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Research Project
Low-cost energy technologies for Universal Access

Appropriate technologies, business models and enabling environment for Universal Access to modern energy services

With high-level descriptions of modeling and analysis tools

Andres GONZALEZ-GARCIA[2], Reja AMATYA[1], Robert STONER[1], Ignacio PEREZ-ARRIAGA[1, 2]

[1] Massachusetts Institute of Technology, USA

[2] IIT Comillas University, Spain

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Research Project Low-cost energy technologies for Universal Access

The UN Secretary General's Advisory Group on Energy and Climate Change defines Universal Access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses". The International Energy Agency (IEA) establishes that achieving a minimum basic Universal Access to electricity and providing clean cooking facilities for 2030 would require around $1 trillion cumulative investment. IEA also highlights electricity as the most critical energy carrier for development while the use of biomass in inefficient stoves remains one of the main causes of premature deaths.

It is clear that a problem of this magnitude cannot be seriously approached without private capital and, most likely, with the serious involvement of major energy companies, although decentralized approaches –either transitory or not– cannot be ruled out and they are already taking place. Obviously this will happen only if an attractive business model can be defined with the participation of the concerned communities. This model must include: the definition of the appropriate (low cost) technologies to be used; a regulatory framework that clearly defines the rights and obligations of all parties involved and, specifically, the rules of remuneration for the provision of the service; and the sources of finance for this activity. Such considerations are central to this research project and represent a considerable challenge for rural areas.

The purpose of this project is to contribute to the development of Universal Access strategies and tools for policymakers, global businesses and practitioners. This Working Paper 3 finalizes Phase I of the Low cost energy technologies for Universal Access project by the Massachusetts Institute of Technology (MIT) acting through MIT's Energy Initiative (MITei) and in collaboration with Fondazione Centro Studi Enel (Enel Foundation).

Phase I of the project comprises the analysis of the State of the Art technologies, strategies and business models for electrification (Working Paper 1) and modern heat (Working Paper 2) as well as the proposal of a methodology to develop country studies for the establishment of roadmaps to universal access (Working Paper 3).

Phase II includes the application of this methodology to different countries, starting with a report for two case studies, Kenya and Peru.

The project is developed in collaboration with Comillas Pontifical University – Institute for Research in Technology (COMILLAS – IIT) under the scope of the Comillas University Massachusetts Institute of Technology Electricity Systems (COMITES) Program.

Working Paper 3 starts framing the challenge of Universal Access in order to propose a comprehensive methodology for the assessment of the appropriate modes of electrification, heating and cooking for specific countries or regions. The methodology covers the collection of data, the logic processes and the potential use of software tools that make possible the development of a proposal including the different choices of technologies, business models, financial, regulatory and policy strategies that could lead to the provision of universal access to modern forms of energy services.

Table of Contents

Abstract

The UN Secretary General's Advisory Group on Energy and Climate Change[1] defines Universal Access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses". Access to modern energy services is a key element for human development and is central for achieving the Millennium Development Goals[2]. The International Energy Agency (IEA) highlights electricity as the most critical energy carrier for development, while the use of biomass in inefficient stoves remains one of the main causes of premature deaths.

Achieving a minimum basic Universal Access to electricity and providing clean cooking facilities for 2030 would require an average investment of $48B per year[3], or $1 trillion cumulative investment. Compared to the energy-related investment estimated by the IEA new policies scenario for 2030, the amount required for this minimum level of Universal Access represents only an increment of about 3%, less than 1,95% of current electricity tariffs in OECD countries[4]. It is clear that a problem of this magnitude cannot be seriously approached without private capital and, most likely, with the serious involvement of major energy companies, although decentralized approaches –either transitory or not– cannot be ruled out and they are already taking place. Obviously this will happen only if an attractive business model can be defined with the participation of the concerned communities. This model must include: the definition of the appropriate (low cost) technologies to be used; a regulatory framework that clearly defines the rights and obligations of all parties involved and, specifically, the rules of remuneration for the provision of the service; and the sources of finance for this activity. Such considerations are central to this research project and represent a considerable challenge for rural areas.

This Working Paper is the third report of the *Low cost energy technologies for Universal Access* project by the Massachusetts Institute of Technology (MIT) acting through MIT's Energy Initiative (MITEI) and in collaboration with Fondazione Centro Studi Enel (Enel Foundation). The project is developed in collaboration with Comillas Pontifical University – Institute for Research in Technology (COMILLAS – IIT) under the scope of the Comillas University Massachusetts Institute of Technology Electricity Systems (COMITES) Program.

The purpose of this project is to contribute to the development of Universal Access strategies and tools for policymakers and practitioners. Building over an initial analysis of the State of the Art technologies, strategies and business models for electrification (Working Paper 1) and modern heat (Working Paper 2) the project proposes a

[1] (SG AGECC, 2010)

[2] (ESMAP, World Bank, & IEA, 2013; IEA, 2010; UN Energy, 2005; World Bank, 2013)

[3] (IEA, 2011)

[4] The International Energy Agency makes clear in their reports that this is under the assumption that those people with new Access to electricity will stay below a limit of 750kWh per person and year, half the household consumption per capita of developed countries like Spain or Italy, nearly seven times less than residential per capita electricity use in US or Canada, and between seven and fourteen times less energy than the average EU or US consumption if we include the productive, commercial and community power needs of modern societies. Under this assumption, the impact of Universal Access on climate change would be also negligible, but it is hard to believe that for time range considered in the typical climate change analyses (2050 or the end of this century) the consumption of those with Access to electricity will remain so low (Brazilian & Pielke, 2013; Wolfram, Shelef, & Getler, 2012).

methodology to develop country studies for the establishment of roadmaps to universal access (Working Paper 3). This methodology can be applied to different countries, starting with a report for two case studies, Kenya and Peru, as well as a preliminary analysis for other countries as Brazil, or India to be issued in 2015.

Keywords: *Universal Access, off-grid electrification, grid extension, modern heat, business models, regulation, energy policy, enabling environment, decision support models.*

Jel Codes: *Q4, Q41, Q42, Q43, Q47, Q48, N70, O13, O18, O19, O33, O38, O44, Q56*

Corresponding Author

Andres Gonzalez-Garcia

Institute for Research in Technology (IIT) – Comillas Pontifical University

C/ Sta. Cruz de Marcenado 26.

28015 Madrid, Spain

Email: andres.gonzalez@iit.upcomillas.es

1 Framing

1.1 Present situation & trends in universal energy access

Universal Access awareness has grown significantly in the international agenda in recent years. Declaring 2012 as the International Year of Sustainable Energy for All (SE4all), the United Nations General Assembly declared Universal Access as one of the three global objectives to achieve by 2030, along with doubling the energy efficiency and the share of renewable energy[5].

Satisfying user needs and fostering development processes for energy deprived population require not only an appraisal of the demand characteristics, in terms of capacity of payment and required service supply, but an integral assessment of the beneficiary population and their multifaceted cultural, political, socioeconomic and natural environment, to determine not only the value of energy for them, but the value proposition of products and services to be supplied, as shown in Figure 1.

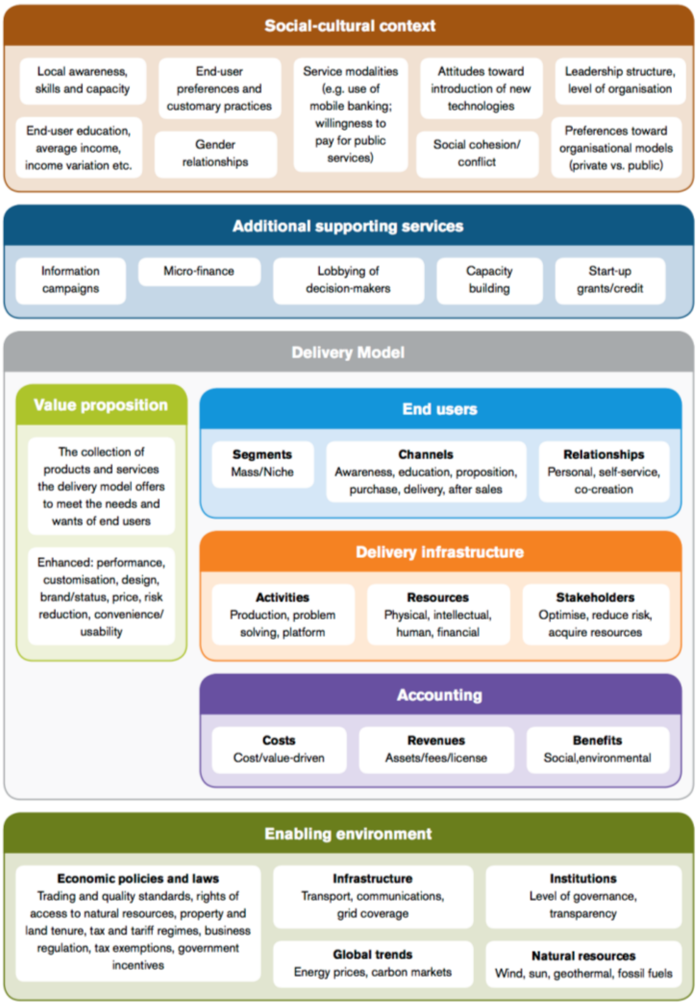


Figure 1: SE4all Wilson et al. Delivery Model Map[6]

[5] www.se4all.org/actions-commitments/country-level-actions/

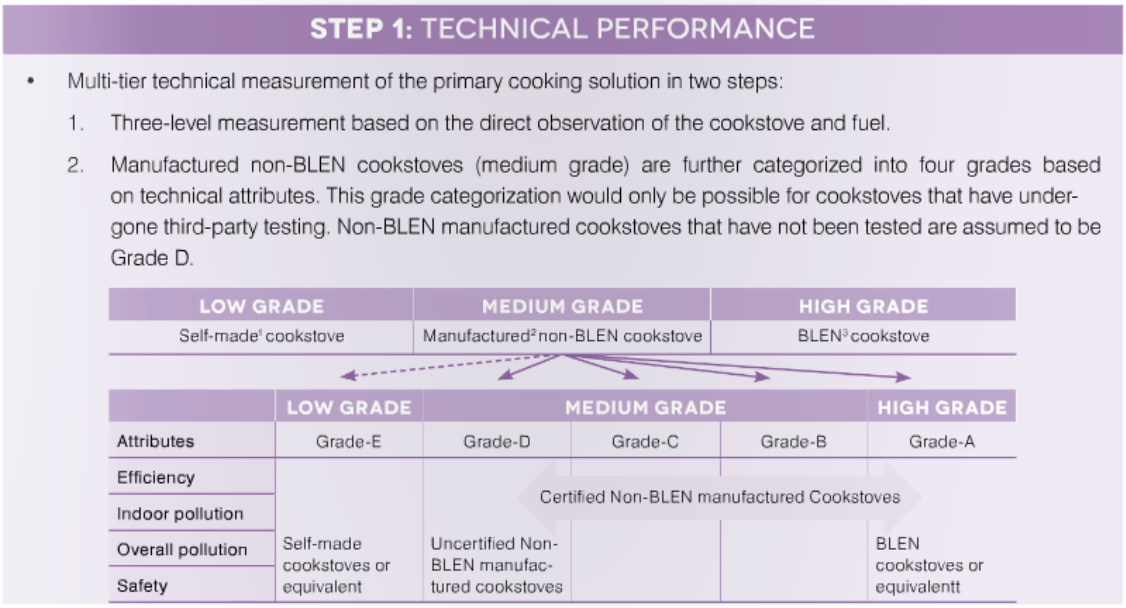
[6] (Garside & Bellanca, 2013)

1.1.1 A user centered approach

A successful strategy towards Universal Access requires assessing carefully the diverse energy services from the perspective of the beneficiaries[7], the impact on their economic and social development and the environmental consequences[8]. Establishing properly both the targets to be achieved and the mechanisms and effort to apply require grounding them in the final user present and future needs[9].

1.1.1.1 Modern heat

Access to clean and affordable modern fuels for cooking and heating is a key element for human development. Currently 2.7 billion people worldwide rely on traditional biomass and inefficient cookstoves, and this number is projected to rise to 2.8 billion in 2030. According to the World Health Organization, exposure to smoke from traditional cookstoves and open fires causes 1.9 million premature deaths annually, with women and young children being most affected. Even though there is no clear consensus about the definition of Universal Access to modern energy services, the World Bank along with ESMAP has a multi-tier framework for measurement of household cooking solution in SE4all, which will be taken as a baseline consideration for this study [Figure 2]. The multi-tier framework has 6 levels (Tier 0 to Tier 5) of services for cooking solutions, with Level 0 representing self-made cookstoves (three-stone fire or equivalent) without conformity, convenience and adequacy (CCA). The highest-level service is provided by **Grade A**, Biogas-LPG-Electricity-Natural gas (BLEN) cookstoves with CCA. Level 1 will include self-made cookstoves with CCA and manufactured uncertified cookstoves that do not comply with CCA requirements. Levels 2, 3 and 4 would be transition stages towards Universal Access by using advance cookstoves with solid, liquid or even gas fuels. Level 5 could be considered absolute achievement of Universal Access for cooking.



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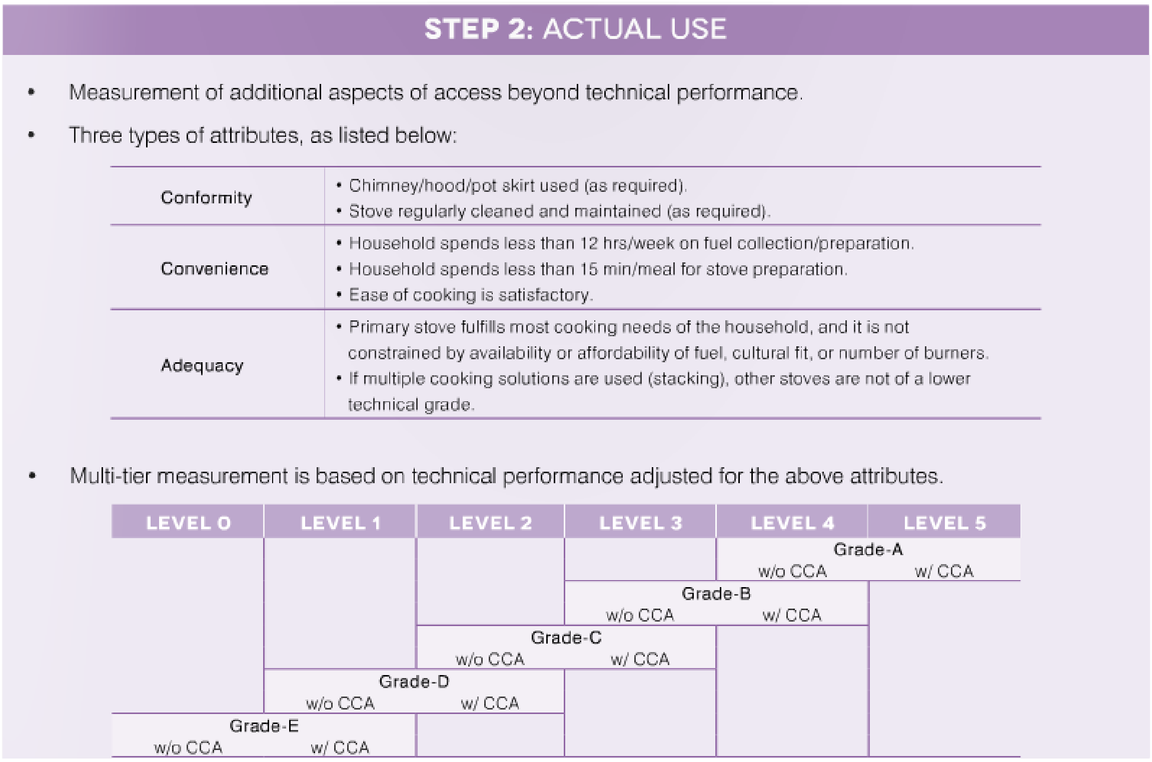
[7] (Schillebeeckx, Parikh, Bansal, & George, 2012)
[8] (Brazilian & Pielke, 2013)
[9] (Bhanot & Jha, 2012)



STEP 2: ACTUAL USE

- Measurement of additional aspects of access beyond technical performance.
- Three types of attributes, as listed below:

Conformity	• Chimney/hood/pot skirt used (as required). • Stove regularly cleaned and maintained (as required).
Convenience	• Household spends less than 12 hrs/week on fuel collection/preparation. • Household spends less than 15 min/meal for stove preparation. • Ease of cooking is satisfactory.
Adequacy	• Primary stove fulfills most cooking needs of the household, and it is not constrained by availability or affordability of fuel, cultural fit, or number of burners. • If multiple cooking solutions are used (stacking), other stoves are not of a lower technical grade.

- Multi-tier measurement is based on technical performance adjusted for the above attributes.

Figure 2: Framework for multi-tier measurement of household cooking solution as developed by SE4ALL [10]

1.1.1.2 Electrification

In 2008 electrification rates (percentage of households with access to electricity according to the World Bank's definition) amounted to 99.8% in transition and OECD countries, but to only 72% in developing countries. Among these countries, low electrification rates are concentrated in rural areas (electrification rate of 58.4%, versus 90% in urban areas), where 55% of the population lives in the less developed regions[11]. Specifically, in 2010 about 85% of the 1.3 billion people who lack access to electricity lives in rural areas, with the majority in sub-Saharan Africa and South Asia. Without additional dedicated policies, by 2030 the number of people without access to electricity drops only to 1.0 - 1.2 billion[12].

[10] (ESMAP et al., 2013)
[11] (UN, 2010)
[12] (IEA, 2010, 2011)

The SE4all multi-tier framework establishes 6 levels of access for electricity according to the supply characteristics and also related to the energy services provided to the end users.

ACCESS TO ELECTRICITY SUPPLY

ATTRIBUTES	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Peak available capacity (W)	-	>1	>50	>200	>2,000	>2,000
Duration (hours)	-	≥4	≥4	≥8	≥16	≥22
Evening supply (hrs)	-	≥2	≥2	≥2	≥4	≥4
Affordability	-	-	√	√	√	√
Legality	-	-	-	√	√	√
Quality (voltage)	-	-	-	√	√	√

- Five-tier framework.
- Based on six attributes of electricity supply.
- As electricity supply improves, an increasing number of electricity services become possible.

Index of access to electricity supply = $\sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

USE OF ELECTRICITY SERVICES

TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
–	Task lighting AND phone charging (OR radio)	General lighting AND television AND fan (if needed)	Tier 2 AND any low-power appliances	Tier 3 AND any medium-power appliances	Tier 4 AND any high-power appliances

- Five-tier framework.
- Based on of appliances.

Index of access to electricity supply = $\sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

Figure 3: SE4All framework access levels to electricity and modern cooking technologies[13].

Accordingly, different technologies can satisfy different access levels for different uses as analyzed by Practical Action[14] for household electricity access, community and productive uses (see WP1 for a breakdown of services available at each Tier). In WP1 it is clarified that technology choices can provide different levels of service for different Tiers (for instance we find Tier 1 electrification supply models that use Stand-Alone-Systems or Micro-grids and even connection to the power network, while Tier 5 can be provided also hi-power stand-alone home systems, not only connected to the grid).

Nevertheless, the initial choice of technology sets a pathway that will determine the future ability of the system to provide more advanced energy services up the energy ladder. It will also restrict future choices concerning cost of the technological upgrades, fuel expenses, carbon emissions, safety, reliability or pollution. Therefore, an adequate technology choice should not only take into account present needs and capabilities, but also the future evolution of the system not only regarding household uses but also productive and community uses.

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[13] (ESMAP et al., 2013)

[14] (Practical Action, 2010, 2012, 2013)

1.1.2 Introduction to energy access technologies

1.1.2.1 Modern heat

In most developing countries, heating (both space and water), has not been given enough priority in the energy discussion. In many African nations, due to warm climate, this may be a non-issue. Even in places where cold weather does demand some form of heating, biomass burning is the most obvious solution. In this study, we look at potential technology choices for water heating that will provide some modernity to the population that is either used to cold water or biomass heating. One of the most successful approaches in this space has been solar water heater, championed by China. Using direct sunlight, this technology can heat water to comfortable levels for daily household use. Other obvious competitors in this market are electrical and natural gas water heaters, which are more common in developed countries. The solar water heater technology is discussed in detail in the Working Paper 2 (WP2)[15].

For Universal Access, clean cooking involves modern solutions, which will replace the conventional three-stone fire that is predominantly used for biomass burning in most rural areas of developing countries. Even though modern fuels such as LPG, biogas, DME, CNG, and electricity for cooking are the ultimate choices for Universal Access, advanced clean/efficient biomass cookstoves will be the transitional solution. These clean burning cookstoves can provide better access to energy for lots of household in the near future. Renewable solutions such as solar cookers can also be added to this mix of technologies for achieving Universal Access.

1.1.2.2 Electrification

Electrification technologies are one of the main factors determining the features of the viable business model for universal access to energy. The interrelations of electrification technologies and supply models are thoroughly described in Working Paper (WP1)[16], based on the following classification of electrification modes:

- Small-and-Pico-Lighting-Systems (SPLS). These light portable devices have emerged as one of the most promising solutions to provide Tier 1 supply to un-electrified population. Recent innovations in higher efficiency (e.g. LED lights or solar panels), lighter weight and more reliable maintenance (e.g. Li-ion batteries) allow these systems to provide chargeable travelling light, stand alone low consumption street lights, or power two or three household lights for up to 4 hours, charge a phone and power a radio or even in some cases a high-efficiency TV, with less than 50Wp.
- Stand-Alone-Systems (SAS). These independent power systems provide supply for a single house or customer. They can supply household, commercial, domestic and community services ranging from Tier 1 (over 50Wp) to Tier 5. SAS can be powered by a choice of individual or mixed sources from diesel generators to solar, wind, micro-hydro or biomass.

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[15] Working Paper 2: Preliminary candidate list of appropriate technologies, business models and enabling environment for Universal Access to Heating and Cooking.

[16] Working Paper 1: Preliminary candidate list of appropriate technologies, business models and enabling environment for Universal Access to Electricity.

- Isolated Mini-grids. They provide electricity service through distribution networks within a limited area, not connected to the main grid. They can be intended for any mix of domestic, community, commercial and productive uses ranging from Tier 5 down even to Tier 1. Their choice of distributed power sources is greater than the one of SAS, as higher capacity solutions might prove cheaper for a larger amount of customers clustered within the scope of the micro-grid.
- Grid extension. Being the most common access mode, in some cases the isolation of the users makes commercially impracticable their connection to the grid. Grid extension also faces the challenges of achieving lower connection costs for population with a low capacity of payment and of providing reliable supply while the capacity of the connected system in many countries does not cover the present demand in their system. The emergence of low-cost grid extension technologies (e.g. Single Wire Earth Return) and interruptible connected micro-grids with distributed generation provide resourceful technological perspectives.

The choice of the right electrification mode is one of the main challenges approached by this project, as explained in Section 3.1.

1.1.3 Introduction to energy access business models

As mentioned earlier, due to low affordability among poorer households, which is the main target group for Universal Access, the private sector is not attracted in general towards projects related to promotion or deployment of technology and services to this sector. Over the years, governments, NGOs, private philanthropic foundations, non-profit organizations, developmental banks and cooperatives have mostly carried the financial burden for project involving any kind of work for the bottom of the pyramid (BoP). However, in the recent past, people have slowly begun to realize the potential of the BoP, and understand the purchasing power of the poor [17]. This new mindset is beginning to attract the private sector to look at the bottom strata as a potential customer rather than charity case. Innovative financing schemes such as microfinance, '*Enterprise*' finance, and carbon finance can make this segment of population attractive for private investment, also including external financial support, when necessary. The problems of providing Universal Access are not only limited to business/finance or commodity distribution; there are a lot of social aspects involved in the success of any project. Public private partnerships have become common where the risks are shared among various entities. In-depth analysis of various financial sources is presented in WP2.

1.1.3.1 Electrification

The variety of business models for access to electricity is adapted not only to the diverse economic, social, cultural, regulatory, financial and institutional ecosystems of supply to poorly or non-electrified users around the World. It is highly dependable of the electrification mode selected, as defined in the previous Section 1.1.2.2.

Business models for SPLS usually show characteristics similar to the retailing of IT and other mobile technologies, radically different from traditional grid supply, but also diverting from SAS and Micro-grids. The usual transference of the ownership of the supply devices to the final users is another distinctive characteristic that completely changes the operation, maintenance and risk management of these models. They show a stronger resiliency to weak

[17] (Prahalad & Hammond, 2002)

regulatory and institutional frameworks in many developing countries but also their capacity to satisfy the growing needs of the population is very limited.

SAS is probably the most versatile and popular off-grid electrification mode for achieving multi-tier service in isolated rural areas, not only for domestic but also commercial, productive and community uses. Accordingly there is a wide range of business model experiences, from pay-as-you-go systems at the low-end to rental, community or cooperative exploitation and fee for service tariffs. Their need for an enabling environment is higher and their success stories are usually linked to the existence of adequate financial mechanisms, stable regulatory frameworks and sound incentive and subsidy schemes for low-income users. A critical issue for these business models lays in an adequate operation and maintenance through the whole life of the systems, entailing the creation of a sustainable life-long operation supply framework that reaches every user.

Isolated Mini-grids represent a next step in supply complexity and versatility for the users. They range from very basic Tier 1 DC micro-grids for a few users to large village supply and are able to reach a performance nearly equivalent to grid supply. The aggregation of customers results in economies of scale not only in the size and operation of the system, but also in the maintenance and ancillary services provided. Their higher technical and commercial complexity requires the participation of more skilled personnel, both technical and administrative. Their overall higher investment costs also result in the upsizing of the business models, usually ranging from mini-utilities for small, low-power systems, to large centralized agents in charge of the decentralized electrification of whole developing regions.

Finally, connection to the national grid is considered as the final stage of electrification process. However, this electrification mode might not be suitable for all the geographical locations and user needs, as will also be detailed later in Section 3.1.1. Grid extension increases the demand of energy generation in countries where there is usually a lack of generation and transmission capacity, so the cost of new supply must consider not only the connection costs but also the associated investment in new capacity.

Grid extension in populated areas receives usually higher attention from companies and policy makers, because of its typically lower costs, higher impact and faster results. Nevertheless, specific governmental planning that considers both grid and off-grid complementary approaches is needed so that agents and consumers outside the scope of grid-extension plans know that alternative approaches should be implemented. For a detailed description and classification of electrification business models, see WP1.

1.1.4 Introduction to energy policy and international framework

Energy policy measures for Universal Access cover a multiplicity of dimensions and approaches, from the international agenda to the national, regional and local strategies, and also from the establishment of a comprehensive regulatory framework to awareness raising campaigns that accompany the transition from traditional to modern energy supply.

For a community, a choice of a cooking fuel is not only a matter of cost and availability, it is also dictated by convenience and preference. Many times people often switch to better type of cooking only in a partial or gradual manner. For example, people in Kenya, even in urban areas, prefer some of their staple diet cooked in open fire as they like that taste better. Even though they have electricity and LPG for cooking, they would still burn biomass. Therefore, it is essential to consider policies and programs that encourage faster adoption of modern fuels along with efficient biomass stoves. Country or region specific regulatory policies will help in wide acceptability of a technology. Government and institutional organizations should work together to put in place policies that encourage entrepreneurs to work in this sector. Policies can help organizations and business to run smoothly either by providing regulatory framework such that there is less procedural bureaucracy or by financial support via capital grants, subsidies, tax breaks etc.

Access to electricity also requires, as specified in WP1, tailored governance, regulatory and financial measures for each electrification mode. But these specific measures must not also be harmonized within the national energy policy (as explained further in Sections 3.3 and 3.4), but considered within the framework established by international commitments and initiatives for targeting and monitoring access provision[18].

At a Global level the most relevant frameworks are the Sustainable Energy for All initiative (SE4all)[19], the International Energy Agency (IEA)[20], and formerly the UN Millennium Project[21]. At a regional level the most significant initiatives are now taking place in Africa, as Lighting Africa[22] (with its spin-off for Asia/India Lighting Asia[23]), Power Africa[24] or the Africa-EU Partnership[25] while other regions and nations are following this lead, as well as other country agencies as Germany (GIZ), Netherlands (MFA NL), Norway (MFA NO), Australia (AusAID), United Kingdom (DFID) or Switzerland (SDC) working together in the program *Energising Development* (EnDev)[26]. The European Union has committed to provide an immediate 50M€ fund for the EU Technical Assistance Facility and to raise several hundred M€ to leverage private funds and give access to 500 million people by 2030.

Moreover, power technologies in developing countries need to address climate change together with their challenge of providing their population with access to modern form of energy. Compared to the International Energy Agency New Policies Scenario (NPS), "achieving universal access by 2030 would increase global electricity generation by 2.5%. Demand for fossil fuels would grow by 0.8% and CO2 emissions go up by 0.7%, both figures being trivial in relation to concerns about energy security or climate change"[27]. The small increase in emissions is attributable to the low level of consumption per capita and to the high proportion of renewable solutions in the NPS; both assumptions must be subject to

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[18] (Bhanot & Jha, 2012)

[19] SE4All by UN (www.se4all.org) has launched an international initiative joined by more than 80 countries, as well as private sector and multilateral institutions for achieving three global targets by 2030:

- Providing universal access to modern energy services.
- Doubling the global rate of improvement in energy efficiency.
- Doubling the share of renewable energy in the global energy mix.

[20] www.iea.org & www.worldenergyoutlook.org

[21] UN Millennium Project (www.unmillenniumproject.org) a predecessor of SE4All initiative, aims at achieving by the end of 2015, in parallel with the Millenium Development Goals, the following targets (Modi, McDade, Lallement, & Saghir, 2005):

- Enable the reduction of modern fuels in 50% by:
    - Efforts to develop and adopt the use of improved cooking stoves.
    - Measures to reduce the adverse health impacts from cooking with biomass.
    - Measures to increase sustainable biomass production.
- Ensure reliable access to electricity to all in urban and peri-urban areas.
- Provide access to modern energy services (in the form of mechanical power and electricity) at the community level for all rural communities)

[22] www.lightingafrica.org

[23] www.lightingafrica.org/asia

[24] www.usaid.gov/powerafrica

[25] www.africa-eu-partnership.org

[26] endev.info

[27] (IEA, 2009)(IEA, 2011)

careful scrutiny. Business as usual scenarios would consider a higher share of Diesel generation for off-grid electrification that could increase the emissions to 1.5%. Additionally, higher levels of consumption up to 2000 kWh per year per person associated with a desirable economic growth would result in a worst-case scenario where emissions could climb up to a range from 1.6% for the NPS to 3.6%.

The choice of adequate pathways to Universal Access in the first place sets an adequate tendency for the growing needs and energy consumption, specially considering productive uses.

1.2 A review of major issues to be covered

Table 1 and Table 2 show a brief enumeration of the main issues to be covered at different levels, to achieve Universal Access. For a detailed description, please see WP1 and WP2

1.2.1 Electrification

	Technology	Business models	Funding	Regulation	Governance
Small and Pico Lighting Systems	DC Light weight / portable Low maintenance High efficiency	User ownership and fast payback Adapted to the BoP capacity of payment Resilient to deregulated environments Distributed and decentralized Franchising success stories Distributed O&M Demand pull vs. push	Focus on user funding and micro-credits Need for funding by agents at different levels (producers, wholesalers and distribution)	Need of quality standards Less dependency on subsidies and incentives Need for technological regulations to avoid market spoilage Competition in the market	On the ground awareness campaigns Complex relations with existing distribution chains (synergies and competition). Creation of local capacities and businesses Need of technology hubs
Stand Alone Systems	AC and DC SAS Relevance of O&M Need of quality standards	Distributed vs. Mini-utilities approach Distributed and centralized O&M (depending on distances and weight)	Hybrid models with property of agents or users. Need of micro-credits for ownership or connection costs	Need of quality standards Regulation of off-grid tariffs, incentives and subsidies Competition in the market and for the market (distribution)	Complex governance, requiring high maintenance. Emergence of PPP
Isolated Mini-grids	AC and DC microgrids Essential O&M	Mini-utilities Centralized O&M Complexity of billing	High need of installation funds Micro-credits for connection	Stronger enabling environment needed. Distribution concessions.	Complex governance, requiring high maintenance Emergence of PPP
Grid Extension	AC extension and AC/DC interruptible microgrids Distributed generation Essential O&M	Large and mini-utilities Centralized O&M More adapted to traditional approaches	Higher need of funds for deployment Micro-credits for connection	Sound regulatory framework, specific connection incentives for low-income population. Distribution concessions and impact of connected micro-grids suppliers and independent power plants	Complex governance, requiring high maintenance Emergence of PPP

Table 1: Matrix of electricity supply modes key success issues.

1.2.2 Modern heat

	Technology	Business models	Funding	Regulation	Governance
Water Heating	Solar Water Heater (SWH)	Overview: Low use (requirement), lower income/affordability NGO/Institutional/Government funding; cooperative mode; private (for profit) companies (manufacturer + sales); Enterprise financing	Cost subsidy/reduction for SWH in the form of direct financial subsidies, low-interest loans, regional investment subsidies, leasing schemes, carbon trading mechanisms	Energy efficiency and building regulation mandates for use of SWH in new constructions in the form of solar obligation (e.g. Israel, Spain, Portugal, US (Hawaii))	Stringent quality standards for system hardware with standardized product testing and product verification
Cooking	Advance Cookstove	NGO/Institutional/Government funding; cooperative mode; private (for profit) companies (manufacturer + sales); Enterprise financing	Improve affordability by providing microcredit or loans to lower upfront payments; applicable grant programs also maybe used to lower cost to consumers; carbon finance	Provide technical assistance for better stove development and partial subsidies for improved and advanced stoves; traditional fuel (biomass) price should be set by market	Encourage local tree plantation and forest management; quality control for cookstove products
	Solar Cooker			Energy efficiency and regional portfolio mandates including solar (roadmaps for technology adaption)	Quality control and product verification for cookers
	Modern Fuels	Government, NGO, Private, Public-Private Partnership	Modern and transition fuel should be priced at level similar to fuel price in urban market, perhaps through cross-subsidy mechanism that makes up for higher distribution cost	Minimized taxes/subsidies for urban sector; encourage greater distribution of modern fuels and partial subsidies for stoves and or cylinders	Provide proper distribution channels and avoid black market price hike up

Table 2: Matrix of modern heat supply modes key success issues.

1.3 Learning from experiences

1.3.1 Electrification

The 1.3 billion people without access to electricity are unevenly distributed in the World, and so it is the expected demand growth, as shown in Figure 4.

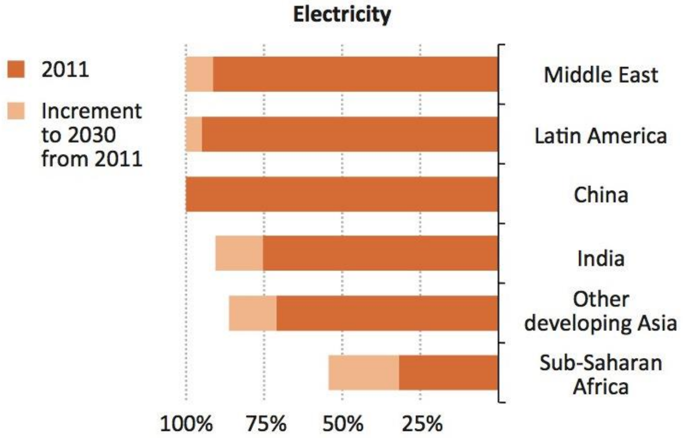

Figure 4: Shares of population with access to electricity by region in the New Policies Scenario [28]

As described in more detail in WP1, there is a commercially addressable market in this base of the pyramid that can be served by different electrification technologies with different capacities and at different costs.

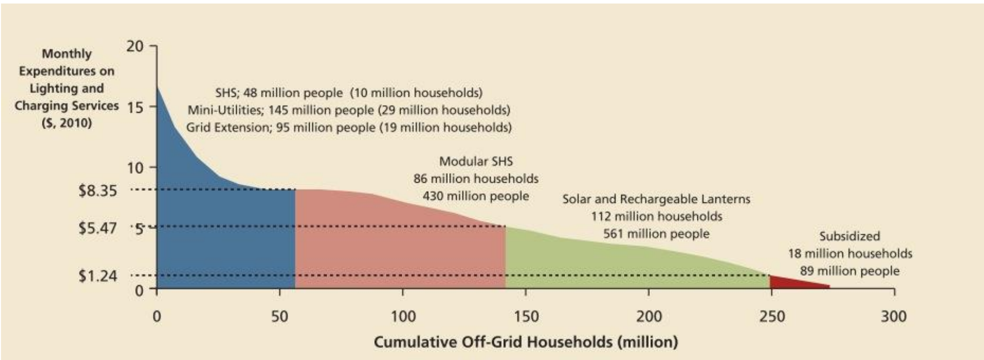

Figure 5: Addressable market for modern electricity services [29]

However, to reach the 18 million houses with the lowest income level, around 90 million people under the $1,25 line, commercial approaches would never suffice. Subsidies or other targeted actions should be made available to enable the business models required to service this last-mile and achieve Universal Access as will be discussed later.

Although this estimation greatly simplifies the electrification access market[30] it highlights two important facts: that the available technology matches the capacity of payment of more than 1.2 billion un-electrified population (and their actual expenditure in traditional lighting, batteries and charging phones) for the electrification needs of the lowest tiers where the utility for the use of

[28] (IEA, 2013)

[29] (IFC World Bank, 2012)

electricity is largest, and that 90% of the supply could be provided by off-grid technologies. It also stresses the opportunity of achieving basic electrification for all based on long-term sustainable business models.

As Universal Access to modern energy services has gained weight in the international and national political agendas in recent years, new analytical tools and reports are being developed that allow a deeper understanding of the complexity of this energy transition, with an important milestone achieved with the launching of the SE4all Global Tracking Framework last year[31], that allows the identification of key issues for a successful policy-making and upscaling of business models.

Reaching isolated communities, around 60% of the total population with lack of access to electricity presents the greater challenges, demands innovative business models far from the traditional utilities and some times more similar to fast growing markets as those of the mobile businesses, as the experiences shown in Figure 6. These few cases exemplify that significant electrification rates can be achieved by means of different approaches and technologies as mini-grids for rural Cambodia, network extension in Guatemala, solar home systems in Bangladesh or solar kits in Kenya, but also that combined on and off-grid electrification strategies show faster results, as in the cases of Morocco or South Africa.

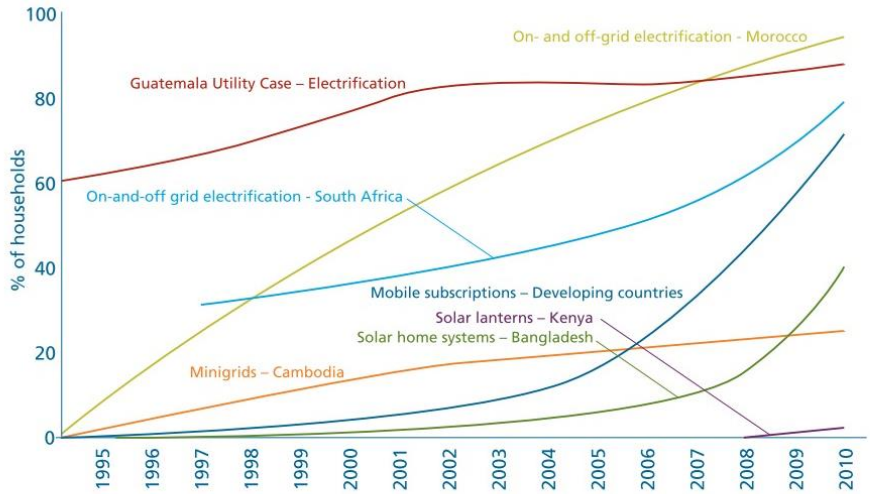

Figure 6: Penetration rates of energy and mobile phone services in developing markets[32].

WP1 includes a detailed description of business model experiences in different countries, both for grid extension and off-grid electrification, classified according to each electrification mode, which are summarized here:

- SPLS are perhaps the most promising solution for providing basic access to most of the population in the base of the pyramid, with a total annual expenditure of 4b$/year. This segment shows nowadays more dynamic and innovative approaches. Successful small for profit and non profit decentralized models for small retailing or rental/leasing of

[30] The authors base their calculations on flat levelized commercial costs, considering neither the diverse technology choices and costs within each electrification mode (e.g. microgrid unit cost varies greatly with the number of customers, microgrid size, density of users and supply profiles, varying from very low cost Tier 1 access in high density villages to expensive Tier 5 supply where affordable) nor the uneven distribution of fixed and variable costs (investment, fuel, maintenance and operation) through time and geography.

[31] (ESMAP et al., 2013)

[32] (IFC World Bank, 2012)

equipment as Barefoot Power[33] in Africa and India, OMCPower[34] in India, Sunlabob[35] in Laos or Soluz[36] in Central America coexist with multinationals as Schneider[37] in India or Philips[38] in Africa and India, or large enterprises as Tata Power Solar[39] in India with complex distribution channels, and social enterprises as ToughStuff[40] in Africa, AccionaME[41] in Mexico and D.Light[42] in Asia and Africa focusing on the creation of local capacities and markets. A very interesting approach of a large utility in this field can be found in the partnership between ENEL Green Power and Barefoot College[43] for the Enabling Electricity Program of rural electrification in Guatemala, Peru, Chile, Colombia and El Salvador, where local partially illiterate women between 35 and 50 years old are trained as technicians (for building, installing and repairing solar lamps) together with other Indian "grannies" at the Barefoot College in India (Tilonia, Rajasthan) so later, back at home, they become active agents to train other women and to extend this model to neighboring villages.

- Stand-Alone-Systems provide a second step in the electrification ladder, suitable for around 50 million people, a 1b$/year market. The critical need of continuous maintenance of this equipment throughout its whole life requires the establishment of sustainable service models far beyond the investment period. Maybe the most successful examples for servicing isolated areas are found here, whether with full market approaches as the case of Grameen Shakti[44] in Bangladesh (also taking into account the international and national credits they receive for their capital costs), or within regulated environments that establish both official off-grid tariffs and subsidies as the case of AccionaME in Peru. In Chile and Peru, ENEL Green Power and ENEL Cuore are engaged in installing a hybrid PV wind[45] and hydroelectric[46] plants respectively to provide reliable power to villages in remote off-grid locations, providing clean energy at affordable prices that can meet the household and productive demands of their population.
- Isolated Mini-grids also present a wide range of technological configurations and supply capacities for isolated villages and population clusters, for a market around 4b$/year. Very low-cost solutions, with lower up-front costs, attract small entrepreneurs as independent power producers and distributors like Sunlabob power[47], OMCpower – telecom power solutions[48] and Scatec Solar[49]. Small Cooperatives and social enterprises like Mera Gao Power[50] are also present in the market of light micro-grid models at village level while larger companies as Schneider provide community solutions for all sizes and supply ranges.

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[33] www.barefootpower.com
[34] www.omcpower.com/communities/business-in-a-box
[35] www.sunlabob.com
[36] www.soluzusa.com and www.soluzhonduras.com
[37] www.schneider-electric.com/bipbop and bipbop.3c-e.com
[38] www.lighting.philips.com/main/application_areas/solarlighting/
[39] www.tatapowersolar.com
[40] www.toughstuffonline.com
[41] www.accioname.org
[42] www.dlightdesign.com
[43] www.enelgreenpower.com/en-GB/company/csr/enabling_electricity/
[44] www.gshakti.org
[45] www.enelgreenpower.com/en-GB/plants/ongoing_projects/chile/chile_ollague/
[46] www.enel.com/en-GB/sustainability/energy_access/projects/peru_huallin/
[47] www.sunlabob.com/hybrid-village-grids.html
[48] www.omcpower.com/telecom/power-solutions
[49] www.scatecsolar.com
[50] meragaopower.com

- Network Extension utilities can still extend their traditional market to 95 million un-electrified urban and peri-urban people with a high purchase capacity for a total of around 4b$/year. In many developing countries the capacity of the already weak network supply can hardly accommodate new customers, so the establishment of a strategy at national level for network extension is critical. But the most important challenge lays in the need to connect low-income users and villages located near the grid. This fragile population cannot afford the cost of a standard connection, so incentives and subsidies must be provided to companies to fill in the gap between the capacity of payment and the cost of service. Successful examples would be the single-wire-earth-return and low-cost nation wide network extension strategies in South Africa or Morocco. In absence of these national planning and subsidies, innovative approaches and tailored solutions to this population are being experienced, as independent service providers and connected minigrids like the case of Sunlabob in Laos.

One final consideration to be remarked once more is the fact that rural electrification programs, both in developed (several decades ago, already forgotten by most people) and developing countries, have been systematically subsidized, either by public budgets or by some sort of uplift by the already electrified consumers. It would be paradoxical that this almost universal principle might not apply to the poorest of the world.

1.3.2 Modern heat

Despite the lack of modern cooking solutions for nearly 2.7 billion people, there has been slow but steady transition towards Universal Access in many parts of the world. Middle East and Latin America have more than 80% clean cooking solutions with projected increase towards Universal Access by 2030 [Figure 7]. China is leading other Asian counties by slowly progressing with nearly 35% rural household now using LPG or electricity as their main cooking fuel [Figure 8].

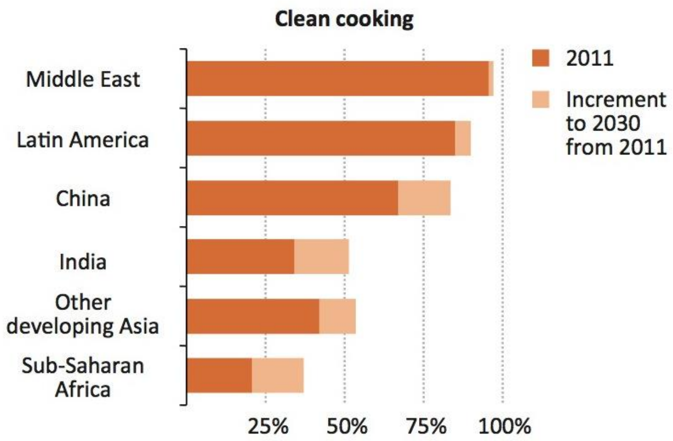

Figure 7: Shares of population with access to clean cooking facilities by region in the New Policies Scenario [51]

[51] (IEA, 2013)

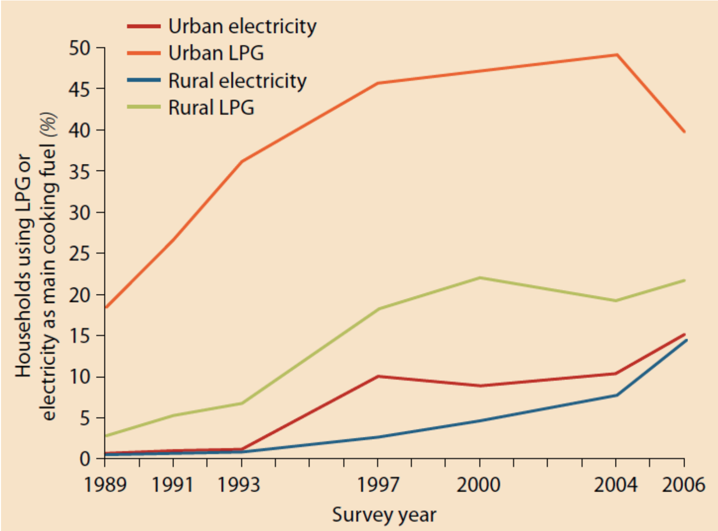

Figure 8: Households cooking mainly with LPG or electricity in China, 1989-2006 [52]

There are many success stories from different countries that tell us about transitions to modern solutions for Universal Access. These experiences involve both innovative technologies and business models. For example, Thailand's successful approach with LPG promotion has been remarkable. With the central government regulating wholesale price, and subsidizing the cost for transport and distribution of LPG, Thailand was able to achieve 78% penetration of LPG as the cooking fuel into its households by 1989 [53].

Successful business operation is also a key aspect for wide deployment of any technology. GERES, an NGO working in Cambodia was able to sell more than 1 million units of their charcoal stoves around the country in less than 7 years by consolidating the scattered production to five centralized facilities. Within these facilities, they trained people to produce high quality product, and the NGO also helped set up a local supply chain with extensive participation of women, who managed retail shops and promoted the stove [54].

New financing tools, especially those concerning Climate and Carbon funding mechanisms can be leveraged to fund many development and deployment of modern solutions [55]. The World Bank, and many multilateral development banks have climate investment funds and other carbon funds that can be channeled towards such projects, which are deemed unsuitable for 100% private investment.

Along with success stories, failures can also be great learning experiences. Even though China is increasing its Universal Access with promotion of modern services such as electricity and LPG for cooking, more than 130 million households still use biomass for their main cooking fuel. Production of low-emission, high efficiency biomass stoves has not kept pace with the dimension of the challenges. With government support for such programs being curtailed, the private sector has tried to pick up the pace. However, due to low affordability, the promotion of advance cookstoves is not very attractive to the private sector.

The main challenge for modern cooking solutions has been to promote and replicate successful approaches. One can learn from other successful global and institutional models. One such example is the Water and Sanitation Program (WSP) administered by the World Bank. WSP is a multi-donor partnership, where a strong focus is put on capacity building by forming partnerships between academia, civil society organizations, donors, governments, and private

[52] (Ostojic et al., 2011)

sector. WSP works at local and national levels in 25 different countries, and has been able to share best practices across regions. In the last three decades, the program has led or supported many of the advances made in the water/sanitation sector [56].

[53] (Ostojic et al., 2011)
[54] (Adams, 2011; Group for the Environment, 2014) www.geres.eu
[55] (Adams, 2011; HERA (Household Energy Services), 2011; UNEP Risore Center, 2010) cdmpipeline.org
[56] (Water and Sanitation Program, 2014) www.wsp.org

2 Situation analysis

This section provides a preliminary list of the information needed for the assessment of energy access policies and decision-making. Taking into account scarcity of information available in many developing countries, the list intends to specify the ideal information to be gathered, or that should be somehow estimated if not available.

For planning and policy purposes the selection of the energy access mode and the electrification design (described in 3.1 and 3.2) require statistically significant information about user locations (individual geo-referenced points or raster information down to a very low geographic scale) along with economic situation and energy profiles. The evaluation of the future macro level impact of access (detailed in 3.3) might be able to provide useful insights considering broader geographical regions but would also greatly benefit from the accuracy of the analysis derived from 3.1 and 3.2. However the accurate design of actual energy systems will always require a precise determination of the user location and load characteristics, and might involve the use of canvasing methodologies, field measures and customer surveys. Moreover, the information required for the analysis of sustainable business models and policymaking is of a different nature as described in 3.4.

The recent establishment of the Sustainable Energy for All (SE4all) Global Tracking Framework is a major breakthrough in the availability and comparability of energy access data across different countries[57]. It fosters the development and convergence of criteria for energy databases at international and country level.

To gather the required data for the development of the Phase II of this study, the following data sources have been identified at this early stage, with a specific focus on Kenya and Peru, the two first countries of interest:

- United Nations Development Maps[58];
- International Energy Agency[59];
- World Bank[60];
- Landscan data[61] by Oak Ridge National Laboratory on global population distribution;
- World Resources Institute[62];
- The Renewable Energies Rural Electrification Africa tool by the European Commissions

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[57] In (ESMAP et al., 2013) SE4all proposes a new framework to track progress in the three objectives (universal access to modern energy services, doubling the rate of improvement of energy efficiency and doubling the share of renewables in the global energy mix) in order to

1. Identify suitable global and country-level tracking indicators.
2. Establish the starting point for 2010 against which progress round to 2030 will be charted.
3. Identify countries that had made rapid progress in the past to provide others with policy lessons.
4. Assess the scale of the challenge understanding the relationships between these three objectives and their reinforcement potential.

[58] unmapper.developmentmaps.org
[59] www.iea.org/statistics
www.iea.org/Sankey and
www.iea.org/media/weowebsite/energydevelopment/WEO-2011_new_Electricity_access_Database.xls
[60] data.worldbank.org/topic/energy-and-mining
[61] web.ornl.gov/sci/landscan/
[62] www.wri.org/resources

Joint Research Center[63];

- Kenya Open Data Initiative[64];
- The Peruvian Energy and Mines Ministry Rural Electrification General Directorate[65].
- National census data will be used to obtain household profiles including demographic, socio-economic, productive, appliances and energy uses to the higher degree of granularity possible (at household level where available, or at least down to sub-district level);
- Specific data sources for the description of the national or regional energy systems might include gathering information from energy agencies, ministries and regulators or incumbent utilities, taking into account the levels of accuracy, comprehension, availability and standardization of these data;
- Other general-purpose geographic data sources will be used for ancillary purposes.

2.1 Relevant information about the enabling environment

The following is information that would be needed from a country in order to analyze its energy consumption pattern and understand the Universal Access situation. If the information is available down to household level, it can allow the design of actual heating and electrification systems and supply models. If only available at national, regional or at district level, it will allow reference technical modeling, business model planning and energy policymaking. Apart from generic information such as population (total, allocation to provinces and districts, and densities), diversity and geographic locations, information with a different level of geographical granularity can be classified as:

1. Socio-economic variables.
    - Income level (household, village or area level).
    - Education level (household, village or area level).
    - Occupational status (household, village or area level).
    - Ownership of household assets (household, village or area level).
2. Socio-demographic information (household, village or area level).
    - Gender.
    - Age.
    - Employment status.
3. Detailed description and characterization of the energy sector: access, geographical coverage, cost, availability, reliability, efficiency and losses, carbon emissions, black carbon and indoor pollution, other environmental impacts.
    - Energy resources (village or area level).
    - Current electricity and modern heat infrastructure: generation, transformation, transport, distribution networks (household, village or area level).
    - Traditional supply: lighting, heat and mechanical technologies and energy services supplied (household, village or area level).
4. Accessibility: transportation and communications networks (household, village or area level).
5. Economic and financial environment (local, regional or national level).

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[63] re.jrc.ec.europa.eu/re2naf.html
[64] opendata.go.ke
[65] sigfoner.minem.gob.pe/webgisfoner ; dger.minem.gob.pe/atlaseolico ; dger.minem.gob.pe/atlassolar ; sigfoner.minem.gob.pe/hidro

6. Regulatory and governance framework (local, regional or national level).
7. Energy, environment, and other related goals or policies (local, regional or national level).
8. Land use, productive, commercial and other anchor activities (household, village or area level).
9. Political, social, cultural and environmental issues.
10. Other geographical characteristics: terrain, water bodies, protected areas, weather conditions and natural hazards (village or area level).

2.2 Characterization of access to modern energy

Along with country specific information, user centric information is critical in utilizing the modeling tools to access energy supply and demand. The following attributes will provide the user information that is needed:

1. Population profile (household, village or area level).
    - Location, diversity, and distribution.
    - Number of households, commercial and productive facilities, and institutions (schools, hospitals/health care facilities).
    - Current primary level of energy service tier for electricity and heat.
    - Income level, economic activities and growth.
2. Energy uses (household, village or area level).
    - Residential: illumination, refrigeration, cooking, heating, cooling, individual water pumping, powering home appliances, etc.
    - Commercial: maintenance and charging stations, food vending, etc.
    - Industrial: vehicle repairs, tailoring, woodwork, laundry, ironing, small manufacturing, etc.
    - Community: health, education, community meetings, street lighting, etc.
3. Monthly household spending on traditional energy sources -indication of affordability vs. willingness to pay- (household, village or area level).
4. Existing energy supply (household, village or area level).
5. Value of supply (household, village or area level).

Granularity for the above-mentioned attributes in 2.1 and 2.2 varies. Ideally, household level data for socio-economic variables and energy use (demand and supply) would be preferred, along with the GIS data having similar level of granularity, though alternatives will be provided for village or area level approaches as detailed in 3.1.1 and 3.2. A countrywide census data could provide few of the socio-economic variables such as education level, income level and population profile; and also provide some insight to the current energy service tier. However, generally available census data does not break down the attributes to a single household level but gives data on average for a sub-district level. Depending on countries, a single sub-district could have 10-1000s of villages. In the case of Kenya, available census data is a sample of only 10% of the population. Thus, we will be working with averages and estimations based on this sample size when we consider census data. Similarly GIS based data is hard to obtain on a single household level. Landscan provides a worldwide population density distribution map at a granularity level of 1 km by 1km area, which again can have more than one village within. In any case, for the country level analysis of Universal Access sub-district level data will provide a very useful perspective of the current energy situation.

2.3 Inventory of expert opinions

Provision of modern energy services for both electricity and heating & cooking requires a wide perspective that considers these services as a factor within a set of development issues to be addressed in order to achieve Universal Access targets. This has to start from a user-centric approach[66] that guarantees the *affordability, reliability* and *local embeddedness* of the business model and requires innovative business solutions that overcome the cultural barriers, in terms of distribution channels, customer relationships, risk aversion, raising awareness of customers, and gaining their trust.

The nature of this information is different from the data gathered at country level and for the characterization of energy access. The main purpose of expert opinions is the assessment of qualitative, attitudinal, procedural and conceptual factors for the management of the technological change. Collecting these data usually requires canvasing methodologies and surveying the different stakeholders, so in most actual cases the information available will be incomplete or unevenly distributed for different countries and regions. Some particular concerns that ideally could be taken into account are:

- Level of awareness in a region.
- The multi-faceted impacts of poverty (on health, education, infant mortality, safety and environmental problems).
- Lack of access to other basic infrastructures (running water, telecommunications, sanitation, health, education, and cultural services).
- Community organization (the involvement of local institutions, any ethnic or clan hierarchies, social cohesion or conflict).
- Cultural resilience, in particular, adaptation to meaningful values and traditions of local cultures that have endured the globalization influence.
- Cultural barriers and low education levels of the population involve higher transaction costs and need of additional efforts in raising awareness and training of users and intermediaries.

[66] (Schillebeeckx et al., 2012)

- Pre-existing notions on particular technologies.
- Lack of government recognition in slums or informal settlements (this “illegal” status means that public services and infrastructure are rarely provided or developed).
- Political isolation of certain communities, which has resulted in traditional exclusion from the decision making process.
- High supply costs and low capacity of payment.

These key issues regarding pre-conceptions, perception, and awareness of government officials, regulators, practitioners, utilities, financial institutions, local authorities, international organizations, investors and donors, academia, community and other auxiliary agents for universal energy access need to be understood.

This type of knowledge is focused mainly in the development of suitable business models and regulatory recommendations. These insights about pre-conceptions, perceptions and level of awareness among various stakeholders will help not only to realize the current situation, but also to understand the mindset of people within various organizations who would be key players in providing Universal Access for a country.

3 The Plan

3.1 Methodologies for the selection of the mode of provision of access

In this chapter we are providing a view of our vision of the methodology –including data, logic processes and the potential use of software tools– that we consider should be used to make a comprehensive assessment of the appropriate modes of electrification, heating and cooking for the entire population in a large region or a country, as well as the technologies, the business models and the enabling environments that would provide universal access to modern forms of energy services.

All the software tools that are mentioned in this chapter are presently under development by the teams of researchers at MIT and IIT-Comillas. For the most part, the development of these tools was not contemplated as included into the scope of this research project explicitly. A preliminary specification of the tools will be provided here, and a more detailed evaluation of the use of the tools and their specification will be performed during the second phase of the project, in parallel with the analysis of the case studies of Kenya and Peru. At least one of the software tools –the MASTER4all model– will be fully developed and applied to both case studies during the second phase of the project.

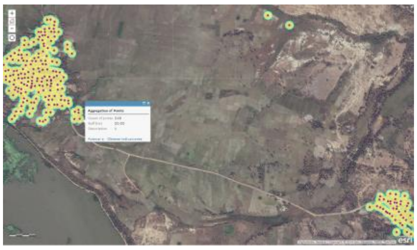
3.1.1 GIS-aided electrification planning

The establishment of sustainable business models for universal electrification needs a proper identification of the conditions under which different electrification modes are more suitable than others for the satisfaction of the present and future needs of the un-electrified or under serviced population. The focus of this approach is on making use of a geographic information systems (GIS) methodology to estimate the size, scope and geographic location of the potential consumer base for different modes of electrification and to serve as a useful, early-stage electrification planning tool at both the national and individual project level.

GIS is a useful way of structuring, storing and handling data, and can provide compelling, accessible visualizations and quantitative results to answer strategic spatial questions about the types of places best suited to different electrification strategies, or where to site potential electrification projects – useful for government planners, practitioners, and off grid electrification entrepreneurs.

The first challenge for electrification planning in developing countries is the scarcity of accurate data about user location, demand profiles, socioeconomic status, or resource availability. GIS databases and tools can help estimate some of these necessary parameters where not available, and therefore accommodate different levels of detail in the information and results.

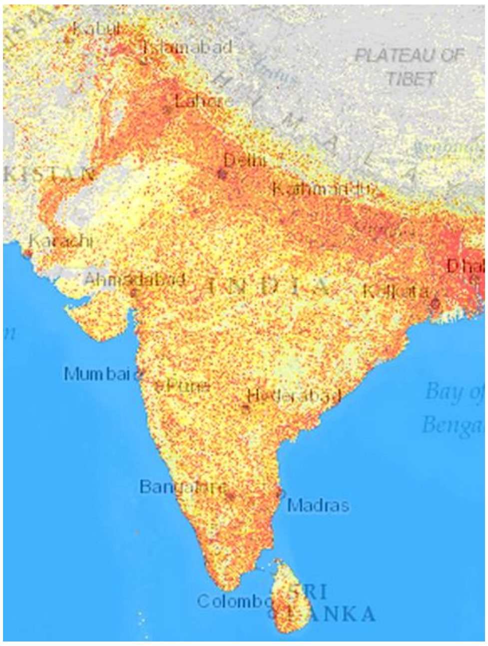
1- The first step is the **determination of the location of electric demand**. Two alternative approaches are being implemented.
   a. Where available, the models will use the precise location and profiles of demand (houses, commercial, productive or community connections) in vectorial coordinates. These data



Pinpointed location of isolated and clustered users can be gathered using individual household census data, satellite image processing or crowdsourced pinpointing of users. This information can be processed in different ways to group the demand into clusters of users for further use (user clusters).

b. Landscan[67] provides a standardized worldwide estimation of ambient population (average over 24 hours) at approximately a 1km x 1 km resolution (30’’x30’’) tailored for each individual country and region. By combining the measure of population count in each grid cell with other information (e.g., census data about primary source of lighting) on the population in that region, an estimate of electricity demand can be derived and processed to determine the location and density of demand, which could also be grouped into potential electric clusters of cells (Landscan clusters).

in a rural area of India



Sample Landscan representation of ambient population in India

2- Once the data is organized in the GIS, specific information can be extracted that, following some logic steps (with slight differences depending on data type), will allow to later determine the most suitable electrification mode for each site.

a. **Determining electricity access:** Is the cell or user electrified? Is it grid-connected or off-grid?

b. **Proximity to the existing grid:** If there is no supply, how far is any given cluster from the nearest distribution line or substation?

c. **Reliability of the existing grid**: What is the reliability of the nearest grid supply?

d. **Energy resources**: What is the potential for different sources of distributed energy generation?

GIS mapping of electrification modes according to input data, analysis using the lookup table

Once this preliminary spatial data analysis has been made, the information can be enriched further by taking into account other elements of information that can also be captured in GIS format. This includes the following demand characteristics, either actual, expected or targeted:

e. Geographic and administrative classification (urban, rural, isolated).

f. Local context: socioeconomic details from the Census, existence of anchor loads, ability to pay, access to financing, land use, protected areas and policy restrictions.

[67] web.ornl.gov/sci/landscan/

3.1.2 Cooking and heating

The two energy services considered for Universal Access under modern heat are water heating and cooking (see Figure 9). The primary technologies for consideration are also shown, and detailed discussions of these are presented in WP2. The energy resource for a particular technology is considered as an input in the selection tool. Apart from the energy resources, each technology will have to be considered along with few other parameters, which will either be financial, technical, social, environmental or operational considerations.

Important parameters for each technology are listed here, which will be incorporated in the modeling tool. Each parameter will be given a weight for consideration, represented by appropriate coefficients, and the desired function (investment, CO_2 emission, level of service, total number of people with Universal Access) will be optimized accordingly. This calculation and optimization will be a part of the MASTER model described in detail in the next section.

Even though within modern heat water heating and cooking can be considered two energy services, there is synergy between them both. As mentioned previously in Section 1.2.2, traditionally in rural areas, people use cookstoves to heat water for daily use. Given this use pattern, modern cooking solutions can also be used for water heating services. For example, a household can invest in an advanced cookstove to provide for both cooking and heating. Cookstoves will be considered as a technology for water heating as well. This will hold true for households without internal plumbing and tap systems.

In some cases, there may be two or more ideal modes of cooking solutions for the region. For example, in the case of solar cookers, as mentioned in WP2, this technology by itself in the current form is not suitable to be the only cooking solution. Jointly with advanced cookstoves or modern fuels, it can limit the cost of expensive fuel by utilizing free solar energy whenever possible. Knowing people's preferences, cooking style, and energy use, a combination of multiple technologies for cooking can be obtained.

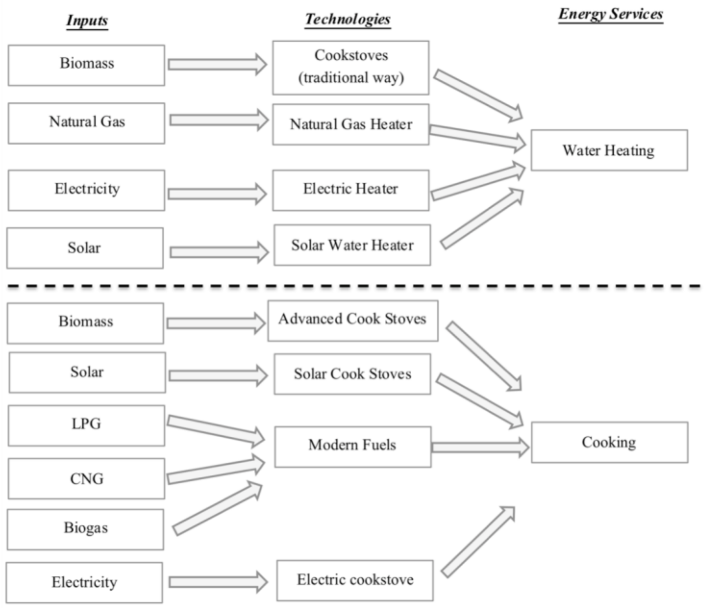


Figure 9: Choices of various energy sources (Input) and supply technologies for the two energy services considered in this report (water heating and cooking)

Heating services:

For any technology evaluation, apart from the technical performance, there are additional aspects that have to be considered to determine actual use. Thermal efficiency of a solar collector is a system performance parameter that tells us how efficiently a solar water heater can heat water. It takes into account all the losses (reflective, radiative, convective and conductive) in the system. Higher thermal efficiency indicates high hot water temperature that can be achieved in relatively less time. The technical attributes that determine a SWH's performance are:

- Mass of water (kg) → total volume required
- Hot water temperature (°C) ~ 50-60 °C
- Initial water temperature (°C)
- Time it takes to heat water (s)
- Environmental conditions (temperature, wind etc.)
- Solar flux (W/m^2)
- Collector area (m^2)

Other important considerations for technology evaluations are:

1. Capital cost
2. Availability/manufacturability of SWH/quality of the product/reliability
3. Availability of financing/discounts/incentives
4. The cost of convection fuels (competition: natural gas, oil, and electricity)
5. The cost of the fuel you use for backup water heating system, if you have one

Cooking services:

SE4all framework will be taken as the basis for evaluating various household cooking solutions as mentioned in Section 1.2.1. The multi-tier framework allows for determining the overall technical performance of the primary cookstove while taking into account the CCA attributes which touch upon the issues of maintenance, convenience, social and cultural fit, and availability and affordability of fuel. The overall access to modern cooking solution can then be determined based on the total number of households at various tiers of service.

Various technologies under different tiers will have different environmental impacts as well. The primary characteristic that defines the environmental impact is the CO2 emissions. Apart from the emission values, indoor pollution attributes such as black carbon and smoke can be considered for different tiered solutions. Within the *MASTER* model, used for an environmental impact study, CO_2 emissions can be considered within the optimization options. Therefore, the resulting combination of technologies for Universal Access may have to respect a maximum level of emissions, or the social cost of CO2 might be added to other social costs considered in the objective function as the cost of energy deprivation. Accordingly, the optimal solution will take into account the final cost of the energy system, the cost of lack of access and the cost of CO2 emissions altogether.

Apart from the environmental consideration on the demand and technology sides, there is a huge need to consider environmental impact on the energy resource side, especially for the use of biomass. With deforestation and desertification becoming a critical issue in many developing nations, land use and sustainable biomass supply are important constraints for many advanced cookstove technologies that rely on forest supplies such as wood. In order to properly consider these constraints, the GIS-aided tool can help in identifying locations with forest resources. The environmental degradation of forest for biomass use must be incorporated as a constraint for the availability of the energy resource. Similar to considering national grid availability for the use of electricity, access and availability of land resources, as well as animal resources (for dung) will be considered for modern heat. Any kind of protected land site identified on the GIS data cannot be classified as energy resource. Similarly, cost of transportation and supply chain of biomass should be taken into account in the model in order to find a sustainable solution.

3.2 Electrification design

The research group is developing a *Reference Electrification Model (REM)*[68] in the spirit of the Reference Network Model[69] (RNM) developed at IIT. The REM aims to design a near-optimal power system to provide electricity access to a region, including the type, size, and locations of electricity generation, storage, and distribution assets. The model requires, as an input, the location and load profile of all the individual customers to be connected. As for 3.1.1 (step 1.a) the geographic location of each connection can be gathered using individual household census data, satellite image processing or crowd sourced pinpointing of users while the load profiles might be estimated according to the average income level and service tier of these customers or, where a increased precision is needed, deducted from specific surveys that assess the energy services required by these users. This model could be used by planners (including distribution companies, policy makers, regulators) to estimate electrification costs and appropriate electrification modes (network extension, isolated mini-grids and stand-alone-systems) at a regional level. Additionally, engineers and designers intending to electrify specific areas could use this tool to facilitate design decisions that appropriately balance level of service and costs.

There are a few main steps that must be taken in order to design the power system. These steps could be performed in an automated fashion, in the case of regional planning, or performed with more user-interaction, in the case of design for a specific location. These steps are briefly described below:

- **Division of area into separate analysis regions:** If the area of interest is large (e.g. a country) it must first be divided into regions, which can be analyzed and optimized separately, in order to manage computational burden. This could be done, for example, based on demand density or based on distances between demand points.
- **Division of analysis regions into electrically isolated clusters:** It must be determined which demand points will be electrically connected (into microgrids or grid extension areas) or remain isolated with home systems. This decision could be made flexibly, and re-evaluated based on the outcomes of later design steps.
- **Design of electricity supply for each isolated cluster:** For each cluster, local generation and storage and/or a grid connection must be selected to optimally serve the cluster's demand. This will entail selection of supply components from a catalog of components, based on the cluster's demand, energy resources, and costs.
- **Design of distribution network for each isolated cluster:** Given power profiles of demand and generation points, wires, transformers, and other distribution network components must be selected at minimum costs, considering technical constraints and losses.
- **Determination of final power system:** If multiple clustering options are explored, the one which leads to the best power system design should be selected. Assessments could be based on maximizing social welfare or profits, depending on the perspective of the user.

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[68] The REM development exceeds the scope of this *Low-cost Energy Technologies for Universal Access Project* but the present methodology integrates its functionalities for the support of the decision-making process.

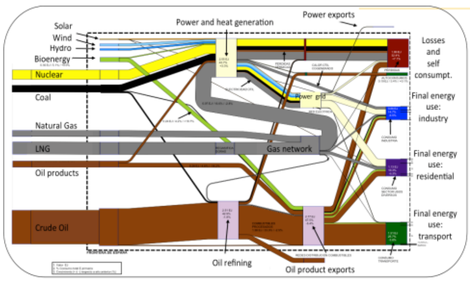
[69] (Mateo Domingo, Gomez San Roman, Sanchez-Miralles, Peco Gonzalez, & Candela Martinez, 2011; Peco, 2004; Pieltain Fernandez, Gomez San Roman, Cossent, Mateo Domingo, & Frias, 2011). The RNM model is the outcome of more tan a decade of research and successful implementation projects in distribution network planning at the Institute for Research in Technology (IIT) at Comillas University in Madrid. RNM has been used by the Spanish Energy Regulatory Commission to remunerate the distribution companies in Spain, with about 25 million customers, with the agreement and collaboration of these companies. RNM has been used for similar purposes in another countries and in several European research studies.

3.3 Evaluation of the future macro level impact of access

Building a successful strategy for universal access to modern energy services requires the assessment of the diverse present and future needs of energy services for development with a user centered approach[70]. It also needs to consider the technological alternatives together with the funding restrictions and regulatory environment according to the country strengths, to make use of limited resources in an efficient manner[71].

To do so, countries need to establish an appropriate framework for the energy transition, involving the final users and establishing the right incentives and regulatory measures to guarantee the long-term sustainability of the supply models. The diversity of user profiles, energy sources, geographic and socio-economic constraints requires the consideration of multiple technological solutions for electrification and modern heat, as well as a variety of scenarios and pathways to address universal access, taking into consideration their interactions with other energy, economic, environmental or social policies competing for usually scarce government resources. Utilities in charge of electrification of large regions may also find this model useful for the assessment of their investment strategies[72].

The research group is developing a *Model for the Analysis of Sustainable Energy Roadmaps for all (MASTER4all)*[73] based on the MASTER_SO model[74] developed at IIT, for the provision of useful insights about the trade-offs between different technological, financial, environmental and energy policy alternatives specifically focused on energy poverty reduction and energy transition to modern supply.



Sankey representation of energy flows in the Spanish System (ref)

1- The process starts with the description of the initial stage of the energy system, considering:
   a. The energy services provided to the final users, considering the whole energy system, with a detailed focus on energy services required by people depending on traditional energy supply (Tier 0 for electrification and heat) or with a poor modern service.
   b. The energy flows from each energy source to the final energy services supplied and the transformations and transport processes, which can be described in a Sankey diagram.

2- The model requires an abstraction process to describe the energy system and flows in terms that the model can optimize following these flows upstream from the demand sectors (DS) through the transport (TE), conversion of energy (CE) to the primary energy (PE) either imported or from the national supply.

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[70] (Brazilian & Pielke, 2013; Schillebeeckx et al., 2012)

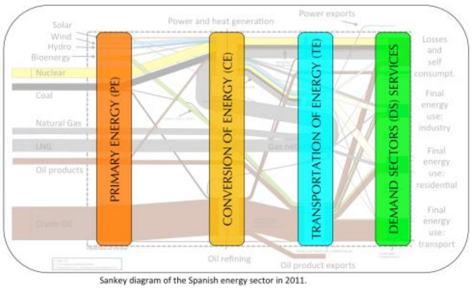
[71] (Brazilian et al., 2010; IFC World Bank, 2012; Khennas, 2012; World Bank, 2010)

[72] (González-García, Pérez-Arriaga, & Moreno-Romero, 2014)

[73] The MASTER4all, although not part of the expected deliverables, will be fully developed by the end of the second year of the *Low-cost Energy Technologies for Universal Access Project*.

[74] (López-Peña, Linares, & Pérez-Arriaga, 2013)

For the description of the Demand Sectors, MASTER4all can consider the national energy system as a whole (single node) or specifically take into account geographical diversity in terms of number of user profiles with equivalent energy needs, electrification mode and supply technologies, generation potential, costs and capacity of payment. This classification of users can be established according to national surveys and expert estimation of supply in a few similar regions, but it can also receive a thorough classification of users if used in combination with GISE4all model.



MASTER4all abstraction cathegories

3- MASTER4all now calculates the optimal supply within a year, according to two main policy perspectives but integrating several optimization choices.
   a. Blanket electrification: This social approach is associated to a political logic frame for equitable energy access, where targets are universal use of electricity for every customer, usually under a rights based approach, with adequate quality, environmental and social performance. Blanket optimization focuses on minimizing lack of energy access with minimum subsidies considering budget restrictions.
   b. Selective electrification: This business approach is usually divided in three stages: initial connection, densification of supply and reinforcement or upgrading of service. The focus is on commercial strategies that allow small positive financial returns with lower costs and higher sustainability, but poor households receive access last (or not at all if they cannot afford it). Priority of selective approach is on business model development and market minimization of costs, with or without any subsidy scheme.

MASTER4all starts the optimization procedure from the detailed characterization of energy services required by each access profile[75] and considering the supply technologies available for each class of users, capacity of payment, incentives and subsidies and other energy policy restrictions, and providing also an estimation of the social cost of CO2 emissions, pollution and energy deprivation. Other political objectives can also be considered as minimizing emissions, energy losses, reliability, fossil fuels, energy dependency, renewable supply or efficiency targets.

Establishing the cost for energy deprivation poses and important challenge. Though a growing number of academic references and policy documents emphasize the impact of access to modern energy services on income generation, health, education, environmental and social development, there are no reference values or standard methodologies for the quantification of the cost of energy poverty. Establishing and appropriate cost for different electrification and heat supply levels will allow the model to address the energy access choices according to a rational energy access ladder.

[75] Type of energy services for basic access: ES:
- Residential: lighting, charging phone, radio, TV, fan, heating, cooking, fridge, washing machine or others.
- Productive: specific agricultural, industrial and commercial appliances as pumping, electric saws, sewing machines, or others; depending on the traditional and modern productive sectors.
- Community: street lighting, health, education, sanitation, telecommunications.

The estimation of the social cost of emissions faces similar problems. Where CO2 markets exist, the cost of emissions can be established using the CO2 price. Additionally, the model can consider a maximum cap for the total emissions of the energy systems, as well as limits per sector or technologies, also providing the opportunity of setting appropriate targets for renewables and energy efficiency, covering the different SE4all goals.

MASTER4all can be set to optimize the investment decisions considering the existence of present capacity (brownfield operation) or without considering any previous capacity (greenfield operation), or to optimize the actual operation of the existing capacity (without investing in any new capacity).

3.4 Considerations for sustainable business models, regulation and governance

As shown in Figure 1 (Section 1.1) any effective delivery model depends on a complex set of internal and external activities. For the analysis of each business model, and taking into account the approaches for business models and their enabling environment detailed in WP1 and WP2[76], we propose a comprehensive methodology that can be summarized in the micro and macro dimensions shown in Figure 10.

We cannot expect the methodology to provide a unique answer for the most suitable business model for each particular case. On the contrary, several adequate solutions might be possible, depending on external circumstances that may be external to the decision maker, or which might be decided by a centralized planner. The discussion that follows provides guidelines that can be useful to discard some approaches and to consider other plausible ones in the future provision of modern electricity services. In any case, these considerations should never be ignored.

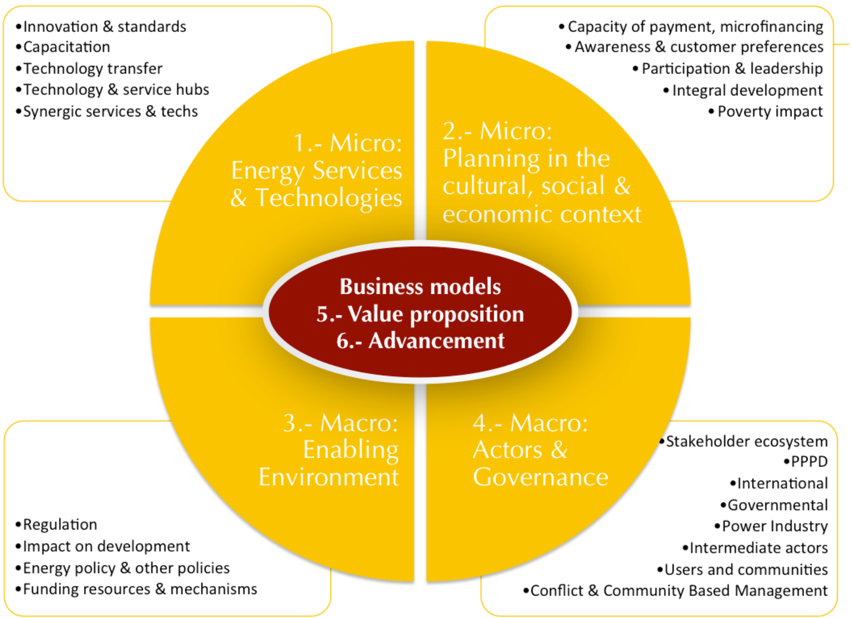


Figure 10: Micro and macro dimensions of the analysis of sustainable business models

[76] (Garside & Bellanca, 2013; Izquierdo & Eisman, 2009; Mataix, Borrella, & (dir), 2012; Reiche, Tenenbaum, & Torres de Mästle, 2006; Wilson, Wood, & Garside, 2012; Yadoo, 2012)

The methodology for the selection of business models is built bottom-up focusing first on the user needs[77] and favoring the approaches with a higher impact in development and reduction of energy poverty[78] (Step 1), then focusing on the business model planning choices according to the conditions of the customer base (Step 2). At the macro level the business model must take into account the available enabling environment (Step 3) to finally pay close attention to the analysis of the institutional ecosystem of stakeholders for energy access (Step 4). Finally at the business model level the decision-making must first analyze the actual value proposition (Step 5) and the future conditions for sustainability and advancement of the delivery model (Step 6).

Step 1. Micro. Energy Sevices Demand		
1.1	Which energy services are needed by the customer base? And what level of service?	Users needs and their value for the customer. Access Tier.
1.2	What are the characteristics of the customer base?	Focus of the business model on mass market / niches / segments. Diversification and escalability. Anchor loads and singular users. Geographic distribution - GISE4all
1.3	What type of relationship does each customer segment expect?	Self-service, individual user service, cooperation, communitarian, gender approach
1.4	Which are the local skills, capacities and awareness for modern access adoption?	Creation of awareness, training, capacitation, organizational preferences
1.5	Which are the channels for the participation of the user communities?	Local and regional implication in decision-making.
1.6	What bundles of technologies, products and services can we offer to each customer segment?	Value propositions of the business model
1.7	What is the impact in local development directly and from an integral perspective?	Direct/indirect creation of local jobs. Direct/indirect promotion of development (productive, community, household). Capacity building. Technology transfer and appropriation.

Step 2. Micro. Business model planning context		
2.1	Which technology choices are there for the supply of required energy services?	Electrification modes according to geographic, socio-economic, demographic and resources and policy constraints - GISE4all / REM / MASTER4all
2.2	Which resources are there for the establishment of the energy supply?	Natural and generation resources, existing energy infrastructure, logistic supply chain. GISE4all / REM / MASTER4all
2.3	Which additional support services are available / required at local level?	Micro-financing and auxiliary infrastructure (transport, communications) GISE4all+. Community organization, social cohesion, conflict management and resolution mechanisms, leadership structure
2.5	What is the distribution of investment, operation, maintenance and logistics costs? What is the	Assessment of electrification costs according to supply tier and geographic constraints. GISE4all / REM

[77] (Schillebeeckx et al., 2012)
[78] (Pueyo, Gonzalez, Dent, & DeMartino, 2013)

	reference cost each electrification supply mode?	

Step 3. Macro. Enabling environment		
3.1	What is the existing regulatory and energy policy framework? Is it possible to improve it?	Tariffs, subsidies and incentives, electrification planning, conflicting policies, competition policy, selection of operators, risk allocation, quality of service standards, maintenance responsibilities, form of ownership, institutional framework and regulatory agencies and universal electrification bodies GISE4all / REM / MASTER4all
3.2	What are the characteristics of the economic, environmental and other related policies and laws?	Trading and quality standards, righst of access to natural resources, protery and land tenure, tax regimes and non-energy incentives and targets, business regulation, tax exemptions
3.3	What is the level of infrastructure available?	National / regional capacity and constraints of the energy and logistics infrastructure
3.4	What is the national and international energy and economic framework?	Energy prices, carbon markets, financial markets and donors

Step 4. Macro: Actors and Governance		
4.1	Which ones are the key actors of the electrification process?	Value chain and strategic analysis of clients, suppliers, existing and new providers of modern energy services, and alternative solutions (traditional energy services or lack of service).
4.2	What is the stakeholder ecosystem?	International, Governmental, power industry, intermediate actors, funding, donors, competition, NGOs, users and communities, Public-private-partnerships for development
4.3	What are the key relationships and drivers for the institutional ecosystem?	Management of interests of the universal access stakeholders
4.4	Are there other synergic activities?	Synergetic value added services: micro-financing, telecommunications, productive, commercial support

Step 5. Business model: Value proposition		
5.1	Which delivery infrastructure?	Purchases, production, sales and aftersales, finances and administration, problem solving?
5.2	Which resources are needed?	Physical inputs, equipment, financial, human, organizational, knowledge
5.3	Which channels and supply modes are suitable?	Customer satisfaction, purchases and contracting of products and services, value supplied through the whole life of the supply, maintenance and aftersales
5.4	Where should the business model locate the different supply technologies? Where to establish the user service centers for sales?	Location of power supply generation / distribution assests. GISE4all / REM. Location of service centers for sales, operation and maintenance and value added services. Assessment of logistic costs. GISE4all+

5.5	What is the cost structure of our business model?	Cost of resources and key activities. Focus on value creation or minimum costs. Equilibrium of fixed and variable costs. Economies of scale and scope
5.6	What is the revenue chain? Is it sustainable in the long term?	Customer capacity and willingness to pay. Present level of service and expenditure (traditional technologies). Expected level of service and expenditure. Expected growth and scalability. Official tariffs, available subsidies and other support
5.7	Value for the client / shareholder / stakeholder?	External and internal value creation activities
5.8	What is the corporative culture?	Leadership, participation, relations with the social environment
Step 6. Business model: Advancement		
6.1	What are the main issues to assess the long-term sustainability?	Economic, social and environmental conditions that guarantee the service model along the whole life of the energy service.
6.2	Is the model replicable in other environments and circumstances?	Asessment of public, private and social factors to replicate and adapt a sucessful experience in different contexts
6.3	Which are the conditions for the scalability of the model for more users?	Challenges for multiplying personel for sales and maintenance, capacitation, capital costs, expansion and diversification of supply sources, synergies with other activities
6.4	How will the energy access technologies address future demand growth?	Upgrading of capacity of existing access modes, transition to more powerful heat supply technologies and electrification mode evolution

Table 3: Tool for ascertaining sustainable business models towards universal access to modern energy services

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