bn USD are needed to achieve SDG7 in the uEA scenario with minimum energy supply levels for households. Moving the supply levels one Tier up to improve livelihoods and productive use, 50% more investments are required. Strong focus on off-grid (prOG scenario) electrification would cut investment needs by 30% in the low demand and still by 5% in the high demand case. SHS are identified as the most cost-competitive solution for household electrification expecting low to medium demand levels (Tier 2 and 3).

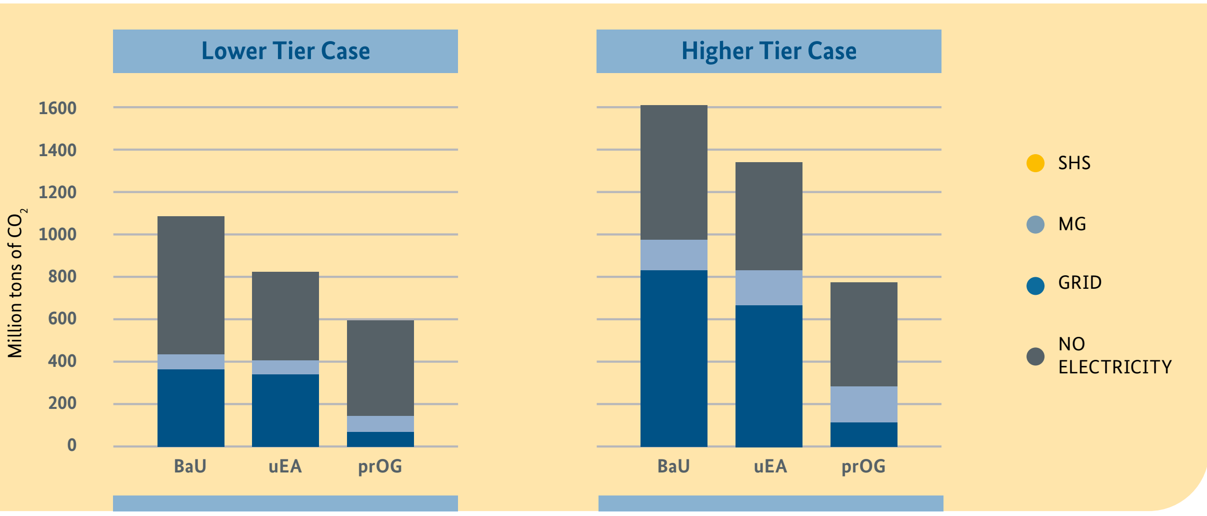
Initial investment needs until 2030 in USD Billion




## Cleaner

Our analysis of the GHG emissions related to new electrification reveals a strong mitigation effect through off-grid renewables. This is due to the effect that highest per capita emissions occur for people with no electricity access (using kerosene lamps) or with grid connection. In contrast to this, off-grid electrification has minor (mini-grids) or zero (SHS) related emissions. Cumulated $CO_2$ reductions for the electrification scenarios range from 211 to 283 million tons (uEA) and from 488 to 872 million tons (prOG) compared to BaU for the period 2017–2030.

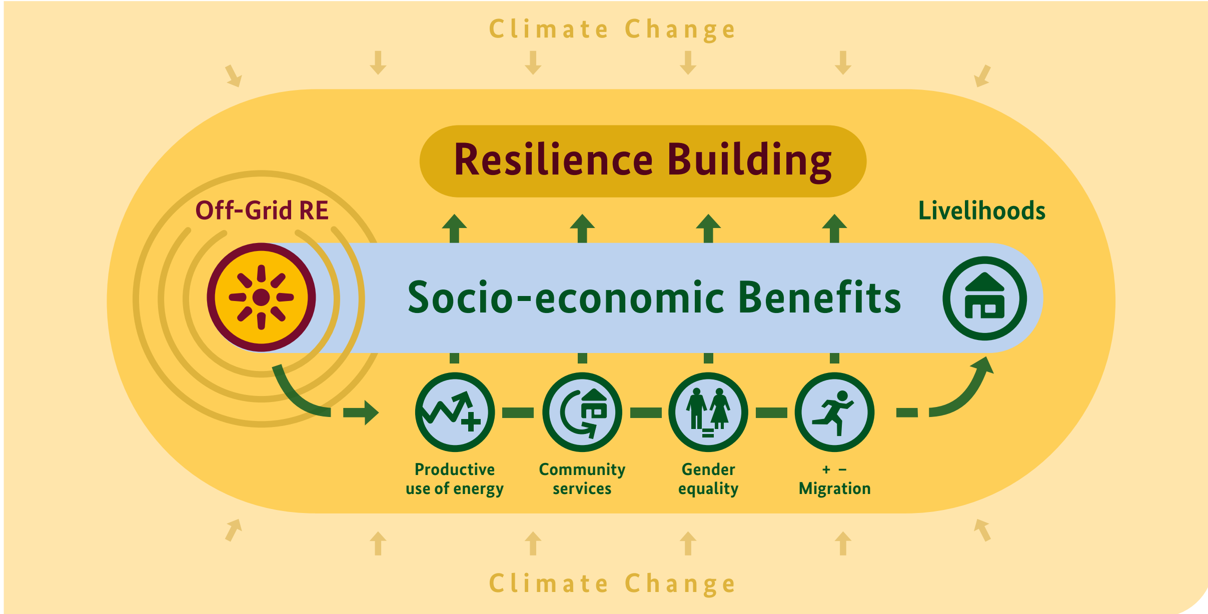
Cumulated GHG emissions in million tons of $CO_2$ (2017–2030)




## Smarter

Comparing off-grid solutions with grid electrification reveals that grid extension often fails to bring reliable energy access, as it provides high capacities but only little energy in the case of weak grids. In contrast to this, off-grid electrification is often the smarter solution, providing flexible and reliable electricity for the fast implementation of various activities to improve livelihoods in rural areas. In the context of climate action, off-grid renewables provide not only GHG emission reductions, but also adaptation services and sustainable development tailored to the local needs.

Nexus between off-grid renewable energy and livelihoods




In order to support the implementation of off-grid renewables we also looked into ***barriers and solutions*** for off-grid electrification. The successful development of off-grid renewables requires appropriate ecosystem frameworks. The four key dimensions include planning, policies & regulation, financing & business models, technology as well as human & institutional resources. Typical barriers and suitable solutions for the ecosystem dimensions can be identified on a global level but country-specific conditions need proper reflection.

***International support*** will play a crucial role for the successful development of off-grid renewables. Many developing countries need substantial international assistance to set the enabling frameworks necessary to achieve universal electrification by 2030. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement support climate action through financial resources, capacity building and technology transfer. Under the Paris Agreement, countries communicate their needs with National Determined Contributions (NDCs). Since NDCs rarely reflect off-grid RE yet, many countries can improve the communication of their ambitious off-grid electrification targets and support needs in the upcoming NDC revision. Our Deep Dive Case Studies (Ethiopia, Nigeria, Madagascar) confirm the need for strong international support and an enhanced reflection of off-grid renewable targets and needs in the respective NDCs.

The findings of our study underline ***the importance of off-grid renewable technologies for global electrification and climate action***. National and international institutions as well as the private sector need to work together to urgently implement the recommended mini-grids and SHS for the benefit of the un-electrified populations.

Suggested actions are based on the global and country specific numbers that define the different electrification pathways. The scenarios and demand cases provide boundaries for decision-makers to accelerate off-grid electrification and quickly harvest the important co-benefits to foster rural development and increase resilience of communities.

# Electricity Access, Off-Grid Systems, and Climate Action

## Sustainable Development Goals

The Sustainable Development Goals (SDGs) were adopted by all United Nations Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

The 17 SDGs are integrated – that is, they recognize that action in one area will affect outcomes in others, and that development must balance social, economic and environmental sustainability.

**Read more:** https://sustainabledevelopment.un.org

### SDG 7 – Affordable and Clean Energy

**1 in 7**

One in seven people still lacks electricity, and most of them live in rural areas of the developing world.

**60%**

Energy is the main contributor to climate change, it produces around 60 percent of greenhouse gases.

### SDG 13 – Climate Action

**2050**

To limit warming to 1.5 °C, global net $CO_2$ emissions must drop by 45% between 2010 and 2030, and reach net zero around 2050.

**1/3**

Climate pledges under The Paris Agreement cover only one third of the emissions reductions needed to keep the world's mean surface temperature below 2 °C.

# Electricity Access and Electrification Options (SDG7)

Electricity access remains a top priority for policymakers globally. Still, the number of people without access to electricity has been relatively constant around 1 billion people.

As a baseline for this study, we look at all countries with more than 1 million people without access to electricity in the year 2017 (IEA 2017). This results in 52 countries, representing a total of 970 million non-electrified people. These countries are shown in the following map together with their specific electrification rates. Considering population growth, we estimate that the number of people without electricity will further increase to 1.2 billion people in 2030. This is the target number for all electrification scenarios in our study to analyze the respective measures necessary to achieve SDG7.

SDG7 addresses the need for universal access to affordable and clean energy. Most people lacking energy access are situated in rural areas (84%) and in developing countries (95% in Sub-Saharan Africa and developing Asia). According to IEA, progress in providing electrification in urban areas has outpaced the development in rural areas two to one since 2000. Thus, most efforts are needed to electrify rural and remote areas.

The three common electrification options are Solar-Home Systems (SHS), decentralized mini-grids (based on diesel generators and/or renewable energy and storage) and grid extension of existing centralized system. More details on these options and their applicability are given in Figure 2.

**Figure 1:** Electricity access map, based on own GIS analysis and IEA 2017

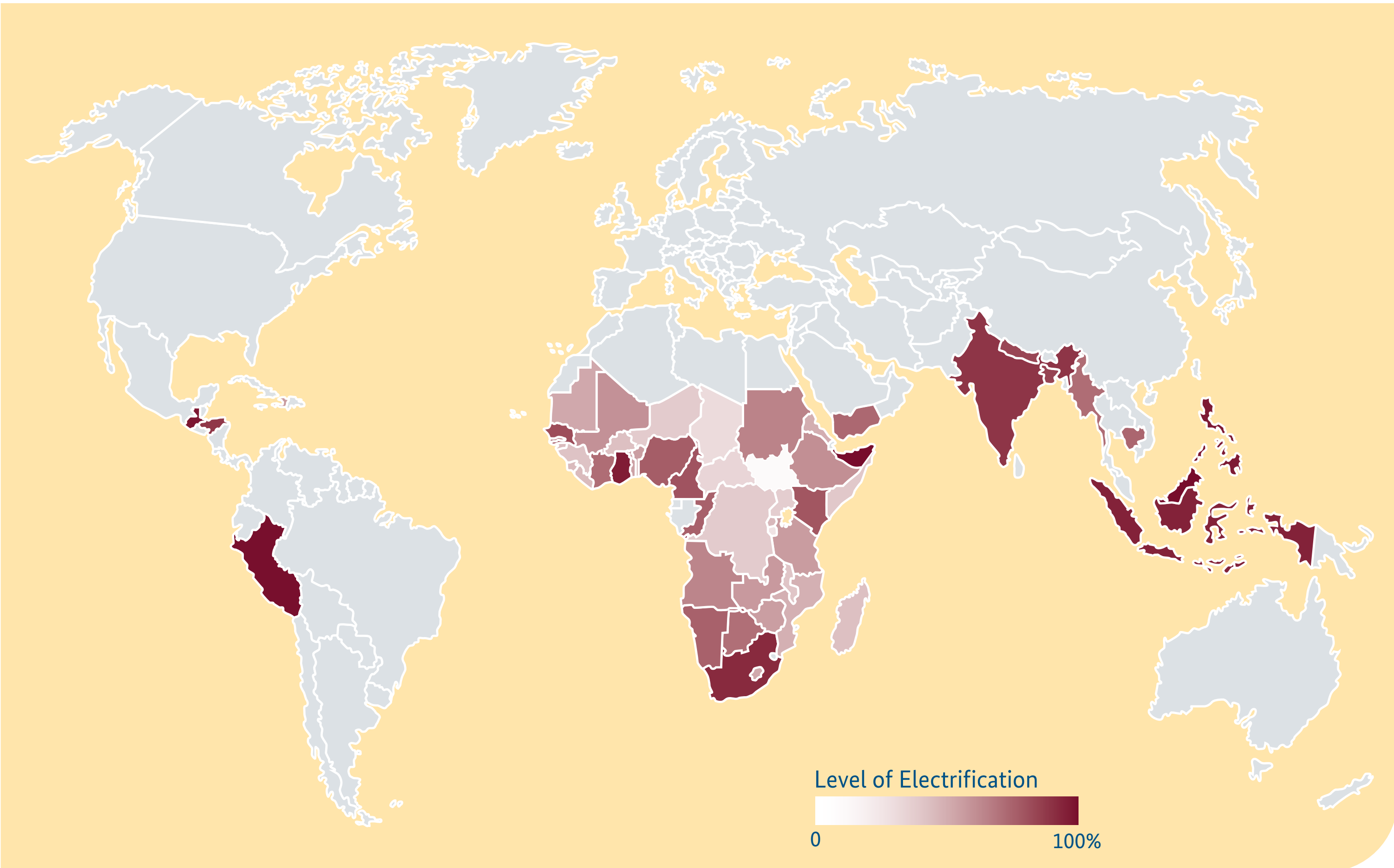
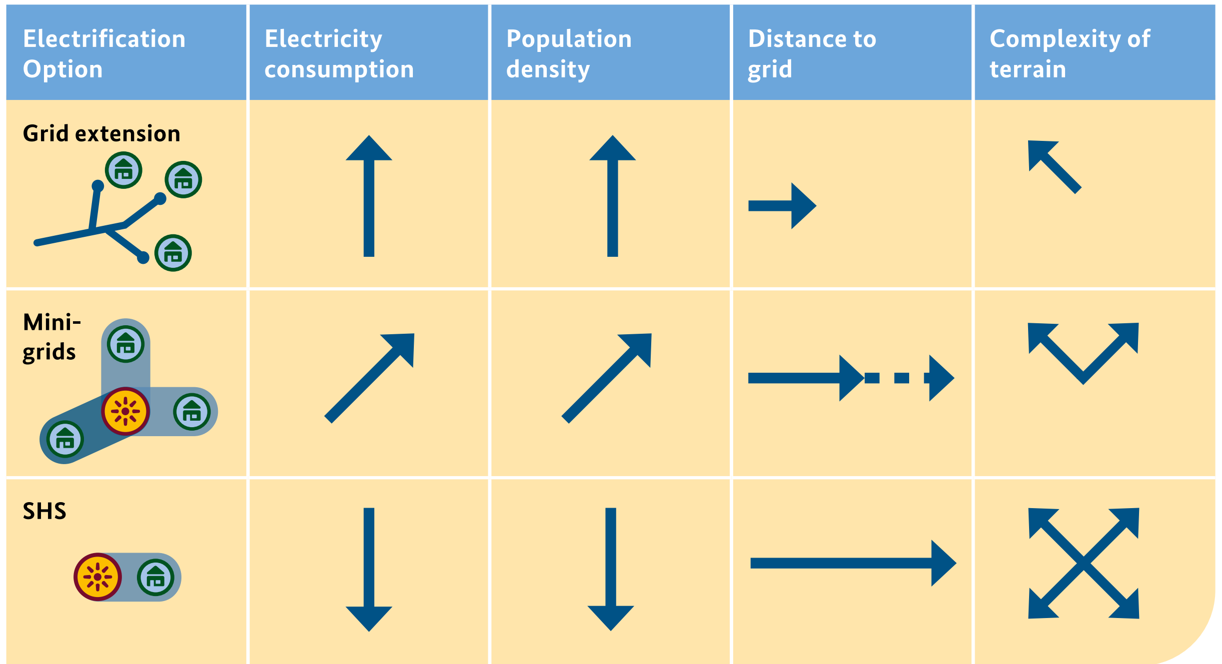





**Figure 2:** Electrification approaches and their application, based on Franz et al. 2014




The traditional approach for electrification is grid extension. This becomes increasingly challenging due to

- long distances to remote and low densely populated areas,
- weak quality of supply in the on-grid sector, resulting into frequent power outages and forced load shedding, and
- low end-consumer tariffs which challenge utilities' business models.

In contrast, off-grid options have become more competitive and attractive

- Mini-grids to supply larger villages and productive loads and
- SHS for individual households and small commercial users.

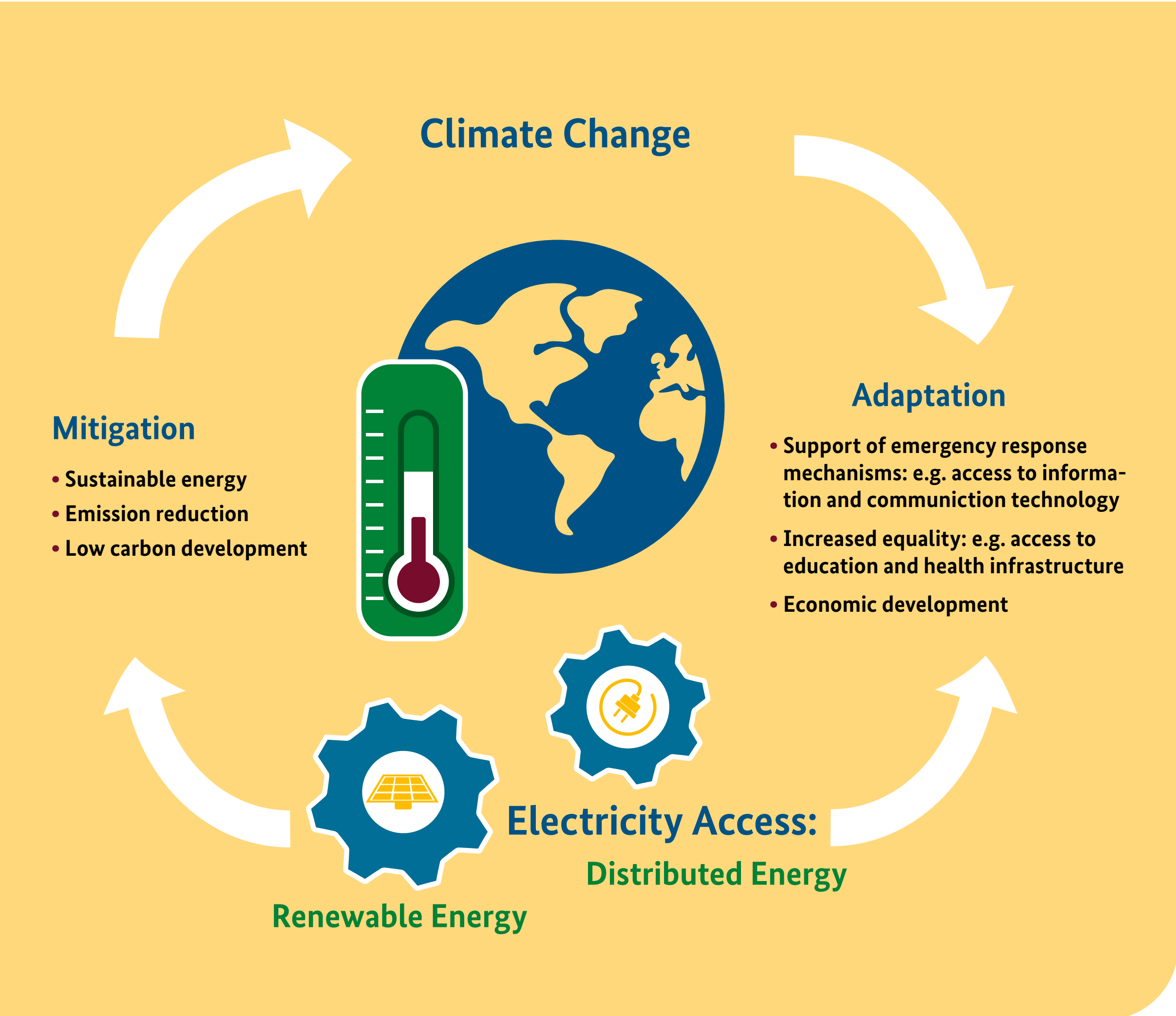
In our study we mainly focus on renewable off-grid solutions. This means fully solar powered SHS and mini-grids with an average share of 80 per cent renewable energy. The remaining 20 per cent are assumed to be covered by diesel generators as backup generation. Pure diesel based mini-grids are excluded as current price developments – increasing fuel prices and decreasing solar PV and battery costs – show that they will not present a financially viable future electrification solution, besides their environmentally harmful emissions.

In conclusion, we consider and compare all three electrification options – grid extension, mini-grids and SHS – for the development of global electrification scenarios and aim to find the best supply combination according to the given economic, geographical, technical and political framework (see also Figure 2).

## Climate Action and Resilience (SDG13)

SDG7 is strongly interlinked with SDG13, as energy supply is one of the main contributors to global warming. The process of climate change and global warming leads to large-scale shifts in the world's climate, economic, and societal systems. Thereby this global change is rapidly redesigning the realities and livelihoods of humankind, as they are as simultaneously affected of those changes, but also driving them. The Asia-Pacific Economic Cooperation Organization (APEC) states that especially remote rural areas – in many cases non-electrified communities – are affected by climate change due to their geographic, social, and economic constraints and are therefore particularly vulnerable (APEC, 2017).

**Figure 3:** Energy Access: mitigation and adaptation effects; own illustration, based on Franz et al. 2014




The negative impacts of anthropogenic climate change require systems, societies and individuals to adapt quickly to those changes, favoring those with the highest resilience (IPCC 2014). Thus, it is crucial to discuss measures and options to address both, $CO_2$ emission mitigation to slow down climate change and adaptation measures to improve the resilience of areas and communities at most risk.

***Resilience*** is often considered the flipside or even the positive connotation of vulnerability. Resilience defines how individuals, communities or societies continue to thrive and develop under shocks and stresses (Walker et al. 2004). Climate resilience means the capability to prepare for, withstand, and recover from stresses and disasters caused by the impacts of climate change (Miller et al. 2010). Strategies to build resilience combine preparedness to respond immediately under extreme events along with long-term sustainable development objectives that increase socioeconomic and environmental capacity to function under new climate conditions (Engle et al. 2014).

According to UNDP, ***climate action*** – as stated in SDG13 – combines greenhouse gas emission reduction efforts (mitigation) on the one hand and improved resilience and adaptive capacity (adaptation) on the other hand. Both – mitigation and adaptation measures – are crucial to reach the SDGs' overarching vision to end poverty, protect the environment and ensure that all people enjoy peace and prosperity by 2030.

Figure 3 shows ***mitigation and adaptation*** measures for energy-related fields as an example. In this context, electricity access and renewable & distributed energy, have the potential to contribute to both sides.

In our analysis, we specifically focus on the connection of ***electrification and climate action***. As mentioned above, more than 1.2 billion people should receive new electricity access until 2030. Considering the $CO_2$ emissions of the energy sector, there is potential to reduce future emissions evolving from electrification efforts by choosing more sustainable supply options. For this reason we developed and evaluated different electrification scenarios regarding their expected related investment costs and $CO_2$ emissions.

***Sustainable electricity supply*** can trigger a community's overall socio-economic development and goes hand in hand with the potential to improve their resilience. Various aspects that strengthen the adaptive capacity and thus resilience are improved by sustainable electricity access as it contributes to many vital functions of a community (Perera et al. 2015). Accordingly, we also analyze the special role of electricity access and off-grid technologies in improving rural livelihoods and resilience for climate action. This is further aligned with a study of barriers and solutions for off-grid electrification and the specific role of international support and the National Determined Contributions (NDCs). We find that only international efforts that consider local needs, ultimately lead to an achievement of these two strongly interlinked SDGs: ***Access to sustainable energy (SDG7) and climate action (SDG13).***

# How to achieve SDG7 – Global Electrification Scenarios

More than 1.2 billion people need to be newly electrified until 2030 and 80% of them live in rural areas.

Only a smart combination of electrification options (grid extension, mini-grids, SHS) can ensure achieving SDG7.

Off-grid electrification will play a major role for the success in rural areas.

In order to understand the different impacts of the different electrification and climate action pathways, we developed three scenarios. They reveal the respective electrification mix, initial investments needed and the related GHG emissions to secure energy access for all by 2030. Different circumstances such as current infrastructure, population density, and socio-political frameworks influence these scenarios. Details on the methodology can be found in Annex: References ans Methodology.

Our study is the first ever estimation of electrification efforts considering grid extension, mini-grids and solar-home-systems (SHS) on a country level with a global scope. To structure the results we have three guiding scenarios that are presented in the following Table 1.

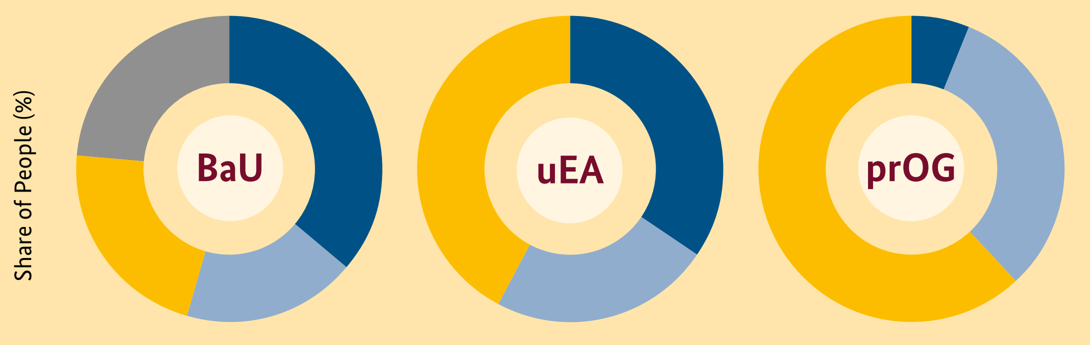
**Table 1:** Overview on electrification scenarios

| Business-as-Usual (BaU) | Universal-Electricity-Access (uEA) | Progressive Off-Grid (prOG) |
|---|---|---|
| **Background:** Relative values applied for people to be electrified based on New Policy scenario of IEA | **Background:** Based on GIS analysis of current grid infrastructure and settlement patterns combined with current policy frameworks | **Background:** Based on GIS analysis of current grid infrastructure and settlement patterns combined with most progressive policy frameworks for off-grid |
| • Focus on grid-extension<br>• SDG7 not achieved | • Mix of off-grid and grid-extension<br>• SDG7 achieved for 100% electricity access | • Strong focus on off-grid electrification<br>• SDG7 achieved for 100% electricity access |

The described scenarios were developed by applying different methods such as literature surveys, GIS and framework analyses. As a first step the electrification mix for each of the three scenarios was calculated.

In the BaU scenario, SDG7 is not achieved until 2030. Globally, it reveals that almost 300 million people being left un-electrified. The suggested electrification mix has almost half grid extension and one quarter mini-grids and one quarter SHS. uEA and prOG show both 100% electrification rates in 2030. In the uEA scenario a stronger focus is set on mini-grids (30%) and SHS (42%). This reflects the current grid infrastructure, settlement patterns and the current Regulatory Indicators for Sustainable Energy (RISE)[1], which allow already a shift towards mini-grids and SHS away from grid extension on the global scale. Assuming the most favorable policy and regulatory frameworks for both, mini-grids and SHS, we observe a very low grid-based electrification (only 78 million people) and a strong shift from grid-based electrification towards SHS (2/3) and mini-grids (1/3) in the prOG scenario.

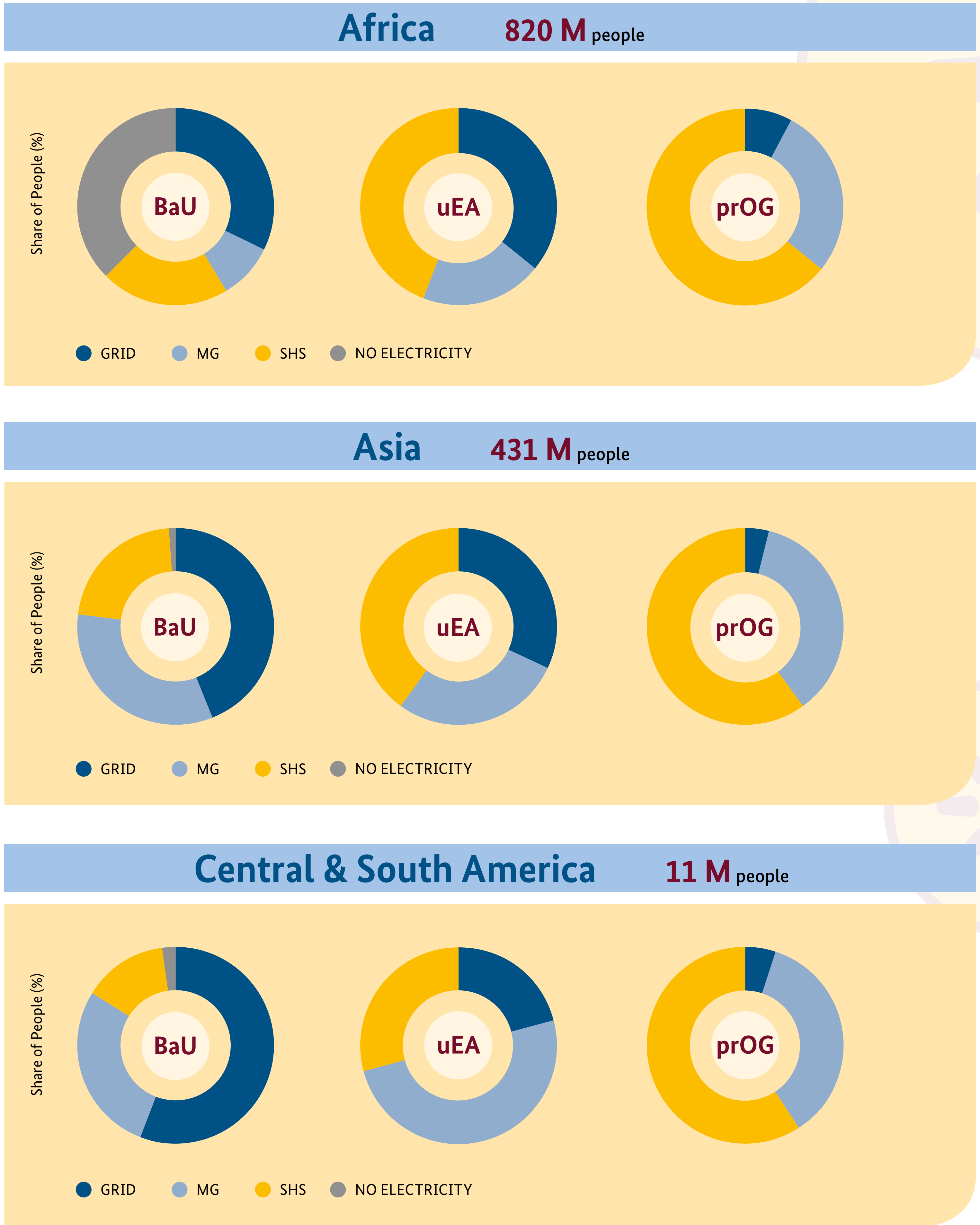
**Figure 4:** Share of people gaining electricity access until 2030: different scenarios all countries




| | BaU | uEA | prOG |
|---|---|---|---|
| GRID | 458 M | 435 M | 78 M |
| MG | 230 M | 294 M | 405 M |
| SHS | 276 M | 532 M | 780 M |
| NO ELECTRICITY | 297 M | – | – |

1 RISE is a set of indicators developed by the World Bank to help compare national policy and regulatory frameworks for sustainable energy organized by the three pillars energy access, energy efficiency, and renewable energy. https://rise.esmap.org/

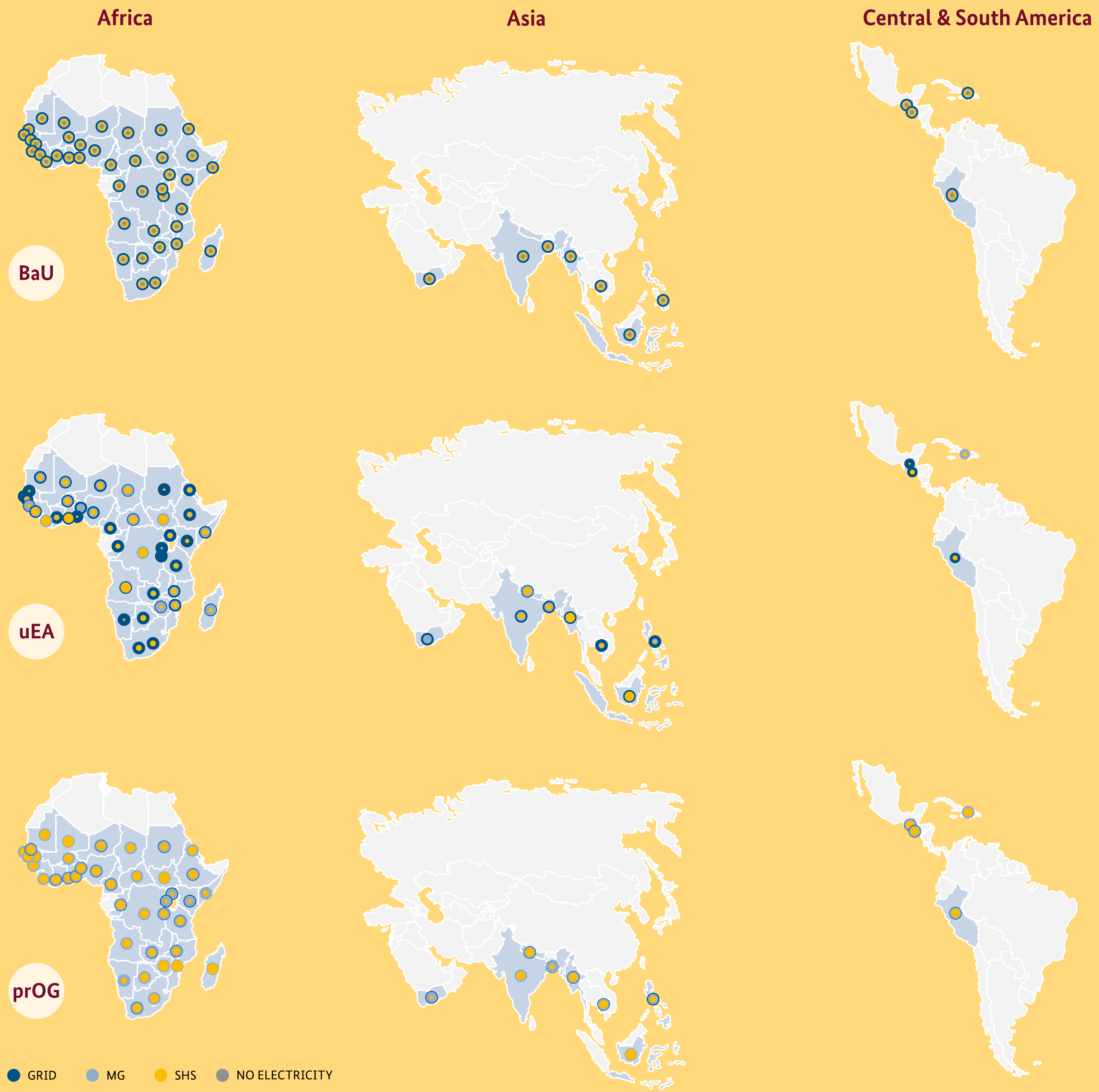
**Figure 5:** Electrification mix per region: people in million for different scenarios




Africa has the largest share of population to be electrified until 2030 with more than 800 million people. In the BaU scenario, still 295 million people are left without electricity access, while in Central & South America and Asia a 99% electrification rate is achieved even in the BaU scenario. Central & South America have only about 10 million people to be electrified, contrary to Asia, where we found that more than 400 million need new electricity access until 2030.

SHS play the biggest role in achieving universal electrification in Africa for both uEA and prOG scenario, while mini-grids are most prominent in Central & South America. The Asian electrification mix shows a little less grid extension for uEA and more mini-grids for uEA and prOG compared to the global average. In general, SHS dominate in all regions in the prOG scenario as the most important electrification option.

A detailed view at country level is given in the next figure, which illustrates the influence of current infrastructures, population densities and socio-economic frameworks.




## Electrification mix for each country for each scenario

- 3 scenarios are calculated in detail for each of the 52 countries
- Off-grid solutions become significantly more important in all countries in the prOG scenario
- Highly populated countries such as Nigeria, India and the Philippines have the highest mini-grid shares
- Countries with low population densities and low electricity demands favor mostly SHS, for example Madgascar, Myanmar, and Zambia

All scenarios can be seen online:
www.reog-x.com

# Cheaper – Off-Grid reduces Investment Needs

- To achieve SDG7 in the uEA scenario with minimum energy supply levels for households, initial investments of approximately 400 bn USD are needed.
- Moving the supply levels one Tier up to improve livelihoods and productive use 50% more investments are needed.
- Strong focus on off-grid (prOG scenario) electrification would cut investment needs by 30% in the low demand and still by 5% in the high demand case.
- SHS are the most cost-competitive solution for household electrification expecting low to medium demand levels (Tier 2 and 3).

Taking the development scenarios, we address the question of how much initial investment is needed for their implementation. For all scenarios we calculate the specific initial investment costs per technology and country. We focus on initial investments only (re-investments / replacements of technology are not considered), which are cumulated for the year 2030. For grid extension a generic value of 2,500 USD per household (HH) connection (excluding central power generation investments) is assumed. For off-grid technologies, we distinguish between the different capacities based on consumption levels. Thus, mini-grid investments are based on capacities and relative Tier level. We estimate investment costs of 1,000 to 6,000 USD per HH connection (including generation, storage and distribution grid). For SHS, investments are based on the size class of SHS and range from 300 to 1,300 USD per SHS per HH (solar PV plus storage plus direct current (DC) appliances).

**Figure 6:** Description of lower and higher Tier demand cases

For each scenario we estimate two different demand cases:

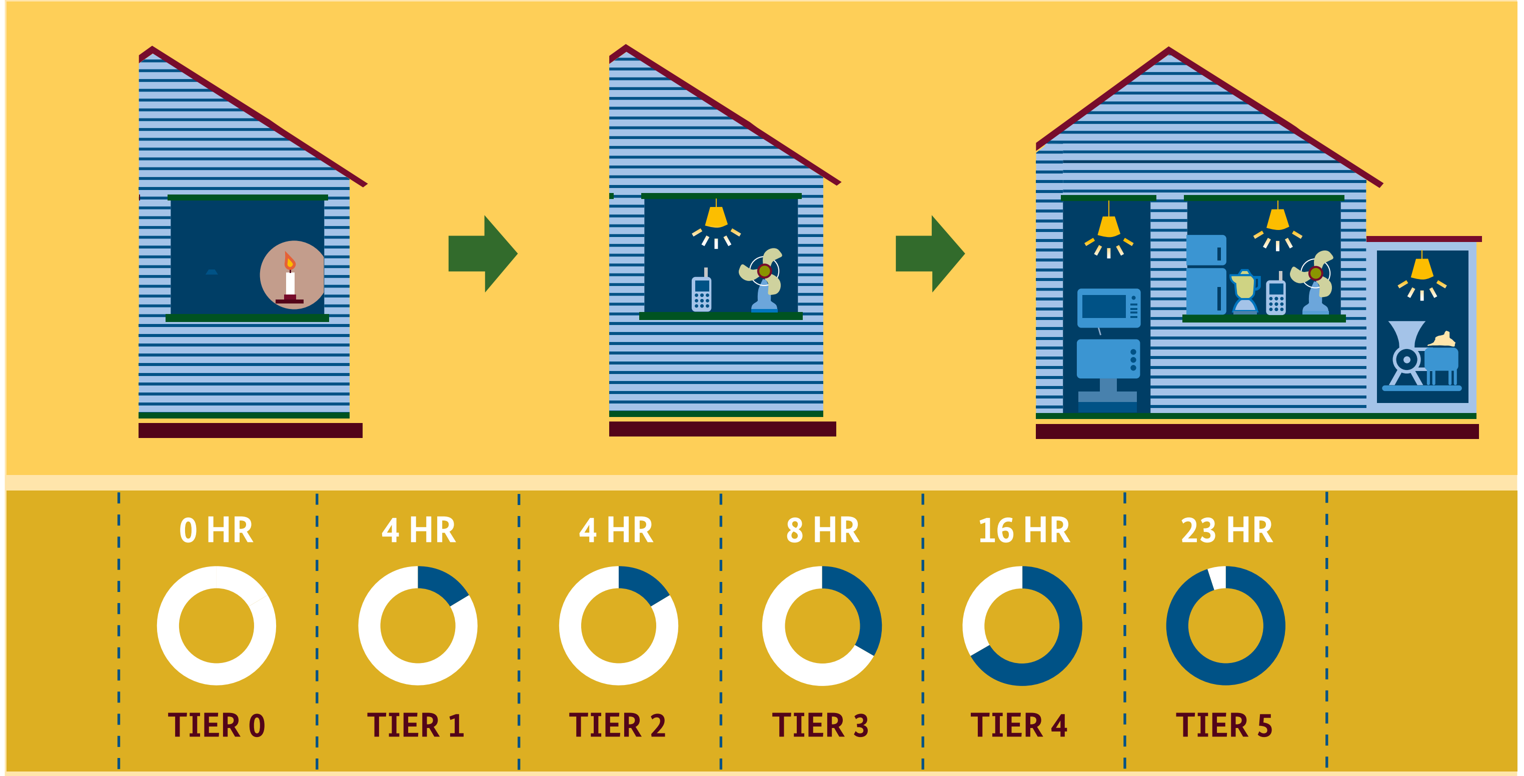
## Lower Tier Case

In this case, the minimum threshold for electricity access is defined as the equivalent of ESMAP's Tier 2 (compare Figure 5) where SHS find application, and Tier 3 where mini-grids are deployed or grid extension takes place.

## Higher Tier Case

In this case, the minimum threshold for electricity access is defined as the equivalent of ESMAP's Tier 3 where SHS find application, and Tier 4 where mini-grids are deployed or grid extension takes place.

### The Tiers of Electricity Access of the Multi Tier Framework




**Improving attributes of energy supply leads to higher Tiers of access**

Source: Lighting Africa 2016 (https://www.esmap.org/node/55526)

**Figure 7:** Initial investment needs until 2030 in USD Billion

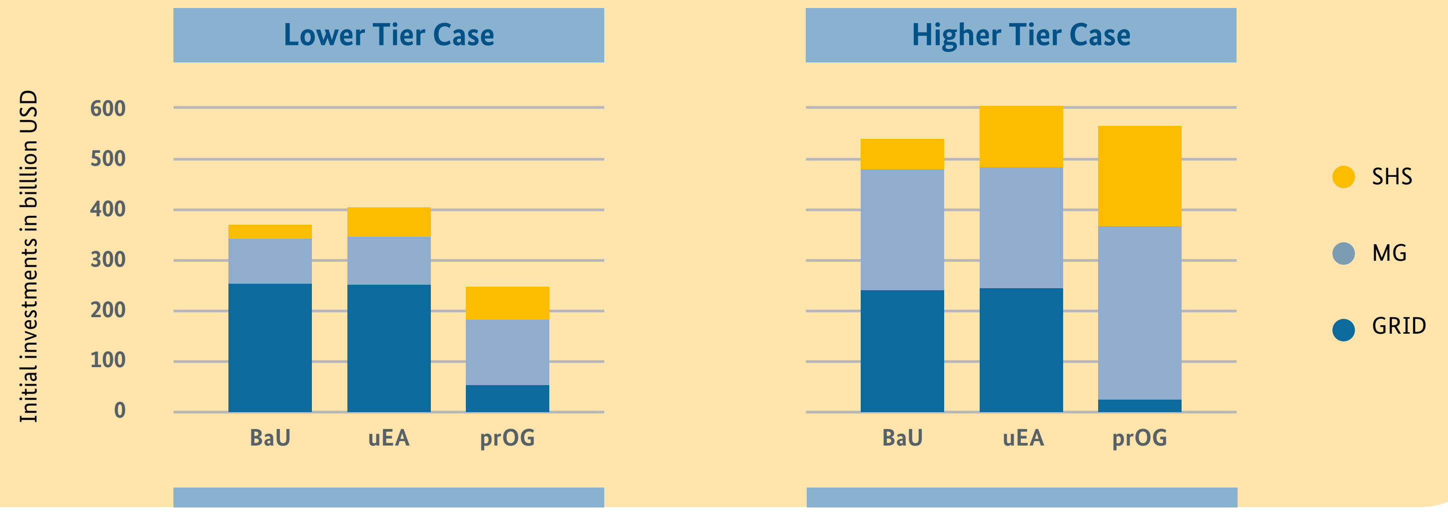



**Table 2:** Initial investment needs until 2030 in USD Billion

| | Lower Tier Case | | | Higher Tier Case | | |
|---|---|---|---|---|---|---|
| | BaU | uEA | prOG | BaU | uEA | prOG |
| Grid | 236 | 226 | 41 | 236 | 226 | 41 |
| Mini-Grid | 98 | 103 | 141 | 226 | 250 | 341 |
| SHS | 34 | 64 | 94 | 72 | 138 | 202 |
| **Total** | **368** | **393** | **276** | **534** | **614** | **584** |

We define two different demand cases, one "lower Tier" and one "higher Tier" case, which are described in Figure 6. These are needed to show the influence of the specific demand on the off-grid investment needs and later on the GHG emissions.

The initial investments needed to achieve the electrification mix for the different scenarios are shown in Figure 7 + Table 2. They reflect both cases, lower Tier and higher Tier electrification, which affects the minimum size of mini-grids and SHS.

Even though in BaU 300 million people remain without access to electricity, the scenario has the second highest initial investment needs for the lower Tier case. For both Tier cases, uEA requires the highest initial investments.Especially the investments for mini-grids increase when moving from minimum Tier 3 to 4. SHS remain the most cost-effective option, suggesting a prOG scenario. This scenario requires the comparably lowest investment needs in the lower Tier case but still enables electricity access for all by 2030.

In summary, to achieve the uEA, initial investments of 393 bn USD are needed. This would supply all people with minimum needs of Tier 2 for SHS and Tier 3 for grid and mini-grid (lower Tier case). By moving these Tier levels one up, leading to improved livelihoods and productive uses (see also Chapter "Smarter" below), 614 bn USD are needed (higher Tier case). A strong focus on off-grid (prOG scenario) would lead to reduced investment needs of only 277 bn USD (lower Tier case) or 584 bn USD (higher Tier case).

Most investments, namely 170 to 322 bn USD, would go to Africa, while Asia follows with 126 to 294 bn USD. Central & South America only require 1 to 7 bn USD for the different electrification scenarios and cases. For both, Asia and Central & South America, the BaU Scenario requires the most investments as it shows almost 100% electrification but also focuses on more expensive technology options (grid extension and mini-grids) than the uEA and prOG scenario. For all regions, the competitiveness of off-grid as electrification decreases in high Tier cases, as especially mini-grids become more expensive (cf. Table 4).

The per capita investments underline the regional differences in household size and specific electricity demand. This affects especially the investments into off-grid technologies. While for grid extension the global average investment of approximately to 500 to 600 USD per capita has only few variances for all countries, the per capita investments into mini-grids and SHS vary enormously between countries and demand cases. SHS for lower demand levels range from 100 to 120 USD per capita and go up to 250 USD for higher demand levels. Despite this range, they show only little differences among the different regions. The differences between regions become more significant for mini-grids. The per capita investments range from 240 to 660 USD in Africa (low to high demand) and almost double in Asia and Central & South America due to the specifically higher demand in the related countries.

In conclusion, off-grid technologies can be a very cost-competitive solution for achieving universal electrification. SHS are competitive for both Tier cases. Considering this solution can significantly lower initial investment needs for household electrification. Mini-grids can become quite expensive in higher Tier cases but the investment costs cover not only the distribution grid but also PV and battery systems, which are associated with very low operational costs. Thus, investing in mini-grids for electrification is cheaper for lower Tier levels, but they become more expensive for higher Tier levels. In return, those higher Tier level mini-grids would enable productive use customers to power various devices. The grid electrification costs depend very much on distance to grid, which would require detailed studies for each country. Our generic value is rather conservative, but it excludes the costs for investments into the central power generation. In summary, off-grid solutions are especially cheaper for low demand cases and can be a faster and more reliable solution than grid extension for high demand cases.

**Table 3:** Total initial investments for different electrification scenarios

| | Lower Tier Case | | | | | | | | | Higher Tier Case | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Africa | | | Asia | | | Central & South America | | | Africa | | | Asia | | | Central & South America | | |
| | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG |
| Total sum in Billion USD | 171 | 231 | 149 | 191 | 159 | 126 | 5 | 2 | 1 | 233 | 347 | 322 | 294 | 260 | 257 | 7 | 5 | 4 |

**Table 4:** Per capita initial investments for different electrification scenarios in USD

## Africa

| | Lower Tier Case | | | Higher Tier Case | | |
|---|---|---|---|---|---|---|
| | BaU | uEA | prOG | BaU | uEA | prOG |
| Grid | 500 | 515 | 533 | 500 | 515 | 533 |
| Mini-Grid | 244 | 225 | 240 | 663 | 621 | 657 |
| SHS | 112 | 113 | 114 | 257 | 251 | 253 |
| Total | 326 | 281 | 182 | 444 | 423 | 393 |

## Asia

| | Lower Tier Case | | | Higher Tier Case | | |
|---|---|---|---|---|---|---|
| | BaU | uEA | prOG | BaU | uEA | prOG |
| Grid | 531 | 529 | 529 | 531 | 529 | 529 |
| Mini-Grid | 539 | 525 | 519 | 1,177 | 1,167 | 1,127 |
| SHS | 135 | 137 | 137 | 271 | 274 | 275 |
| Total | 445 | 369 | 293 | 685 | 603 | 598 |

## Central & South America

| | Lower Tier Case | | | Higher Tier Case | | |
|---|---|---|---|---|---|---|
| | BaU | uEA | prOG | BaU | uEA | prOG |
| Grid | 583 | 606 | 607 | 583 | 606 | 607 |
| Mini-Grid | 378 | 240 | 328 | 900 | 747 | 823 |
| SHS | 69 | 70 | 69 | 149 | 149 | 148 |
| Total | 451 | 270 | 185 | 612 | 548 | 412 |

- Off-grid electrification allows a very cheap per capita electrification for low demand households.
- Grid extension investments[2] are around 500 to 600 USD per capita no matter which demand level is assumed.
- SHS are the cheapest per capita electrification option for all demand cases.

- Initial investments in mini-grids increase significantly per capita for higher demands as the power generation and storage capacities need to be increased.
- Total per capita investments into electrification are the highest in Asia due to the relatively high current demand levels in this region.
- In contrast to that, they are the lowest for African countries, due to low power demands and larger household sizes.

2 Investements only in grid infrastructure, not into power generation

# Cleaner – Off-Grid reduces GHG Emissions

Highest per capita emissions occur for people with no electricity access (using kerosene lamps) or with grid connection.

Off-grid electrification have minor (mini-grids) or zero (SHS) related emissions.

Cumulated $CO_2$ savings for uEA range from 211 to 283 m tons and for prOG from 488 to 872 m tons compared to BaU for the period 2017–2030.

We further address the implications of the electrification efforts on climate change. Similar to the investment needs, we calculated the related GHG emissions for all scenarios under the two demand cases. It needs to be notified that also emissions of non-electrified people based on the use of kerosene lamps are considered in the results. The emissions of non-electrified people might even be higher than in our assumptions as sometimes small-scale diesel generators are used for informal electricity access. Those are currently not included in the CDM AMS.I-L method[3] to assess emissions and therefore neglected for our study[4]. As we are looking at an electrification pathway until 2030, we can still observe a significant amount of cumulated emissions related to non-electrified people, even if in 2030 universal electrification would have been achieved.

3 https://cdm.unfccc.int/methodologies/index.html

4 We acknowledge that a huge amount of GHG emissions is assigned to back-up diesel generators which are used by grid-connected customers in regions with frequent power outages. As we only look at new electrification efforts we do not consider these emissions, but they need to be reduced as well by either improved grid supply quality and/or renewable back-up solutions.

**Figure 8:** Cumulated GHG emissions in million tons of $CO_2$ (2017–2030)

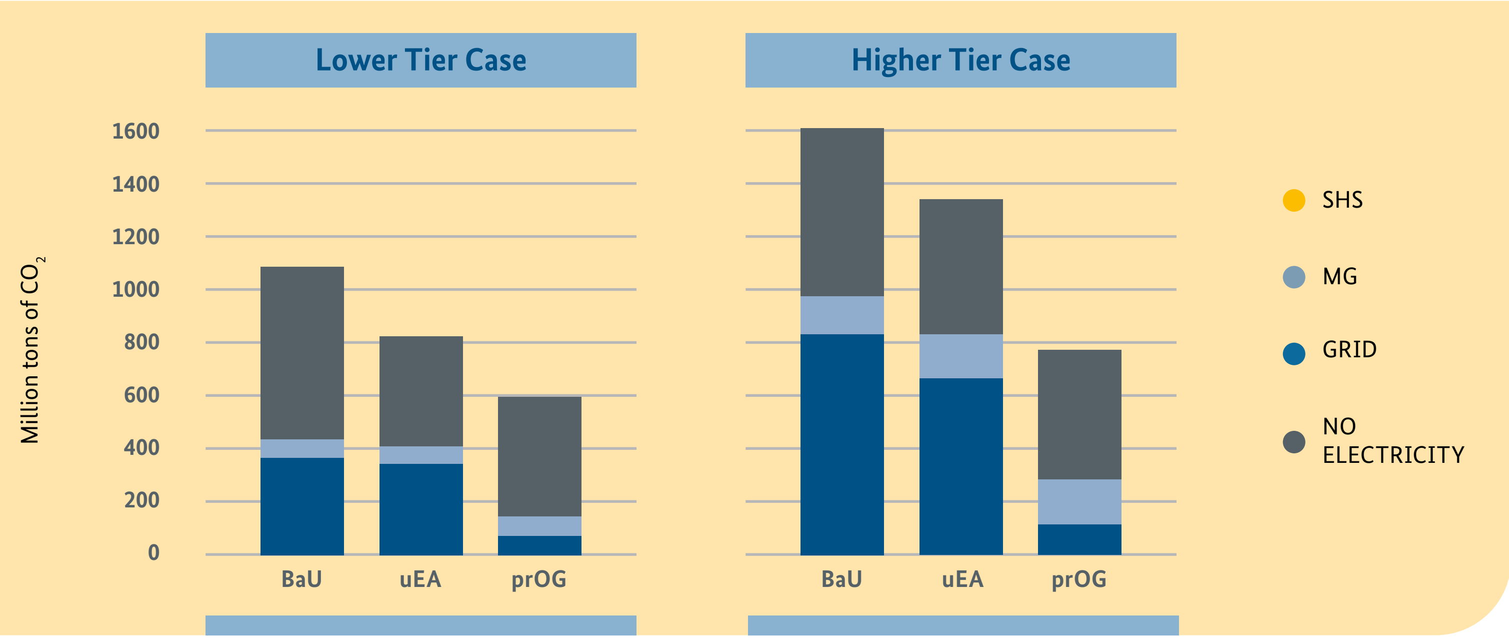



**Table 5:** Cumulated GHG emissions in million tons of $CO_2$ (2017–2030)

| | Lower Tier Case | | | Higher Tier Case | | |
|---|---|---|---|---|---|---|
| | BaU | uEA | prOG | BaU | uEA | prOG |
| **Grid** | 403 | 348 | 49 | 872 | 738 | 104 |
| **Mini-Grid** | 54 | 55 | 76 | 114 | 121 | 166 |
| **SHS** | 0 | 0 | 0 | 0 | 0 | 0 |
| **No access** | 681 | 525 | 525 | 681 | 525 | 525 |
| **Total** | 1,138 | 928 | 650 | 1,667 | 1,384 | 795 |
| **Emission reductions from BaU** | **0** | **–210** | **–488** | **0** | **–283** | **–872** |

For the BaU scenario, the highest cumulative number of people does not get access to electricity and therefore continues to use kerosene lamps that emit significant GHG emissions. In contrast, the uEA and prOG scenarios achieve universal electrification by 2030, leading to a substantial emission reduction. The cumulated emission reduction potential can reach 201 to 490 $MtCO_2$ between 2017 and 2030, compared to the baseline scenario (BaU) under consideration of the lower demand case. For a higher consumption level, simulated through an increased Tier level, the aggregated emission reduction until 2030 rises from 280 to 870 $MtCO_2$. For all scenarios, the cumulated GHG emissions related to non-electrified people are among the highest. The faster the electrification of all people can be achieved, the earlier can those emissions be reduced.

Comparing the different regions reveals that Asia has by far more GHG emissions connected to new electrification than Africa, even though only 400 million people will be newly electrified in Asia, compared to 800 million people in Africa. Africa's cumulated emissions are dominated by the emissions related to "no electricity access" households, which account for 460 $MtCO_2$; 80% of cumulated emissions in the lower Tier case and 60% of emissions in the higher Tier case. Asia and Central & South America have the most emissions based on grid electrification, which is very significant considering higher Tier cases and the BaU and uEA scenario, where 50 to 70% of emissions are based on grid electrification. Thus, off-grid electrification in Asia and Central & South America shows the highest potential for GHG emission mitigation due to higher specific demands which make grid electrification more polluting than off-grid.

The specific numbers for the projected emissions in 2030 underline two main findings: First, no access to electricity is more polluting than off-grid electricity access; and second grid based electrification is by far more polluting than off-grid electricity. This is true for both figures, total emissions and per capita emissions, comparing the cases and technologies.

In conclusion, electrification can be seen as a mitigation measure, especially if one is focusing on off-grid technologies. Due to the low electricity demands of the households, the relative per capita emissions remain low and range from 130 kg $CO_2$ per year (BaU, high demand) to 10 kg $CO_2$ per year (prOG, low demand). Even in the high demand case SDG7 – access to electricity for all – can be achieved with only a minimum of additional GHG emissions, accounting for around 40 Mt $CO_2$ annually when using the progressive off-grid scenario. Choosing this progressive way of electrification would reduce 120 Mt $CO_2$ in the year 2030, and a cumulated amount of more than 870 Mt $CO_2$ (2017–2030) compared to BaU. Even though emission savings in 2030 would only represent 1% of the current global electricity related GHG emissions, it reveals the importance to follow this cleaner path. As every contribution to reducing global $CO_2$ emissions is important, the progressive electrification pathway is beneficial to achieve both, SDG7 and SDG13. Thus, off-grid technologies can directly reduce emissions for new electrification efforts and can act as a role model for emission reduction measures in already electrified areas.

**Table 6:** GHG emissions in the year 2030

| | Total GHG emissions (in M tons $CO_2$ per year) | | | | | | Per Capita GHG emissions (in kg $CO_2$ per year) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower Tier Case | | | Higher Tier Case | | | Lower Tier Case | | | Higher Tier Case | | |
| | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG | BaU | uEA | prOG |
| Grid | 57.7 | 49.7 | 7.0 | 124.6 | 105.5 | 15.0 | 130 | 110 | 90 | 270 | 240 | 190 |
| Mini-Grid | 7.7 | 7.8 | 10.8 | 16.3 | 17.3 | 23.7 | 30 | 30 | 30 | 70 | 60 | 60 |
| SHS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No access | 22.2 | 0 | 0 | 22.2 | 0 | 0 | 70 | – | – | 70 | – | – |
| Total | 87.6 | 57.5 | 17.8 | 163.1 | 122.8 | 38.7 | 70 | 50 | 10 | 130 | 100 | 30 |
| Difference to BaU | 0 | −30.1 | −69.8 | 0 | −40.3 | −124.4 | 0 | −20 | −60 | 0 | −30 | −100 |

# Smarter – Off-Grid Electrification Benefits

- Electricity access improves livelihoods and resilience of rural communities which leads to various socio-economic benefits.
- Grid extension often fails to bring reliable energy access, as it provides high capacities but only little energy in the case of weak grids.
- Compared to grid expansion, off-grid electrification is often the smarter solution, providing flexible and reliable electricity for the fast implementation of various activities in rural areas.
- In the context of climate action, off-grid renewables provide not only GHG emission reductions, but also adaptation services and sustainable development tailored to the local needs.

The global electrification scenarios have been developed as electricity access is a prerequisite for local development and improved livelihoods. Thus achieving SDG7 is not only about enabling energy services but to harvest various co-benefits. Traditionally, electricity access is linked to grid extension and connection. In this context, off-grid technologies are often described as a fallback option or second-best choice compared to on-grid electrification that is typically associated with a high capacity level, required to fulfil high demands. However, in many cases off-grid renewable energy, particularly mini-grid solutions, are equally able to support applications that improve livelihoods. These applications can ultimately lead to an increase in income, reduce poverty, deliver community services or absorb adverse impacts of climate induced hazards through various application options. Hence, the global community acknowledges more and more the vital role that off-grid technologies play for faster and smarter electrification pathways.

Our global analysis has shown that off-grid technologies can offer electrification with often lower initial investments and lower GHG emissions compared to grid extension. Furthermore, they also provide specific smart advantages due to their technical characteristics in contrast to on-grid connections. These benefits of off-grid RE systems, particularly in rural communities, will be further elaborated below.

## Advantages of off-grid electrification compared to grid-connected systems

Despite the cumulative off-grid RE capacity (micro-hydro, SHS, bioenergy, solar mini-grids and others) has experienced a strong growth from 231 MW in 2008 to nearly 1.2 GW in 2017, their available individual capacity is usually lower compared to grid-connections (IRENA 2018, p.3). However, on-grid systems face two major challenges. First, on-grid electricity is not always reliable. Frequent black-outs are common in low-developed regions. Second, establishing access to on-grid energy in the context of rural areas in developing countries is often not feasible due to long distances, difficult terrain and low projected levels of consumption in remote areas (Yadoo et al. 2012, p. 593). Off-grid solutions can therefore help to expand electricity access in a more flexible and decentralized way and increase the reliability of the energy supply.

In the context of predicted climate hazards, energy security becomes increasingly threatened and at the same time more important for adaptation. Various studies have highlighted the general vulnerability of centralized energy systems to extreme weather events, like the disruption introduced by specific events (demand spikes, transmission interruption), as well as material risks associated with the energy infrastructure (compare Gerlak et al. 2018). Because many centralized grids run near critical capacity, a dysfunction in a small part of the system can cause a failure of the entire central system. Off-grid technologies with their decentralized renewable nature can alleviate this risk (Hirsch et al. 2018, p.405). Thus, off-grid RE solutions represent a climate change adaptation measure itself while improving the overall adaptive capacity of communities to climate related impacts through various applications (Yadoo et al. 2012, p.592 and the following chapter).



Moreover, some renewable energy systems show more resilience to climate effects than others. Hydropower for example is highly vulnerable to the impact of climate change due to its dependency on stable precipitation and water supply (Agrawala et al. 2003, p. 43). Thus, for stable provision of energy in changing climate contexts it is beneficial to diversify energy supply to different renewable energy sources where available and implement energy storage systems where possible (Yadoo et al. 2012, p. 594). In conclusion, the solar driven SHS and mini-grids used in the global electrification scenarios hold several advantages, compared to grid extension, which makes them not only cheaper and cleaner but also smarter.

## How off-grid technologies contribute to adapted and improved livelihoods

As indicated, off-grid RE can contribute to improved livelihoods in the context of a changing climate by fostering socio-economic benefits. In this context, productive uses and community services play a pivotal role.

### Productive uses

Productive use is defined as all agriculture or commercial activities, which generate income (EU Energy Initiative Partnership Dialogue Facility, 2015, p. 4 and World Bank, ESMAP 2017, p. 12). Electricity access enables various applications that contribute to productive uses serving as income-generating activities (compare Figure 9). Hereby, some applications are only feasible with higher capacity levels usually provided by mini-grids, referring to the high demand case as described in Figure 6.

Typical productive uses are related to ***agricultural activities and food security***. Climate change induced extreme weather events such as droughts, floods and storms and higher probability of pests and diseases increase the likelihood of partial or total failures of harvest (IPCC 2014, p.512). This has a significantly negative impact on the livelihood conditions of millions of smallholders. Hereby, access to electricity for irrigation, processing equipment or early warning systems entails significant benefits to increase the resilience of farmers, particularly smallholders. A typical example of productive use to improve crop yields and shield against global warming hazards is electric-powered farming equipment such as water pumps, fodder choppers, threshers, grinders, and dryers (EUEI 2015, p. 5). Nowadays, this equipment is often provided with solar-based off-grid power supply.

But power access also allows an increased productivity of other existing ***commercial services*** through e.g. extended operation hours, mechanization, and preservation of products or enhanced communication. Typical examples of such productive uses are lightning, cooling, grinding, milling, drying, smoking, expelling, transportation or access to information via mobile devices and internet ( Lecoque and Wiemann 2015, p. 5). It also enables diversification of activities moving beyond traditional structures and ideally leverages other kinds of investments in various business activities. Consequently, electrification can stimulate employment and generate additional income (Cook 2013, p. 25). Particularly beneficial are off-grid RE solutions for ***Small & Medium Enterprises (SMEs)*** that can generate increased productivity, income and business development with enabled productive uses. Regarding future activities, they can scale up, diversify and expand their production. Several case studies have explored the impact of SME electrification through off-grid RE solutions, demonstrating the ability to scale up their business by expanding their production and staff, meanwhile developing new projects and securing financing (see e.g. IRENA (2018), p. 16; Kirubi et al. (2008) or Obeng et al. (2010),p. 229).

However, the correlation between electrified productive uses and economic growth is not linear. Development progress does not solely occur because of electrification, but in the context of many socio-economic factors contributing to it. The contribution of electricity to this development process depends on the availability of financial and human resources, the level of prior development, the political framework, the quality of implementation, the precondition of general market access and the reliability of power supply (Fluitman 1983, p. 32 f.). Thus, the possibilities for productive uses are highly dependent on the local context.

**Figure 9:** Energy services for productive uses and related income-generating values (adapted from World Bank 2017, p. 54)

| Energy services | Income-generating value | Applicable energy technology |
|---|---|---|
| Irrigation | Better crop yields, higher value crops, greater reliability of irrigation systems, enabeling of crop growth during periods when market prices are higher | **SHS**, Mini-Grids |
| Illumination | Reading, extending operating hours | **SHS**, Mini-Grids |
| Grinding, milling, husking | Creation of value-added products from raw agricultural commodities | **Mini-Grids** |
| Drying, smoking (preserving with process heat) | Creation of value-added products, preservation of products that enables sale in higher-value markets | SHS, **Mini-Grid** in combination with solar heat |
| Expelling | Production of refined oil from seeds | SHS, **Mini-Grid** in combination with solar heat |
| Transport | Reaching new markets | **Mini-Grids** for e-mobility charging |
| TV, radio, computer, internet, telephone | Support of entertainment businesses, education, access to market news, co-ordination with suppliers and distributors | **SHS**, Mini-Grids |
| Battery charging | Wide range of services for end-users (e.g., phone charging business) | SHS, **Mini-Grids** |
| Refrigeration | Selling cooled products, increasing the durability of products | SHS, **Mini-Grids** |

## Community services

Besides productive applications for smallholders and the private sector, also the public sector can gain benefits from off-grid electrification. Public entities providing essential services like water or health as well as administration and security have the potential to improve their reliability, operations and services for the population (IRENA 2018, p. 15). For instance, off-grid RE systems can have direct as well as indirect benefits for ***healthcare.***

Directly, they provide reliability and resilience by securing medical cooling chains or supporting secondary electricity supply for hospitals during black-outs (Hirsch et al. 2018, p. 406). ***Early warning systems*** alert the public and health authorities before disasters occur, also in rural and less developed areas (Lowe et al. 2011, p. 4624). Furthermore the above discussed off-grid solutions for agriculture and water access can address malnutrition and related health challenges (Hirmer et al. 2017, p. 926).

Indirectly, the usage of renewable energy sources in households can also improve the health conditions for inhabitants. When switching from fossil fuel-based energy sources to renewables, ***pollution levels are lowered,*** reducing also the probability of respiratory diseases and eye problems (GOGLA 2018, p. 16).

Extended access to information via computers or mobile phone can also improve ***administrational services*** (Hirmer et al. 2017, p. 925). A case study from Peru has shown that off-grid energy can also be used to improve communication and entertainment services, improving the living standard of the local community (Yadoo et al. 2012, p. 598). Finally, off-grid RE can also ***improve education.*** Hirmer et al. (2017, p. 925) summarize the improvements through renewable off-grid energy ***that benefits education*** in rural areas: Extended lightning, access to computer and mobile phones (information, improved digital literacy), radio (information, awareness of current events), television (access to informative programs) and school workshops and laboratories. However, they only unfold their potential benefits if other factors, such as adequate infrastructure, financial support for further educational equipment, human resources like teachers and time for further studying are given.

## Socio-economic aspects

Based on the direct productive uses and community services described above, off-grid RE technologies can create positive long-term impacts for the socio-economic development of society (Chaurey et al. 2004, Parikh et al. 2012, Kanagawa et al. 2008). According to the UN (2012), electricity supply represents in this context a "golden thread that connects economic growth, social equity, and environmental sustainability".

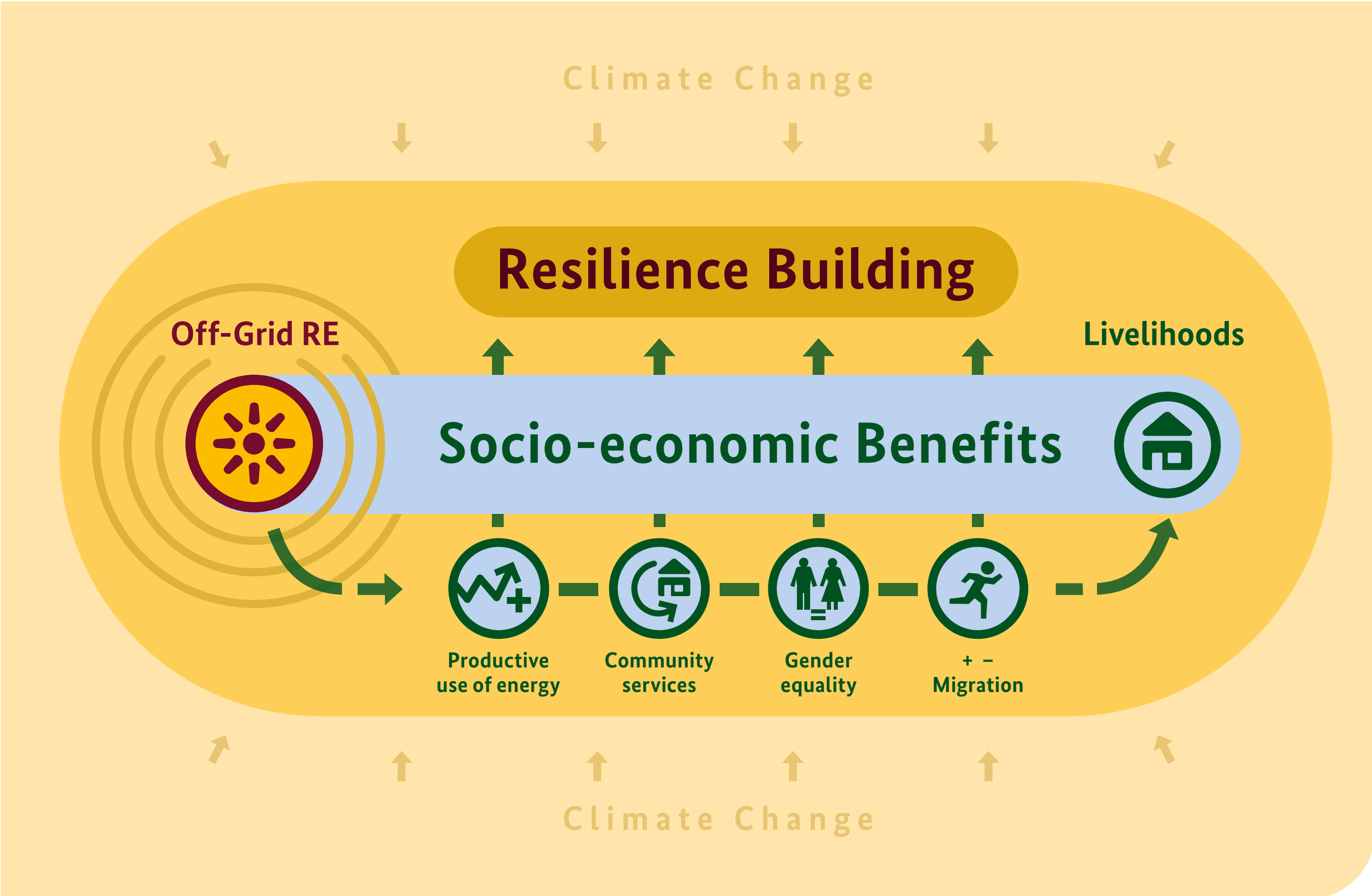
Economic growth induced by electrification can lead to growing employment opportunities and ***income-poverty reduction.*** According to studies, SHS users were able to increase their existing working hours and income while also various new jobs can be created. These are created throughout the entire value chain of off-grid renewables from the installation and supervising of the systems to productive use of energy which for example leads to longer opening hours of shops through lighting (GOGLA 2018, p. 15, Acumen 2017, p. 22). Furthermore, depending on generation costs of the off-grid RE electricity, households or small enterprises can save money when substituting fuels such as kerosene in the mid- to long run (GVEP 2011, p. 5). The favorable outcome for poverty alleviation therefore depends very much on the individual technology, applicability, stable financing and management.

As access to electricity can be especially beneficial for the livelihoods of women, it contributes to ***gender-equality.*** With access to lighting, they are less exposed to safety risks such as sexual and gender-based violence during the night (UNHCR 2015, p. 16). As women in most countries with more traditional role sharing models spend more time in-house than men, they are usually more exposed to toxic fumes from traditional fossil fuel-based energy generation (Berkeley Air Monitoring Group 2018, p. 7f.). Better water pumping facilities and applying washers or dryers can reduce the time spend on typical tasks for women in many communities (Cook 2013, p. 23; Hirmer et al. 2017, p. 925). Access to renewable energy therefore can lead to increased gender equality through improved safety conditions and health levels as well as provide women with more opportunities to save time and generate income.

Finally, off-grid RE can contribute to changes of ***migration patterns*** (compare e.g. IOM 2019, Morales 2017, p. 15). With regards to forced displacement primarily due to climate change induced extreme weather events, off-grid RE technology can mitigate global warming with emission reductions of 210–870 million tons $CO_2$ in the timeframe 2017 to 2030. More important, off-grid solutions can contribute to improved livelihoods of populations that lack access to electricity. The resulting impact is twofold: On the one hand, people can use increased income from productive uses for mobility towards livelihoods with better socio-economic chances (compare Haas 2010, p. 10). There are indications that enhanced income levels initially contribute to an increase of migration and with increasing wealth and income levels, this trend reverses over time and migration flows tend to decrease. On the other hand, lack of energy access is strongly and mutually interconnected with maladaptation such as food insecurity, vulnerability to climate change, economic conditions and lack to social services that are recognized as migration drivers.

Off-grid electrification can address these shortcomings and therefore reduce the motivation to migrate as it contributes through various applications to increased livelihoods and climate change adaptation as discussed above. Thus, the precise impact of improved livelihoods on increased or decreased migration flows is therefore highly contextual and cannot be generalized. Nevertheless, there is strong evidence that off-grid RE significantly enhances the opportunity of the affected population to ***voluntarily decide whether to migrate*** or not.

**Figure 10:** Nexus between off-grid RE and livelihoods




Summarizing the co-benefits of off-grid electrification show a strong positive impact of electricity access on climate action but also other important SDGs, such as gender equality (SDG5), health (SDG3), and economic growth (SDG8). As off-grid solutions can be more flexible, reliable and directly adopted to the local energy needs, they often represent a smarter solution than grid extension, allowing a cost-effective and clean way of quickly harnessing the co-benefits of SDG7.

# Key Barriers and Solutions for Off-Grid Electrification

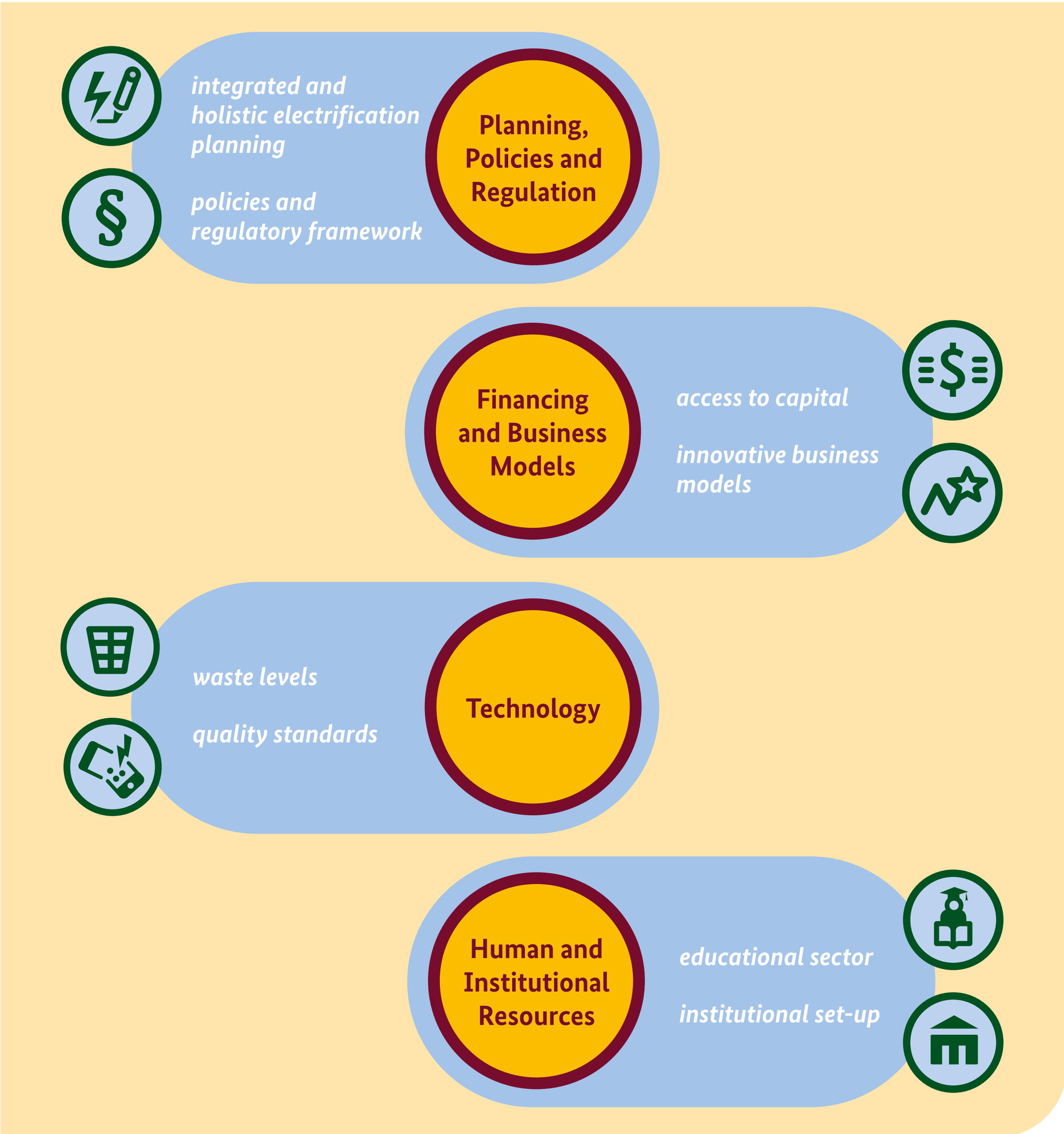
- The successful development of off-grid RE requires appropriate ecosystem frameworks.
- The four key dimensions include Planning, Policies & Regulation, Financing and Business Models, Technology as well as Human & Institutional Resources.
- Typical barriers and suitable solutions for the ecosystem dimensions can be identified on a global level but country-specific conditions need proper reflection.

Off-grid technologies are a key driver in achieving SDG7. Still, their implementation lacks the necessary speed to achieve universal electricity access by 2030. The application of off-grid solutions in recent years has generated helpful lessons-learned about key barriers that hinder a rapid success as well as suitable solutions addressing those. In order to facilitate a more rapid development, the following section further expands on these barriers and related best-practice solutions that are able to address the remaining challenges for off-grid RE development. The rise of off-grid RE solutions over the past years has been enabled by support frameworks. Within the off-grid community there is a lively debate around what includes such favorable ecosystems. Several approaches have been proposed, for example by the International Renewable Energy Agency (IRENA), the World Bank (WB) and the SELCO

Foundation (see e.g. IRENA 2017 and 2018, Hande et al. 2015). As a synthesis of these approaches, the framework presented in Figure 11 reflects four main dimensions. An analysis of each dimension, considering differences between SHS and mini-grids, reviewed the most recent studies and market reports on off-grid RE application (for example GOGLA 2019, HYSTRA 2017, IEA 2017, IFC 2018, IRENA 2017) and included interviews with relevant implementation stakeholders[5]. The assessments' results point out typical barriers and shows solutions for each of the four dimensions.

A brief description of the identified key barriers and best-practice solutions for the promotion of off-grid RE is outlined below.

**Figure 11:** Ecosystem to support off-grid RE solutions




5 Interviewees included representatives from AMMP Technolgies B.V., atmosfair, Fosera, GIZ, GOGLA, SACREEE and Solarkiosk.

## Planning, Policies and Regulation

The public sector plays a vital role for integrating off-grid solutions into the process of achieving universal energy access and can encourage private sector activities with sector-enabling policies and regulations (IFC 2018, p. 150f). The first lesson learned in this regard is that ***integrated and holistic electrification planning*** is key for supporting off-grid RE. This means that electrification planning provides an effective way to ensure electricity access. Including electrification planning in official strategies mitigates risks for businesses and investors (IFC 2018, p. 157, GOGLA 2019, p. 34). Another takeaway addresses the lack of awareness about off-grid RE among potential consumers.

To overcome this barrier, there are some examples from African countries for public-sector supported awareness campaigns (e.g. announcements on TV, radio, newspaper) (GOGLA 2019, p. 48f; Acumen 2017, p. 28ff). A specific barrier for mini-grids that can be addressed by the public sector is the absence of suitable ***policies*** and a ***regulatory framework***. As mini-grid technology comes with long-term investment frameworks and high up-front costs, a defined regulatory framework is an important prerequisite, including tariffs or environmental, safety and service standards (World Bank 2017, p. 36, Hystra 2017, p. 59; IRENA 2016). In the context of appropriate regulation, fiscal incentives make technology solutions affordable for the local market.

The public sector can support off-grid RE in this regard by allowing a reduction of or exemption from the value-added tax (VAT) or import tariffs for whole products or parts of those, in case manufacturing takes place locally (IFC 2018, p. 158, GOGLA 2019, p. 37ff, World Bank 2017).

## Financing and Business Models

According to SEforALL and CPI (2019, p. 12), current financial flows to off-grid electrification of about USD 430 million in 2017 for off-grid electrification are still modest compared to the required investment needs. The particular challenge for most actors in developing countries is ***access to capital.***

To establish operational, international or domestic market players in the off-grid RE sector, public funding can represent helpful support in form of early-stage equity and grants at seed stage. It is used to mobilize additional private finance capital, to absorb certain costs (e.g. financing due diligence or feasibility studies) or to de-risk the investment (GOGLA 2019, p. 44f, Acumen 2018, p. 16ff). Apart from public funding, there are also private investors, which have become strong partners of the off-grid RE industry. These include large impact investors, crowd funding as well as foundations and family offices (IFC 2018, p. 112ff). At the same time, as it remains difficult for off-grid RE industry stakeholders to secure commercial finance capital.

The reluctance of many banks is due to the persisting high-risk perceptions for off-grid technologies, for example based on low-income households as target groups or a lack of finance performance data for credit evaluation (IFC 2018, p. 116f, HYSTRA 2017, p. 61f). This barrier will be resolved once there are more business cases for off-grid RE available, but can be addressed in the meantime through public funding as a complementary source to mitigate the anticipated risk. Another aspect related to financing deals with the sources of funding or supply of equipment. As the majority of funding in the sector is coming from international sources and technological equipment is usually purchased in foreign currency while targeted markets often face currency volatility, off-grid stakeholders experience significant foreign currency risks. Companies therefore need to mitigate such risks by e.g. increasing local currency funding, forex hedges or off-balance-sheet financing (IFC 2018, p. 122f, GOGLA 2019, p. 43). A further important aspect are appropriate, ***innovative business models.*** For instance, pay-as-you-go (PAYGO) systems, which can be used as a rent-to-own model (i.e. regular payments lead to ownership) or as a perpetual leasing model (i.e. paying for energy consumption without acquiring ownership) have recently accelerated the spread of off-grid solutions (Acumen 2017, p. 23ff, HYSTRA 2017, p. 41ff). Using PAYGO as a business model approach can provide an opportunity for companies to reduce transaction costs by offering flexible financing models and builds on synergies with the expanding market of mobile money.



## Technology

With regards to the technological side of off-grid solutions, scalability of renewable energy as well as the technological innovations infor sales and monitoring activities have contributed to the growth of the sector (IRENA 2017, p. 88f). Between 2010 and 2016 prices for certain products in the off-grid sector declined significantly due to improved product economics, especially for SHS (IFC 2018, p. 46ff, HYSTRA 2017, p. 39). In the service section, mobile-based applications have contributed to an improvement of processes for providers of off-grid solutions. In the case of SHS, the work of field staff can be monitored through a mobile phone application, which has become common practice of companies such as Mobisol or Lumos (HYSTRA 2017, p. 47). The need for defined ***quality standards*** is also a particular barrier for SHS. To avoid that low-quality products overstock the market and cause reputational damage for off-grid RE solutions, respective quality standards, such as the World Bank's Lightning Global Standard, can be introduced for imported or locally manufactured products (GOGLA 2019, p. 46f). Although current ***waste*** levels produced by the off-grid sector are rather neglectable, broken or unused products can become an increasing problem with larger volumes of distributed off-grid systems in the future. Thus, appropriate technology standards are required to products off-grid products leading to minimized e-waste (GOGLA 2019, p. 50f).

## Human and institutional resources

The growing off-grid sector demands human capacity across different dimensions that mainly rely on the local labour market and ***educational sector.*** To create an enabling regulatory ecosystem and enforcing quality standards, the public sector requires a suitable ***institutional set-up*** and sufficient human capacity. Donor support programs can provide capacity building in relation to managing the off-grid solar market, while governments are urged to dedicate sufficient resources towards this purpose (GOGLA 2019, p. 47). Another stakeholder in need of qualified staff is the off-grid RE industry. Private sector companies engaged in the off-grid market hire local staff for all activities alongside the value chain, mainly in distributional and technical roles and partly in local manufacturing (GOGLA 2019, p. 41). Governments can support the sector with skilled labour by providing dedicated curricula and vocational trainings within their education system (GOGLA 2019, p. 42). As challenges in relation to commercial finance for off-grid projects have shown, the financial sector also faces significant shortcomings in market expertise. On the one hand, many commercial banks are unable to address requests by off-grid project developers due to the unfamiliarity with characteristics of the market and therefore need capacity building programs. On the other hand, there is also a lack of capacity amongst project developers to successfully access grant and concessional financing for their projects. Thus, the sector needs an increasing number of professionals familiar with off-grid RE investments. Dedicated capacity building programs can address this problem (SE4All 2018, p. 70).

# Implementing Solutions – International Support and the Role of NDCs

- Many developing countries will need substantial international support to set the enabling frameworks necessary to achieve universal electrification by 2030.
- The UNFCCC and the Paris Agreement support climate action through financial resources, capacity building and technology transfer.
- Under the Paris Agreement, countries communicate their needs with NDCs.
- Since NDCs rarely reflect off-grid RE yet, many countries can improve the communication of their ambitious off-grid electrification targets and support needs in the upcoming NDC revision.
- The Deep Dive Case Studies (Ethiopia, Nigeria, Madagascar) confirm the need for strong international support and an enhanced reflection of off-grid RE targets and needs in the respective NDCs.

Many developing countries, particularly Least Developed Countries (LDC), require international support to achieve the ambitious goal of universal electrification by 2030. Since off-grid REs significantly contribute to climate action elements including mitigation and adaptation, the international framework under the United Nations Convention on Climate Change (UNFCCC) can play an important role to leverage the necessary support.

In this context, the Paris Agreement (PA), adopted by 192 Parties to the UNFCCC in 2015, ***includes three dimensions of support from developed to developing countries.*** Based on Article 9, the Conference of Parties (COP) decided that developed Parties have to provide at least USD 100 billion per year of financial resources from various sources such as public funds and mobilized private climate finance to developing countries (UNFCCC 2015, CP21). These funds shall enable the recipients to pursue a low-carbon and climate-resilient development pathway (compare UNFCCC 2015, Article 2). Further, the PA stipulates ***technology transfer and capacity building*** as means of support (UNFCCC 2015, Article 10 and 11). To date, UNFCCC institutions and developed Parties have already initiated several support initiatives for off-grid RE development. To address several of the identified ecosystem barriers, various bilateral and multilateral activities have been initiated, providing direct subsidies, financial risk-mitigation, policy development, technical assistance and capacity building[6]. The most prominent UNFCCC related institutions and initiatives that are universally accessible by developing countries comprise:

- ***The Global Environment Facility (GEF):*** The GEF provides financial support and capacity building for renewable energy access for transition and developing countries. Since its establishment the GEF has invested more than USD 1.1 billion in 249 stand-alone renewable energy projects, as well as USD 277 million in 54 mixed projects with renewable energy components, in 160 different countries. In collaboration with the SCCF (Special Climate Change Fund), the GEF has also launched the Climate Resilience and Adaptation Finance & Technology Transfer Facility (CRAFT). The initiative was the first private sector climate resilience and adaptation investment fund and technical assistance facility for developing countries globally. Other initiatives also aiming to improve adaptation to climate change in developing countries are: Scaling-up of Renewable Energy Technologies in Rural Cambodia (S-RET) and RLACC - Rural Livelihoods' Adaptation to Climate Change in the Horn of Africa (PROGRAM). Both aim to provide rural communities with energy access to improve adaptation to climate change through financial support and capacity building from the GEF and the SCCF.
- ***The Green Climate Fund (GCF):*** The GCF has been established as one of the main institutions for channeling a substantial part of the USD 100 billion to developing countries. According to its mandate, it has to balance resources equally between mitigation and adaptation activities. To date, the GCF supports two mini-grid development programs in Africa with co-financing from the African Bank for Development (AfBD). One of them is the Democratic Republic of Congo (DRC) Green Mini-Grid Programme, which will finance three pilot solar PV plants and battery storage via loans. The program is estimated to result in a reduction of about 560,000 t $CO_2$ over the 20-year lifespan of the project. The second is the Yeleen Rural Electrification Project in Burkina Faso, which aims to create a paradigm shift towards low-emissions electricity access by providing supportive environments for the private sector to operate solar mini-grids. The project will include installing 100 mini-grids in Burkina Faso. The project is estimated avoid 390,000 t $CO_2$ of GHG emissions. In collaboration with the AfDB, GCF has also launched its "Desert to Power (DtP)" initiative, which aims to light up and power the Sahel by building electricity generation capacity of 10 GW through photovoltaic (PV) solar systems via public, private, grid and off-grid projects by 2025.

6 For instance, a donor mapping by DEM identified more than 65 active initiatives for renewables in Southern- and East-Africa only, many focusing on off-grid solutions.



Besides these institutions under the financial mechanism of the UNFCCC, various other multilateral and bilateral programs and initiatives are in place that often focus on specific regions. Thus, most Multilateral Development Banks (MDBs) include support for off-grid RE in their portfolios. Particularly the World Bank (WB) is active in promoting off-grid RE support in various ways. According to WB information, it approved USD 600 million in 2017 to financially support the development of off-grid RE systems[7] and intends to continue such levels of. Also the Climate Investment Funds (CIFs), along with MDBs, provided more than USD 140 million of financial resources for a Scaling Up Renewable Energy Program in Low Income Countries (SREP) to improve energy access in off-grid communities. Many other industrialized countries and the EU engage bilaterally in fostering off-grid RE implementation.

An important link from national planning to international climate policy and finally to the mobilization of international support are ***Nationally Determined Contributions (NDCs).*** These documents represent the centerpiece of the PA, embodying efforts by each country to reduce national emissions and adapt to the impacts of climate change. In this context, developing countries also inform about their financial needs to implement the defined activities. An analysis of the intended NDCs revealed total financing needs for NDC implementation of USD 4.4. trillion or about USD 350 billion annually (compare Weischer et al. 2016). A significant share[8] of these activities are conditional actions, subject to international financial support. Thus, NDCs are used as a key instrument to inform about financial- as well as capacity building- and technology transfer support needs. With regards to off-grid RE, developing countries have been reluctant to provide information about targets and financial needs. Of all 182 submitted NDCs, only about 25 refer to off-grid solutions. Despite the limited GHG reduction potential of off-grid RE, the majority of NDC formulate mitigation targets. Only four countries reflect off-grid RE solutions in the context of adaptation and increased resilience. With regards to required support means, only very few inform about related financing needs. In conclusion, there is a great chance to streamline international support and link electrification with climate action. Parties that intend to further develop RE off-grid solutions might consider reflecting related targets and support needs in their upcoming revision of the NDCs that is due by 2020 (see United Nations, 2015, CP21/23 & 24 and Paris Agreement Article 4.2).

In the absence of formal guidance by the PA or technical guidance from the UNFCCC Secretariat, Parties are free to decide on the nature and form of their NDC update. For many Governments, the NDC revision process is embedded in several parallel and synchronized planning processes, considering potentially more ambitious mitigation and adaptation objectives. In this context, the respective Ministries, e.g. Ministry of Energy or Ministry of Environment are usually responsible to provide detailed information for reflection in the NDC. Typical elements that should be considered during the NDC revision (compare e.g. Weischer et al.):

a. ***Reflecting off-grid RE in the mitigation and adaptation section of the NDC:*** As described, current NDCs mainly refer to mitigation benefits. Hereby, Parties can describe the (relative) mitigation potential or target of off-grid RE solutions. Alternatively, or in addition, the adaptation and sustainable development benefits of improved livelihoods can be communicated. In both cases, it can be considered to raise the ambition of the off-grid RE targets as the INDC elaboration five years ago potentially reflected different circumstances and market environments.

7 See https://www.worldbank.org/en/news/feature/2018/07/10/the-race-for-universal-energy-access-speeds-up

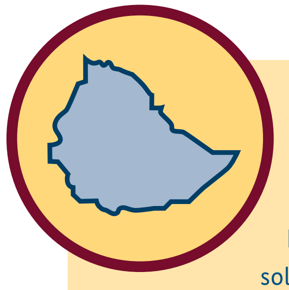
8 The precise volume of conditional financing needs is unclear, as the communication across NDCs is not sufficiently comparable and often lacks informational details.

**b.** ***Quantifying costs and financing needs:*** The first round of NDC submissions provided only limited information on costs and financing needs. To enhance planning processes, Parties should be encouraged to improve the information quality with regards to quantified investment needs, costs and financing strategies for the envisaged mitigation and adaptation activities. Also, related timeframes for financial flows as well as currency requirements for e.g. technology imports can be reflected.

**c.** ***Conditional and unconditional elements:*** In their NDCs, Parties can highlight what they can achieve unilaterally and what is conditional on external support. Hereby, NDCs represent helpful vehicles to communicate international support needs about financial-, technology- and capacity building requirements. Based on the experience of the first round of submitted NDCs, it would be helpful to include the precise type of condition, e.g. financial support, intended application of market mechanisms, capacity building or technology transfer (compare identified categories in Weischer et al. 2016, p. 12).

## Deep Dive Results

**The study includes three country deep-dives that aim to assess the respective status-quo of off-grid RE development, the way forward and how it is reflected in the countries' NDC as well as an identification of support gaps and promising solutions. The results are compared to the global findings presented in the previous chapters.**

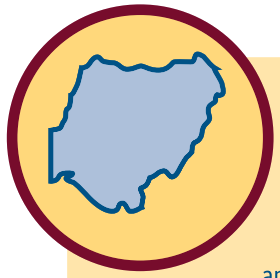


**Ethiopia** has one of the lowest rates of electrification, only about half of the population has access. However, electrification targets are highly ambitious. Universal access shall be achieved by 2025, predominantly powered by grid-connected large-scale hydropower plants that face challenges in construction and operationality. Thus, off-grid solutions are envisaged to bridge the time until grid-connection can be realized with a short-term electricity access share of 35%.

Despite strong efforts from international donors, off-grid RE implementation continues slowly, especially due to inadequate access to foreign currency required for the import of technology, insufficient institutional capacity and the lack of an appropriate ecosystem framework for the private sector. Particularly, missing regulation of tariffs, standards and the integration of privately operated mini-grids or SHS into the grid-expansion hinder private engagement.

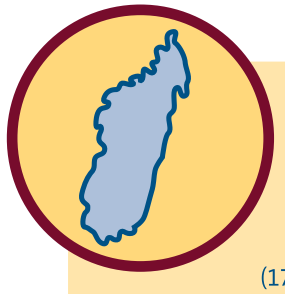
International support will be pivotal to achieve the ambitious electrification targets. The country requires foreign capital, capacity-building, institutional support as well as technology transfer. Ethiopia has not prominently placed these support needs in its Intended NDC but will have the chance to do so in the 2020 revision. It has the opportunity to integrate its ambitious electrification goals with conditional elements and quantify the financial needs. Hereby, it would be appropriate to focus rather on the adaptation and sustainable development benefits in the context of climate action, instead of emphasizing mitigation benefits that are rather neglectable due to the low grid emission factor.





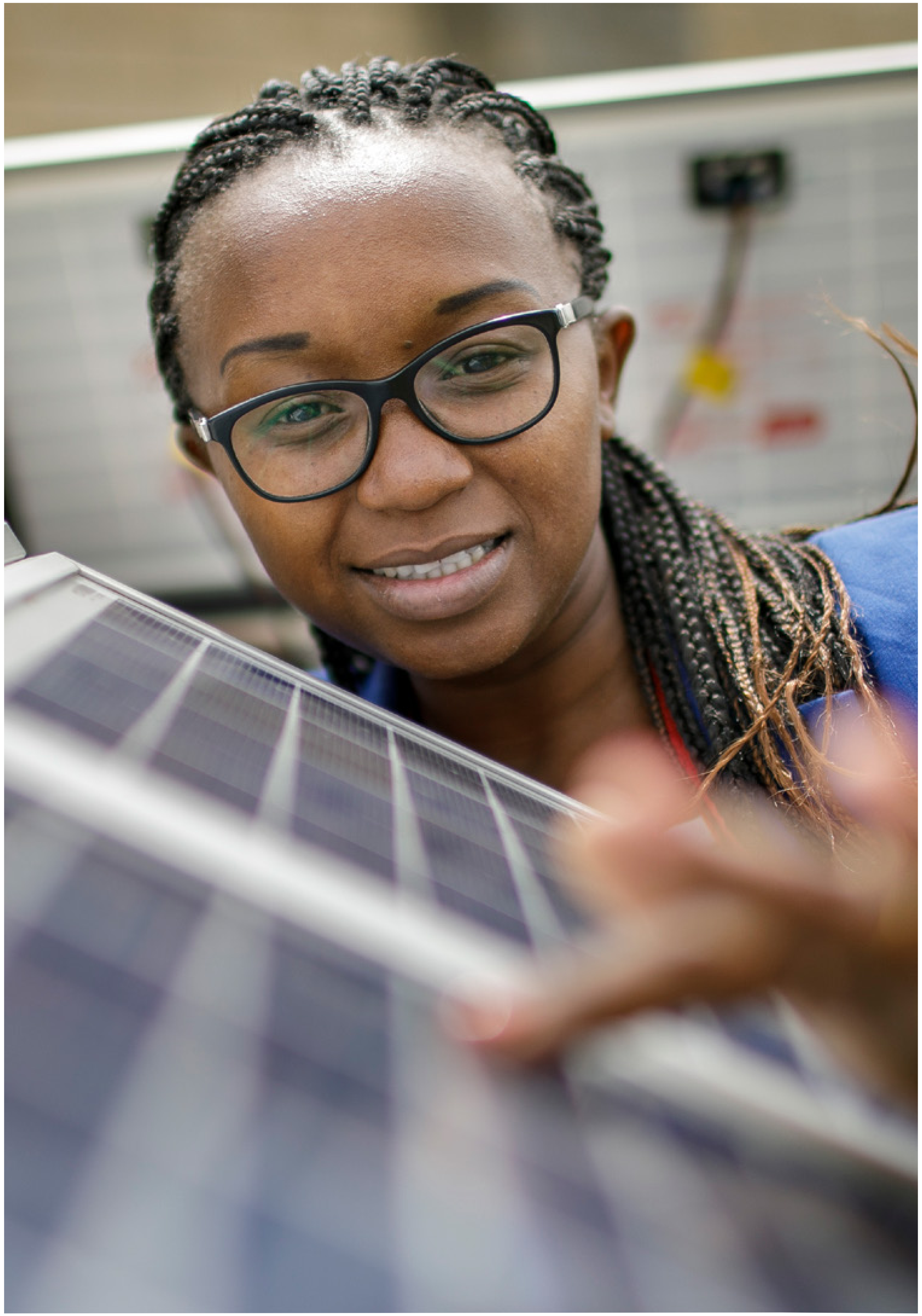
**Nigeria**, as a lower-middle income but highly vulnerable country with more than 42% of the population lacking access to electricity, faces energy poverty as the single largest brake on development. The national plans including Nigerias NDC foresee universal electrification by 2040 and solar off-grid targets while emphasizing development benefits and economic growth. Despite regulatory complexity and remaining uncertainty, the deep dive analysis has revealed strong dynamics in the off-grid sector during the recent years.

To achieve the Nigerian electrification target, strong domestic and international investments are required. This can be realized by private finance flows as well as public support initiatives, particularly first-loss loans or guarantees. Despite the advantages of decentralised solar PV, Nigerian SMEs are still struggling to design, commercialise and scale solar PV products to replace fuel generators. Nigerian industry partners indicate that this is due to a poor understanding of diverse productive consumer needs, technical challenges in the design of suitable products and services and a lack of matching financing and business models. Hence, the development of a strong pipeline of investable projects, both those proposed by the government and by the private sector, has proven challenging. Also, the current policies and regulations represent a barrier for further off-grid RE development. Quality standards, more favorable import tariffs and an appropriate mini-grid regulation are required. In terms of improved governance, the planning process could better synchronize alignclimate action under the UNFCCC and the countries SDG targets better, particularly in the field of food security. Thus, Nigeria should consider that off-grid RE can be included in both the mitigation and adaptation parts of the NDC and is encouraged to communicate strengthened targets and flag conditional elements in the upcoming NDC revision.

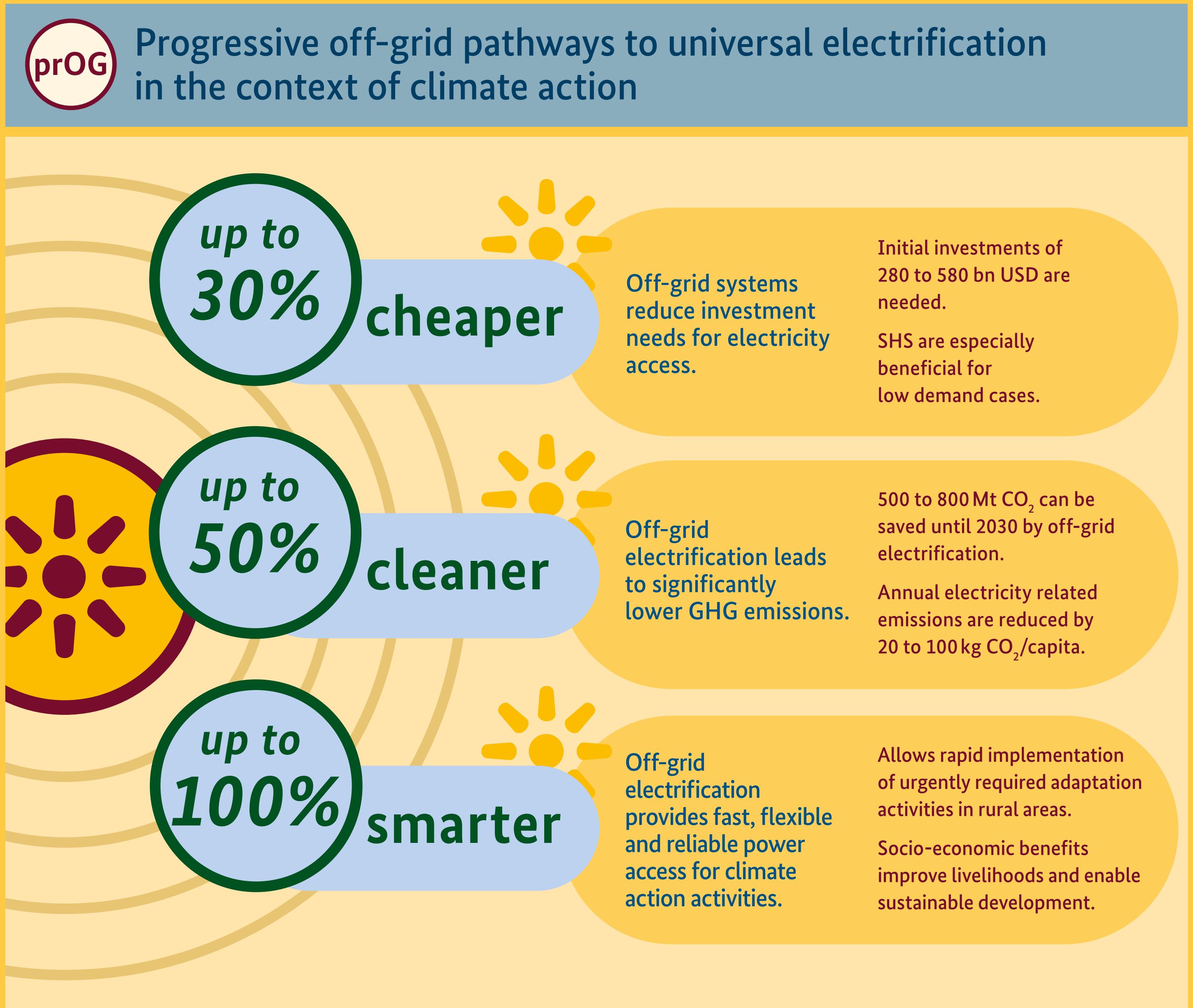


**Madagascar** is among the poorest countries in the world with 75% of the population living on less than $1.90 per day. It has an electrification rate of 23.0% in 2017, considering both urban and rural populations. This is one of the lowest rates in sub-Saharan Africa with considerable disparities between urban areas (67.3%) and rural areas (17%). The National electrification plan foresees a 70% electrification rate in 2030, considering both on-grid and off-grid technologies. A lack of reliable data as well as poor stakeholder coordination and low institutional capacities severely complicate the electrification planning process. The end users' very low ability to pay as well as insufficient financing and subvention mechanisms make it less attractive for private operators to launch electrification projects. The implementation of regulations is furthermore necessary to foster RE off-grid systems that are already favoured in existing laws. Quality standards for the technologies and appropriate monitoring are important to ensure the sustainability of the electricity systems.

Further international support is necessary to facilitate more holistic electrification planning, e.g. through capacity building, institutional support and primary data collection, processing and management. In its 2015 (I)NDC, Madagascar mentions the promotion of RE and rural electrification in its mitigation section, however it does not specify the actions and related support needs. Revising the NDC in 2020, Madagascar has the opportunity to specifically include off-grid technologies, and quantify the GHG emission reduction potential as well as required financial support. Furthermore, it could include (off-grid) electrification in its adaptation section, as it can further strengthen climate resilience, which is highly relevant since Madagascar is one of the most vulnerable countries to extreme climate events.



# Conclusion and Recommendations




We can clearly state that electrification and climate action should be stronger linked together in the global effort to achieve the Sustainable Development Goals. Off-grid RE can play a new and important role in achieving SDG7 in a cheaper, cleaner and smarter way compared to a centralized business as usual approach.

The findings of our study underline the importance of off-grid RE technologies for global electrification and climate action. National and international institutions as well as the private sector need to work together to urgently implement the recommended mini-grids and SHS for the benefit of the un-electrified populations.

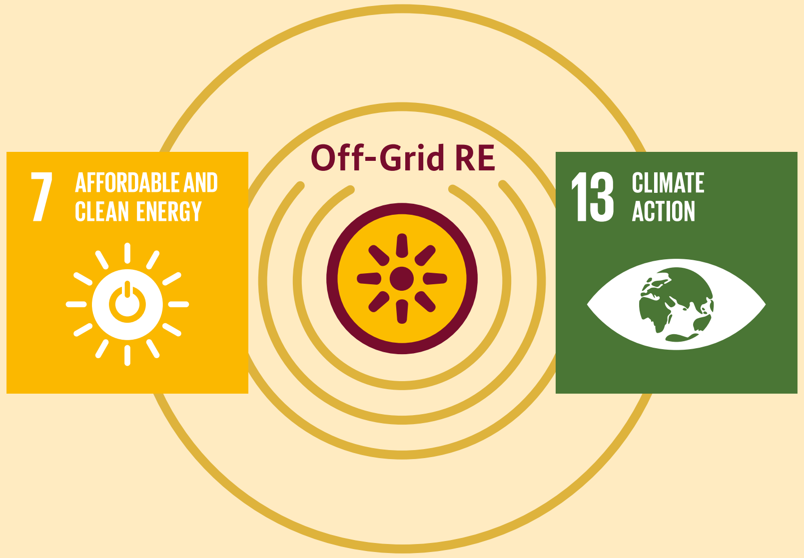
Suggested actions are based on the global and country specific numbers that define the different electrification pathways. The scenarios and demand cases provide boundaries for decision-makers to accelerate off-grid electrification and quickly harvest the important co-benefits to foster rural development and increase resilience of communities. In order to facilitate the implementation of off-grid technologies we suggest to focus on nine fields of intervention, which are derived from the detailed analyses of key barriers and solutions for off-grid electrification and from the country deep dives.

**Policies and regulation:** A major requirement for the expansion of off-grid solutions are appropriate regulatory frameworks. As particularly mini-grid projects have a long-term investment framework and come with high up-front costs, investors need to be certain under what conditions they provide their electricity services to consumers, including tariffs or environmental, safety and service standards. Local policy makers and regulators need to make sure that they set their policies and regulations for mini-grids and SHS as favorable as possible. South-South and other international exchange is needed to support especially those countries with currently weak regulatory frameworks for off-grid electrification.

**Institutional set-up:** Promoting the development of a successful off-grid sector should build on a robust partnership between the government, the private sector and other relevant stakeholders. This requires strong institutional structures that have the capability and capacity to work with the private sector and to follow latest technological innovations. It does not necessarily require the establishment of completely new structures or processes thus should build on existing elements. International capacity-building and capacity-development activities can facilitate the adjustment and strengthening of existing institutions.

**Reflecting off-grid RE in the NDC revision process:** In the context of the Paris Agreement, Parties have to revise their NDCs by the end of 2020. Countries that intend to further develop off-grid RE solutions should consider reflecting related targets and support needs in their upcoming revision of the NDCs. NDCs represent important communication vehicles for conditional mitigation and adaptation activities that require international support such as capacity-building, technology transfer and financial assistance for implementation.

**Access to finance:** In order to achieve SDG 7 by 2030, the identified investment needs of USD ~280 to ~580 billion has to be addressed through facilitated access to finance. Consequently, various actors including commercial investors will have to be mobilized. This requires more capacity building as well as innovative approaches to enhance attractiveness and decrease risk of investments through domestic and international support based on financial and technical cooperation.




**International support:** Many developing countries will not be able to move forward the off-grid RE sector development unilaterally. Most of them are LDCs and SIDS with limited domestic resources, low-income levels, vulnerable economies as well as institutional and human capacity constraints. Thus, they need substantial international support to implement the enabling frameworks necessary to achieve universal electrification by 2030. Multilateral and bilateral initiatives in the context of the UNFCCC and the Paris Agreement support climate action in developing countries through financial resources, capacity building and technology transfer.

**Technology standards & waste management:** To avoid that low-quality SHS and mini-grid components are floodingthe market and cause reputational damage for off-grid RE solutions, respective quality standards should be introduced and enforced. Such standards and management procedures are relevant for the increasing ecological and health related problem from broken or unused products. The challenge of waste management and recycling has to be addressed with systems that are easy to maintain and repair and avoid the usage of hazardous substances. Ideally, a recycling system will be established for products no longer in use, which is self-sufficiently financed through the revenues generated from the resale of materials.

**Integrated and holistic electrification planning:** Electrification planning should not only include least-cost approaches but also focus on the environmental and social impact of electrification measures which further enhances off-grid technologies. This goes in line with improving the local data situation: For any planning institution, but also for international support and designing of financial interventions, it is crucial to have very good knowledge and data of the local situation. Interventions support should enable transparent data gathering and open publishing of relevant data sets. In addition, holistic planning should use off-grid RE electrification as example for decentralized clean energy supply. In that way, central coal power plant projects can be substituted by decentral renewables which avoid locking in fossil fuel energy generation; thus, having a high positive impact on reducing future GHG emissions of grid connected customers.

**Innovative business models:** With commercial funding becoming available only on a slow pace, one of the main remaining challenges is the design and implementation of attractive business models that successfully mobilize private equity. For instance, the PAYG approach can provide an opportunity for companies to reduce transaction costs by offering flexible financing models and builds on synergies with the expanding market of mobile money. However, recent developments have shown that geographical limitations and redemption risks can jeopardize the sustainability of such approaches. Governments, donors and the private sector will have to support the application of innovative approaches in order to expand the distribution of off-grid RE as well as mobilize private capital to close the financial gap.

**Educational programmes:** The public sector including planning authorities such as Ministries, the private sector as well as the financial sector require well-trained employees and experts that understand the specific off-grid RE characteristics. Currently, a lot of training activities remain a responsibility of the respective institutions, companies, banks or project owners. Governments can improve the availability of trained personnel with dedicated education streams within their education system, including e.g. specific curricula at universities or vocational training at technical colleges and schools.

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# Annex – Methods

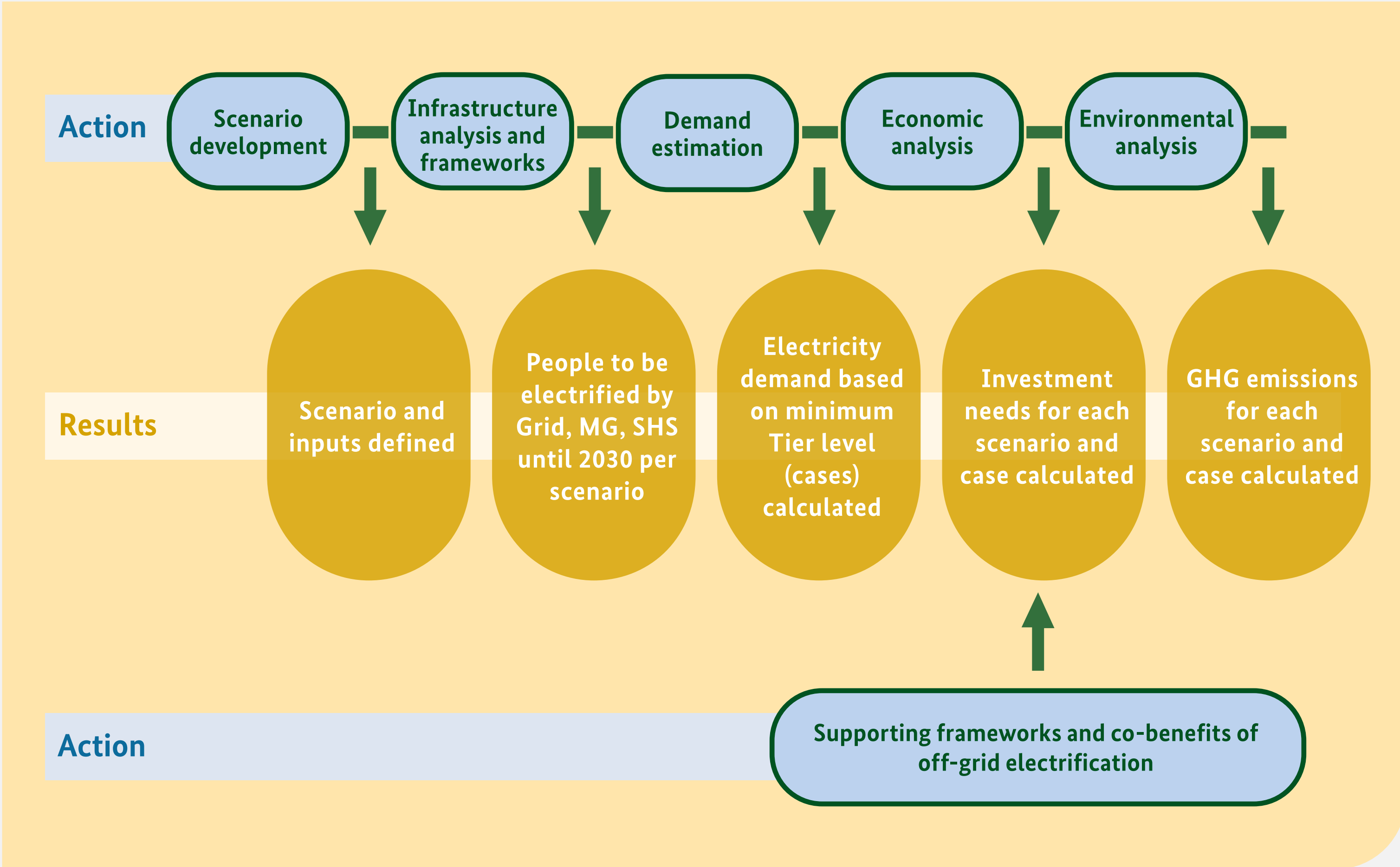
## Methodology for scenario development and electrification solutions

The methodology for calculating and quantifying different electrification scenarios for this study is explained here. It was developed to answer the following main questions:

- How can different electrification scenarios for 2030 look like on a country level?
- What is their climate and economic impact?

The following figure illustrates the stepwise approach for our study.

**Figure 12:** Stepwise approach for quantifying electrification scenarios.



We developed three different scenarios showing potential electrification pathways on how to electrify the people without energy access considering grid extension, mini-grids and solar-home-systems (SHS).

## The Business-as-Usual (BaU) Scenario

***What it shows:*** The Business-as-Usual (BaU) scenario quantifies the number of new technology-specific electrifications (grid extension, mini-grids or SHS) until 2030 by projecting current business-as-usual growth rates into the future.

***How it is obtained:*** Regional projections of electrification rates and technologies are mapped to the country-level and modelled until 2030. The BaU scenario is based on the "New Policies" Scenario of the International Energy Agency's World Energy Outlook 2018).[9]

## The Universal-Electricity-Access (uEA) Scenario

***What it shows:*** The Universal-Electricity-Access (uEA) scenario estimates the number of new technology-specific electrifications (grid extension, mini-grids or SHS) necessary to achieve the universal access goal until 2030. These estimations account for expected population growth rates and current infrastructure and current regulatory frameworks.

***How it is obtained:*** Existing datasets providing night lights, population densities and transmission grids are combined to estimate the number of people lacking access to electricity. Appropriate electrification options are determined based on the remoteness and density of neglected populations. In this way the model estimates the share of people that remain to be electrified by either grid extension, mini-grid deployment or SHS adoption until 2030.

The GIS-based estimates are further refined by accounting for (the lack of) favourable technology-specific frameworks through the integration of ESMAP's RISE Indicators) into the model's calculations.[10]

## The Progressive-Off-Grid (prOG) Scenario

***What it shows:*** The Progressive-Off-Grid (prOG) scenario estimates the number of new technology-specific electrifications (grid extension, mini-grids or SHS) necessary to achieve the universal access goal until 2030. These estimations account for expected population growth rates and current infrastructure and progressive regulatory frameworks.

***How it is obtained:*** Existing datasets providing night lights, population densities and transmission grids are combined to estimate the number of people lacking access to electricity. Appropriate electrification options are determined based on the remoteness and density of neglected populations. For the 2030 horizon, in this way the model estimates the share of neglected people that remain to be electrified by either grid extension, mini-grid deployment or SHS adoption.

In the prOG scenario, the GIS-based estimates are modified to showcase the impact of fully favourable off-grid (mini-grid and SHS) frameworks through the integration of maximized ESMAP's RISE scores into the model's calculations.

In order to identify the non-electrified population on country level, a night light analysis is conducted. This means, satellite images showing light emissions are taken to identify electrified areas. This is combined with spatially dissolved population data to quantify the location and number of people without energy access. The baseline year for this study is 2017. All population figures are extrapolated until 2030 according to the national population growth rates. In conclusion, for all three scenarios the same total number of people "to be electrified until 2030" is taken.

9 https://www.iea.org/weo2018/scenarios/
10 https://rise.esmap.org/

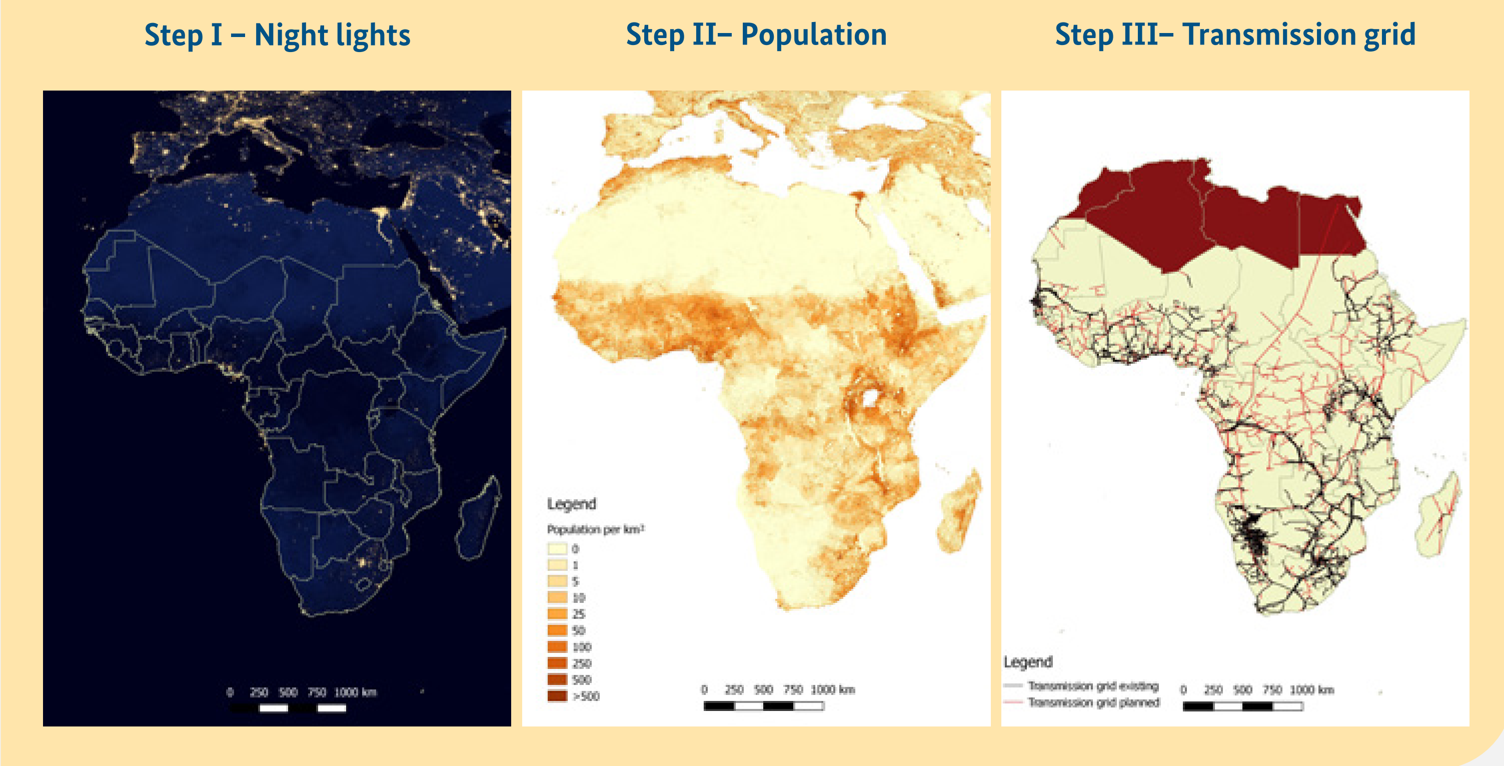


The next step is to assign the electrification mix to the total number differentiating among grid extension, mini-grids and SHS.

For the BaU scenario, the relative values of the IEA. (2017). World Energy Outlook 2017: Special Report on Energy Acces are taken, which are defined in the New Policies Scenario. These values are only available in aggregated form for each continent, thus we took these average values for each respective country. The relative values of the electrification mix are applied to all people to be electrified, which leads to the situation that still people remain un-electrified in 2030.

For both, the uEA and prOG scenario, at first an infrastructural analysis is conducted to understand a realistic electrification mix on country level. The decisive factors for this GIS based infrastructure analysis are night lights for already electrified areas, population density to identify larger settlements and distance to existing grid infrastructure. The occurrence of nightlights determines electrified and non-electrified areas. For non-electrified areas, SHS are assigned to areas with low population density. Areas with high population densities are assigned to grid connection, if within 20 km grid buffer, or to mini-grids, if outside the 20 km grid buffer.

**Figure 13:** Illustration of geospatial input data sets for infrastructure analysis

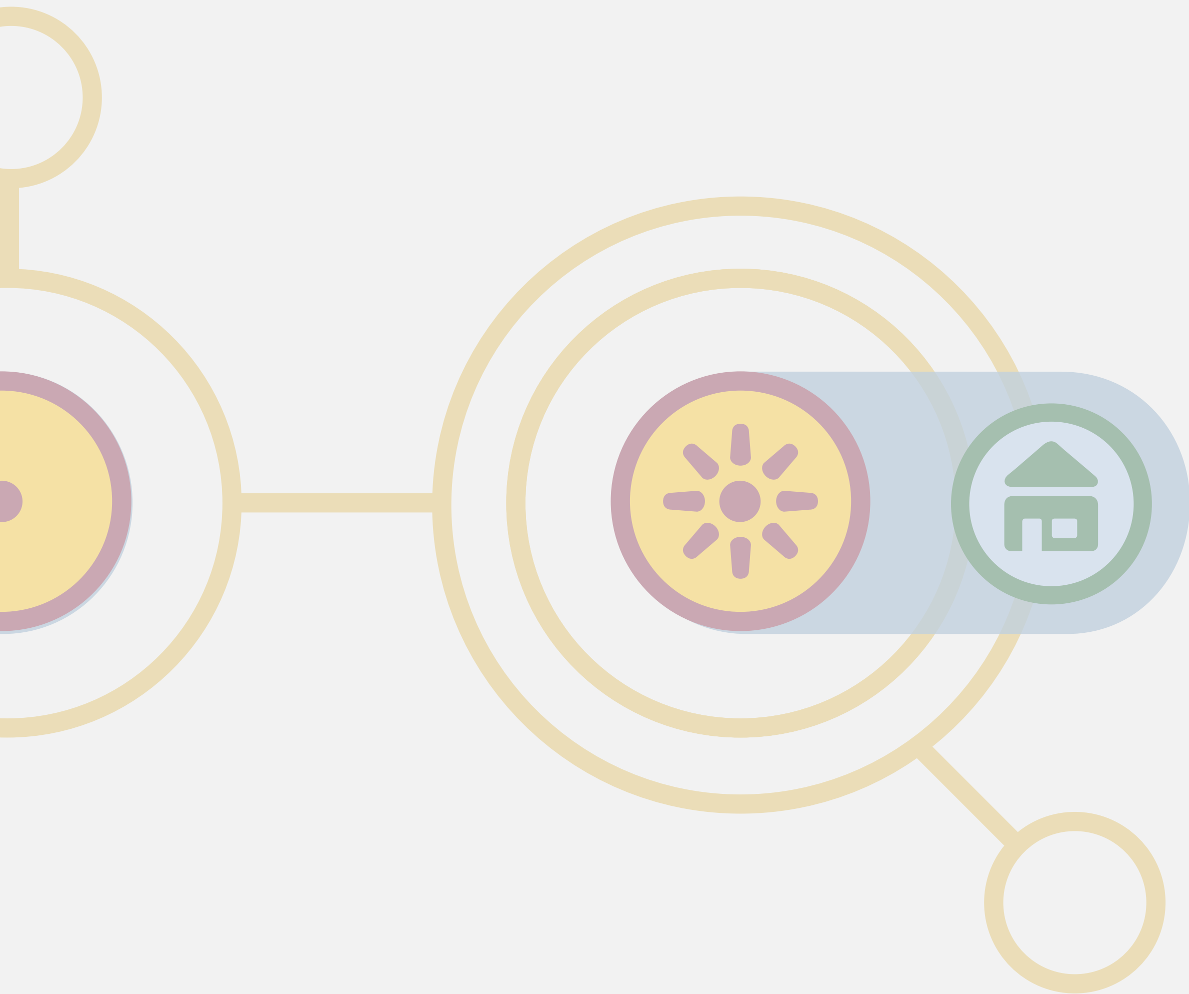



The infrastructure analysis is the same for both uEA and prOG scenario. However, they both differ in terms of the assumptions on policy and regulatory frameworks. The framework used is based on the Regulatory Indicators for Sustainable Energy (RISE) of Worldbank. We focus on 3 out of 8 Indicators within the Energy Access Indicator group reflecting frameworks for grid based electrification, mini-grids, and SHS (cf. Table 7). Taking the electrification mix from the infrastructure analysis as baseline, the RISE indicators can create shifts towards a certain electrification option. The higher the difference between two indicators is [0;100], the higher is the shift from one option to another.

**Table 7:** Illustration of geospatial input data sets for infrastructure analysis

| | RISE3: Grid | RISE4: MG | RISE5: SHS |
|---|---|---|---|
| 1 | Funding support for grid electrification | Existence of national program | Existence of national program |
| 2 | Funding support for customer connections | Financial incentives | Financial incentives |
| 3 | Standards of performance on quality of supply | Standards and quality | Standards and quality |
| 4 | | Legal Framework for MG operation | |
| 5 | | Ability to charge cost- reflective tariffs | |

For uEA the current frameworks are taken to calculate the shift, for prOG the frameworks of mini-grids and SHS are set to the maximum value of 100 to reflect the most progressive off-grid frameworks possible.



## Methodology for demand estimation

After the calculation of the electrification mix, the demand per household needs to be estimated in order to quantify the investment needs and GHG emissions per electrification option. To reflect a broader variety of future developments we defined a lower and higher demand case. The cases are calibrated along the Multi Tier Framework of the Worldbank and therefore called lower and higher Tier Case.

**Figure 14:** Description of lower and higher Tier demand cases

For each scenario we estimate two different demand cases:

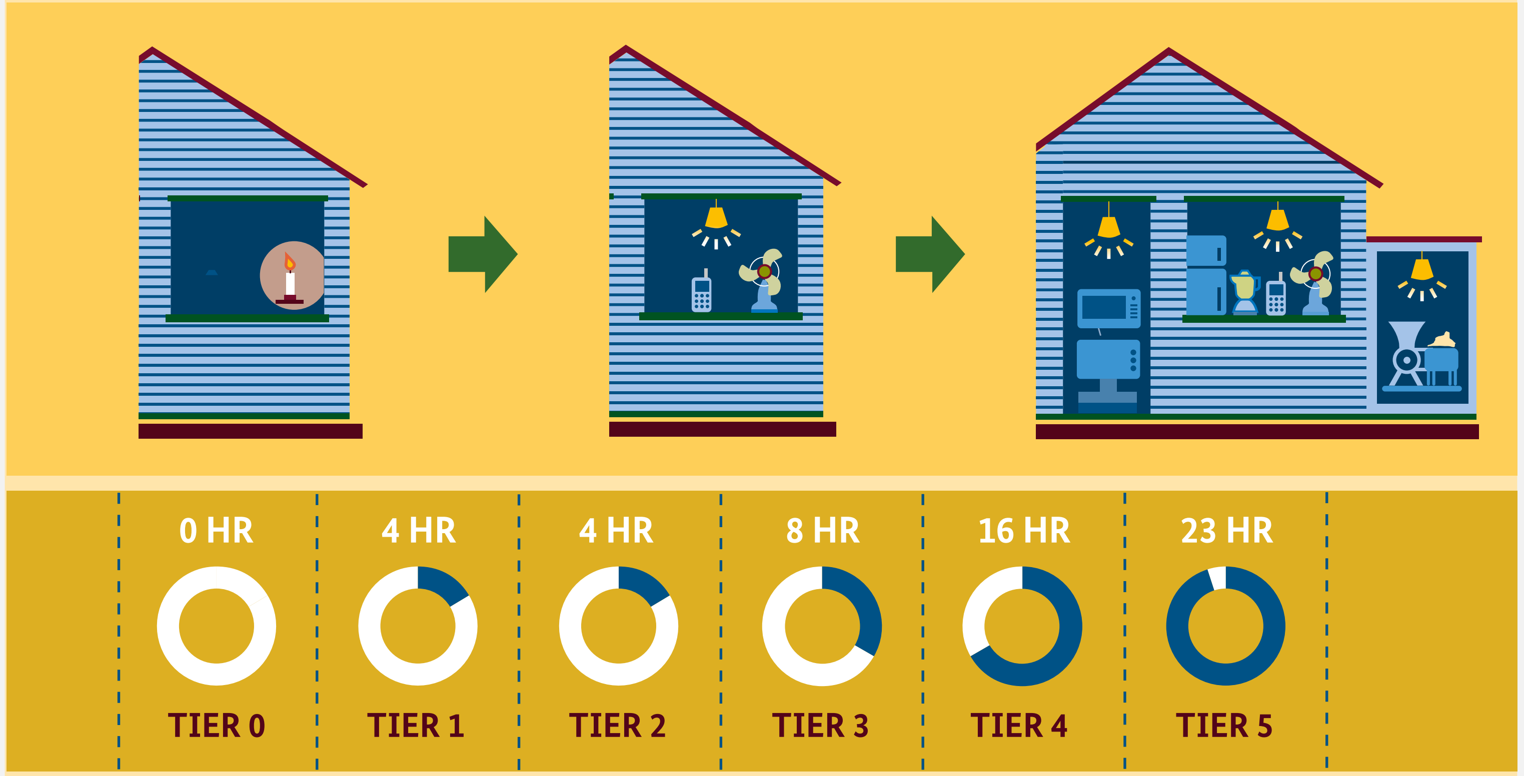
### Lower Tier Case

In this case, the minimum threshold for electricity access is defined as the equivalent of ESMAP's Tier 2 (compare Figure 5) where SHS find application, and Tier 3 where mini-grids are deployed or grid extension takes place.

### Higher Tier Case

In this case, the minimum threshold for electricity access is defined as the equivalent of ESMAP's Tier 3 where SHS find application, and Tier 4 where mini-grids are deployed or grid extension takes place.

**The Tiers of Electricity Access of the Multi Tier Framework**




**Improving attributes of energy supply leads to higher Tiers of access**

Source: Lighting Africa 2016 (https://www.esmap.org/node/55526)

Taking the three scenarios and two cases we define six different electrification pathways. These are the baseline for calculating the investment costs and GHG emissions.

## Methodology for assessment of investment needs

The demand estimation leads to certain electricity consumption and peak demand for each electrification option. This is translated into capacities needed which eventually leads to the investment needs. We focus on initial investments only (re-investments / replacements of technology are not considered). These initial investments are cumulated for the year 2030 along the following metrics for each electrification option.

***Grid extension:*** Generic value of 2,500 USD per HH connection (excluding central power generation investments) is assumed. This is similar for each investigated country. For grid extension only the grid infrastructure costs (extension of medium voltage grid plus distribution grid and household connection are considered). This is a common approach in electrification planning is to only consider grid infrastructure investments and not investments into the central power generation. Those will follow based on the increased on-grid demand, but the costs for grid supplied electricity will remain the same.

***Mini-Grids:*** Investments are based on needed capacities and relative Tier level. The costs cover generation, storage, distribution grid and household connection. Depending on Tier level / HH consumption we estimate investment costs of 1,000 to 6,000 USD per HH connection. The higher the Tier level, the higher the costs per connection as the generation and storage capacities need to be significantly increased.

***SHS:*** Investments are based on size class of SHS. Depending on Tier level / HH consumption we estimate investment costs of 300 to 1,300 USD per SHS per HH (solar PV plus storage plus DC appliances).

## Methodology for estimation of the GHG reduction potential

In order to determine the emission reductions (ER) caused by the assessed electrification options, elements from approved CDM methodologies, tools and standards are used. To derive the total mitigation potential of off-grid RE for until universal electrification is achieved by 2030, the cumulated emissions from a Business as Usual scenario are compared with the uEA and prOG scenarios as follows:

$$ER_y = BE_{y,BaU} - EP_{y,uEA/prOG}$$

Where:

| | | |
|---|---|---|
| $ER_y$ | = | Emission reductions in year y (t $CO_2$/y) |
| $BE_{y,BaU}$ | = | Baseline emissions in year y (t $CO_2$/y) under the BaU scenario |
| $EP_{y,uEA/prOG}$ | = | Emission path (EP) per country scenario in year y (t $CO_2$/y) |

### Determining the energy supply per technology option

Based on the numbers of people and households gaining access to energy of different types until 2030 – grid, mini-grid or SHS –, the overall energy consumption is estimated per country. Hereby two demand cases are reflected.

Under the BaU-scenario (baseline scenario) a significant number of households will not gain access to modern energy. It is assumed that these household will meet their energy demand traditionally, e.g. by using kerosene lamps for lighting. The following assumption according to CDM AMS.I-L has been applied:

| | |
|---|---|
| HH consumption equiv. Tier 1 / 2 | = 55 [kWh/a/HH] |
| Emission factor for Tier 1 / 2 | = 6.8 [t$CO_2$/MWh] |

### Emission determination

Emissions are the product of the amount electricity produced by the different generating types (grid, mini-grids, SHS) and an emission factor.

$$B_{Ey,BaU} = EG_{y,j,BaU} \times EF_{CO2,j}$$

$$EP_{y,shift} = EG_{y,j,uEA/prOG} \times EF_{CO2,j}$$

Where:

| | | |
|---|---|---|
| $BE_y$ | = | Baseline emissions in year y (t $CO_2$) |
| $EG_y$ | = | Quantity of net electricity consumed by generating type j under respective scenario in year y (MWh) |
| $EF_{CO2,y}$ | = | Emission factor for different generating type j (t $CO_2$/MWh) |

### Applied emission factors

Emission factors for national grids are sources from either IGES's CDM Database on Grid Emission Factors or, if not available, from IEA Data ($CO_2$-Emissions from Fuel Combustion 2017). If grid emission factors from IGES and IEA are available for the country under consideration, the IGES data are to be preferred.

For the mini-grid systems an average share of 20% of fuel oil and/or diesel fuel and 80% solar PV is assumed. The emissions are the annual electricity generated by the mini-grid unit times 20% of the emission factor for a modern diesel generating unit of the relevant capacity operating at optimal load. The emission factors for PV / diesel generator hybrid systems are derived from AMS.I-F[11] and lead to 0.2 t$CO_2$/MWh.

The sum of all ER for each electrification option represents the emissions path of each individual scenario. The difference between the uEA/prOG scenario and the BaU scenarios are the potential emission reductions.

11 According to AMS-I.F, Table 2

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