MSc Program
Renewable Energy in Central and Eastern Europe

ENERGY FOR ALL

The Case for Inclusive Business Models for the Provision of Off-Grid Photovoltaic Systems to the Base of the Pyramid in Central America

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 14.10.2013

Affidavit

I, **Lorenz Artaker**, hereby declare

1. that I am the sole author of the present Master Thesis, "Energy For All: The Case for Inclusive Business Models for the Provision of Off-Grid Photovoltaic Systems to the Base of the Pyramid in Central America", 130 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Lack of access to electricity is a main factor for 1.3 billion globally in their struggle to escape poverty. This Thesis stems from the conviction that an approach based on the concept of Inclusive Business Models is indispensible to achieving sustainable development, considering the limited success of top-down efforts by national governments, multilateral development organizations and non-governmental organizations so far. Extended work experience in Central America determined the focus on the region. The core objective was to determine more specifically the viability of Inclusive Business Models for the provision of off-grid Photovoltaic (PV) systems to low-income households, defined as the Base of the Pyramid (BOP), in rural regions of Central America. To do this, definitions for BOP and Inclusive Business were established as a basis for a market assessment. Subsequently, an energetic assessment, categorizing segments of the BOP, followed by a technical assessment, presenting respective solutions were detailed. Finally, PV was shown to be the most suitable renewable energy technology for the Central American BOP market, and its social, ecological and economic impact was highlighted, as well as three case studies presented. The results showed for-profit models to be commercially viable, achieving a triple-bottom-line return as defined by Inclusive Business, and PV systems to be the most beneficial, reliable and easily affordable solution for off-grid electricity access for the Central American BOP. Based on these results, it was concluded that provision of PV to the BOP by a private sector based on Inclusive Business is an indispensable step towards achieving each one of the three goals set out by the UN Initiative *Sustainable Energy for All*, and towards achieving the Millennium Development Goals of an end to poverty.

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List of Acronyms

ACS	American Chemical Society
ADA	Austrian Development Agency
ADB	Asian Development Bank
AEA	Austrian Energy Agency
AIDG	Appropriate Infrastructure Development Group
ARPU	Average Revenue per User
BC	Black Carbon
BCIE	Banco Centroamericano de Integración Económica
BOP	Base of the Pyramid
B$	Belizean Dollar
CA-4	Central America - 4
CDM	Clean Development Mechanism
CEPAL	Comisión Económica para América Latina y el Caribe
CFL	Compact Fluorescent Light
CO_2	Carbon Dioxide
Covelo	Fundación José María Covelo
CSR	Corporate Social Responsibility
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
ENEE	Empresa Nacional De Energía Eléctrica
ESMAP	Energy Sector Management Assistance Program
GEF	Global Environmental Facility
GENI	Global Energy Network Institute
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GHR	Global Horizontal Radiation
GSMA	International Association of Mobile Phone Operators
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
h	hours
IDB	Inter-American Development Bank
IEA	International Energy Agency
IFC	International Finance Corporation

ILO	International Labor Organization
Kg	Kilogram
kV	kilo Volt
kW	kilo Watt
kWh	kilo Watt hour
LED	Light Emitting Diodes
lm	lumen
MDB	Multilateral Development Bank
MDG	Millennium Development Goal
MFI	Micro Finance Institution
MIF	Multilateral Investment Fund
mm	Million
NGO	Non-Governmental Organization
NCIIA	National Collegiate Inventors and Innovators Alliance
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-operation and Development
OAS	Organization of American States
OFID	Organization of the Petroleum Exporting Countries Fund for International Development
OMJ	Opportunities for the Majority
PAYG	Pay As You Go
PE	Potential Energy
PERZA	Proyecto de Electrificación Rural para Zonas Aisladas
PPP	Purchasing Power Parity
PR	Performance Ratio
PV	Photovoltaic
REDCAMIF	Red Centroamericana y del Caribe de Microfinanzas
RE	Renewable Energy
RFID	Radio Frequency Identification
SE4All	Sustainable Energy for All
SEDLAC	Socio-Economic Database for Latin America and the Caribbean
SELCO	Solar Electric Light Company
SHS	Solar Home Systems
SICA	Sistema de la Integración Centroamericana

SIEPAC	Sistema de Interconexión Eléctrica para los Países de América Central
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
UNODC	United Nations Office on Drugs & Crime
US$	United States Dollars
V	Volt
W	Watt
W_p	Watt peak
Wh	Watt hour
WHO	World Health Organization
WB	World Bank
WRI	World Resources Institute
$	International Dollar

1 Introduction

1.1 Motivation

Lack of access to modern energy, defined by the International Energy Agency (IEA) as access to clean cooking facilities and access to electricity (section 2.1), is a main factor in the struggle to escape poverty. Traditional energy sources currently used by affected low-income households are not only more expensive, but also often substandard in terms of the energy provided and have detrimental health impacts.

Given personal professional interests and the academic focus of this Master´s Program, this Thesis will focus on the electricity component of modern energy.

Providing access to electricity is a top priority for governments, multilateral development organizations such as the World Bank (WB) and non-governmental organizations (NGOs) around the world. Despite extensive efforts, approximately 1.3 billion people still remain without access to electricity today (section 2.1).

Given the limited success of these top-down programs, this Thesis will look at a market based alternative strategy to providing access to electricity to those at the base of the energy access ladder, living predominantly in rural areas. If universal access to modern energy is to be achieved within a foreseeable timeframe, a range of complementary strategies needs to be developed and implemented concurrently. The alternative strategy analyzed here is an approach based on the concept of Inclusive Business Models (section 4.1.2).

The regional focus stems from my extended work experience in Latin America, and the fact that within Latin America, Central America represents the region where the issue of access to modern energy is most pressing (section 2.1.1).

1.2 Core Objective

The core objective is to determine the viability for Inclusive Business Models for the provision of off-grid Photovoltaic (PV) systems to low-income households, defined as the Base of the Pyramid (BOP) (section 4.1.1), in rural regions of Central America.

To address this objective, the following areas will be analyzed:

(i) Market assessment: What is the potential market size in Central America for off-grid energy solutions?

(ii) Technical assessment: Why is PV the most suitable renewable energy technology for meeting rural off-grid energy needs?

(iii) Energetic assessment: What are the nominal power requirements of PV systems to meet BOP households' energy needs?

(iv) Social assessment: What is the social impact on the BOP of substituting traditional energy sources with PV systems?

(v) Ecological assessment: What is the ecological impact of the BOP substituting traditional energy sources with PV systems?

(vi) Economic assessment – end-user side: What are the financial implications for the BOP of substituting traditional energy sources with PV systems?

(vii) Economic assessment – business side: What is the commercial viability of providing PV systems to the BOP?

The aim is to draw well-founded conclusions about the feasibility of Inclusive Business Models for the provision of off-grid PV systems, by analyzing as thorough a range of existing data as possible and a number of representative case studies from the region, as a complete assessment of all current projects would go far beyond the scope of this Thesis.

1.3 Citation of Main Literature

The research methods employed here can be broadly categorized into five forms: (i) Review of primary and secondary scientific literature covering a range of areas such as the underlying idea of Inclusive Business Models for the BOP, a global energy outlook, ecological impacts of traditional energy sources, an analysis of numerous Renewable Energy (RE) technologies and strategies for introducing these technologies, as well as empirical evidence of case studies; (ii) Following regularly updated online resources for information, such as population statistics published by the World Bank or retail prices of technology suppliers in Central America; (iii) Attendance of energy conferences and events such as the *Vienna Energy Forum 2013* hosted by the United Nations Industrial Development Organization (UNIDO) to identify current issues being discussed in the industry; (iv) Referencing original documents from international development organizations, notably the Inter-American Development Bank (IDB), on the sizing of the BOP market; (iv) Collecting empirical data stemming from field work done in relation to IDB projects being financed in Central America; (v) Conducting an interview with the CEO of a local technology supplier operating in Central America.

1.4 Structure of Work

In order to answer the core questions stated in section 1.2, this Thesis is structured into 7 principal parts.

Part one (section 2) provides a background on the concept of energy poverty and how it impacts sustainable development. It further highlights the different strategies to electrification and explains the focus on off-grid electricity solutions.

Part two (section 4.1) introduces the concept of Inclusive Business Models for the BOP, explaining the motivation and idea behind this approach as developed by C.K. Prahalad.

Part three (section 4.2) provides an estimation of the potential Central American market for a company providing off-grid PV systems to this region, by looking at the current electrification rates across said countries, as well as determining the size of the BOP across the region.

Part four (sections 4.3 and 4.4) looks at why PV is a particularly suitable off-grid technology to be employed across rural Central America and introduces the kind of devices which would be required to meet the electricity needs of rural BOP households.

Part five (section 4.5, 4.6 and 4.7) makes an assessment of the social, ecological and financial impacts on the BOP, resulting from substitution of traditional lighting sources with PV systems.

Part six (section 4.8) makes an assessment of the commercial viability of providing off-grid PV systems to rural BOP households, by looking at a number of for-profit companies operating in this space, and identifying the factors behind their varying degrees of success.

Part seven (section 5 and 6) summarizes the main findings of this work and puts them into the wider context of reducing energy poverty as a means to achieving global development.

2 Background Information

2.1 Energy Poverty

Energy Poverty is defined as the lack of access to modern energy services. There is no universally adopted definition of modern energy access, but the IEA defines it as *"a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average."*[1]

Rapid economic growth in several countries, increasing urbanization, and a vast number of ongoing energy access programs have enabled access to modern energy services for hundreds of millions over the past two decades, particularly in China and India. However, despite these achievements, in a world with a consistently growing population, the IEA estimates that today around 1.3 billion people in developing countries still remain without access to electricity and around 2.6 billion people still rely on traditional biomass (i.e. log wood) for cooking and heating purposes.[2] Beyond being an obvious development imperative, it is even argued by some[3] that access to modern energy should be considered a justice and human rights issue, as access to reliable and affordable electricity is fundamental among other things to running hospitals and schools effectively.

The above definition of modern energy is principally composed of two components: clean cooking facilities and a connection to electricity. The focus here will be on the access to electricity component. The largest share of people without access to electricity is located in sub-Saharan Africa and the developing parts of Asia. In Latin America 30 million people lack access to electricity (Figure 2.1).

[1] IEA (2011): p.12

[2] IEA (2012): p.29

[3] UNIDO (2013 - Vienna Energy Forum): Robinson M., Mary Robinson Foundation

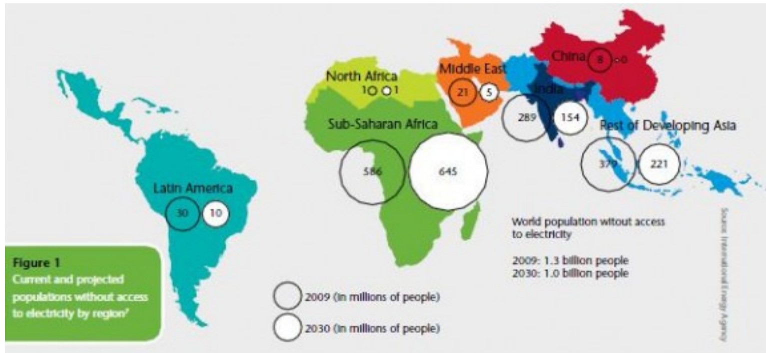

Figure 2.1 – Current (2009) and Projected (2030) Populations without Access to Electricity[4]

The IEA estimates that following the status quo, taking into account existing government policies and cautious implementation of declared policy intentions (*"New Policies Scenario"*)[5], would still leave around 1 billion people without access to electricity by 2030 (Figure 2.1). This calls for a radical rethinking of existing policies in order to alleviate the global energy poverty problem.

2.1.1 Energy Poverty in Latin America

Within Latin America the lack of access to modern energy services is most pressing in Central America, affecting between 50-70% of the population (Figure 2.2).

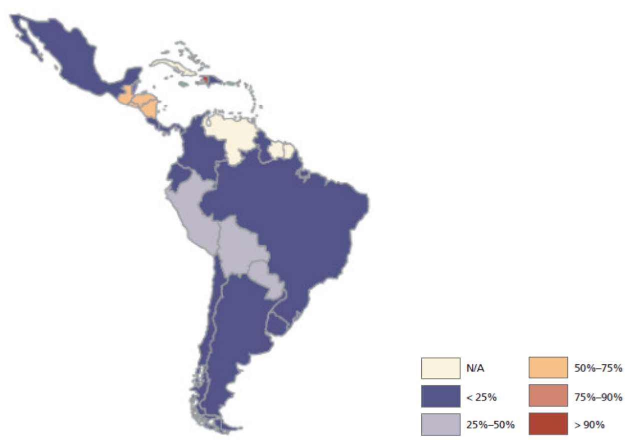

Figure 2.2 – Share of People without Access to Modern Energy (2007)[6]

[4] Gulchard, F. et. al. (2012): p.4, Fig.1 (cited as IEA (2010))

[5] IEA (2011): p.9

[6] Bardouille, P. et. al. (2012): p.22, Fig.1.1

Of this population without access to electricity around 87% live in rural areas,[7] which has important implications when seeking to identify the most appropriate technological solutions to this energy access problem. Given the high costs of extending the national electricity grid to many rural communities (section 2.4), decentralized energy systems such as mini-grids and standalone off-grid solutions are often a more appropriate, reliable and cost-effective strategy for providing access to energy in this region.

2.2 Sustainable Development

The United Nations (UN) World Commission on Environment and Development defines sustainable development as *"(…) meeting the needs of the present without compromising the ability of future generations to meet their own needs."*[8]

Hence, the employment of renewable energy (RE) systems forms an integral component of achieving sustainable development as defined above. Not only does access to electricity facilitate development, but the employment of RE systems avoids the depletion of finite fossil fuel based resources, and eliminates the emissions associated with burning these fossil fuels, which impact the global climate (section 4.6), impacting future generations.

The United Nations Millennium Summit in the year 2000 resulted in the internationally agreed Millennium Development Goals (MDGs), a global agenda to reduce poverty defined as specific targets to be achieved by the year 2015. Despite not being formalized as one of the eight MDGs, lack of access to modern energy will be a major impediment to achieving them.[9] The IEA argues that access to affordable and reliable energy services is fundamental to reducing poverty and improving health amongst children and women, broadening the reach of education, increasing productivity, enhancing competitiveness and promoting economic growth. This is because modern energy is essential for sanitation and healthcare, as well as fostering development through the provision of reliable and efficient lighting, heating,

[7] IEA (2011): p.16, Table 2

[8] UN World Commission on Environment and Development (1987): p.15

[9] ADA/AEA (2012): Öppinger-Walchshofer B., Managing Director of the ADA

cooking facilities, mechanical power, transport, and telecommunication services. Annex A highlights the importance of modern energy to achieving each of the MDGs.

2.3 Sustainable Energy for All

In recognition of the importance of modern energy access for the achievement of the MDGs, the UN founded the initiative *"Sustainable Energy for All"* (SE4All) in the year 2012. This initiative not only raises global awareness of the importance of energy in a development context, but will engage governments, the private sector, and civil society partners to achieve three major goals by 2030:[10]

(i) **Universal Access:** Ensure universal access to modern energy services. As was shown above, sustainable development cannot be achieved universally without access to sustainable energy. The Initiative recognizes that private sector investment is key to building and servicing these markets in order to achieve this goal.[11]

(ii) **Energy Efficiency:** Double the global rate of improvement in energy efficiency. Increasing the global resource productivity ensures that future energy demands can be met, while mitigating climate change. Energy efficiency also makes energy more affordable, as it reduces the demand for energy.

(iii) **Renewable Energy:** Double the global share of renewable energy to 30%. This improves energy security for countries that lack domestic fossil fuel resources and insulates them from fuel price volatility. On a global scale it also helps mitigate climate change.

The IEA estimates in their *"Energy for All Case"* that nearly US$1 trillion in cumulative global investment is required to achieve the goal of universal access to modern energy by 2030.[12] The resulting annual average investment of US$48 billion over the period 2010 to 2030 is more than five times the level of global investments

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[10] SE4All (2013), www

[11] SE4All (2013), www

[12] IEA (2012): p.529

in the year 2009.[13] The majority of the estimated cumulative investments, approximately US$640 billion, will be required to achieve universal access to electricity, with about 10% of those investments applying to Latin America.[14]

Given that it is unlikely that public funding alone will be able to close the funding gap, the private sector is increasingly called upon to be part of the financing solution. As Ban Ki-moon, Secretary-General of the UN, stated: *"We need innovation to spread throughout the world – specifically where energy demand is growing fastest. We need partnerships with the private sector, the global engine of growth and the primary source of new investments"*[15]

To attract the private sector, it is important to remember that while the above figures are often viewed as costs, they should actually be considered investments which generate social returns for countries and communities and financial returns for businesses.

2.4 Strategies for Achieving Universal Access to Energy

Broadly speaking, there are three overarching strategies for achieving universal access to electricity: extensions of the national grid, community level mini-grids, and standalone off-grid energy solutions at the level of individual households, micro-businesses or community buildings such as schools.

2.4.1 Centralized versus Decentralized Energy Solutions

Some utility companies have come up with innovative solutions for overcoming some of the challenges associated with the extension of national grids, such as: setting affordable connection charges, connecting households with no property rights and addressing the issues of managing existing illegal connections. For instance, Empresas Públicas de Medellín in Columbia has introduced pre-pay

[13] IEA (2011): p.3

[14] IEA (2011): p.22, Table 5

[15] SE4ALL (2012): p.16

devices for electricity consumption to best match the often irregular income flows of low-income households, as opposed to introducing a monthly or bimonthly charge. However, the high cost of grid connections of up to US$10,000 per kilometer,[16] in conjunction with the limited electricity consumption levels of low-income households, means that purely commercial models for grid-electrification, particularly in rural areas, are still rare. Public funding has played an important role in the success of most truly large-scale extension programs.

In light of the fact that an estimated 84% of the global un-electrified population (87% in Latin America – section 2.1.1) lives in sparsely populated rural areas, there is a common understanding across the sector that decentralized energy solutions are key to achieving the 2030 goal of universal access to electricity. Decentralized solutions not only avoid the high costs of extending the grid, but also the high energy losses associated with long distance transmissions. In their *Energy for All Case*, the IEA estimates that centralized solutions would be the most suitable solution for all urban zones, but only for up to 30% of rural areas.[17] The remaining 70% of rural areas would require decentralized solutions, such as mini-grids or standalone off-grid systems.

2.4.2 Mini-Grid versus Standalone Off-Grid Systems

Within the space of decentralized energy solutions, there are varying standpoints on whether community mini-grids, defined as isolated community or district level distribution networks with loads between 5 kilo Watts (kW) and 500kW,[18] or standalone off-grid systems are the preferable solution.

For instance, in their *Energy for All Case,* the IEA estimates that 65% of rural areas covered by decentralized solutions would, in theory, be best served by mini-grids, with the remaining 35% by standalone off-grid solutions.[19] In practice, mini-grids are commonly operated by rural cooperatives, sometimes referred to as mini-utilities,[20]

[16] Prahalad, C.K. (2010): p.361 (cited as Baron, S. and Weinmann, G. 2003)

[17] IEA (2011): p.21

[18] Umesh, K. et. al. (2007): p.xxiv

[19] IEA (2011): p.21

[20] Bardouille, P. et. al. (2012): p.16

enterprises which are at least partially owned and/or operated by the community. Decisions are usually taken by consensus, as the entire community is impacted by the outcome of these decisions, and it is argued that this improves the quality and long term sustainability of the cooperative. However, as a result, rural cooperatives tend to be complex to finance, set up and operate and hence a sustainably profitable operation has so far not been accomplished in practice. [21]

This major drawback of mini-utilities is due to a number of reasons such as:[22] (i) The sustainable operation of a mini-grid requires sufficient demand for the produced electricity and therefore enough economic activity in the community; (ii) High up-front investments are required for larger scale generation equipment; (iii) Generation equipment requires more maintenance by trained technical staff (e.g. technically complex hydropower turbines) who might be reluctant to remain in the rural village given the earnings potential of their technical skills; (iv) Distribution costs can be considerable, varying from US$3,500 per circuit-km for low voltage networks (0.2 kilo Volt – kV) to US$5,000 per circuit-km for medium voltage (33 kV).[23] A further disadvantage of mini-utilities is that there are only limited possibilities for scaling or replicating rural cooperatives given their complexity and the fact that each cooperative is tailored to the community in terms of locally available resources, the level of local energy demand as well as social structures within the community. Finally, in some countries mini-utilities are not permitted and in others they are subject to onerous regulations or tariffs which undermine their commercial viability.[24]

Given the complexity and bespoke nature of mini-utilities, as well as their lack of financial sustainability in practice, identifying a market based solution to global energy poverty suggests quite a different approach.

In their effort to size the global Energy Access Market,[25] the International Finance Cooperation (IFC) bases its analysis on the principal underlying assumptions of IEA's *Energy for All Case.* However, in addition to these assumptions, the IFC takes

[21] Kayser, O. et. al. (2009): p.71

[22] Kayser, O. et. al. (2009): p.71

[23] Umesh, K. et. al. (2007): p.42

[24] Bardouille, P. et. al. (2012): p.14

[25] Bardouille, P. et. al. (2012): p.27, Chapter 2

into consideration current household cash expenditure levels on traditional lighting solutions, mainly based on kerosene, as well as a range of prices for various energy products and services.

The IFC finds that of all global households currently without access to electricity, 75% could be commercially served by standalone off-grid solutions[26], 10% by mini-grids, and 8% by grid extensions, while maintaining households´ current energy expenditure levels. The remaining 7% are not commercially addressable at all, due to lack of disposable income.[27]

This discrepancy between the above strategies to achieving universal access to energy proposed by the IEA and the IFC might be explained by the quality of the national electricity service delivered. In practice, even when access to the grid is available, customers in many developing countries are plagued with unreliable power. Hence, it is not unusual for households and businesses to rely on expensive power from back-up generators to make up for poor utility services.[28] Therefore, even people currently connected to the grid might experience financial benefits from switching to more reliable standalone off-grid energy systems, thus vastly increasing the potential market for these solutions.

2.4.3 Focus on Strategy to Universal Access to Energy

Given the predominant importance of decentralized, standalone off-grid systems demonstrated by the IFC's study and bearing in mind the limited market based opportunities for mini-utilities the Thesis objective of evaluating the viability of a market based approach for access to energy to the BOP in rural Central America will focus on Inclusive Business Models for standalone off-grid systems.

[26] The off-grid solutions considered in the IFC study are Solar Lanterns, Solar Kits and Solar Home Systems. See section 4.4.3 for more details

[27] Bardouille, P. et. al. (2012): Percentages calculated from absolute numbers provided in Figure 2.5, p.32

[28] Bardouille, P. et. al. (2012): p.15

3 Method of Approach

The method of approach to answer the core questions of this Thesis is as follows:

(i) Base of the Pyramid: Defining the concept of the BOP, based on the work done by the World Resources Institute (WRI) and the IFC.

(ii) Inclusive Business: Providing an overview of the concept of Inclusive Business Models to serve the BOP, highlighting the motivation and underlying idea behind this approach developed by C.K. Prahalad

(iii) Market Assessment: Establishing the size of the potential BOP market for off-grid energy solutions in Central America, by looking at the size of the BOP population segment in each country, as well as analyzing the status-quo of Central American electricity markets in terms of their electrification levels.

(iv) Technical Assessment: Looking at the major energy uses by off-grid BOP households and the traditional energy sources utilized to meet them. Justifying why PV is a particularly suitable renewable energy technology to serve rural households across Central America, as opposed to alternatives such as wind or hydropower which are fairly location-dependent.

(v) Energetic Assessment: Categorizing rural households into three groups based on their annual electricity consumption levels. Given average Global Horizontal Irradiance levels across Central America, determining the required minimum capacities to meet each of the three electricity consumption levels.

(vi) Social Impact Assessment: Determining the social impact on the BOP in terms of job creation, health and safety, and education, resulting from the substitution of traditional energy sources with PV systems.

(vii) Ecological Impact Assessment: Determining the ecological impact of off-grid BOP households in Central America substituting current traditional energy sources, such as kerosene-based lighting systems, with PV systems, and looking at emission savings which could be achieved.

(viii) Economic Impact Assessment – End-user side: Determining the financial implications for BOP households in Central America of substituting traditional energy sources with PV systems. A comparison is made of households' current expenditure patterns on traditional energy solutions with expenditure that would result from a microcredit repayment, the most common and widely tested consumer financing option in the region, under typical conditions available in Central America. Reflecting the three energy consumption levels of the energetic assessment (point (v) above), rural off-grid households were divided into three categories, based on their monthly expenditure on traditional energy solutions.

(ix) Economic Impact Assessment – Business side: Determining the commercial viability of a for-profit business providing off-grid PV systems to rural households in Central America. This is done by looking at the empirical evidence of companies currently operating successfully in this space and analyzing the key factors underlying their success. Furthermore, the key challenges faced by these businesses are analyzed, as well as their increasing opportunities for access to finance, as a result of growing recognition of the importance of Inclusive Business Models by Multilateral Development Banks (MDBs).

(x) Results: Based on the results of the above analysis, determining whether all the requirements for viability as an Inclusive Business Model are met at both ends: for companies looking to provide off-grid PV systems to BOP households in Central America and for the BOP households themselves.

4 Assessment – The Case for Inclusive Business Models for the Provision of Off-Grid PV Systems

4.1 Inclusive Business Models for the Base of the Pyramid

4.1.1 Defining the Base of the Pyramid

The concept of the socio-economic pyramid is used as a symbol for global income distribution. The top of the pyramid is represented by the wealthy minority while the vast majority of the pyramid is made up by the low-income segment, or the *"Base of the Pyramid"*[29].

The original definition of the BOP developed by C.K. Prahalad was based on a simple premise: *"….4-5 billion poor who are unserved or underserved by the large organized private sector, including multinational firms"*.[30]

Since then there has been a lot of discussions amongst academics and professionals on what exactly constitutes the BOP, in order to better define the size of a given potential market. A definition which has been widely adopted by the main institutions in the industry, such as the Inter-American Development Bank for its BOP Initiative *Opportunities for the Majority* (OMJ) (section 4.8.4.1), is based on an

[29] C.K. Prahalad first referred to the term *"Bottom of the Pyramid"*. Stu Hart and Ted London coined the term *"Base of the Pyramid"* to describe the same 4 billion poor, as this was considered more intellectually appealing. In current debates, both terms are used interchangeably and BOP stands for both formulations (Hammond, A. et. al. (2007): p.24)

[30] Prahalad, C.K. (2010): p.6

extensive study which was carried out by the WRI and the IFC, which has given granularity to the composition of the global BOP by country and income level.[31]

Apart from its granularity, what gives real weight to the results of this study is the fact that the data underlying the report is based on surveys on household income and expenditure, conducted by the national statistics offices in the respective countries. This is important for the validity of the data, considering that economic activity and employment in low-income markets are largely dominated by the informal economy.[32] Consequently, the output of this "informal" activity is not accurately reflected in the determination of a country's GDP, despite the fact that the informal sector accounts for a major share of economic activity in some developing countries. Hence, an accurate calculation of per capita income cannot be based purely on official GDP numbers.

In their study, the WRI and the IFC define the BOP segment as those people with an annual per capita income below 3,260[33] international dollars ($) in local purchasing power (Figure 4.1).[34] Translated into US dollars (US$), this reflects a daily income level of less than US$7.32 in Belize, US$2.22 in Guatemala, or US$1.10 in Honduras.[35]

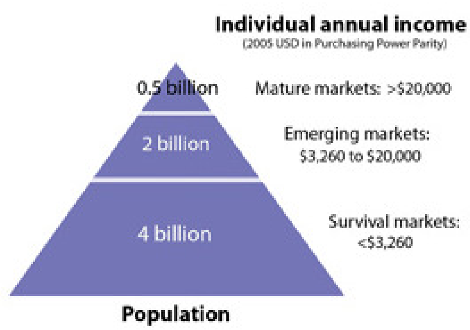

Figure 4.1 - The World Socio-Economic Pyramid[36]

[31] Hammond, A. et. al. (2007)

[32] ILO (International Labor Organization) (2012): p11, Fig.1

[33] 2005 international dollars – adjusted for local purchasing power

[34] This is an adjusted figure of the $3,000 per year per capita in international dollars 2002, the base year to which household surveys in the WIR/IFC report have been normalized (Hammond, A. et. al. (2007): p.11)

[35] Own calculation - full calculation and referenced sources see Annex B

[36] WRI (2013), www

Despite the fact that the income level of each individual is low, the study has shown that the BOP consumers together account for a global market of $5 trillion in purchasing power parity (PPP)[37] terms, presenting a potentially attractive market for the private sector.[38]

4.1.1.1 Latin American BOP Energy Market

Developing country energy markets are predominantly in the BOP. The WRI and IFC have estimated the global BOP household energy market at $433 billion per year, and Latin America's BOP household energy market at $31 billion and 360 million people.[39] After food and housing, energy ranks third in BOP household expenditures. Of Latin America's BOP household expenditure, about 7% is on energy (with slight variations to this average between individual countries).[40]

4.1.2 Inclusive Business Models

Despite more than 50 years of efforts and development interventions by national governments, multilateral development institutions such as the WB, donor nations, various aid organizations, and, most recently, civil society organizations, global poverty is still a reality. With the need for alternative and innovative strategies for poverty reduction and the increasingly important role of the private sector in an ever more globalized society, new private sector-led models for development have evolved.

One of these models, which forms the basis for the analysis in this Thesis, is the concept of Inclusive Business Models for the BOP, developed by C.K. Prahalad and Stuart Hart.[41]

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[37] The concept of PPP is used to determine the relative value of national currencies. It allows an estimation of what the exchange rate between two currencies would have to be, in order to be on par with the local purchasing power of each currency in their respective country.

[38] Hammond, A. et. al. (2007): p.3

[39] Hammond, A. et. al. (2007): p.77

[40] Hammond, A. et. al. (2007): p.78

[41] Prahalad, C.K. and Hart, S. (2002): p.54-67

The underlying idea of the concept was explained by Prahalad as follows:

"What is needed is a better approach to help the poor, an approach that involves partnering with them to innovate and achieve sustainable win-win scenarios where the poor are actively engaged and, at the same time, the companies providing products and services to them are profitable"[42]

According to this approach, the BOP is considered an underserved or untapped market with a huge potential for a win-win situation for business as well as society. By entering into these markets, private sector companies have an opportunity to generate profits while at the same time improving the living standards of the poor by engaging them as suppliers (e.g. cooperatives working together with larger private sector companies), as employees (i.e. the creation of local employment), as distributors (i.e. fostering of local entrepreneurship), and/or as customers (i.e. the delivery of tailored goods and services). Large-scale and wide-spread entrepreneurship is at the heart of the solution to eradicate poverty.

Sustainable earnings and greater empowerment of the poor is, by definition, an explicit corporate goal for an Inclusive Business and forms and integral part of its value chain.[43] The fact that Inclusive Business Models generate a profit while having a social impact means that they achieve a so called "double-bottom-line" return. If, in addition to the social impact, the sustainable Inclusive Business Model also has a positive ecological impact (e.g. mitigating climate change) it achieves a so called "triple-bottom-line" return.

The idea of Inclusive Business Models challenges the traditional assumption by the private sector that the low income population cannot be targeted as customers due to their apparent lack of purchasing power,[44] or because they would not have a use for products that are typically provided to higher income markets. This explains why the BOP has remained a largely underserved market. Both the lack of goods and

[42] Prahalad, C.K. (2010): p.27

[43] Sobhani, S. (2008): p.14

[44] As will be shown in later parts of this Thesis, many of these Inclusive Business Models involve the use of microcredits as a means of creating the necessary purchasing power in the BOP population at the time of the transaction.

services tailored to the needs of the BOP and the lack of efficient methods to facilitate business transactions with the BOP, mean that people in this segment often have to pay higher prices for the same basic goods and services than higher income customers, in monetary terms, or in the effort to obtain the goods (e.g. the global median time for water collection was estimated at 1.6 hours per day in the dry season[45]), thereby incurring the so called "poverty penalty".[46]

The emphasis on profit of the Inclusive Business approach differs from other private sector based models of economic development which are based on corporate social responsibility (CSR) or philanthropy. The Inclusive Business approach recognizes the potential of the BOP as customers, producers and entrepreneurs, and is attractive for companies trying to reach new markets, as opposed to companies using sponsorships or community outreach as public relations tools. This makes market based for-profit Inclusive Business Models a sustainable solution for combating poverty, as it does not depend on aid funds or philanthropy. Finally, a market based approach recognizes that only sustainable solutions can scale to meet the needs of 4 billion people globally who make up the BOP (Figure 4.1).[47]

C.K. Prahalad argues that those people who live in extreme poverty, defined by the World Bank as an average daily consumption of $1.25 or less at PPP, and those who are deprived and afflicted by war and disease, require other forms of help, such as government subsidies, multilateral aid, and philanthropy. However, even in such circumstances the *"…goal should be to build the capacity for those people to escape poverty and deprivation through self-sustaining market based systems."*[48]

In practice, five broad strategies can be distinguished that are employed by companies which have been operating successfully in the BOP markets (section 4.8.2):[49]

(i) Product tailoring: Focusing on the BOP with unique products, unique services, or unique technologies that are appropriate to BOP needs.

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[45] Smith, J. (2000): p.iv

[46] Prahalad, C.K. (2010): p.36

[47] Hammond, A. et. al. (2007): p.7

[48] Prahalad, C.K. (2010): p.8

[49] Hammond, A. et. al. (2007): p.30

(ii) Localizing value creation: Franchising or agent strategies involving building local infrastructures of vendors or suppliers. This usually involves substantial investment in capacity building and training.

(iii) Enabling access to goods and services, both physically and financially: Physically, through novel distribution strategies or development of low-cost technologies. Financially, through packaging strategies (e.g. single use packages), pre-paid solutions or a range of end-user financing approaches. Using existing distribution platforms as a means to reaching scale quickly while controlling costs has often proven crucial for the success of an Inclusive Business Model.

(iv) Unconventional partnering with local governments, NGOs or groups of multiple stakeholders (e.g. the local communities themselves): Bringing the necessary capabilities (such as cultural understanding) into the model, as well as the buy-in from the local communities being served.

(v) Reaching scale: The possibility to scale a business model is crucial both from a business and an impact point of view. Businesses serving the BOP require volume to make up for the low margins per customer.[50] Only if a model can be scaled to reach a large number of people at the BOP, will it have a significant development impact.

4.1.2.1 The Importance of Inclusive Business Models in Rural Electrification

It was shown in section 2.1.1 that more than 8 out of 10 people without access to modern energy in Latin America live in rural areas and that around 70% of these rural populations will require decentralized solutions to receive electricity (section 2.4.1).

The traditional approach to electrification in rural areas has been one of generally large-scale, project-oriented investing through government programs or grants to in-country NGOs. Many of these programs took the form of aid financing sponsored by multilateral institutions such as the WB for electricity grid extension or for subsidized "give-away" programs to the rural poor. The expectation was that access to modern

[50] Bardouille, P. et. al. (2012): p.16

energy would generate a number of additional benefits including greater economic prosperity, which in turn would allow the government to repay the aid financing and would support further growth of the energy infrastructure. In practice, however, many of these programs were not sustainable.[51]

The common flaw in these programs was how they ignored fundamental market forces when targeting underdeveloped areas. With grid extension programs in rural areas where people were subsistence farming, the government or an NGO would install power lines and lights and then expect to charge a monthly bill at the same rates as for the urban population. Often farmers did not have sufficient disposable income and the project would fail.[52]

In other cases, NGOs would get a grant to install a certain number of solar panels at no cost in a specific region. Although these heavy subsidies initially lead to wide distribution, these programs would only be successful until the panels stopped working because of faulty installations, lack of maintenance, worn out batteries or other problems, as there was inadequate emphasis on maintenance or follow-up after the initial installation. In addition, malfunctioning systems severely damaged the reputation and potential of a given technology in the area. Also, subsidized programs reach only a predetermined population and in some cases these would unknowingly undercut and sometimes destroy the business of a small local entrepreneur who had seen the market demand and created a business selling off-grid energy systems in these communities. People deciding to wait for the next subsidized program can distort markets for many years (section 4.8.3.1).

In contrast to these top-down structured plans, successful Inclusive Business Models work from the bottom up, identifying local market opportunities by involving local entrepreneurs who then identify and meet the energy needs in their communities. Once a concept and a structure have been proven to work, the model scales to other communities and eventually other areas and regions.

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[51] Baron, S. and Weinmann, G. (2003): p.10

[52] Baron, S. and Weinmann, G. (2003): p.11

4.2 Size of the Potential Market in Central America

The following section will make an assessment of the potential market for off-grid energy solutions, as stated in the Thesis objective.

4.2.1 Background on Central America

Central America is located in the central geographic region of the Americas, connecting North and South America. It consists of seven countries: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, and has a population of approximately 43 million.[53]

Figure 4.2 - Political Map of Central America[54]

Central America has gone through a continuous process of economic integration over the past decades, with first economic treaties being signed between individual countries in the 1960s.[55] In 1991, the institutional framework of the *Central American Integration System* (*Sistema de la Integración Centroamericana* – SICA) was established as the institutional framework for regional integration, which also represents their interests at organizations such as the UN. Belize joined as a full member in 2000. In 2006 El Salvador, Guatemala, Honduras and Nicaragua formed the *Central America - 4* (CA-4), establishing a process of political, economic, cultural and migratory integration and almost completely eliminating trade barriers and

[53] World Bank (2013): Population data, www

[54] Johnson, A. (2012): p.5, Fig.1

[55] General Treaty on Central American Economic Integration between Guatemala, El Salvador, Honduras and Nicaragua, signed on 13 December 1960. (OAS (2013), www)

enabling free movement across borders among the member states. Belize, Costa Rica and Panama later joined the CA-4 in matters of economic integration.

This process of moving towards a common Central American market facilitates the scaling of successful business models across national borders, a characteristic which is essential to achieving a substantial development impact through Inclusive Business Models (section 4.1.2).

4.2.2 Base of the Pyramid Market in Central America

4.2.2.1 Methodology of Determining the Size of the BOP Market

In order to determine the size of the BOP market in Central America, the definition of BOP as developed by the WRI and the IFC has been adopted (see section 4.1.1). Their study covers detailed household income distribution data for all of the Central American countries, with the exception of Belize. Furthermore, as their report uses data from the year 2000, the numbers have been updated in line with the most recent data available in the WB's online poverty analysis tool PovcalNet.[56] The underlying work for this update has been done by the IDB's OMJ Initiative, with detailed results by country presented in Annex B.

For the case of Belize, a similar approach has been adopted in order to ensure consistency for the results across countries. Household income data for 2010 was derived from the 2007 private consumption figures in the national accounts in the *Abstract of Statistics 2008*, published by the Statistics Institute of Belize.[57] The data presented in these national accounts is split into quintiles, and to establish the percentage of the population that falls within the adopted BOP definition, per capita income in international dollars had to be calculated. For this purpose, the average household income was calculated using the average household size for each quintile, as well as applying the PPP ratio for the Belizean dollar (B$) for the year 2010. Furthermore, a uniform distribution of income was assumed within each household income quintile. The details underlying this calculation methodology are presented in Annex B.

[56] World Bank (2013): Online poverty analysis tool, www

[57] Hydroplan (2011): p.39

4.2.2.2 Size of the BOP Market in Central America

Based on the above calculation, it was established that, with a share of 77.8%, the majority of the population in Central America belongs to the BOP, which equates to approximately 33.7 million people, or 7.5 million households. Table 4.1 provides a breakdown of the share of the BOP population by country. This shows that there is quite a variation between countries, with Nicaragua having the highest share at 89.1% and Costa Rica the lowest share at 53.7%.

Table 4.1 - Base of the Pyramid in Central America[58]

COUNTRY	Population ('000)	BOP Population (%)	Size of BOP ('000)	BOP households ('000)
Belize	357	54.7%	195	49
Costa Rica	4,727	53.7%	2,538	705
El Salvador	6,227	79.9%	4,975	1,276
Guatemala	14,760	82.7%	12,207	2,491
Honduras	7,755	78.8%	6,111	1,358
Nicaragua	5,870	89.1%	5,230	1,006
Panama	3,571	67.7%	2,418	653
Central America	**43,267**	**77.8%**	**33,674**	**7,538**

4.2.3 Central American Electricity Markets

4.2.3.1 Background

Central American countries are heavily dependent on oil for their electricity production and all countries are net importers of hydrocarbons. According to the *Central American Bank for Economic Integration* (*Banco Centroamericano de Integración Económica* - BCIE), the region currently generates 45% of its electricity using oil, spending approximately US$7 billion annually on oil imports.[59]

To foster regional economic integration, Central America is also going through a process of integration of its electricity networks. The construction of the *Central American Electrical Interconnection System* (*Sistema de Interconexión Eléctrica para los Países de América Central* - SIEPAC) from Guatemala to Panama is now nearly complete and will integrate the electrical grid across Central America,

[58] Own calculation - full calculation and referenced sources see Annex B

[59] Johnson, A. (2012): p.7

facilitating energy trading across national boundaries. However, the SIEPAC system will not automatically connect those households currently not connected to the electrical grid.

4.2.3.2 Current Level of Electrification

The market potential for off-grid renewable energy solutions in Central America depends on current levels of electrification. Table 4.2 provides a breakdown of these levels by country, showing that approximately 6 million people, or 1.3 million households, in Central America remain without access to the electrical grid today.

Table 4.2 - Electrification Levels in Central America[60]

COUNTRY	Population ('000)	Electrification rate (%)	Population without access ('000)	Households without access ('000)
Belize	357	91.0%	32	8
Costa Rica	4,727	99.2%	38	11
El Salvador	6,227	91.2%	548	141
Guatemala	14,760	85.3%	2,170	443
Honduras	7,755	81.3%	1450	322
Nicaragua	5,870	74.6%	1,491	287
Panama	3,571	90.1%	354	96
Central America	**43,267**	**85.9%**	**6,083**	**1,308**

Some of the BOP population is located in urban areas (i.e. urban slum formations) and will have access to the electrical grid. However, the majority of the BOP is located in rural areas, and some in remote areas beyond the reach of the national electricity grid. Given that the size of the BOP segment in Central America (Table 4.1) greatly exceeds the population without access to electricity (by a factor of 5.5 for the whole of Central America, and by a factor of at least 3.5 on a national level in the case of Nicaragua), almost all rural households without access to the national electricity grid belong to the BOP.

The most common traditional lighting solution by un-electrified rural households are kerosene based lamps or lanterns. For instance, according to the Honduran National Electricity Utility (*Empresa Nacional De Energía Eléctrica* – ENEE), 86% of un-electrified households are using kerosene or a combination of kerosene and

[60] Own calculation - full calculation and referenced sources see Annex C

other sources such as candles or dry cell batteries for their lighting purposes.[61] For this reason, kerosene will be considered the basis of traditional lighting technology in this analysis.

4.2.3.3 Potential Market for Off-Grid Solutions

Applying the IFC's estimation that 75% of the un-electrified population can be commercially served through standalone off-grid systems (section 2.4.2), results in a potential market in Central America of approximately 1 million households, or 4.6 million people. Guatemala, Honduras and Nicaragua represent the countries with the highest market potential, making up 80% of the estimated market (Annex C).

Given that, in practice, national grid extension programs are often politically motivated and might even be carried out in areas without commercial viability of service for the utility, the actual market might be somewhat smaller. Even applying the more conservative estimates of the IEA, that the national grid could, in theory, penetrate up to 30% of rural areas to achieve universal access (section 2.4.1), this would still represent a considerable potential market in Central America of 3.7 million people, or 800,000 households (Annex C). Furthermore, rural households expecting to be connected to the national grid in the foreseeable future could still be targeted by services such as micro-rentals for off-grid PV systems (section 4.7.3.2), as an interim solution to pre-electrification.

4.2.4 Conclusions on Central American Market Assessment

This section has shown that the majority of the Central American population is classified as BOP. It was further shown that there is considerable market potential for off-grid energy solutions, particularly in rural areas, to meet universal access to modern energy in Central America.

[61] ENEE (2005): p.5

4.3 Technical Assessment – Overview of Small Scale RE Technologies and the Importance of PV

4.3.1 Assessment & Overview of Potential Off-Grid RE Technologies

The following section will make a high-level comparative analysis of PV, wind energy, and hydropower to show the importance and suitability of PV in the Central American region, as stated in the Thesis objective.

4.3.2 Electricity Uses and Technologies Employed in Rural Areas

To understand why PV might be the most suitable RE technology for meeting rural off-grid energy needs in Central America, it is important to consider the current uses of energy in un-electrified rural households.

The demand for energy in rural un-electrified households is mainly driven by the need for lighting, cooking (which does not fall into the scope of the analysis of this Thesis – section 2.1), and charging or powering small electric devices. In addition, some home-based micro businesses may require energy for productive uses such as irrigating fields, water pumps or operating basic machinery (e.g. sewing machines working from home). Table 4.3 lists a range of conventional technologies, ranging from candles and kerosene lamps to re-chargeable car batteries, currently being used to meet these rural household energy needs.

Table 4.3 - Traditional Fulfillment of Rural Off-Grid Household Energy Needs[62]

Rural Household Energy Need	Primary Source of Energy				
	Kerosene/ Candles	Dry Cell Batteries	Re-chargeable Car Batteries	Human Energy	Not Used
Lighting	x	x			
Radio		x			
Television			x		
Fan					x
Refrigerator					x
Warm water					x
Potable water (pumping)				x	

[62] Smith, J. (2000): p.4, extract from Fig.1

4.3.3 Overview of Photovoltaic Power Systems

Photovoltaic is a marriage of two words: '*photo*', from Greek roots, meaning light, and '*voltaic*', from '*volt*', which is the unit used to measure electric potential at a given point. PV systems use cells to convert solar radiation into electricity. The cell consists of one or two layers of a semi-conducting material (such as silicon). When light shines on the cell it creates an electric field across the layers, causing electricity to flow. The greater the intensity of the light, the greater the flow of electricity.[63]

The most common cell technology representing about 90% of the market today are Crystalline Silicon Cells. Figure 4.3 shows the process of producing Crystalline Silicon Panels. There are a series of processing steps to create a single slice of silicon from the raw material which is subsequently used to create one solar cell. These silicon cells are then assembled together into modules and the modules, in turn, are assembled together to produce the solar panel.

Figure 4.3 - Production Process of Crystalline Silicon Based Photovoltaic Panels[64]

The thin slices of silicon used for producing the cells are cut from a single crystal of silicon (mono-crystalline) or from a block of silicon crystals (poly-crystalline). Commercial modules of mono-crystal cells achieve efficiencies of turning sunlight into electricity of around 18% with poly-crystalline commercial modules approaching efficiencies of 15%.[65]

[63] European Photovoltaic Industry Association (2012), www

[64] European Photovoltaic Industry Association (2012), www

[65] Fechner, H. (2012): p.7

The suitability of a location for harnessing PV power depends on the level of local solar irradiance, which is the power of electromagnetic radiation from the sun per unit area. The total solar irradiance on a horizontal surface is referred to as the Global Horizontal Irradiance (GHI), and the unit of measure is Watts (W) per square meter (W/m^2). GHI is the sum of the Direct Normal Irradiance (DNI), solar radiation which arrives on a direct path from the sun at its current position in the sky, and the Diffuse Horizontal Irradiance (DHI), solar radiation that has been scattered by molecules and particles in the atmosphere and comes equally from all directions. On a clear day, most of the solar radiation received by a horizontal surface will be DNI, while on a cloudy day most will be DHI.[66] The GHI multiplied by the number of hours of exposure gives the total Global Horizontal Radiation (GHR), measured in Watt hours (Wh) per square meter (Wh/m^2).

4.3.3.1 Main Advantages of PV Systems

There are several characteristics of PV systems which make them a suitable option for providing off-grid energy solutions to rural communities in Central America:

(i) Regional levels of solar radiation: As can be seen from Table 4.4, strong GHR exists across the whole of Central America, thus making it a suitable region to employ PV. For regional GHR Maps see Annex D. To put this into context, the annual GHR in Central Europe is approximately 1,100 kWh/m^2 per year.[67]

Table 4.4 – Annual Global Horizontal Radiation in Central America[68]

COUNTRY	Min (kWh/m^2)	Max (kWh/m^2)	Average (kWh/m^2)
Belize	1,757	2,094	1,926
Costa Rica	1,537	2,222	1,880
El Salvador	2,206	2,206	2,206
Guatemala	1,778	2,355	2,067
Honduras	1,789	2,181	1,985
Nicaragua	1,621	2,387	2,004
Panama	1,523	1,921	1,722
Central American Average	**1,744**	**2,195**	**1,970**

[66] Reno, M. et. al. (2012): p.9

[67] Weiss, W. (2012): p.15, Table 3

[68] Breyer, C. and Schmid, J. (2010): p-10, Table 1 (Appendix)

(ii) Universally applicable technology: Unlike other RE technologies, such as hydropower which is very location specific, solar radiation can be harnessed across the whole region. This makes PV a very attractive technology for an Inclusive Business Model trying to reach scale across Central America.

(iii) Modular structure of PV systems: The advantage of the modular structure is twofold:

a. Figure 4.3 showed that the silicon modules are assembled to produce a solar panel. This process allows panels of different capacities to be produced easily, to most efficiently meet the energy needs of the end-users (Table 4.6).

b. It has been shown that as people's living standards increase, so do their consumption levels of electricity. In fact, the part of the IEA's definition of modern energy relating to electricity states "[……] *a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average"* (section 2.1). Given its modular structure, PV is an ideal off-grid technology which can grow hand-in-hand with the living standard and thus the level of electricity consumption of the household, simply by adding additional capacity in the form of panels to a system.

(iv) Lifetime of panels: PV panels have a proven lifetime of 20-25 years,[69] thereby increasing the return of a household's investment, particularly important for BOP households. Furthermore, silicon cell based PV panels are a tried and tested technology and most manufacturers are offering extended warranties of 20-25 years (section 4.8.2.2).

(v) Low maintenance: As opposed to wind or hydropower systems based on a turbine, PV systems do not have any "moving parts", thus reducing the amount of required maintenance. Essentially the PV panel needs to be kept free from debris (e.g. leaves) and dirt, by means of wiping it with a cloth or a broom to ensure maximum possible output.

(vi) No noise pollution: PV systems operate entirely noise free.

[69] Umesh, K. et. al. (2007): p.10, Table 2.1

4.3.4 Overview of Pico-Hydroelectric Power Systems

The hydrologic cycle of evaporation and precipitation is driven by solar energy. Through evaporation and transpiration, water is lifted and its potential energy (PE)[70] is increased. Through the runoff mechanism a natural river dissipates this PE along its course. Hydropower utilizes the difference in PE between suitable locations along a river and transforms it into kinetic energy by powering a turbine. This kinetic energy in turn is converted into electrical energy by means of a generator.

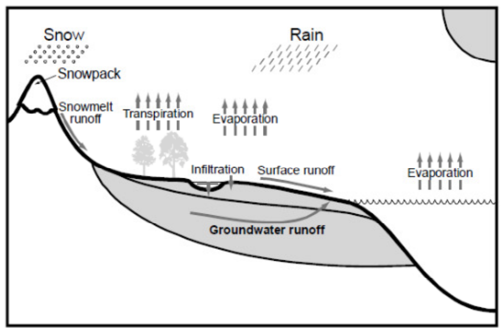

Figure 4.4 - Hydrologic Cycle[71]

Pico hydro is the term used for hydroelectric power generation of up to 5 kW.[72] A pico-hydroelectric power plant incorporates all of the electro-mechanical elements into one portable device. The newer devices also come with embedded power electronics to regulate voltage and balance loads, to minimize lighting flicker and avoid potential damage to connected appliances. The smaller devices with a capacity of 200 - 300 Watt (W) require only very low heads of 1-2 meters to operate. Devices with larger capacities (e.g. 1kW) typically require some additional construction work, thereby increasing the overall cost of the system, to achieve the higher head requirements of 5-6 meters. The devices are installed on the river or stream embankment and the set-up is typically a “run-of-stream”, meaning that no dams are required, but rather pipes or other means are used to divert some of the river’s flow to achieve the required head. There are several different turbine options for low-head sites, including the traditional water wheels. The latter tend to be large and to run slowly, but they have the advantage of allowing leaves and other matter to flow through without blockage.

[70] Potential energy = Energy of water mass due to its position in the gravity system of the earth (Kraus, H. (2012): p.3)

[71] Blöschl, G. (2012): p.3/17

[72] University of Nottingham (2013), www

4.3.4.1 Main Drawback of Hydropower Systems

The main drawback of this technology is that it is location specific, as it requires a river or stream at close proximity to the rural household or village to avoid the cost and energy losses associated with a transmission line. Hence, this cannot constitute the core technology for an Inclusive Business Model trying to reach scale across Central America. Furthermore, the lower capacity devices of 200 – 300 W have a relatively short lifespan of 5 years,[73] compared to the 20-25 years of a PV panel. Higher capacity systems have longer life-spans (e.g. 1kW – 15 year lifespan[74]) and this technology is thus often preferred for energy solutions on a community scale. An example of this is the *Pico-Hydropower Franchising* project of the National Collegiate Inventors and Innovators Alliance (NCIIA), which has developed and installed several pico-hydropower systems in remote villages in Honduras.[75] However, as was highlighted in section 2.4.2, the operation of mini-utilities has not been proven to be financially sustainable.

4.3.5 Overview of Small Wind Power Systems

The earth's atmosphere is provided with a constant source of energy in the form of solar radiation, heating land surface, oceans and air to varying degrees, and causing air masses of different air pressures to form. In order to equalize the pressure, air masses begin to shift and the resulting wind is a long-range or local compensatory movement between high and low pressure areas.[76] Wind power systems harness this flow of air, transforming it into kinetic energy by powering a wind turbine. This kinetic energy in turn is converted into electrical energy by means of a generator.

Wind turbines are classified into two types: small (up to 100 kW) and large. Small wind turbines can be used for off-grid, mini-grid as well as grid-connected applications. The principal components of a wind turbine include the rotor blades, the generator, power regulation, aerodynamic mechanisms, and the tower.

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[73] Umesh, K. et. al. (2007): p.24, Table 2.11

[74] Umesh, K. et. al. (2007): p.24, Table 2.11

[75] NCIIA (2013), www

[76] Krenn, A. (2012): p.1

4.3.5.1 Main Drawback of Wind Power Systems

The main drawback of this technology is that, given the numerous mechanical parts of a wind turbine, the maintenance requirements are relatively high. This particularly becomes an issue when the installations are in remote rural areas. Furthermore, the wind map in Figure 4.5 shows that the greatest wind potential is in the coastal areas of Central America, with mostly poor wind conditions in the rural areas inland. Hence, wind energy cannot be the core technology for an Inclusive Business Model trying to reach scale across Central America.

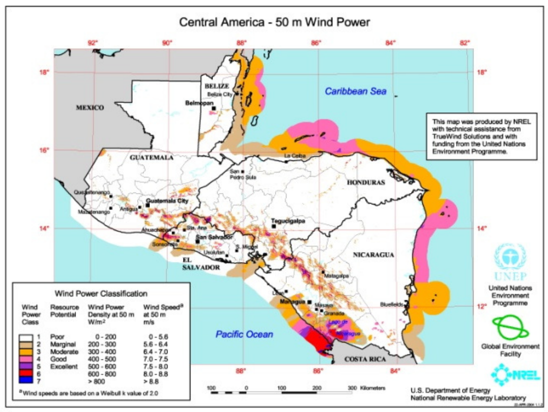

Figure 4.5 - Wind Map of Central America[77]

4.3.6 Conclusions on Technical Assessment

This section has shown that PV systems are the most suitable off-grid technology for rural electrification in Central America for a number of reasons, ranging from the universally available resource of the sun across the region, their modular structure and relatively easy maintenance to their comparative longevity. For individual communities, wind or hydropower might be an appropriate technology, but due to their geographic limitations they cannot form the core technology for an Inclusive Business Model looking to reach scale across Central America. For these reasons, PV forms the basis of analysis here.

As will be shown in later sections, all of the household energy needs highlighted in Table 4.3 could be met through PV systems.

[77] NREL – Central America Wind Map (2013), www

4.4 Energetic Assessment of PV Systems

The following section will make an energetic assessment of the proposed off-grid PV systems, looking at the capacity required to meet the Central American BOP households' energy needs, as stated in the Thesis objective.

4.4.1 Determining Electricity Consumption Levels of BOP Households

4.4.1.1 Definitions and Assumptions for the Analysis

Definitions:

(i) Luminous Flux: A measure of the *perceived* (by the human eye) power of light.[78] The unit of measure of luminous flux is the lumen (lm).

(ii) Luminous Efficacy: A measure of the efficiency of a device in converting electrical power to visible light. The unit of measure is lumens per Watt (lm/W).

(iii) Electrical Power: The power is equal to the luminous flux, divided by the luminous efficacy. The unit of measure of power is the Watt.

Assumptions:

(i) Average demand for lighting services for a rural household is 4 hours per day.[79]

(ii) Luminous Efficacy: The two lighting sources most commonly used in PV devices (section 4.4.3) are compact fluorescent light (CFL) bulbs and light emitting diodes (LED). There is a range of luminous efficacies depending on the subtype of these technologies so average efficacies will be used in the calculations. For illustrative purposes, Table 4.5 also displays the average luminous efficacy of traditional lighting sources.

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[78] This differs from "radiant flux" which is the measure of the total power of electromagnetic radiation, including infrared, ultraviolet, and visible light.

[79] Barnes, D. et. al. (2005): p.61, Box 8

Table 4.5 - Average Luminous Efficacy by Lighting Source[80]

Light source	Luminous Efficacy (lm/W)
Kerosene Lamp (with wick)	0.10
Wax Based Candle	0.11
Kerosene Pressure Lamp	1.75
CFL	50
LED	100[81]

4.4.1.2 Electricity Consumption Levels

The analysis determines the following three household consumption levels of electricity:

(i) *Subsistence Level* of consumption: As stated in section 4.2.3.2, rural households in Central America mainly rely on kerosene lamps for lighting. The *Subsistence Level* assumes replacing this kerosene lamp with a PV device, while essentially not affecting the household´s energy consumption (i.e. lighting from a single mobile source). Adopting the assumption used by the IFC in its efforts to determine the global energy market, one solar lantern (section 4.4.3) replaces one kerosene lamp.[82] While meeting the assumed lighting requirement of 4 hours per day, a typical solar lantern using LED provides approximately 120 lm of light,[83] far superior to the 8 - 45 lm achieved with a kerosene lamp.[84]

Section 4.4.1.2 showed that Electrical Power is defined as follows:

$$\textit{Electrical Power} = \frac{\textit{Luminous Flux}}{\textit{Luminous Efficacy}}$$

[80] Schwarz, D. et. al. (2005): p.6, CFL: Table 2

[81] Schwarz, D. et. al. (2005): p.6. In 2005, LEDs offered about 60 lm/W. Given that this is an emerging technology, the LED industry projected to achieve 200 lm/W by 2015. The conservative assumption of an average luminous efficacy of 100 lm/W was made for this analysis.

[82] Bardouille, P. et. al. (2012): p.159, Appendix B

[83] Phocos (2013), www

[84] Mills, E. (2003): p.11 , Table 2

Applying the Luminous Flux of 120 lm of a LED solar lantern, and the LED luminous efficacy of 100 lm/W (Table 4.5), results in an electrical power of:

$$\text{Electrical Power} = \frac{120}{100} = 1.2\ W$$

Hence, the daily electricity consumption at the assumed lighting requirement of 4 hours per day is equal to:

*Daily electricity consumption = 1.2 W * 4 hours = 4.8 Wh*

This corresponds to an annual level of electricity consumption of approximately 2 kilo Watt hours (kWh) per household.

(ii) *Basic Level* of consumption: A level of illumination of 300lm is not only considered the typical western standard for tasks such as reading,[85] but also provides sufficient lighting for the illumination of a living room or kitchen working area.[86] Applying the assumed average CFL luminar efficacy of 50lm/W (Table 4.5), which is commonly used for indoor lighting purposes, such an illumination can be easily met by a 7W CFL bulb. Additional electricity for small electrical devices (powering a radio, charging a mobile phone, etc.) - amounting to 3W – results in an anticipated demand for electricity of 10W. Applying the same methodology as for the *Subsistence Level* of consumption, and assuming a usage of 4 hours a day, results in a daily electricity consumption of 40Wh and an annual electricity consumption of approximately 15 kWh per household.

(iii) *MDG-compatible Level* of consumption: Given the range of income levels within the BOP (see Annex B), and the fact that electricity consumption increases with income levels, the third level of electricity consumption adopted for this analysis will be set at the estimated *MDG-compatible Level* of consumption of 75 kWh per year per household, as defined by the UN Millennium Project.[87]

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[85] Mills, E. (2003): p.3

[86] Schwarz, D. et. al. (2005): p.3, Table 1

[87] Barnes, D. et. al. (2005): p.90, Table III.2

Table 4.6 provides a summary of the above three levels of household electricity consumption:

Table 4.6 – Annual Household Electricity Consumption Levels

Subsistence Level of consumption	2 kWh
Basic Level of consumption	15 kWh
MDG-compatible Level of consumption	75 kWh

To put these consumption levels into context, the average annual household electricity consumption *per capita* is 1,500 kWh per year in western Europe and 4,500 kWh per year in North America.[88]

4.4.2 PV System Capacity Requirements

Having determined the three levels of BOP households´ electricity consumptions (Table 4.6), the varying capacities of PV systems will now be analyzed to determine their respective suitability to meet these needs. PV systems are categorized by their "Nominal Power", defined as the system's peak power under standard conditions,[89] which is denoted by the unit Watt peak (W_p).

4.4.2.1 Assumptions for the Analysis

(i) Technology: PV panels based on crystalline silicon cells, the most commonly applied and most established technology today, will be the basis of this analysis. Given that the PV systems are aimed at BOP households, the somewhat cheaper option of poly-crystalline cells (section 4.3.3) is used to make the systems more widely affordable for rural households.

(ii) Efficiency: Given the use of poly-crystalline cells, a solar cell efficiency of 15% is assumed.[90]

(iii) Performance Ratio (PR): The PR is defined as the ratio of the actual amount of electricity produced by a given PV system to the theoretical optimum

[88] Lapillonne, B. et. al. (2008): p30, Fig.2.22

[89] Standard conditions are defined as: Solar Irradiance of 1,000 W/m^2, Temperature of 25 degrees centigrade, and 1.5 of air mass.

[90] Fechner, H. (2012): p.7

amount of electricity produced, based on the system's nominal power. For Crystalline Silicon installations a PR of 80% can be achieved.[91]

(iv) Solar radiation: Average Annual GHR by country as per Table 4.4

(v) Operation of the PV plants: It is assumed that the PV panels are mounted in an ideal location with regards to the surroundings to minimize shadow effects. Furthermore, the panels are held clean from debris (through rain and regular maintenance), thus ensuring the maximum possible output.

(vi) Storage: Given that these are off-grid solutions, each PV system is assumed to have sufficient battery storage capacity to store electricity for periods of lower power generation (i.e. during night hours).

4.4.2.2 Calculation Methodology

The annual electricity produced by an off-grid PV system is calculated as follows:

*Annual Electricity Production = Nominal Power of PV System * Full Load Hours*

where,

$$\text{Full Load Hours} = \text{Performance Ratio} * \frac{\text{Annual Solar Radiation}}{\text{Reference Irradiance}}$$

where,

Performance Ratio = 80% as per section 4.4.2.1

Annual Solar Radiation = Average GHR as per Table 4.4

Reference Irradiance = A global constant equal to 1kW/m^2

Units:

- *Annual Electricity Production: (Wh)*
- *Nominal Power of PV System: (W)*
- *Full Load Hours: (h)*
- *Performance Ratio: (%)*
- *Annual Solar Radiation: (kWh/m*^{2}*)*
- *Reference Irradiance: (kW/m*^{2}*)*

[91] SMA (2010), p.2

4.4.2.3 Summary of Calculation Results

Detailed calculations of the annual electricity production can be found in Annex E. A summary of the results of this analysis is presented in:

Table 4.7 – Annual Electricity Produced by PV Panels with Different Nominal Powers at Average GHR[92]

COUNTRY	$1.5W_p$ (kWh)	$10W_p$ (kWh)	$50W_p$ (kWh)
Belize	2.3	15.4	77.0
Costa Rica	2.3	15.0	75.2
El Salvador	2.6	17.6	88.2
Guatemala	2.5	16.5	82.7
Honduras	2.4	15.9	79.4
Nicaragua	2.4	16.0	80.2
Panama	2.1	13.8	68.9
Central American Average	**2.4**	**15.8**	**78.8**

The above table shows that to produce sufficient electricity to meet the *Subsistence*, *Basic*, and *MDG-compatible Levels* of consumption (Table 4.6), would require PV systems with peak capacities of $1.5W_p$, $10W_p$, and $50W_p$ respectively, when measured at the average annual GHR levels in each country. Panama, which has slightly lower GHR levels compared to the rest of Central America, is an exception, and would require approximately 10% more nominal power to meet all three household consumption levels.

4.4.3 Suitable PV Devices to Meet Rural Electricity Demands

There are a number of suitable PV systems on the market today with the relevant peak capacities that broadly line up with the respective BOP rural households' consumption needs highlighted in Table 4.6.

PV lighting systems can be broadly categorized into three groups: Rechargeable solar lanterns, Solar Kits, and Rooftop Solar Home Systems (SHS).

(i) Solar lanterns: These are integrated devices combining a small solar panel (typically in the range of $2W_p$ – $3W_p$), batteries, and typically LED lights. A wide range of solar lanterns has been developed to meet the requirements of

[92] Own calculation - full calculation and referenced sources see Annex E

BOP households. Most of these have different illumination levels to provide ambient lighting, task lighting, or to light the way for travel. Some of the more sophisticated devices also have integrated radios and offer limited external charging for small electrical devices such as mobile phones.

Figure 4.6 - Examples of Basic and Advanced Solar Lanterns[93]

(ii) Solar Kits: These are portable systems which allow households to power multiple lights and have a number of sockets for charging electrical devices such as mobile phones, as well as run small appliances such as radios or even black and white TVs with the larger Kits. Capacities typically range from $10W_p$ to $75W_p$, thereby meeting a range of different household electricity requirements. They have surfaced as an interesting alternative to traditional SHS, as they do not require an installation and also tend to come in smaller capacities, thereby making them more affordable to end-users.

Figure 4.7 - Example of a $10W_p$ Solar Kit[94]

(iii) SHS: These are more sophisticated systems which typically come in capacities slightly larger than those of Solar Kits, usually ranging from $60W_p$ to around $200W_p$.[95] Due to the size of the panels, these are fixed installations where the PV panel either gets mounted on the rooftop or a pole (Figure

[93] Bardouille, P. et. al. (2012): p.29, Fig.2.2; Phocos (2013), www

[94] Quetsol – $10W_p$ Solar Kit sold in Guatemala (2013), www

[95] Tecnosol – Retail prices of PV systems sold (2013), www

4.8). The advantage of having a mounted system is that the panel can be installed with the optimal orientation and angle, to maximize the efficiency of the system. Depending on the capacities they can power multiple lights as well as run a range of electrical appliances such as color televisions or even small refrigerators.

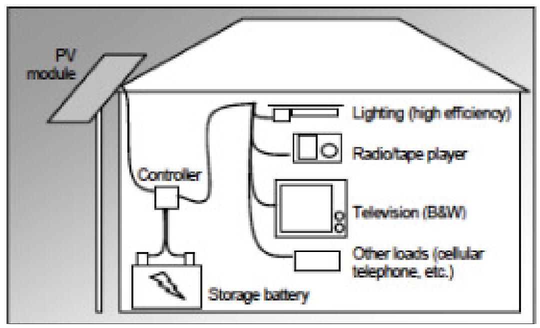

Figure 4.8 – Typical Components of a Solar Home System[96]

4.4.4 Conclusion on Energetic Assessment

This section has shown that there are a number of suitable PV systems on the market today with the required peak capacities to meet the annual electricity consumption levels by rural BOP households. Three electricity consumption levels were established as part of the analysis (Table 4.6). Based on the energetic assessment, it was shown that solar lanterns would be the ideal devices to meet the *Subsistence Level* of consumption, whereas the range of capacities available for Solar Kits are sufficient for the *Basic* as well as the *MDG-compatible Levels* of consumption. The smaller SHS would also be suitable for the *MDG-compatible Level* of consumption, whereas the larger systems are more appropriate for small businesses requiring multiple lights for more than 4-5 hours per night, and to power machinery or larger fridges or freezers for their products.

[96] Rogers, J. et. al. (2006): p.61

4.5 Social Impact Assessment of Access to PV Energy Services

The following section will analyze the social impact component of the proposed Inclusive Business Model for providing PV systems to households currently without access to modern energy and enabling them to substitute away from traditional energy sources, as stated in the Thesis objective.

Maslow's Hierarchical Pyramid of Needs (Figure 4.9) defines human physiological needs, such as food and warmth, as the base on which safety, social and esteem needs and finally self-actualization needs are arranged. Energy, clean water and lighting are essential for meeting the physiological and safety needs of humans, to be able to move on to fulfill psychological needs. Education and income generation contribute to the social and esteem needs associated with both individual and societal development and energy plays a significant part in this.

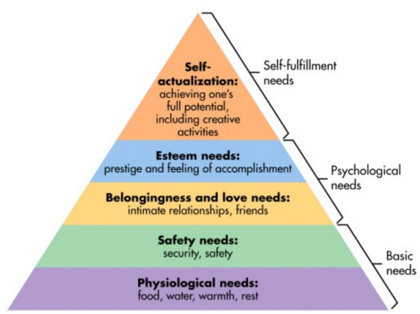

Figure 4.9 - Maslow's Pyramid of Needs[97]

4.5.1 Access to Electrical Appliances

As was shown in section 4.4.3, the majority of PV devices, ranging from simple solar lanterns to more sophisticated SHS, have a plug to charge a mobile phone. In addition, Solar Kits and SHS generally have one or more electrical socket(s), to power electrical appliances such as floor fans, radios, music systems or even low voltage and energy efficient TVs. Access to these electrical appliances greatly improves the lives of the beneficiaries:

[97] Chartdiagram (2013), www

(i) Communication products: Apart from providing entertainment value to their users, these products can support educational awareness campaigns over the radio and TV, or provide the users with a means to accessing financial services (section 4.7.3.3.1).

(ii) Refrigeration: Running a small fridge to keep foods and drinks fresh.

(iii) Ventilation: Powering a floor fan will greatly improve the inhabitants' living conditions by cooling both during the day and particularly during the often hot nights in Central America.

(iv) Warm water: Powering an electric, tank-less water heater, widely used across Central America, for hot showers.[98]

Furthermore, in a lot of communities served by Tecnosol (section 4.8.1.1), the sense of belonging and community life has increased through activities such as watching movies, access to the internet and celebrations in the evening.[99]

4.5.2 Opportunities for Existing Microenterprises

Access to off-grid electricity enables local businesses such as shops, bakeries or rural pharmacies to extend their business hours and stay open until late at night. This enables microenterprises to serve more customers, especially those who are returning home late at the end of a working day, thereby generating more income and improving communal infrastructure. An SHS to run a fridge enables a shop owner to expand their product range to include appropriately stored fresh produce such a diary products, fruits & vegetables and meat. For instance, one shop keeper in Nicaragua found that her income increased by US$40 per day as a result of longer opening hours in the evening due to lighting, as well as having an SHS-powered freezer for her produce. She also found that she saved US$5 per day with this SHS-powered freezer compared to running a kerosene refrigerator, and a

[98] This is stated as a potential use of electricity, given that this Thesis is focusing entirely on PV electricity generation. In terms of energy efficiency, a vastly superior solution for the preparation of warm water would be the use of a solar thermal installation. These systems now also form part of Tecnosol's product portfolio.

[99] Ashden (2010): p.3

further US$10 per week from not having to travel to the nearest town (3.5 hours drive away) to collect ice.[100]

As will be shown in section 4.8.2.4, last mile distribution and sales is one of the key challenges for technology companies aiming to reach BOP customers in remote areas. Many successful technology suppliers are leveraging existing distribution networks and sales ports, such as village kiosks. The inclusion of PV systems in their product portfolio further increases the income generation potential of these local micro-businesses.

4.5.3 Fostering Local Entrepreneurs

An increasing number of rural households gaining access to electricity, and thus consumer appliances (section 4.5.1), creates new market opportunities for local entrepreneurs to set up microenterprises, such as mobile phone shops or electronic repair shops.

Solar powered energy kiosks can offer a wide range of services:

(i) Recharging of mobile phones and other battery powered devices

(ii) Battery rental business for those households which cannot afford the purchase of their own PV system

(iii) Community learning and entertainment center

(iv) Hair cutting and clipping salon

(v) Office applications (printing, scanning, etc.), email and internet access

(vi) Milling facility for crops

There are several examples of companies which have developed and established sustainable PV powered service centers. For instance, the Dutch company *Nice International* has set up numerous of these service centers in Sub-Saharan Africa, operated by local entrepreneurs on a franchise basis, a model which could be replicated in rural areas of Central America.

[100] Ashden (2010): p.2

4.5.4 Impact on Women

Women in rural areas in developing countries are heavily impacted by the lack of access to modern energy, given their role as primary energy procurers and users for the household, agricultural and small industrial subsectors. For many rural households, obtaining fuel for lighting can be a dangerous and time consuming task which often requires traveling long distances across desolate land and is often undertaken by women and children. While this exertion of human energy goes largely unmeasured and non-monetized in energy statistics, it is nonetheless evident when examining economic, health and quality of life indicators at the household level. Apart from the safety issues of obtaining kerosene (section 4.5.5), this is valuable time and energy that women could spend on education or income generating activities.

Furthermore, improved lighting greatly facilitates household work, usually carried out by women. For instance, as one solar micro-entrepreneur trained by Enersol, a sister company of Soluz (section 4.8.1.3), in Honduras explained: *"The women get up at 3 am during the harvest season because they have to cook everyone's food. A light bulb powered by solar energy lights up the whole kitchen. It is much easier to light and it makes it easier to work. With kerosene gas, sometimes the tortillas have a gas flavor, and some people have had accidents with the kerosene lamps."*[101]

4.5.5 Health and Safety

In addition to the health and safety impacts of access to clean energy through PV systems highlighted above, toxicity of traditional energy sources must be mentioned in more detail here.

Apart from providing poor lighting, the use of kerosene lamps is the cause of numerous respiratory diseases such as bronchitis, asthma and pulmonary emphysema,[102] which result from the inhalation of toxic fumes. It is estimated that indoor air pollution resulting from traditional lighting and cooking fuels leads to nearly 1.5 million premature deaths globally, most of them women and children as

[101] Smith, J. (2000): p.18

[102] WHO (2008)

they are most exposed to these fumes on a daily basis.[103] In fact, the IEA estimates that by the year 2030 the number of premature deaths per year attributable to indoor air pollution will exceed what the World Health Organization (WHO) projects for annual deaths from malaria and HIV/AIDS combined.[104] Most of this indoor pollution must be attributed to the burning of biomass for cooking purposes, but part of the pollution is a result of burning kerosene for lighting. In their evaluation of the health impacts of burning kerosene, the IFC estimate that 20% of all indoor fumes are linked to lighting services.[105] Switching to PV systems for electricity generation in rural households in Central America would eliminate this significant share of toxic fumes.

Also, through their use of an open flame, candles or kerosene lamps carry the risk of burns and fires. This is particularly dangerous when lighting is required for reading or studying, as due to the poor light quality (8 - 45 lm) one has to read directly on top of the light source to be able to see.

4.5.6 Education

In addition to the educational impacts mentioned above, as well as the time freed up for education for women with access to PV systems as highlighted in section 4.5.4, CFL or LED provides far superior lighting to kerosene lamps (section 4.4.1.2) or candles, thus enabling children to read and study at night more comfortably and safely. Quetsol (section 4.8.1.2), a technical supplier in Guatemala, has found that 70% of the families they provided with their Solar Kits confirmed that their children studied 1-4 hour more per day as a result of the improved lighting.[106] Similarly positive evidence can be found in other regions. For instance a study of portable solar lighting impact in India found that the introduction of solar lighting raised average study hours of students per household from 1.5 hours to 2.7 hours, with a correlative effect on school performance.[107]

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[103] IEA (2011): p28, Fig.10 (cited as WHO database, 2008)

[104] IEA (2011): p28

[105] Bardouille, P. et. al. (2012): p.159, Appendix B

[106] IDB/MIF (2013): p.10

[107] Lighting Africa (2010): p.16

A study by the Energy Sector Management Assistance Program (ESMAP) attempted to quantify, in monetary terms, the benefits of electricity access in rural households, resulting from improved educational opportunities and conditions. Based on survey data obtained from rural communities in the Philippines, the study estimated the benefits accruing to individual wage earners to be roughly US$37 per month due to *"improved returns on education and wage income."*[108]

4.5.7 Conclusions on Social Impact Assessment

This section has shown that the provision of off-grid PV systems has wide-ranging positive social impacts on rural BOP households, thus meeting the social impact component required to achieve the double-bottom-line return of an Inclusive Business Model.

[108] Barnes, D. et. al. (2005): p.22

4.6 Ecological Assessment of Using PV Systems

The following section will analyze the ecological impact component of the proposed Inclusive Business Model for substituting traditional energy sources with PV systems, as stated in the Thesis objective.

4.6.1 Climate Change Impact of Traditional Lighting Solutions

Many of the 250 million households globally lacking access to electricity rely on kerosene lamps as their sole source of lighting. As was shown in section (4.2.3.2), kerosene also forms the basis of traditional lighting sources in the majority of rural households in Central America.

The emissions from these kerosene lamps are almost entirely Carbon Dioxide (CO_2) and Black Carbon (BC),[109] the two largest causes of climate warming in today's atmosphere. BC is a particle, as opposed to the greenhouse gas (GHG) CO_2, and is highly efficient at absorbing sunlight. BC emissions from kerosene lamps are so high, that the BC particles emitted by a basic kerosene wick lamp, warm the climate 20 times more during the first few days following the emission than the CO_2 emitted by the same lamp over 100 years.[110]

The type of combustion greatly impacts the BC emission rates, with poor combustion emitting more BC than good combustion for the same type of fuel. For example, almost one-tenth of the fuel burned in a simple kerosene wick lamp is converted to BC particles. By comparison, a diesel engine emits only about one-thousandth of the original fuel as BC particles.[111] Given that BC particles remain in the atmosphere only for a few days, the climate impact is highest around the source regions. Figure 4.10 shows that climate impact (in W/m^2) in Central America is the highest in the whole of Latin America, mirroring the comparatively high share of people without access to modern energy which was shown in Figure 2.2.

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[109] Jacobson, A. et. al. (2013): p.3

[110] Jacobson, A. et. al. (2013): p.3

[111] Jacobson, A. et. al. (2013): p.3

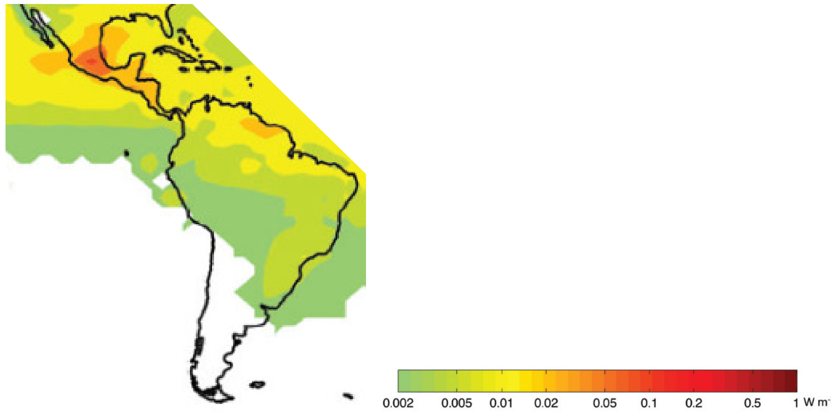

Figure 4.10 - Direct Black Carbon Climate Impact of Residential Kerosene Lighting[112]

Considering the above, enabling rural BOP households´ access to alternative clean lighting sources can have a substantial positive impact on reducing climate change.

4.6.2 Reducing Climate Change By Substituting away from Kerosene Lamps

4.6.2.1 Assumptions for the Analysis

(i) Kerosene lamp technologies: The two most commonly used kerosene lamps in BOP households are simple wick and hurricane lamps, due to the relatively low cost of the devices themselves and the relatively low operation cost resulting from lower kerosene consumption levels, compared with other types of lamps such as the kerosene pressure lamp.

(ii) Hours of lighting per day: Consistent with the energetic assessment above (section 4.4.1), a typical kerosene lamp usage of 4 hours per day will be assumed.

(iii) Emissions: Table 4.8 shows the annual kerosene consumption and the resulting CO_2 and BC emissions for kerosene wick and hurricane lamps, at a daily usage of 4 hours. The detailed calculations underlying these results can be found in Annex F.

[112] Lam, N. et. al. (2012): p.2

Table 4.8 - Annual CO_2 and Black Carbon Emissions[113]

Light source	Light output (lm)	Kerosene consumed per year (liters)	CO_2 Emissions per year (kg)	Black Carbon Emissions per year (kg)
Simple Wick Lamp	7.8	15	38	1.10
Hurricane Lamp	45	43	112	0.18

(iv) Number of households using kerosene lamps: Referring back to section 4.2.3.3, the number of un-electrified households in Central America best served through off-grid energy solutions was shown to be approximately 1 million. In addition, this section highlighted the use of kerosene based solutions for lighting purposes by the majority of these households. Taking the ENEE data as an estimate for the region results in a total of approximately 860,000 households.

(v) Number of kerosene lamps: In their analysis, the IFC assumes that solar lanterns replace one kerosene lamp per household and more sophisticated solar devices replace three kerosene lamps each.[114] Adopting this assumption as a basis, and considering the income distribution of the subcategories within the BOP of each Central American country (Annex B), the following will be assumed:

a. Households belonging to the lowest two categories of BOP500 to BOP1000, only use one simple wick kerosene lamp

b. Households belonging to the categories BOP1500 to BOP2000 use the more sophisticated and thus more expensive hurricane lamp

c. Households of categories BOP2500 to BOP3000 use three hurricane lamps each, due to the positive correlation between income level and demand for energy

4.6.2.2 Summary of Emission Reduction Analysis

Table 4.9 shows that kerosene lamps being substituted by PV powered lighting devices could result in substantial BC, and particularly CO_2, emission savings across Central America. Detailed calculations can be found in Annex F.

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113 Own calculation - full calculation and referenced sources see Annex F

114 Bardouille, P. et. al. (2012): p.159, Appendix B

Table 4.9 - Central America: Potential for Annual Savings in CO_2 and Black Carbon Emissions[115]

Light Source	Number of lamps ('000)	Savings CO_2 Emissions per year (tons)	Black Carbon Emissions per year (tons)
Simple Wick Lamp	377	14,205	413
Hurricane Lamp	779	87,206	139
Total	**1,156**	**101,411**	**552**

In recognition of the substantial emissions reductions that can be achieved, the UN's Clean Development Mechanism (CDM), contains a specific methodology (AMS-III.AR) for calculating emissions reductions achieved by *"substituting fuel based lighting with LED/CFL lighting systems"*,[116] thereby opening the potential for carbon finance for compliant projects (section 4.8.3.2).

4.6.3 Efficient Usage of Limited Resources

„In order for renewable energy to be most effective it needs to be linked to energy efficiency and energy efficient appliances."[117]

The effect of substitution of fossil fuels with PV systems not only leads to reduced emissions as was shown in the previous section, but also to a more efficient use of the planet's scarce natural resources. Table 4.5 showed that the luminous efficacy of CFL and LED is 500 – 1000 times higher than that of a kerosene wick lamp, thereby providing a far more energy efficient solution to lighting.

To further optimize the performance of PV systems they are best used in conjunction with energy efficient appliances. This applies to both illumination technologies such as LED and CFL, as well as the electrical appliances powered by PV systems, such as energy efficient televisions or fridges. To encourage households to use new and more efficient appliances, the PV systems capable of powering these devices are often sold in combination with electrical appliances (section 4.7.2.2).

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[115] Own calculation - full calculation and referenced sources see Annex F

[116] CMD (2013), www

[117] UNIDO (2013 - Vienna Energy Forum): Monga P., Director, Energy and Climate Change, UNIDO

4.6.4 Conclusions on Ecological Impact Assessment

Burning of kerosene was shown to emit the two largest causes of climate warming in today's atmosphere. Therefore, the promotion of off-grid PV systems by BOP households can have a substantial impact on climate change. Also, the use of PV systems raises awareness of energy efficiency, effecting long term ecological impacts due to a reduction in the demand for scarce fossil fuels.

In this positive ecological component, Inclusive Business Models providing off-grid PV systems in rural Central America are able to achieve a triple-bottom-line return (section 4.1.2).

4.7 Economic Assessment - Financial Implications of Introducing PV Systems to BOP households

The following section will analyze the financial implications for the BOP of substituting traditional energy sources with PV systems, as stated in the Thesis objective.

4.7.1 Current BOP Household Expenditure Patterns

BOP households in Central America spend a significant share of around 7% of their disposable income on energy (section 4.1.1.1). The IFC estimates that overall the share of energy expenditure by households without access to modern energy is roughly equal for cooking and *"lighting + electricity"*.[118] *"lighting + electricity"* refers to traditional lighting solutions such as kerosene lamps, candles and disposable batteries, as well as battery-charging services for small appliances such as mobile phones or car batteries to meet basic energy needs. It should be noted that since households often buy kerosene in sub-liter amounts, they are paying premium prices which can be as much as 300% higher than official "port of entry" kerosene costs, depending on the remoteness of the rural community.[119] On a per-kWh basis, the traditional energy sources affordable to BOP households cost between 5-100 times more than modern fuels and electricity.[120]

All of this is a classic example of the "poverty penalty" (section 4.1.2) incurred by the BOP, where BOP households are spending a disproportionate share of their disposable income on a product that higher income segments not only acquire more cheaply, but also of a better quality.

On top of, and often exceeding the actual cash expenditure for the traditional energy sources, are the opportunity costs of the time and human energy devoted to tasks such as fetching kerosene from the closest retailer or fetching water from a well,

[118] The allocation between cooking and *"lighting + electricity"* is correlated with household income, with the former dominating energy spending for the poorest BOP households, and the latter for the wealthier BOP households. Bardouille, P. et. al. (2012): p.146

[119] Lighting Africa (2010): p.53

[120] Prahalad, C.K. (2010): p.360

which could be avoided by using a standard PV system or a solar powered water pump respectively. For example, for some of Tecnosol's (section 4.8.1.1) clients in Nicaragua fetching water equates to about US$40 per month in labor, time spent that could be invested in productive or income generating activities.[121]

In an attempt to reflect the energy services (i.e. illumination and powering basic electrical appliances) available at each of the three energy consumption levels calculated in section 4.4.1.2, the rural off-grid households will be divided into three broad categories, based on their monthly expenditure on traditional energy solutions:

(i) *Subsistence Level* of expenditure: Monthly expenditure of up to US$5.50 on kerosene, candles and disposable batteries for illumination purposes. The IEA refers to these as *lower energy expenditure households*.[122]

(ii) *Basic Level* of expenditure: Monthly expenditure of up to US$10. Monthly expenditure on some of the traditional energy solutions might include: US$5.50 on traditional energy for lighting purposes; US$5 to US$7 for dry cell batteries or car batteries for lighting or to power small electrical appliances; US$3 to US$5 for mobile phone charging.[123] It is assumed that a household uses a combination of these to make up the annual energy requirement of 15kWh which has been specified for this category.

(iii) *MDG-compatible Level* of expenditure: Monthly expenditure of up to US$50. Given that these households rely on the same traditional technologies as those of the *Basic Level*, to reach the annual *MDG-compatible Level* of consumption of 75kWh, it is assumed that their expenditure is five times that of the *Basic Level* households. The household might also choose to use a household level diesel generator to meet some or all of its energy needs, costing US$30 to US$50 per month for operation and monthly installments for repayment of the generator.[124]

[121] Prahalad, C.K. (2010): p.367

[122] IEA (2011), p.30

[123] Bardouille, P. et. al. (2012): p.82, Box 3.7

[124] Bardouille, P. et. al. (2012): p.82, Box 3.7

This reminds us that despite being poorly served, the BOP customers are, in fact, spending on energy. Thus, this represents an existing cash market which could be channeled towards PV systems.

Furthermore, empirical evidence has shown that the price of an energy system is not the only driving factor for BOP households. Instead, reliability and quality (i.e. higher quality illumination, no indoor pollution, etc.) are the most valued attributes. For these, households are often willing to spend more than their current expenditure.[125] This will be analyzed further in the section on commercial viability (section 4.8).

4.7.2 PV System Prices

4.7.2.1 Price Developments in the PV Industry

The PV industry has experienced a steep learning curve over the past few decades, both on the development side, new technologies making the solar cells ever more efficient, and on the production side, manufacturing costs steadily decreasing. This has resulted in an 80% fall in the costs per kWh since 1980,[126] and prices are projected to continue to decline rapidly going forward, mainly driven by crystalline PV price declines, along with a shift towards thin-film technology (Figure 4.11).

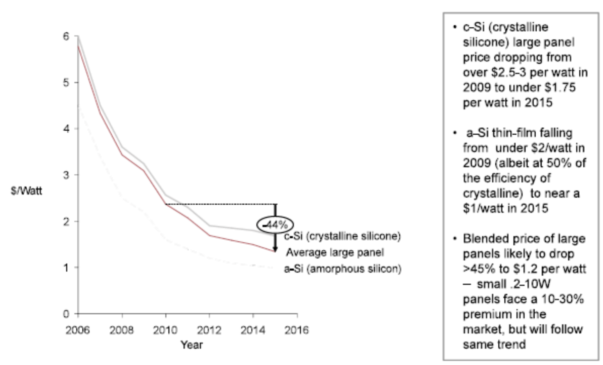

Figure 4.11 - Projected Solar Panel Price Development[127]

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[125] Prahalad, C.K. (2010): p.360

[126] Prahalad, C.K. (2010): p.361

[127] Lighting Africa (2010): p.25, Fig. 10

In addition to advances in the PV technology itself, advances have also been made in the peripheral components of a PV system. For instance, the price of LEDs, today the preferred illumination component in most PV systems, has dropped dramatically and efficiency has more than tripled since 2009.[128]

These design innovations and the development of a range of very low cost products tailored to the needs of BOP customers, such as solar lanterns or Solar Kits mentioned in section 4.4.3, will result in further declines equivalent to 40% over the period 2010 to 2015.[129]

4.7.2.2 Typical Retail Prices of PV Systems

The main driver of the prices of household PV systems is the capacity of the PV panels used. Typical retail prices range from under US$10 for a small solar powered desk lamp to around US$1,000 for a 150$W_p$ SHS, providing sufficient power for a small retail business. A sample of current retail prices of the three types of PV products listed in section 4.4.3 is provided below:

(i) Solar lanterns: Typical retail prices range from under US$10[130] for a small and simple solar powered desk lamp, to around US$50.[131]

(ii) Solar Kits: Retail prices tend to range from around US$100 to US$200,[132] for Kits with capacities of 10-20W_p.

(iii) SHS: These are commonly sold in combination packages, which, in addition to the principal components of the system (PV panels, voltage controller, inverter), also contain numerous CFL bulbs or LEDs, radios, fans and even low voltage TVs for the larger systems. Costs per W of installed capacity tend to fall with the overall capacity of the system. Typical retail prices range from around US$7/W installed capacity for 150W_p systems to around US$8.50/W installed capacity for 60W_p systems.[133] These prices include the

[128] Jacobson, A. et. al. (2013): p.6

[129] Lighting Africa (2010): p.24, Fig.8

[130] Jacobson, A. et. al. (2013): p.6

[131] Bardouille, P. et. al. (2012): p.13

[132] Bardouille, P. et. al. (2012): p.13

[133] Tecnosol (2013), www

labor cost of qualified technicians for installation of the SHS, which can make up as much as 15% of the total system cost for some of the smaller SHS with 60W.[134]

In this analysis of off-grid systems, all of the above need to be considered as island solutions, with a battery bank to store electricity for periods of lower power generation. This is particularly relevant for PV systems, given the inverse relation between hours of peak electricity production during the day, and the main hours of lighting demand during the night.

Retail prices for batteries range from around US$8 for replacement batteries for solar lanterns,[135] US$20-US$30 for Solar Kit batteries, to around US$100-US$120 for the battery banks of SHS.[136] A typical battery life ranges from around 1.5 years for solar lantern batteries[137] to 2 to 5 years for Solar Kit and SHS batteries[138], depending on how well it has been maintained.

4.7.3 Consumer Financing Mechanisms to Match Existing Household Expenditure Patterns

Despite the fact that there has been a considerable drop in PV system prices over the past decades, they still represent considerable initial investment, particularly in the case of SHS and, to a lesser extent, of Solar Kits. Given their limited disposable income, BOP households tend to be very price-sensitive, as they are not able to accumulate the necessary liquidity to independently make these investments up front.

Figure (4.12) shows that the requirement of an upfront payment of more than 30% of the total system cost of an SHS or a Solar Kit essentially kills any potential demand for these products. Given the lower prices of solar lanterns, this cut-off limit lies at around 80%.

[134] Pricing structure of a local technology supplier, anonymous for reasons of confidentiality

[135] Tecnosol (2013), www

[136] Tecnosol (2013), www

[137] Kayser, O. et. al. (2009): p.46

[138] Umesh, K. et. al. (2007): p.10

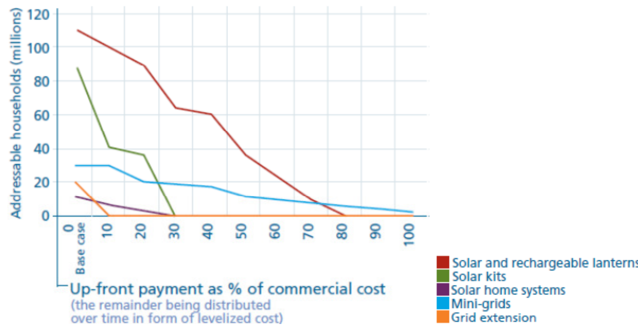

Figure 4.12 - Sensitivity of the Global Addressable Energy Access Market[139]

In an attempt to match the current energy expenditure patterns by rural households, a series of financing mechanisms have been and continue to be developed. The underlying aim is to minimize the required up-front investment associated with the purchase of the system. These mechanisms can be broadly categorized into three groups.

4.7.3.1 Microfinance

The provision of microcredits by Micro Finance Institutions (MFI) to rural households is the most common solution to making the more expensive Solar Kits and SHS accessible to the BOP end-users, with the most wide-spread approach being for the technology supplier to partner with rural banks and MFIs. The advantage is that financial institutions not only have the expertise and the technical personnel for the credit business, but they usually also have access to an established network of branches to attend customers in rural areas.

The *Central American and Caribbean Microfinance Network* (*Red Centroamericana y del Caribe de Microfinanzas* – REDCAMIF) provides a suitable platform for scaling an Inclusive Business Model based on microcredits across Central America. The network was founded in 2002 with the aim of promoting the microfinance industry and its impact on social and economic development in Central America, as well as to influence and promote political and regulatory standards that benefit and strengthen the regional microfinance sector. It further fosters transparency, quality standards and benchmarking of the individual MFIs, helping to build a strong and healthy MFI sector. Table 4.10 shows that REDCAMIF encompasses 128 MFIs with

[139] Bardouille, P. et. al. (2012): p.33

over 1,000 agencies, allowing penetration into remote areas. Testimony to this is that in some countries the majority of the credit portfolio is held in rural areas. The network's overall credit portfolio stands at approximately US$1.3 billion, with 1.2 million clients currently being served.

Table 4.10 - Summary Data of REDCAMIF National Networks (December, 2012)[140]

Network	Country	MFI	Agencies	Clients	Portfolio (US$ mm)	Rural Portfolio (%)
REDIMIF	Guatemala	16	117	117,277	84	58%
ASOMI	El Salvador	11	87	87,349	121	53%
REDMICROH	Honduras	27	264	212,021	268	41%
ASOMIF	Nicaragua	21	187	228,027	159	50%
REDCOM	Costa Rica	17	18	14,940	54	43%
REDPAMIF	Panama	11	47	37,326	164	9%
REDOMIF	Dominican Republic	25	287	453,840	412	24%
		128	**1,007**	**1,150,780**	**1,262**	**35%**

The advantage of a regional MFI network for potential financial providers or technology suppliers looking to partner with MFIs is their immediate access to a regional platform allowing rapid scaling of a business model. An example of this is the *Fundación José María Covelo* (Covelo), based in Honduras, which acts as a regional second-tier financing institution for local MFIs. Covelo has recently established dedicated regional credit lines for off-grid PV systems for rural Central America (section 4.8.4.3.1) and benefited from being able to tap into the national sub-networks of REDCAMIF outside of Honduras, thereby assured of high quality and transparent MFIs as local partners. Access to this platform has been a driving factor in their dedicated PV credit line reaching scale across the region so rapidly.

A number of MFIs working together with Covelo have indicated that the default rates of their PV microcredits were practically non-existent, claiming that once rural households obtained access to electricity they made every effort to meet their credit quotas to avoid losing that access again.[141]

[140] REDCAMIF (2013), www

[141] IDB Due-Diligence Mission for Covelo (2011)

In addition to partnering with MFIs, some technology suppliers, such as Tecnosol (section 4.8.1.1), utilize their wide-ranging network of local branches in rural areas and also run limited credit facilities themselves, in order to offer their customers a complete package. The advantage of in-house financing is that the technology supplier has a complete overview of all business transactions, but this also requires sufficient liquidity and staff, as well as internal processes for credit checks and payment tracking, etc.

A further approach which so far has not been adopted by a business in Central America, but which has proven successful in India, is for the technology supplier to operate a first loss guarantee fund, covering the first 10-15% of the loan amount for the poorest customers which otherwise would not be bankable, even by MFIs. Solar Electric Light Company (SELCO), a rural energy service provider with almost 100,000 customers in rural India, has been operating such a guarantee fund as a sustainable business model since 1995.[142]

4.7.3.2 Micro-Rental

This payment mechanism allows the customer to rent a given PV system, rather than purchasing it outright. The technology supplier remains the rightful owner of the rented components and regularly maintains and services them. The monthly rental charge for use of the PV system is more closely in line with Central American BOP households' current monthly energy expenditure on traditional energy sources, particularly because it does not require the down payment usually associated with the credit purchase of a system. Furthermore, the threat of financial hardship, or the potential arrival of the national grid in the foreseeable future makes flexible offers such as micro-rental very attractive to customers.

The advantage for the technology supplier is that, over the course of a PV system's useful life, the potential income streams coming from rentals can be a multiple of the system's actual retail price. More importantly, it promises increased penetration in areas where a microfinance infrastructure is absent, and reach of the lowest income segments of the BOP households not eligible to purchase on credit. Finally, flexible micro-rental can be pitched as a solution to pre-electrification in conjunction with

[142] Kayser, O. et. al. (2009): p.62

government plans to extend the electrical grid, providing the technology supplier with a larger potential market. The drawback of this business model is, however, that it requires significant up-front capital investment to build up the necessary rental inventory to make the model viable.

Soluz (section 4.8.1.3) has pioneered the concept of unsubsidized micro-rentals in Honduras and the Dominican Republic, offering SHS rentals starting at as low as US$5 per month (Table 4.11) for the module and the mount only. The customer provides the peripheral components such as batteries, lighting, etc. themselves, thereby giving more flexibility as to the components of the system.[143] Such low monthly rentals make SHS an attractive option even to a *Subsistence Level* of expenditure households.

Table 4.11 - Sample Soluz Rental Packages[144]

PV Panel Nominal Power (W_p)	Lights included (in Deluxe)	Monthly Fee Basic (US$)	Monthly Fee Deluxe (US$)
20	1	5.00	10.00
30	2	7.50	12.50
40	3	10.00	15.00
50	4	12.50	17.50
60	5	15.00	20.00
100	7	25.00	30.00

4.7.3.3 Mobile Technology Based Financing Mechanisms

4.7.3.3.1 Mobile Banking for Microfinance

The high rural penetration rates achieved by mobile phone operators, coupled with the rise of mobile banking technologies, mean that potential customers even in very remote areas could be provided with financial services. These mobile banking services are continually being refined to meet the characteristics of rural markets. For instance, MPESO in Nicaragua is piloting a remote payment technology which can be used even with the most basic of mobile phones. After successful implementation in Nicaragua, the plan is to roll out this technology to the whole of Central America.

[143] Rogers, J. et. al. (2006): p.61

[144] Rogers, J. et. al. (2006): p.62

At the same time, mobile phone operators have a vested interest in offering their networks as a platform to provide financing solutions for PV technologies, as only a charged cell phone generates revenue for the mobile phone operator. GSMA, the international association of mobile phone operators, estimates that a lack of access to electricity for charging mobile phones reduces a mobile phone operator's average revenue per user (ARPU) by 10-14%.[145]

4.7.3.3.2 Pay As You Go

The emergence of mobile payment methods has not only facilitated penetration of the most remote areas for microfinance mechanisms, but also for Pay-As-You-Go (PAYG) models. This mechanism is based on a similar idea to the pre-pay concept in the telecommunication sector, giving the individual household more control over their financial commitments.

A good example of this is Quetsol's (section 4.8.1.2) recently developed PAYG Solar Kit, allowing marginalized communities in Guatemala to buy energy generated by their Solar Kits via agents in their communities. Here, the notion has been to move away from the idea of selling the customer the equipment, but rather selling them the electricity their specific equipment generates, as and when they need it. The system is based on codes to unlock the Kits, received as a simple text message by the agent. Quetsol has partnered with Tigo, the largest mobile operator in Guatemala, to collect payments and distribute codes. To reach even the remotest areas without mobile coverage, which make up half of Quetsol's client base, customers can buy codes from sub-agents who distribute pre-bought codes purchased from agents in connected communities. Quetsol claims that this new model will result in savings equivalent to 44%, compared to households' previous candle and kerosene costs, and is currently running a number of pilot projects with these new PAYG Solar Kits. First results are very promising and Quetsol expects to distribute 100,000 PAYG Solar Kits over the next 5 years.[146]

A PAYG model based on Radio Frequency Identification (RFID) payment technology which facilitates mobile payments and enables technicians to turn off

[145] Bardouille, P. et. al. (2012): p.53, Box 3.3

[146] Quetsol (2013): Interview with Juan Fermín Rodríguez, CEO and Co-Founder of Quetsol

households behind on their monthly payments,[147] has been successfully rolled out by the *Solar Energy Foundation* in Ethiopia since 2005. The positive results will prove interesting for Central America in the future too.

Apart from giving the individual household more control over their financial commitments, it provides households with access to cleaner energy of better quality at no added cost to their current expenditure on traditional energy sources. Also, the technology supplier remains the rightful owner of the rented components and is responsible for servicing of the equipment. Finally, it includes those population segments considered not "bankable“, or who live so remotely that MFIs cannot reach them. As in the case of micro-rentals, the advantage for the technology supplier is that over the course of a PV system’s useful life, the potential income streams coming from rentals can be a multiple of the system’s actual retail price.

4.7.4 Financing of PV Systems Aligned with Current Monthly Household Expenditure Patterns

Given that microfinance based credit sales of off-grid PV systems are, to date, the most tried and tested financially sustainable option, this section will look at the monthly payments resulting from a typical microcredit compared to households´ current monthly expenditure on traditional lighting solutions.

4.7.4.1 Assumptions for the Analysis

The assumptions underlying the calculations are based on typical PV system retail prices and financing conditions for a microcredit available in Central America.

(i) PV system prices: Based on the typical retail prices stated in section 4.7.2.2, a price of US$10 per Watt of installed capacity is assumed.

(ii) Down payment: This is typically in the range of 10-20% of the price of the PV system. To limit the front loading of costs, a down payment of 10% will be assumed in the calculations. An exception are solar lanterns, where it is assumed that the *Subsistence Level* of expenditure household makes the maximum down-payment in line with their current expenditure.

[147] Kayser, O. et. al. (2009): p.57

(iii) Interest rate: Typical interest rates by MFIs in Central America oscillate in the region of 24-32% per annum[148], with the exception of Belize, where MFI rates are lower at around 16-20% annually.[149] An average interest rate of 30% will be assumed for this calculation.

(iv) Equipment Insurance: This generally only applies to Solar Kits and SHS. A typical rate applied by the MFIs working with Covelo (section 4.7.3.1) is 0.7% per month.

(v) Loan Tenor: Typically ranges between 2 to 3 years, the latter representing Covelo´s (section 4.7.3.1) upper tenor limit to its MFI clients.[150] Within this range, the shortest possible tenor is assumed while trying to match current monthly household expenditure. For Solar Kits and SHS, tenors are broken down into minimum 6 month installments.

(vi) Collateral: Due to the fact that BOP households often do not have assets to serve as collateral for the microcredit, one method which is being adopted by an increasing number of MFIs in Central America is to designate the PV system itself as a guarantee for the loan. In case of default of payment by the beneficiary, this is an asset which the MFI can reclaim fairly easily and resell on the second hand market.

4.7.4.2 Methodology of Calculation

Repayment schedules of MFIs for their microcredits are structured to ensure that the monthly quota, equal to the sum of interest plus principal repayment, is constant throughout the tenor of the microcredit. In practice, this means that at the start of the repayment period, the capital component is relatively low so as to counterbalance the high interest amounts, and increases monthly as the amount of owed interest diminishes. Such a structure facilitates the financial planning on the part of BOP households, which is particularly important given their limited disposable income.

A sample calculation outlining such a repayment structure, one of the repayment scenarios discussed in more detail below, can be found in Appendix G.

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[148] IDB Due-Diligence Mission for Covelo (2011)

[149] IDB Due-Diligence Mission for Covelo (2011)

[150] IDB Due-Diligence Mission for Covelo (2011)

4.7.4.3 Subsistence Level of Expenditure

Solar lanterns were shown to be ideal devices to meet the *Subsistence Level* of consumption (Table 4.6). In line with current monthly expenditure of US$5.50 by *Subsistence Level* households on traditional lighting solutions, Figure 4.13 shows a range of suitable financing options for differently priced solar lanterns. In practice, many technology suppliers find that microfinance is not usually required for solar lanterns, especially given the radical drop in technology prices. The finite payments compared to current continuous expenditure make this a very attractive option for most BOP households.

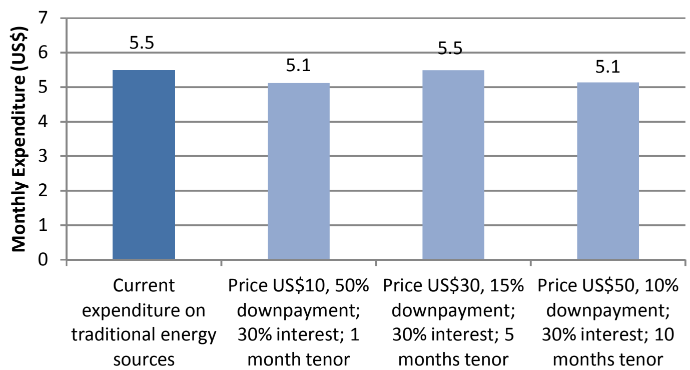

Figure 4.13 - *Subsistence Level*: Current Monthly Expenditure vs. Microcredit Quotas[151]

A further option would be to maintain current expenditure and gain access to more advanced Solar Kits or small SHS systems, considering the low monthly quota for basic micro-rental begins at US$5 (Table 4.11). This would result in a significant increase in value for money for these *Subsistence Level* households.

4.7.4.4 Basic Level of Expenditure

Solar Kits with a capacity of $10W_p$ were shown to be sufficient to meet the needs of households of *Basic Level* of consumption of 15 kWh per year (Table 4.6). Figure 4.14 shows a range of possible financing options at conditions typically available in Central America. It shows that for the minimum system requirement of $10W_p$, the monthly payment quota for a microcredit would be lower than the current

[151] Own calculations based on assumptions in section 4.7.4.1

expenditure of US$10. For larger Solar Kits ($15W_p$ – $20W_p$), the household would obtain 50% to 100% more energy, and the quota for a microcredit would only be marginally higher than current monthly expenditure, albeit at longer credit tenors. Nevertheless, these expenditures would be finite and hence a worthwhile investment, as opposed to the ongoing current expenditure on kerosene.

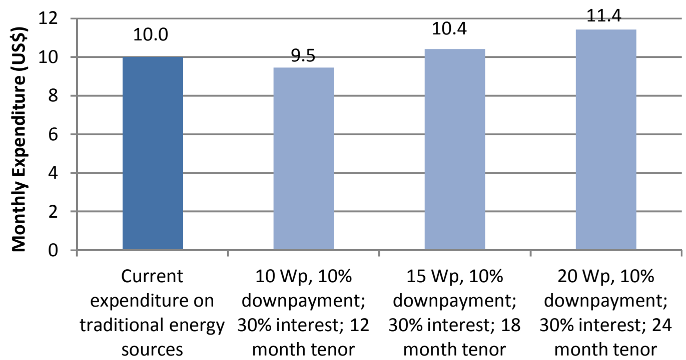

Figure 4.14 - *Basic Level*: Current Monthly Expenditure vs. Microcredit Quotas[152]

Also, given the similarity of the monthly credit quota to current expenditure patterns, a micro-rental or PAYG option would not be of long term interest to *Basic Level* households, as the credit quota is due only for a limited period (up to 24 months in the figure above), whereas rental or usage payments under a PAYG scheme would be incurred as long as the system is being used which, given the life of a PV system, could be up to 25 years.

4.7.4.5 MDG-compatible Level of Expenditure

SHS from around $50W_p$ were shown to be sufficient to meet the *MDG-compatible Level* of consumption of 75 kWh (Table 4.6). Figure 4.15 provides a range of possible financing options at conditions typically available in Central America. It shows that a Solar Kit or SHS with the minimum system requirement of $50W_p$ could be paid off over the course of a year, while essentially maintaining current expenditure levels. At longer tenors, households could even afford larger SHS providing them with superior energy levels.

[152] Own calculations based on assumptions in section 4.7.4.1

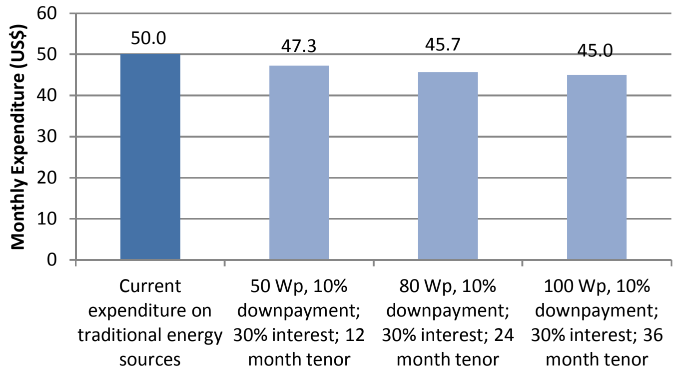

Figure 4.15 – *MDG-Compatible Level*: Current Monthly Expenditure vs. Microcredit Quotas[153]

As with *Basic Level* households, given the similarity of the monthly credit quota to current expenditure patterns, rental or PAYG options would not be of interest to *MDG-Compatible Level* households, as the system could be paid off entirely within 1-3 years, a far shorter timeframe than the useful life of a PV panel.

4.7.5 Recurring Operational Costs of PV Systems versus Kerosene Based Systems

A typical wick kerosene lamp has a life of approximately 5,500 hours,[154] which, at 4 hours of daily usage, equates to just under 4 years. As seen above, for the operation of such a lamp, the household incurs a monthly expenditure of around US$5.50. In addition, base kerosene prices are estimated to increase at 4% annually over the next year,[155] which would have a direct impact on households´ monthly expenditure.

By comparison, PV systems have a useful life ranging from 5-10 years[156] for solar lanterns to 20-25 years for PV panels used in Solar Kits and SHS (section 4.3.3.1). Furthermore, the only recurring operational cost is primarily due to battery replacement costs. It was shown in section 4.7.2.2 that these costs range from

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[153] Own calculations based on assumptions in section 4.7.4.1

[154] Schwarz, D. et. al. (2005): p.13, Table 2

[155] Lighting Africa (2010): p.11

[156] Kayser, O. et. al. (2009): p.46

approximately US$8 every 18 months for solar lanterns to US$20/US$120 every 2 to 5 years for Solar Kits and SHS respectively. These operational costs are often further reduced by battery recycling schemes run by a number of technology suppliers, such as Tecnosol (section 4.8.1.1), with a 10% discount on the retail price of a new battery when the old one is returned.

Hence, in addition to the finite nature of expenditure on a loan repayment, the significantly lower recurring operational costs of PV systems mean households are not only able to maintain monthly expenditure levels while repaying a microcredit for the system, but are in fact able to achieve significant financial savings over the useful life of a PV system, when compared with kerosene based solutions.

4.7.6 Follow-On Financial Benefits for BOP Households

Financial savings made through a switch to a microcredit for PV, as described in sections 4.7.4 and 4.7.5, have a direct financial impact on BOP households, but use of modern energy systems also has important follow-on financial effects.

As highlighted in section 4.5.6, benefits accruing to individual wage earners from access to electricity were estimated to be roughly US$37 per month due to *"improved returns on education and wage income"*. In addition, the introduction and use of modern PV systems directly results in local income generating opportunities, ranging from increased business for existing microenterprises (section 4.5.2), to fostering new local micro-businesses and local entrepreneurs involved in the promotion and sale of PV systems (section 4.5.3).

Finally, the use of PV systems can eliminate the opportunity costs of time and human energy in relation to buying kerosene from the nearest reseller, who might be located some distance away (section 4.7.1).

4.7.7 Conclusion on Household-Level Financial Impact Assessment

A number of financing options were introduced, with the aim of aligning current expenditure by BOP households across Central America with the value add of modern low-cost PV technology, as well as minimizing the up-front investment associated with the purchase of more complex PV systems.

It was shown that for the most basic PV systems (i.e. solar lanterns), current expenditure of *Subsistence Level* BOP households easily covers costs, and that under typical conditions available from MFIs operating in Central America, the monthly repayment quota for more advanced PV systems can closely match *Basic* and *MDG-compatible Level* households' current expenditure.

In addition, due to a longer useful life, finite payments and significantly lower recurring operating costs compared to kerosene based solutions, switching to PV systems would enable BOP households to achieve significant financial savings in the long run. Increasing kerosene prices coupled with falling technology prices means that this savings potential will increase going forward.

Finally, the follow-on financial impact of PV system use, such as increased income generating potential and reduced opportunity costs also received consideration to ensure a holistic assessment of the financial implications of introducing PV Systems to BOP households.

4.8 Economic Assessment – Commercial Viability of Providing PV Systems to BOP Households

The following section will analyze the commercial viability of the proposed Inclusive Business Model for provision of PV systems to the BOP, as stated in the Thesis objective. It will further show how increasing recognition by the Multilateral Development Banks (MDBs) of the importance of private sector solutions in the fight against poverty will foster the implementation and scaling of such Inclusive Business Models by facilitating access to financing.

4.8.1 Financially Sustainable Businesses Operating in Central America

A practical way to determine the commercial viability of market driven models for the provision of off-grid PV systems to BOP communities in Central America is by looking at existing companies which have operated in this space with varying degrees of success. The following three specific for-profit companies were selected for their different approaches to serving this market and the stages of the company life cycle they are in. The key factors underlying their successes and setbacks will be analyzed and presented below.

4.8.1.1 Tecnosol

Founded in 1998, Tecnosol was originally funded through seed capital and technical assistance funds from E+Co, a rural energy finance company. It has since grown to be one of the largest regional suppliers of off-grid solar systems in Central America, based in Nicaragua with small operations in El Salvador, Honduras, and Panama. In Nicaragua it has a network of 17 regional branches, strategically covering the whole country and allowing it to reach even the most remote rural areas. The SHS it sells range from 25W_p to 200W_p, with an average size of 60W_p, in light of their focus on households and micro-businesses. By 2009, Tecnosol had 75 employees and an annual turnover of over US$3 million, with over half of that income generated from sales to rural households or micro-businesses. By January 2010, Tecnosol had installed over 40,000 SHS for households in rural areas across Central America. In addition, it had installed over 1,000 other energy systems such as larger SHS for schools and health centers, PV-powered water pumps, and solar thermal systems for hot water in homes and hotels.[157]

In 2010, Tecnosol was awarded the prestigious *Ashden Award*, in recognition of its success in providing solar-powered electricity, with all its benefits, throughout rural Nicaragua. They have also been identified by Covelo (section 4.8.4.3.1) as a primary regional technology partner for the provision of SHS systems to be financed across Central America.

4.8.1.2 Quetsol

Quetsol was founded in 2010, after being awarded a US$10,000 grant and a US$40,000 loan as winners of the *GuateVerde 2009* competition, an event sponsored by the *Appropriate Infrastructure Development Group* (AIDG). Based in Guatemala City, the company focuses exclusively on the Guatemalan rural off-grid electricity market and during its first year of operation it sold more than 1,000 Solar Kits. Building on that initial success, the company grew from 3 employees to 14 by the beginning of 2013, and distributed more than 3,500 Solar Kits during that time. Furthermore, responding to demand, the company has also expanded its product range from the initial 10W_p Solar Kit to Kits with capacities of 30W_p and 70W_p, enabling them to meet the energy requirements of *MDG-compatible Level* of consumption households (section 4.4.2.3).

Due to demand for their products and services greatly exceeding available capital and human capacity to supply, Quetsol is currently in the process of raising additional funds from commercial lenders to acquire the necessary initial inventory, hire the required personnel, meet working capital needs and build the infrastructure required to provide even more expansive pre- and post-sales services and distribution. The company is already operating profitably and is projecting to reach an annual net profit of US$2.5 million by 2014.[158]

[157] Ashden (2010): p.1

[158] Rodríguez, J. and Aguilar M. (2011): p.12

4.8.1.3 Soluz

Soluz, a for-profit company based in the US, was launched in 1993 with the aim of developing and testing new strategies for commercializing off-grid PV systems in rural areas. The operational entities Soluz Dominicana and Soluz Honduras were launched in 1995 and 1998 respectively to implement these strategies in the field. The needs of Soluz's target customer base for affordable payment plans, even in the absence of third-party credit options, led it to pioneer unsubsidized micro-rentals for PV systems, to complement cash and microcredit sales. Each of the two national operations has grown to 15 employees at each country office, plus an additional 60 to 100 people contracted as "microcenters" in rural areas (section 4.8.2.4).

The two country operations have served some 10,000 households and small businesses in select off-grid areas, through both micro-rentals and microcredit sales. In addition to the many households served by temporary rentals prior to connection to the national grid (classified as "pre-electrification"), up to 1,900 customers were provided with longer-term micro-rentals by each of the two country operations at peak operating times. By 2005, the revenue stream from micro-rentals was over US$2.8 million, representing over 50% of the total revenue. Of the two operations, Soluz Honduras has fared a lot better in recent years, due to a series of challenges and necessary changes in their business model as discussed below.

4.8.2 Factors Underlying Successful PV Inclusive Business Models

A number of common factors have been critical for the success of for-profit companies focusing on the provision of PV systems to rural BOP households. The following section highlights some of these factors and the strategies adopted by the three companies introduced above.

4.8.2.1 Research & Development into Devices

Recognizing the market potential of off-grid energy for the BOP, ever more companies across the globe, ranging from technology start-ups to large multinational companies such as Phillips or Osram, have dedicated significant resources to developing suitable products specifically designed for the BOP - both in terms of their affordability, as well as meeting the range of specific needs of the different segments of the BOP. A range of PV devices was presented in section 4.4.3.

Quetsol is focusing its strategy on the more recently developed Solar Kits, with capacities starting as low as $10W_p$.

Tecnosol is offering a wide range of solar products, ranging from solar lanterns such as the *Pico Lamp*[159], to traditional SHS, and more specific products such as solar water pumps, solar powered fridges or solar electric fences. The vast majority of its sales, around 85% in the year 2010, were SHS of capacities between 36 W_p and 200 W_p.[160]

Soluz has employed SHS with capacities between $20W_p$ and $200W_p$ as their standard sales and rental systems.

4.8.2.2 High Quality of Products

The high quality of PV systems is crucial, as malfunctioning systems severely damage the reputation and potential of new technologies across communities.

Tecnosol buys its systems from suppliers in Europe, USA, Japan and China, for reasons of quality and pricing. It has a robust quality control system and always tests the equipment it orders to make sure its suppliers meet international standards.[161]

Quetsol, Tecnosol and Soluz all offer product guarantees of up to 20-25 years, thereby demonstrating confidence in the quality of their products to their customers. Granting such extended product guarantees is a particularly useful assurance to raise consumer confidence in the quality of a product, particularly for unfamiliar technology.

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[159] Phocos (2013), www

[160] IDB Due-Diligence Mission for Covelo (2011)

[161] Ashden (2010): p.1

4.8.2.3 Raising Awareness of Renewable Energy Technologies

As introduced above, BOP households harbor some misconceptions about PV systems such as systems being unreliable or easily damaged, or financing being unaffordable or even inaccessible. In addition to clarifying these misconceptions, raising awareness is also about educating rural households on the tangible social and economic benefits of a move towards these new technologies, as highlighted in sections 4.5 and 4.7 respectively. Raising awareness impacts the perceived value of a specific energy solution, and thus affects BOP customers´ willingness to pay for it. As was shown in section 4.7.1, reliability and quality of an energy system are already considered the most valued attributes.

Practical channels for raising awareness include local newspapers and especially the radio, as this is a media with high penetration rates, as well as trade fares and road shows that travel from village to village promoting new products in slightly less remote areas. Beyond these, many technology suppliers have found that "word-of-mouth" by satisfied customers was the most effective marketing channel for their solar products in rural areas, especially when potential customers may be illiterate or off the regular media grid.

Tecnosol uses its wide-ranging network of local branches to promote its products, as well as traditional channels such as radio programs, posters on buses or billboards. In addition, it works with the "early adopters" of its products, often rural shopkeepers and trusted members of a community, to act as local agents advertising the benefits of solar energy, as well as reporting back any technical issues with the installed systems.

Enersol, a sister company of Soluz, allows local entrepreneurial forces to drive the promotion and installation of their PV systems, ensuring the availability of systems in rural communities.

4.8.2.4 Distribution and Sales

Last-mile distribution is a key challenge for technology suppliers to remote areas. As was mentioned in section 4.1.2, successful BOP market businesses are often those able to tap into existing distribution platforms and networks for their products.

Sectors such as pharmaceuticals or beverages have already done the legwork for distribution to remote rural areas. These channels can be easily adapted to the distribution of solar lanterns or small Solar Kits and allows for the rapid scaling of an operation.

Mobile telecommunications companies have also been very successful at reaching remote areas. Their networks provide a valuable platform for necessary complementary services such as mobile banking thereby enabling financing of the more expensive Solar Kits and SHS in areas beyond the reach of traditional MFIs (section 4.7.3.3).

Another important element of sales and distribution is trust. Local sales ports, such as local general stores, the rural branches of MFIs involved in the financing of PV systems (section 4.7.3.1), and local micro-entrepreneurs, are also being utilized as sales outlets for PV products. The nature of these local sales ports and door-to-door sales through micro-entrepreneurs in their own and neighboring communities suggests trustworthiness and traceability to often skeptical customers.

Quetsol's sales people on the ground are comprised entirely of Guatemalans who speak local Mayan dialects and are personally familiar with the cultures and beliefs of the diverse communities which Quetsol serves – a crucial strategy for success in a country whose rural population is primarily of indigenous descent and where there are over 20 indigenous languages. Through its new PAYG model, Quetsol is also utilizing the mobile telecommunication sector´s high penetration rates in rural areas.

Soluz has built a franchise network of *Soluz Microcenters*, independent rural microenterprises (typically a local general store), each serving between 20 and 100 customers, handling service requests, and collecting payments. The micro-entrepreneurs receive incentive payments based on factors such as amount of collections, timely collection, and new rental installations or sales.

The disadvantage of relying on third-party distribution networks and sales ports, compared to the integrated distribution networks of more established companies, is that it squeezes the profit margins of technology suppliers. In fact, if a technology supplier manages to develop their own effective distribution network, they can leverage it to cross-sell other products, such as complementary energy access products (e.g. a PV distribution company also selling efficient cooking stoves) or other products suitable for BOP customers, such as mobile phones, radios, water purifiers, etc.

Tecnosol has built up a network of 17 local branches strategically distributed across Nicaragua to allow it to cover most of the country. Over the last 15 years, each branch has been set up with a manager to supervise the salespeople and technicians, usually sourced locally. Tecnosol benefits from their local knowledge and the trust bestowed on them by the community, not least of all as it brings employment and technical skills to rural areas.

4.8.2.5 Extensive Training

Training local sales ports or MFIs, both on the basic functionality of a PV system and its advantages to the end-user, is crucial for the successful promotion of the technology.

Enersol, a sister company of Soluz, has dedicated much of its efforts to developing a base of microenterprises versed in both the technical and business aspects of entrepreneurial energy micro-businesses.

Training of local technicians on the correct installation is also important to optimize the efficiency of a PV system (correct orientation of the mounted PV panel, avoiding shade on the panel, etc.). In addition, local knowledge of how to service PV systems and providing local technicians with a stock of replacement parts ensures that only those PV systems beyond repair need to be taken back to the factory.

Training the customer as part of the sale, both on the operation as well as the maintenance of the system, is also an important part of a successful transaction. In fact, Ms Van Leeuwen, Director of the Energy Access Initiative of the UN Foundation, has argued that training end-users on effective use of technologies is just as important as facilitating access to them.[162]

[162] UNIDO (2013 - Vienna Energy Forum): Van Leeuwen R., Director, Energy Access Initiative, United Nations Foundation

Quetsol trains its customers on how to operate and maintain the system to avoid damages and optimize battery life. It also makes customers aware of the frequency and costs of replacing batteries.

Tecnosol has created communal lighting committees to provide training on the use and maintenance of its SHS.[163] On top of verbal training at installation, new customers are given a picture based instruction poster, mounted above their charge controller and explaining the regular maintenance needed to keep the system working. They are also provided with a user manual and instructions to contact a technician in case of more serious problems.

4.8.2.6 Consumer Financing Mechanisms

Given the discrepancy between the limited disposable income of BOP households and the considerable investment cost associated with the purchase of a PV system, a number of consumer financing mechanisms were presented in detail in section 4.7.3. These range from bundling PV system sales with microcredits, to micro-rentals, to PAYG models, where the client is paying for the electricity consumed, as opposed to buying the equipment outright. The most tried and tested financially sustainable options are microfinance based models.

Quetsol sells approximately 90% of its Solar Kits through microcredits. They have partnered with Banrural, the country's largest bank with over 900 branches, as well as Genesis Empresarial, an MFI with a strong national presence, to achieve national coverage for its products.

Tecnosol is generating its income through cash and credit sales. In addition to partnering with numerous MFIs, Tecnosol is also running limited credit facilities itself to offer a complete package to end-users, and is looking to expand this business line.

Soluz was shown to be the pioneer of the micro-rental system, but due to varying success (section 4.8.2.8), it is now operating a more balanced product range, including cash and credit sales.

[163] IDB Due-Diligence Mission for Covelo (2011)

4.8.2.7 After-Sales Services

Offering post-installation maintenance service agreements is equally important for overcoming BOP clients´ hesitation to invest in new technology. Ms Van Leeuwen, Director of the Energy Access Initiative of the UN Foundation, has argued that regular maintenance of a system by users, as well as putting in place an appropriate maintenance system for more serious issues, was absolutely crucial for the sustainability of rural PV solutions.[164]

Tecnosol has found that offering a high quality service was crucial to the long term success of its business model, as word-of-mouth was the principal marketing channel for its PV systems in rural areas.

Quetsol has found a way to offer a service of similarly high quality, but at a reduced cost for the company. Regular maintenance days are organized, with all customers in a given area invited to bring their Solar Kits for maintenance and service, and to have functional problems dealt with or batteries replaced where necessary.

Soluz's operational structure consists of a national office and strategically placed service centers designed to serve between 500 – 1,000 rental customers each. [165] Customers have the option of returning faulty mobile devices (such as solar lanterns or Solar Kits) to the point of sale or dedicated service centers for replacement with the next delivery. A survey of Soluz's customers found them to be very satisfied with the systems, based on a number of attributes such as safety, convenience, and reliability.[166]

As a final, important point regarding maintenance, experience has shown that regular maintenance of PV systems by customers who purchased these with their own funds was a lot more conscientious and thorough than by recipients of PV systems financed through grants (section 4.8.3.1.2).

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[164] UNIDO (2013 - Vienna Energy Forum): Van Leeuwen R., Director, Energy Access Initiative, United Nations Foundation

[165] Rogers, J. et. al. (2006): p.62

[166] Rogers, J. et. al. (2006): p.65 (cited as Cabot, C. (2002))

4.8.2.8 Strong Overall Business Case

A strong underlying business case means sufficient revenue needs to be generated from the sale or rental of PV systems to be able to provide customers with the holistic service described above while still generating a profit. Involving MFIs for financing, tapping into a third party network for distribution, and utilizing local entrepreneurs for the promotion and sale of the systems and local technicians for maintenance, are all strong elements of a successful business model. At the same time, however, these all chip away at the profit margin.

Tecnosol and Quetsol have both managed to find the right balance between these components and are not only operating profitably, but are looking to expand their operations.

In contrast, Soluz had generated more than US$5.3 million in revenues by 2005, with its operation in Honduras actually proving profitable that same year,[167] but their financial statements had to bear the effects of the significant costs of developing the business model, particularly its innovative micro-rental business. By operating below profitability for a number of years, both local operations had negative retained earnings by 2005, and had to restructure their debt agreements, essentially forcing a liquidation of the operation's rental assets to enable investors to recover their money. This, in turn, led to a decapitalization of the company, reducing employment by 60% and forcing the company to shift its strategy towards a more balanced product range of micro-rentals, cash sales, and credit sales.[168]

Though innovation as discussed in section (4.8.2.1.) is important for serving the BOP market, it is crucial for the overall business model to be financially sustainable. As can be seen in the case of Soluz, too strong a focus on developing innovative services resulted in a neglect of proven profit generating service lines, sacrificing its already established sales market to competing technology suppliers with a more solid overall business case.[169] Soluz might have fared better if it had embedded its innovative micro-rentals product as a pilot business line into a wider portfolio of variable products.

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[167] Rogers, J. et. al. (2006): p.65

[168] Rogers, J. et. al. (2006): p.72

[169] Rogers, J. et. al. (2006): p.70

4.8.3 Main Challenges Faced by PV Inclusive Business Models

For a comprehensive understanding of the financial sustainability of PV Inclusive Business Models, this section will follow on from the critical factors underlying success by looking at a range of challenges faced by technology suppliers serving rural off-grid markets.

4.8.3.1 Policy Framework

Beyond the control of any private sector business is the policy framework it needs to operate within. While the operational and regulatory environments in many developing countries can be challenging, there have been encouraging developments in several Central American countries. For instance, starting a legitimate business in El Salvador used to take 115 days and many separate procedures until recent reforms reduced the effort to 26 days and allowed registration with four separate agencies in a single visit. Implementation of these reforms has resulted in five times as many businesses registering annually.[170]

Given that it is predominantly rural areas that lack access to the electrical grid, Central American governments are increasingly acknowledging that they do not have the capacity to meet energy needs of this population segment without help from the private sector. Instead, they are looking to revise policy and create frameworks to facilitate the operation of private sector. For instance, the director of energy policy for Nicaragua's National Commission of Energy stated: *"Investment in the energy sector must be from private sources because the government does not have the capacity to make the necessary investment. Thus [….] companies that develop technology for energy projects will be looked upon highly. There are not many companies yet, but it is the government's intention to support private developers in the energy sector to augment the government's capacity."*[171]

In recognition of this fact, governments and multilateral institutions have started adopting policies such as removing legal and regulatory barriers that stand in the way of business innovation and private sector investments. This includes keeping

[170] Hammond, A. et. al. (2007): p.8

[171] Prahalad, C.K. (2010): p.368

import duties on imported components of PV systems low, and building programs aimed at supporting the expansion of private businesses for provision of energy services to rural communities.

Nevertheless, as detailed below, there have also been several policies and public sector programs which have had a market dampening effect.

4.8.3.1.1 Lack of Transparency of Government Policy

Grid extensions are often politically motivated and have been implemented in rural areas despite doubtful financial sustainability for the utilities and scarcity of power to serve new customers (often resulting in power cuts). This made predicting long term off-grid areas even more difficult for technology suppliers and hence greatly impacted strategic business modeling and planning. Such uncertainty particularly impacted Soluz, given that its micro-rental product range is particularly attractive to households in communities with near term prospects of receiving grid service. The lack of transparency in national electrification planning in Honduras meant that Soluz was unable to determine when and where grid extension was going to take place, or even the extent of that expansion, thus making strategic investment particularly challenging.[172]

4.8.3.1.2 Market Dampening Effects of Government Programs

Despite public declaration of a strong interest in mobilizing private sector funds to help achieve universal access to energy, some of these programs, often based on the provision of subsidies to make systems more affordable to BOP households, were shown to have been ill-planned and of market dampening effect.

An example is the project for *Rural Electrification of Isolated Zones* (*Proyecto de Electrificación Rural para Zonas Aisladas* - PERZA) implemented in Nicaragua from 2003 to 2011. Implemented by the National Energy Commission (*Comisión Nacional de Energía*) and financed through funds from the WB and other multilateral institutions, this program offered rural households subsidies for PV systems. Despite impressive uptake and the high number of resulting installations, it proved not to be

[172] Rogers, J. et. al. (2006): p.59

a sustainable solution, as subsequent to the funds of PERZA drying up, Tecnosol experienced a significant drop in sales and it took several years for the market to normalize again.

Another example is a 10,000 household PV project with little or no cost recovery announced by the government of the Dominican Republic in 2005. Despite the project not advancing rapidly in practice, and in fact becoming the subject of a corruption investigation, its mere announcement continues to fuel a significant force of hesitation in the market, hindering Soluz's sales and rentals.[173]

To avoid such market dampening effects of free or heavily subsidized PV systems, some form of public-private planning linkage is critical. Government funds might best be used for educational and PV awareness raising campaigns. Subsidies might even be targeted towards peripheral system components such as light bulbs or wiring in order to minimize the market distorting effect of these subsidies while increasing affordability of technology solutions to BOP households. The actual selection of power components (choice of technology, capacity of a PV panel, etc.) or type of energy supply (off-grid versus mini-grid) is left to the market, with customers, suppliers and financial institutions jointly selecting technologies and financial product ranges.

4.8.3.2 Macroeconomic Situation

Macroeconomic developments often expose the volatility of rural populations' income streams. For instance, when international coffee prices fell to a 70 year low at the turn of the century, rural households in coffee growing regions across Central America suffered financially, and consequently their spending power was significantly reduced. This severely impacted Soluz, as its early customer base included a large segment of the population in coffee growing regions in the Northwest of Honduras. To overcome this issue and to avoid a similar risk going forward, Soluz since tried to diversify its customer base in terms of their income source, by expanding operations to rural areas dominated by industries other than

[173] Rogers, J. et. al. (2006): p.72

coffee, such as fishing or other agriculture.[174] While this reduces the risk of local disruption, it obviously increased transportation costs and operational complexity.

4.8.3.3 Natural Disasters

Natural disasters, as in the case of Hurricane Mitch in 1998, can seriously affect the economy and spending power of rural customers for several years. Soluz's financial performance in Honduras suffered greatly as a result in 1998, and there was little in terms of remedy or protection they could undertake.

4.8.3.4 Security Situation

Over the past decade the security situation has rapidly deteriorated in several Central American countries. In the most recently published statistics by the UN Office on Drugs & Crime (UNODC), Honduras and El Salvador are the two countries with the globally highest homicide rate per 100,000 inhabitants. Belize (number 5 on the list) and Guatemala (number 8 on the list) are two further Central American countries among the top ten of the UNODC list. Soluz has felt this in losses of income and customers as a result of rural banditry in Honduras.

4.8.4 Financing Options and Inclusive Business Opportunities Resulting from Increasing Recognition by Multilateral Development Banks

4.8.4.1 Dedicated Business Units within Multilateral Development Banks

MDBs are increasingly recognizing the importance of Inclusive Business Models as an indispensable strategic step towards eradicating global poverty. This has led to the creation of dedicated business units for Inclusive Business Models within these organizations. The IDB was the pioneer in this field, creating the *Opportunities for the Majority Initiative* in 2007, promoting and financing market-based, sustainable business models that engage private sector companies, local governments and communities in the development and delivery of quality products and services for the BOP in Latin America and the Caribbean. In 2010, further MDBs followed suit,

[174] Rogers, J. et. al. (2006): p.70

with the IFC launching its *Inclusive Business Models Group* and the Asian Development Bank (ADB) launching its *Inclusive Business Initiative*, to help clients scale up their business models to reach a broader customer segment at the BOP. This recognition by MDBs has important implications for access to finance for Inclusive Businesses at each stage of their lifecycle (Figure 4.16).

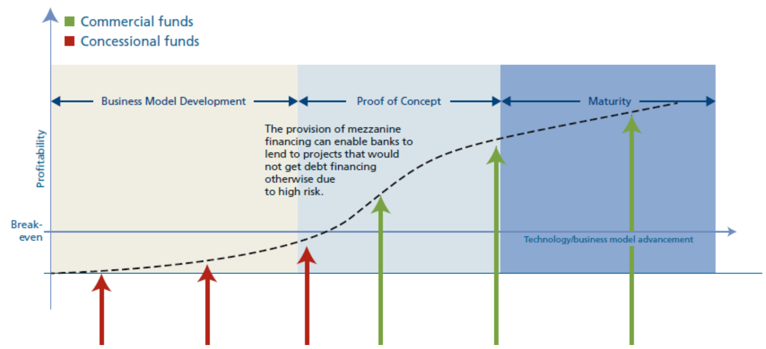

Figure 4.16 – Financing Requirements over a Company's Lifecycle[175]

4.8.4.2 Access to Finance - Launching a New Inclusive Business Model

As is the case for any start-up company, access to some form of concessional finance, patient capital or grant funds in the early stages of the company lifecycle is critical (Figure 4.16). From covering business model conceptualization and piloting innovative new product and service ranges for the BOP, to developing supply chains, capacity building of employees and local sales staff and training of local engineers: the launch of a business involves great expenditures.

MDBs have recognized this fact, and are supporting the launch of a range of Inclusive Business Models through technical assistance funds, channeled through their dedicated business units. For instance, the OMJ Initiative of the IDB, in collaboration with the Multilateral Investment Fund (MIF), is assisting Quetsol in the roll-out of the first phase of its PAYG Solar Kits (section 4.7.3.3.2).

Given the socio-economic importance of universal access to modern energy, not least because of the goals set by the SE4All Initiative and the ecological impact of moving away from fossil fuel based energy sources, a wide range of additional

[175] Bardouille, P. et. al. (2012): p.135, Fig.4.4

concessional funding sources is available, specifically targeting new energy access companies trying to get off the ground. Examples include government-backed initiatives such as the EU *Solar for All Initiative,* multilateral facilities such as the *Global Environmental Facility* (GEF), major multilateral funds such as the *Organization of the Petroleum Exporting Countries Fund for International Development* (OFID), and private foundations such as the Shell Foundation, to name a select few.

4.8.4.3 Access to Finance - Scaling an Existing Inclusive Business Model

Once a business concept has proven to be commercially viable, the company can start tapping into an even wider pool of commercial funding sources to scale its operation and reach more people at the BOP, such as: (i) Local banking sector: Local banks have good knowledge of local businesses and a good understanding of the current state of local markets; (ii) International banking sector: A number of international banks have an institutional interest in financing renewable energy projects, both for their financial returns as well as their public relations value. For instance, Triodos Bank in the Netherlands set up a Solar Investment Fund with the aim of investing several million Euros in PV technology in developing countries; [176] (iii) Impact investors: Investors such as Oikokredit, Triple Jump or the Acumen Fund, to name a few, are prime private sector partners, as they specialize in the double-bottom-line returns delivered by Inclusive Businesses; (iv) Risk capital providers: Finance may also come from specialist risk capital providers such as venture capital funds, private equity funds and pension funds. The main instruments favored by these sources include debt, mezzanine finance and, for some, equity. At the outset of the scaling process, it is particularly important to attract equity investors, as a solid equity base will be a prerequisite for an Inclusive Business to be able to raise further debt going forward.

As will be highlighted in the sections below, MDBs have initiated a range of innovative funding models and resource mobilization initiatives, aimed at facilitating access to these commercial funding sources by Inclusive Businesses.

[176] Wohlgemuth, N. (2000): p.41

4.8.4.3.1 Addressing Financing Bottlenecks through Targeted Investments

Experience suggests that two types of capital are required for the scaling of an operation: (i) Working capital for the operation of the business itself, with tenors of 3-5 years, and (ii) Asset financing with tenors of 6-10 years, in case third party consumer financing options (through, for example, MFIs) are not available.[177] Due to the required long tenors, getting access to asset financing is difficult and expensive. In fact, the main limitation to Tecnosol's growth is the scarce availability of loan finance for customers.[178]

To help overcome this financing bottleneck identified in Central America, the OMJ Initiative of the IDB recently financed a US$3 million loan to Covelo (section 4.7.3.1). This loan forms part of a total project size of US$6 million, with the remainder of the funding coming from other private sector sources. All of the funding, including that from the IDB, is priced at commercial rates. Covelo, which is operating as a regional second tier financial institution, is using these funds to capitalize MFIs across Central America to enable dedicated energy microcredits to end-users for the purchase of off-grid PV systems. By injecting this liquidity into the Central American MFI market, this project is fostering third-party financing options for PV systems, thereby circumventing the requirement of expensive and often difficult to obtain asset financing by the technology supplier. Tecnosol´s growth will be positively impacted by this project, having been identified by Covelo as a primary regional technology partner for the provision of off-grid PV systems to be financed through this credit line.

4.8.4.3.2 Mobilizing Private Sector Funds

There are ever increasing efforts by MDBs to mobilize a range of third party private sector funds to help scale Inclusive Business Models in developing countries.

Involvement of private sector parties is typically through loan syndications organized by MDBs, where the MDB finances a portion of up to 50% of a project, with the remaining funding coming from one or several co-lenders. The thorough due diligence process of MDBs, which not only assesses the social and environmental

[177] Rogers, J. et. al. (2006): p.72

[178] Ashden (2010): p.4

impacts of a model, but also does a thorough analysis of the financial sustainability of a given Inclusive Business Model, provides international private sector partners with the confidence needed to invest in projects in developing countries. A good example of such a loan syndication was the OMJ financing of Covelo described in section 4.8.4.3.1.

To better leverage MDBs' own limited resources, a further instrument employed by these development banks to incentivize private sector investments in developing countries is the provision of first loss coverage and risk guarantees for these investments. Such guarantee instruments have a number of beneficial implications, such as: (i) Covering part of the risk for investors and thereby mobilizing financing for development; (ii) Improving commercial financing conditions (tenors, interest rates, loan amounts) for Inclusive Businesses through an improved risk profile for the investor; (iii) Helping develop local capital markets by attracting investments in new sectors and instruments.

Moreover, in instances where the business case for commercial investment is marginal, but where the Inclusive Business Model is providing a public good, such as enabling access to electricity, government support to enhance or guarantee investment returns are appropriate. Section 4.8.3.1 highlighted the acknowledgement by Central American governments that they do not have the capacity to achieve universal access to electricity without the help of the private sector. Hence, such public sector guarantees are an ideal method for leveraging local governments´ limited resources to enable private sector technology suppliers to scale their operations. To foster such guarantee instruments, a number of MDBs are currently in the process of establishing a framework for flexible guarantee instruments, which will enable local governments to provide necessary first-loss coverage or risk guarantees (in the context of this Thesis to technology suppliers or MFIs), thereby incentivizing more private investments in this sector.

4.8.5 Conclusions on Commercial Viability of PV Inclusive Business Models

The case study analysis of Tecnosol and Quetsol showed that the provision of off-grid PV systems to rural BOP households in Central America is commercially viable and meets the financial sustainability characteristic required to achieve the double-bottom-line return of an Inclusive Business. The example of Soluz underlined the importance of a strong business case for this to be true.

A number of critical success factors as well as key challenges were highlighted. Even commercially successful models often required some form of concessional financing at the outset to conceptualize the business model and run pilot projects, but subsequently matured into sustainable for-profit businesses. Tecnosol has been particularly successful, operating sustainably for more than 15 years and continuously scaling its operations across the region.

Finally, recognition of the importance of Inclusive Business Models by MDBs and the resulting opportunities for access to finance for start-ups were presented.

5 Summary of Results

The core objective was to determine the viability for Inclusive Business Models for the provision of off-grid PV systems to low-income households, defined as the Base of the Pyramid, in rural regions of Central America.

Inclusive Business Models present a market driven strategy to alleviate poverty (section 2.4.1). They are private sector business models which, as part of their value proposition, have a positive social impact on the targeted BOP population segments by engaging them as suppliers, as employees, as distributors and/or customers. Successful Inclusive Business Models thus achieve a double-bottom-line return. The Inclusive Business Models proposed here, for the provision of PV technologies to help move away from fossil fuel based solutions, also have a positive ecological impact, thereby potentially achieving a triple-bottom-line return.

To address this objective, the analysis set out to establish the social, ecological and economic impact of potential Inclusive Business Models in this field and region, and to determine their commercial viability.

5.1 Market Assessment

What is the potential market size in Central America for off-grid energy solutions?

In section 4.2.2.2 it was shown that 78% of the population in Central America belongs to the BOP (Table 4.1). There is considerable variation between individual countries, with the smallest BOP population share found in Costa Rica at 54% and the largest share in Nicaragua at 89%. Costa Rica and Nicaragua also represent the highest and lowest electrification rate, at 99% and 75% respectively. The regional average electrification rate stands at 85% across Central America (Table 4.2).

Given that the share of the BOP population greatly exceeds the share of the un-electrified households, and the fact that lack of access to modern energy is a phenomenon typically linked to low-income households, the assumption is that all households in Central America which are not connected to the national grid belong to the BOP.

Considering that it is predominantly rural areas lacking access to the electrical grid (87% for Latin America – section 2.4.1), decentralized solutions play an important role in providing electricity to these households. The IFC estimates that to achieve universal access through a market based approach, 75% of the households are best served through standalone off-grid solutions (section 2.4.2). For Central America this equals approximately 4.6 million people, or 1 million households (section 4.2.3.3). Guatemala, Honduras and Nicaragua represent the countries with the highest market potential, making up 80% of the estimated market.

This estimate might have to be reduced slightly, as, in practice, national grid extension programs are often politically charged and might even be applied to areas without commercial viability of service for the utility (section 4.8.3.1.1). Applying the more conservative estimates of the IEA, that the national grid might penetrate up to 30% of rural areas (section 2.4.1), this still represents a considerable potential market in Central America of up to 3.7 million people, or 800,000 households. Rural households expecting to be connected to the national grid in the foreseeable future can still be targeted by products and services such as micro-rentals for off-grid PV systems (section 4.7.3.2), as an interim solution to pre-electrification. If and when the national grid arrives in such households' areas, the technology supplier can readily employ the PV systems in other areas.

Also, as shown by the three case studies in section 4.8 technology suppliers are already actively involved in serving this market, so the calculations applied here are representative of a concrete and very current window of opportunity for Inclusive Business start-ups.

5.2 Technical & Energetic Assessment

Why is PV the most suitable RE technology for meeting rural off-grid energy needs?

One practical advantage of RE systems for rural electrification is that they come in scales that are very appropriate for rural households, given their relatively low demands for electricity. More specifically, high regional levels of GHR make Central America a particularly suitable region for the use of PV technology (section 4.3.3.1). Universally applicable across the region, PV is also an ideal technology platform for a company trying to reach scale. In addition, several characteristics of PV systems themselves make them a very attractive option. These include: (i) its modular structure, allowing the PV system to grow in line with a household's income and the resulting increase in electricity demand, (ii) the long lifetime of PV panels, increasing the return on investment; (iii) low maintenance requirements compared to other RE technologies, minimizing potentially costly site visits by trained engineers, and the need for replacement parts.

What are the nominal power requirements of PV systems to meet BOP households' energy needs?

For the purposes of the energetic assessment, rural households were categorized into three groups, based on their annual electricity consumption levels (Table 4.6): *Subsistence Level*: 2kWh, *Basic Level*: 15kWh, and *MDG-compatible Level*: 75kWh. Taking into account GHR levels across Central America, these three levels of electricity requirements could be met by employing PV systems with capacities of 1.5W_p, 10$W_{p,}$ and 50W_p respectively (Table 4.7). In section 4.4.3, three broad categories of PV systems were determined: Solar lanterns, Solar Kits, and SHS. In terms of their output, these three devices roughly match the three electricity consumption levels. There is an overlap between peak capacities of upper range Solar Kits and the lower range SHS, making either of these technologies suitable solutions for *MDG-compatible Level* households. As a mobile system, Solar Kits have an advantage over traditional SHS, however, in that they do not require installation by a qualified technician.

5.3 Social, Ecological and Financial Impact Assessment

Sections 4.5 to 4.7 are an assessment of the social, ecological and economic impact of substituting traditional kerosene based lighting sources with PV systems. Figure 5.1 provides a summary of the overall findings of this analysis, as PV systems were shown to be a *"key link to eliminating poverty, by stimulating social benefits and economic development in an ecologically sustainable manner"*[179]

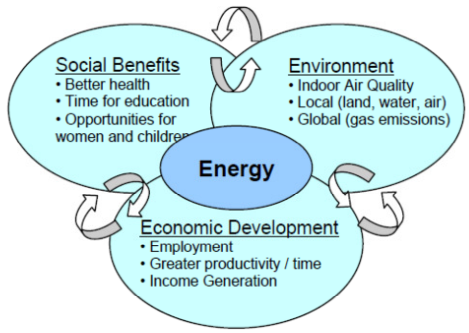

Figure 5.1 – Renewable Energy Impact Assessment[180]

What is the social impact on the BOP of substituting traditional energy sources with PV systems?

Section 4.5 shows that the use of PV systems has far ranging positive social impacts on the concerned BOP households. Some of these include: (i) access to electrical appliances, such as communication products, refrigeration, ventilation and warm water; (ii) creating local income generation opportunities, both for existing micro-businesses, through, for example, extended opening hours, and for new microenterprises, such as energy kiosks (section 4.5.3), as well as for local entrepreneurs, incorporated by technology suppliers into the distribution and sale of PV systems in their communities; (iii) impact on women, freeing up women from tasks such as fetching kerosene from neighboring communities and enabling them to dedicate this time to education or income generating activities; (iv) improved health and prevention of numerous respiratory diseases caused by inhalation of toxic kerosene fumes; (v) improved safety, particularly for women, due to lighting in public spaces from shops or communal buildings, and prevention of fires in the home caused by kerosene lamps; (vi) improved conditions for education due to superior lighting.

[179] Baron, S. and Weinmann, G. (2003): p.12

[180] Baron, S. and Weinmann, G. (2003): p.12

What is the ecological impact of the BOP substituting traditional energy sources with PV systems?

Section 4.6.1 shows that the burning of kerosene for lighting purposes results in substantial CO_2 and BC emissions, the two largest causes of climate warming in today's atmosphere. For the off-grid electricity market in Central America, the significant potential emission reductions achieved by substitution with PV systems are calculated at 101 thousand tons of CO_2 and 552 tons of BC per year (Table 4.9). Furthermore, a PV system is best used in conjunction with energy efficient appliances to maximize the performance of the system, and a move toward PV has been shown to raise awareness of such technologies among BOP households.

What are the financial implications for the BOP of substituting traditional energy sources with PV systems?

Advances in PV technology have lead to rapid declines in retail prices over the past decades and these are projected to continue (Figure 4.11). In addition, advances made in the peripheral components of PV systems, such as LEDs, mean prices have dropped quickly and efficiency has more than tripled since 2009.

Nevertheless, Solar Kits and SHS still represent an expensive upfront investment with savings only felt over time. This is the cash flow pattern least suited to BOP households. To overcome this socioeconomic hurdle, a number of innovative finance mechanisms have been made available, and these are outlined in section 4.7.3. They range from cash sales, suitable for cheaper devices such as solar lanterns, and consumer financing options based on microcredits, to monthly micro-rentals and PAYG models, giving the household total control over their monthly expenditure.

The most commercially tried and tested approach, consumer financing based on microcredits, significantly increases the market opportunity for PV systems and therefore constitutes a crucial component for the success of a technology supplier's business model. The Central American MFI network REDCAMIF (section 4.7.3.1) provides a strategic platform to quickly scale an operation throughout the region.

Section 4.7.4 compares households' current expenditure patterns on traditional energy solutions to a microcredit repayment under typical conditions available from and MFI in Central America. Reflecting the three energy consumption levels of the energetic assessment (Table 4.6), rural off-grid households are divided into three categories (*Subsistence Level, Basic Level* and *MDG-compatible Level*), based on their monthly expenditure on traditional energy solutions. Households in all three categories could essentially maintain their current monthly energy expenditure and move toward PV systems. Section 4.7.5 highlights how a longer useful life of PV systems, and significantly lower recurring operational costs, enable a BOP household to achieve significant financial savings in the long run. Increasing kerosene prices, coupled with falling technology prices, means that this savings potential will continue to increase.

5.4 Commercial Viability Assessment

What is the commercial viability of providing PV systems to the BOP?

Sections 4.4, 4.6 and 4.7 show that the technologies and equipment necessary to provide clean, reliable and affordable energy to BOP households are readily available and well-tested. Hence, the main challenge lies in building a strong, viable business model and developing the enabling political framework to facilitate the implementation of such models.

To determine the commercial viability of market driven models in this area, section 4.8 analyses three for-profit companies currently providing off-grid PV systems in rural Central America. The case made by the examples of Tecnosol (section 4.8.1.1) and Quetsol (section 4.8.1.2), and, to a lesser extent, Soluz (section 4.8.1.3), is that they are in fact commercially viable.

Section 4.8.2 identifies critical success factors at each stage of the supply chain. BOP suitable products at affordable prices, effective promotion, access to a suitable last-mile distribution and sales infrastructure, training local technical staff and customers, and high quality after sales service were all shown to be essential to the success of a model. Those companies employing the five broad strategies shown to be critical for operating successfully in BOP markets (section 4.1.2) tended to excel.

Section 4.8.3 presents a number of key challenges faced by for-profit companies, often beyond the control of the company. The enabling framework to encourage the provision of private sector driven PV solutions was found to be a crucial factor. Despite public declaration of interest in mobilizing private sector funds to help achieve universal access to energy (section 4.8.3.1), public sector programs have often undermined private-sector participation through ill-planned heavy subsidies and give away programs. Despite impressive initial uptake, long term sustainable solutions were jeopardized by leaving markets distorted after completion.

Section 4.8.4 showed the increasing recognition by the development community, and particularly by MDBs, of Inclusive Business Models as an important contributor to alleviating global poverty. This presents a number of opportunities for access to finance at each stage of the Inclusive Business lifecycle and a range of concessional finance sources are available to help launch new off-grid energy businesses. Finally, MDBs have acted as catalysts for mobilizing private sector funds towards Inclusive Business Models by implementing a number of measures, ranging from loan syndications to first loss coverage and risk guarantees.

5.5 Conclusions drawn from the Assessments

"Through both economies of scale in manufacturing and an approach that emphasizes locally managed and controlled energy delivery, the success of energy enterprises using renewable energy technologies at the BOP might prove to be the most important innovation in the energy sector for years to come."[181]

The analysis has shown that there is great potential for Inclusive Business Models providing PV systems to rural BOP households in Central America. The for-profit models were shown to be commercially viable, while at the same time creating a positive social, ecological and economic impact on BOP households, thereby achieving a triple-bottom-line return.

PV systems were shown to be a suitable, reliable and ever more affordable solution for off-grid energy access. Furthermore, it was shown that the BOP in Central

[181] Prahalad, C.K. (2010): p.369

America has the capacity and also the willingness to pay for these technologies to gain access to modern energy.

The three Inclusive Business Models operating in this field were shown to approach the BOP holistically by involvement in various stages of the value chain: (i) as employees: local service staff, local trained technicians, etc.; (ii) as distributors: local sales ports and local micro-entrepreneurs working in the promotion and installation of PV systems; (iii) as customers: providing a triple-bottom-line return as well as training on proper usage.

6 Conclusions

The provision of off-grid PV systems to rural areas is an indispensable step towards achieving each one of the three goals set out by the UN Initiative *Sustainable Energy for All*, and towards achieving the Millennium Development Goals. Of the many complementary approaches, the Inclusive Business Model, applied to the provision of PV as analyzed in this Thesis, presents an effective strategy for the Initiative's first goal of *Universal Access to modern energy services*. Subsequently, for PV systems to unfold their full potential, energy efficient appliances and equipment will enter the increasingly energy-aware market, another essential step towards achieving the Initiative's second goal of *doubling the global rate of improvement in Energy Efficiency*. Finally, the substitution of traditional fossil fuel based solutions with PV systems makes a contribution towards the Initiative's third goal of *doubling the global share of Renewable Energy*.

In addition to the Central American region analyzed here, Sub-Saharan Africa and the developing parts of Asia not only represent the most critical areas for achieving the Initiative goals, but also harbor markets with huge potential. Given the importance of modern energy in socioeconomic development terms and that today 1.3 billion people globally remain without access to electricity, actors from the public sector, the private sector and civil society need to coordinate their efforts to encompass grid extensions, mini-grids and off-grid solutions, ensuring the goal of "Energy for All" is achieved as quickly, efficiently and effectively as possible.

Private sector investments reduce the burden on public and development assistance budgets, allowing those limited resources to be tailored towards segments of the population that can only be served through public means. Involvement of the private sector also brings in key expertise and capabilities, and the private sector is often in a position to act and invest faster than the public sector, when facilitated by insightful policy, thereby greatly accelerating the expansion of modern energy to poor rural communities. In order to truly engage the private sector, governments need to recognize that revenues which reflect the full value of the service provided to rural customers allow for profit and growth. This will prove crucial for many countries if they are to achieve not only sustainable provision of energy, but also innovation in terms of a move away from the traditional conception of economic development based on centralized energy from fossil fuels.

To further support this, Inclusive Business Models could be expanded beyond serving rural BOP households, scaling the model to serve small and medium enterprises with productive energy uses, or providing off-grid electricity solutions on a community level for water pumps or public lighting. In addition to scaling the Inclusive Business approach to include a broader customer base, replication in other regions is critical.

Grameen Shakti celebrated its one millionth SHS installation in the rural areas of Bangladesh at the end of 2012 and is targeting a further million installations by the end of 2016.[182] It is with the support of carefully researched empirical evidence, and hence great confidence, that this Thesis claims that the same could and should be achieved for the BOP in Central America with the indispensible help of Inclusive Business Models, in line with the goal of Universal Access by 2030.

[182] Grameen Shakti (2013), www

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Annex A

Important Links Between Modern Energy Services and the Millennium Development Goals[183]

Millennium Development Goal	Importance of Modern Energy to Achieving the Goal
Eradicate extreme poverty and hunger	- Local energy supplies can often be provided by small-scale, locally owned businesses creating employment in local energy service provision and maintenance, fuel crops, etc - Lighting permits income generation beyond daylight hours - Machinery increases productivity - Privatization of the provision of energy services can help free up government funds for social welfare investment - Clean, efficient fuels reduce the large share of household income spent on cooking, lighting, and keeping warm (equity issue—poor people pay proportionately more for basic services) - Energy for irrigation helps increase food production and access to nutrition - Post-harvest losses are reduced through better preservation (for example, drying and smoking) and chilling/freezing
Achieve universal primary education	- Energy can help create a more child-friendly environment (access to clean water, sanitation, lighting, and space heating/cooling), thus improving attendance at school and reducing drop-out rates - Lighting in schools helps retain teachers, especially if their accommodation has electricity - Electricity enables access to educational media and communications in schools and at home that increase education opportunities and allow distance learning. - Access to energy provides the opportunity to use equipment for teaching (overhead projector, computer, printer, photocopier, science equipment)

[183] Barnes, D. et. al. (2005): p.33, Extract from Table 3

Promote gender equality and empower women	- Availability of modern energy services frees girls' and young women's time from survival activities (gathering firewood, fetching water, cooking inefficiently, crop processing by hand, manual farming work) - Good quality lighting permits home study and allows evening classes - Street lighting improves women's safety - Affordable and reliable energy services offer scope for women's enterprises
Reduce child mortality rates	- Indoor air pollution contributes to respiratory infections that account for up to 20 percent of the 11 million child deaths each year (WHO 2002, based on 1999 data) - Provision of nutritious cooked food, space heating, and boiled water contributes towards better health - Electricity enables pumped clean water and purification
Improve maternal health	- Energy services are needed to provide access to better medical facilities for maternal care, including medicine refrigeration, equipment sterilization, and operating theatres - Excessive workload and heavy manual labor (carrying heavy loads of fuel wood and water) may affect a pregnant woman's general health and well being
Combat HIV/AIDS, malaria and other diseases	- Electricity in health centers enables night availability, helps retain qualified staff, and allows equipment use (sterilization, medicine refrigeration) - Energy for refrigeration allows vaccination and medicine storage for the prevention and treatment of diseases and infections - Energy is needed to develop, manufacture, and distribute drugs, medicines, and vaccinations - Electricity enables access to health education media through information and communication technologies
Ensure ecological sustainability	- Increased agricultural productivity is enabled through the use of machinery and irrigation, which in turn reduces the need to expand quantity of land under cultivation, reducing pressure on ecosystem conversion - Using cleaner, more efficient fuels will reduce greenhouse

	gas emissions, which are a major contributor to climate change - Clean energy production can encourage better natural resource management, including improved water quality - Traditional fuel use contributes to erosion, reduced soil fertility, and desertification. Fuel substitution, improved efficiency, and energy crops can make exploitation of natural resources more sustainable
Develop a global partnership for development	- In cooperation with the private sector, make available the benefits of new technologies, such as off-grid RE systems, to low income households

Annex B

Central American Base of the Pyramid Data

BOP income per capita in US$:

		Units	Year	Source
BOP - Annual income per capita limit	3,260	*$/year*	*2005*	*Hammond, A. et. al. (2007)*
BOP - Daily income per capita limit	8.93	*$/day*	*2005*	*Own calculation based on data above*
PPP (2005)				
Belize	1.22		*2005*	*http://www.indexmundi.com/facts/belize/ppp-conversion-factor*
Guatemala	4.02		*2005*	*http://www.indexmundi.com/facts/guatemala/ppp-conversion-factor*
Honduras	8.15		*2005*	*http://www.indexmundi.com/facts/honduras/ppp-conversion-factor*
				(cited as: World Bank, International Comparison Program database)
Daily income per capita (in US$)				
Belize	7.32	*US$/day*	*2005*	*Own calculation based on data above*
Guatemala	2.22	*US$/day*	*2005*	*Own calculation based on data above*
Honduras	1.10	*US$/day*	*2005*	*Own calculation based on data above*

Opportunities for the Majority Analysis of BOP per country (except Belize):

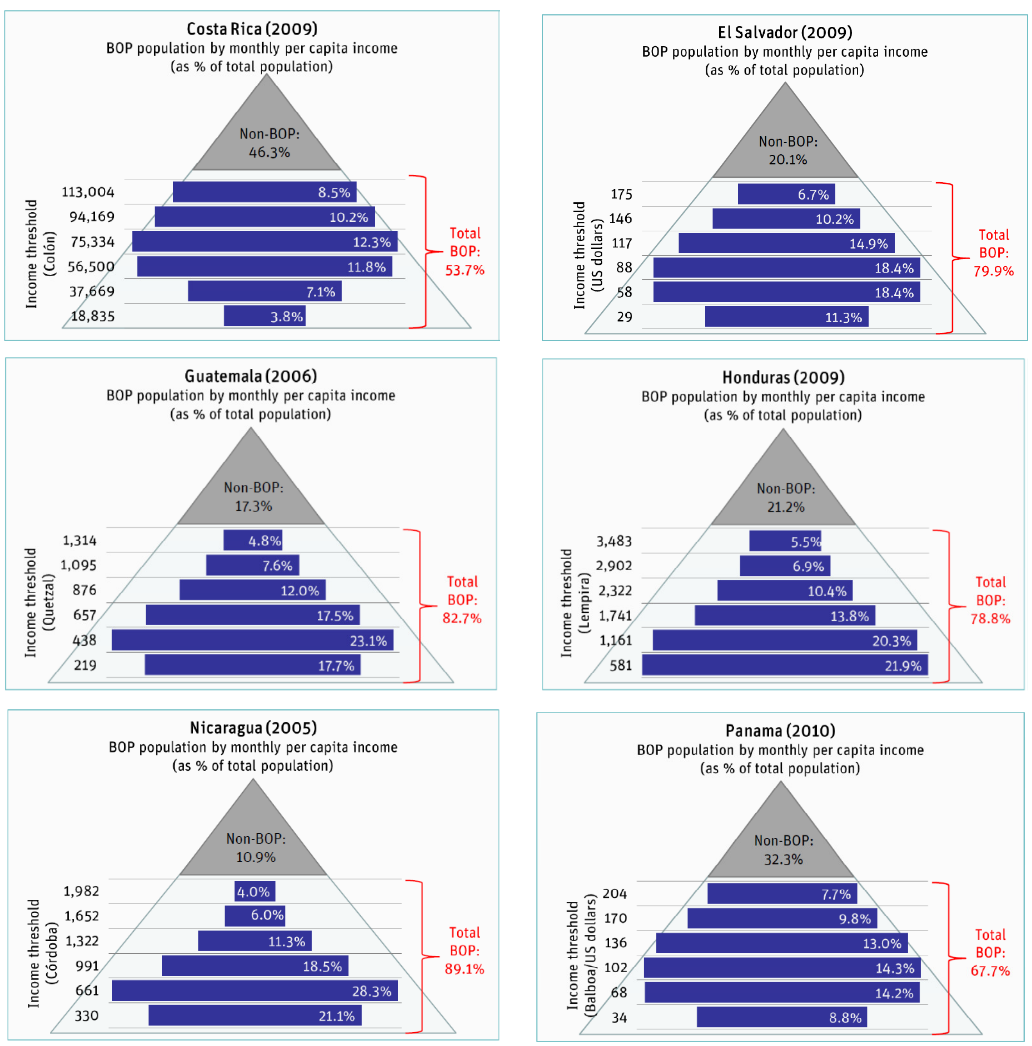

Figure B.1 – Base of the Pyramid by Country[184]

[184] OMJ (2012)

BOP – subcategories:

As can be seen in Figure B.1, the BOP segment is subdivided into six equal income brackets, with the lowest bracket having an annual per capita income up to $500 (BOP500) and the highest bracket having an annual per capita income up to $3,000 (BOP3000). These bracket ceilings were set at 2002 international dollar levels.

BOP Belize:

Year	2004	2005	2006	2007	2008	2009	2010	Source:
US Retail Price Index (RPI)	2.7	3.4	3.2	2.9	3.8	(0.4)	1.6	*http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?page=1*
B$ PPP	1.23	1.22	1.23	1.24	1.25	1.22	1.22	*http://www.indexmundi.com/facts/belize/ppp-conversion-factor*
								(Cited as World Bank, International Comparison Program database)

	Q1	Q2	Q3	Q4	Q5	
	20%	20%	20%	20%	20%	*Hydroplan (2011): p.39 (Cited: Statisitics Institute of Belize)*
Average houshold size	5.7	4.5	4	3.2	2.6	*Hydroplan (2011): p.39 (Cited: Statisitics Institute of Belize)*
No. of HH	11,691	14,809	16,660	20,825	25,631	*Hydroplan (2011): p.39 (Cited: Statisitics Institute of Belize)*
Total number of people	66,639	66,641	66,640	66,640	66,641	*Hydroplan (2011): p.39 (Cited: Statisitics Institute of Belize)*
Average houshold income (B$)	14,756	16,730	19,608	19,035	26,994	*Hydroplan (2011): p.39 (Cited: Statisitics Institute of Belize)*
Average houshold income ($ PPP)	12,095	13,713	16,072	15,602	22,126	*Own calculation based on data above*
Per capita income ($ PPP)	2,122	3,047	4,018	4,876	8,510	*Own calculation based on data above*

Assumption: Uniform distribution of income within each quintile

Incremental income per 1%	40.18	*Own calculation based on data above*
BOP 3000 ($ PPP)	3,636	*Own calculation based on data above*
Difference to BOP 3000	589	*Own calculation based on data above*
% of Q3 falling into BOP 3000	14.7%	*Own calculation based on data above*
Total BOP 3000 %	**54.7%**	*Own calculation based on data above*

Determining the number of BOP people and BOP households:

Data Sources:

Population (´000)		*Unit*	*year*	*source*
Belize	**357**	*´000*	*2011*	*http://data.worldbank.org/country/*
Costa Rica	**4,727**	*´000*	*2011*	*http://data.worldbank.org/country/*
El Salvador	**6,227**	*´000*	*2011*	*http://data.worldbank.org/country/*
Guatemala	**14,760**	*´000*	*2011*	*http://data.worldbank.org/country/*
Honduras	**7,755**	*´000*	*2011*	*http://data.worldbank.org/country/*
Nicaragua	**5,870**	*´000*	*2011*	*http://data.worldbank.org/country/*
Panama	**3,571**	*´000*	*2011*	*http://data.worldbank.org/country/*
Average household size				
Belize	4.0	*units*	*2007*	*Hydroplan (2011):*
Costa Rica	3.6	*units*	*2009*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
El Salvador	3.9	*units*	*2009*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
Guatemala	4.9	*units*	*2006*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
Honduras	4.5	*units*	*2009*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
Nicaragua	5.2	*units*	*2005*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
Panama	3.7	*units*	*2010*	*http://sedlac.econo.unlp.edu.ar/eng/statistics-detalle.php?idE=36*
BOP Population (%)				
Belize	54.7%	*%*	*2010*	*Own calculation - See Beliz section*
Costa Rica	53.7%	*%*	*2009*	*OMJ (2012) - see Figure B.1*
El Salvador	79.9%	*%*	*2009*	*OMJ (2012) - see Figure B.1*
Guatemala	82.7%	*%*	*2006*	*OMJ (2012) - see Figure B.1*
Honduras	78.8%	*%*	*2009*	*OMJ (2012) - see Figure B.1*
Nicaragua	89.1%	*%*	*2005*	*OMJ (2012) - see Figure B.1*
Panama	67.7%	*%*	*2010*	*OMJ (2012) - see Figure B.1*

Percentage split by BOP500, BOP1000, BOP1500, BOP2000, BOP2500, BOP3000

Belize	Assumption of uniform distribution within Belize BOP
Central America (except Belize)	*OMJ (2012) - see Figure B.1*

Calculation results based on source data above:

COUNTRY	Population ('000)	BOP Population (%)	Size of BOP (‘000)	Number of BOP households ('000)
Belize	357	54.7%	195	49
Costa Rica	4,727	53.7%	2,538	705
El Salvador	6,227	79.9%	4,975	1,276
Guatemala	14,760	82.7%	12,207	2,491
Honduras	7,755	78.8%	6,111	1,358
Nicaragua	5,870	89.1%	5,230	1,006
Panama	3,571	67.7%	2,418	653
Central America	**43,267**	**77.8%**	**33,674**	**7,538**

COUNTRY	Population ('000)	BOP 500 - 1000 (%)	BOP 1500 - 1500 (%)	BOP 2500 - 3000 (%)
Belize	357	18.2%	18.2%	18.2%
Costa Rica	4,727	10.9%	24.1%	18.7%
El Salvador	6,227	29.7%	33.3%	16.9%
Guatemala	14,760	40.8%	29.5%	12.4%
Honduras	7,755	42.2%	24.2%	12.4%
Nicaragua	5,870	49.4%	29.8%	9.9%
Panama	3,571	23.0%	27.3%	17.4%
Central America	**43,267**	**35.7%**	**28.3%**	**13.9%**

COUNTRY	BOP 500 - 1000: Population ('000)	BOP 1500 - 2000: Population ('000)	BOP 2500 - 3000: Population ('000)
Belize	65	65	65
Costa Rica	515	1,139	884
El Salvador	1,849	2,074	1,053
Guatemala	6,022	4,354	1,830
Honduras	3,273	1,877	962
Nicaragua	2,900	1,749	581
Panama	821	975	621
Central America	**15,445**	**12,233**	**5,996**

COUNTRY	BOP 500 - 1000: Households ('000)	BOP 1500 - 2000: Households ('000)	BOP 2500 - 3000: Households ('000)
Belize	16	16	16
Costa Rica	143	316	246
El Salvador	474	532	270
Guatemala	1,229	889	374
Honduras	727	417	214
Nicaragua	558	336	112
Panama	222	264	167
Central America	**3,369**	**2,770**	**1,399**

Annex C

Central American Off-Grid Electricity Market

Electrification Levels in Central America:

Data Sources:

	Year	Source
Electrification rate: Belize	*2010*	*Dougal, M. et. al. (2010)*
Electrification rate: Central America (except Belize)	*2010*	CEPAL (2011)

COUNTRY	Population ('000)	Electrification rate (%)	Population without access ('000)	Number of households without access ('000)
Belize	357	91.0%	32	8
Costa Rica	4,727	99.2%	38	11
El Salvador	6,227	91.2%	548	141
Guatemala	14,760	85.3%	2,170	443
Honduras	7,755	81.3%	1450	322
Nicaragua	5,870	74.6%	1,491	287
Panama	3,571	90.1%	354	96
Central America	**43,267**	**85.9%**	**6,083**	**1,308**

Central American Off-Grid Electricity Market:

Scenario IFC		*Unit*	*Source*
Percentage of unelectrified households served by off-grid	75%	*%*	*Bardouille, P. et. al. (2012)*
Population served by off-grid	4,562	*(´000)*	*Own calculation based on data above*
Households served by off-grid	981	*(´000)*	*Own calculation based on data above*
Scenario IEA			
Rural unelectrified households in Latin America	87%	%	*IEA (2011)*
Population served by off-grid	1,138	*(´000)*	*Own calculation based on data above*
Households served by off-grid	5,292	*(´000)*	*Own calculation based on data above*
Rural unelectrified households served by decentralized solutions	70%	%	*IEA (2011)*
Population served by off-grid	797	*(´000)*	*Own calculation based on data above*
Households served by off-grid	3,705	*(´000)*	*Own calculation based on data above*

Annex D

Global Horizontal Radiation in Central America

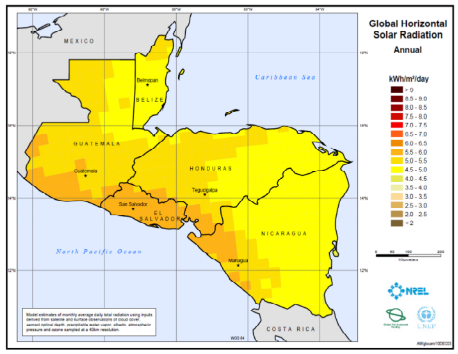

Figure C.1 - Global Horizontal Radiation Map - Central America (excl. Costa Rica & Panama)[185]

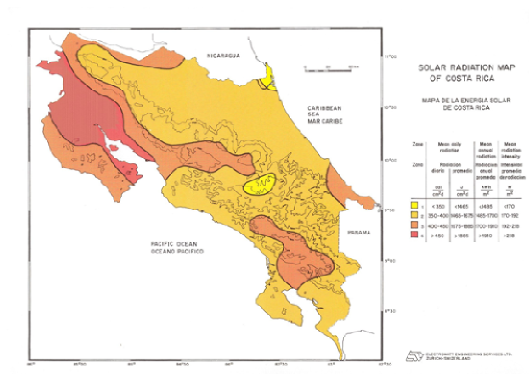

Figure C.2 - Global Horizontal Radiation Map - Costa Rica[186]

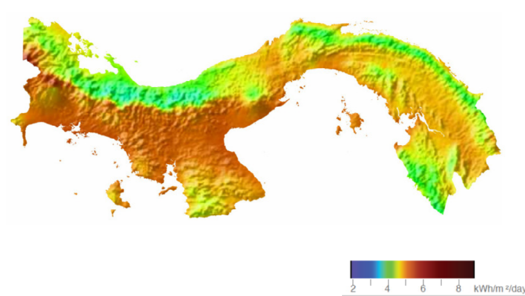

Figure C.3 - Global Horizontal Radiation Map - Panama[187]

185 NREL – Central America GHR Map (2013), www

186 GENI - Costa Rica GHR Map (2013), www

Annex E

Energetic Assessment per Country and GHR Level

Annual Global Horizontal Radiation in Central America

Source: *Breyer, C. and Schmid, J.*

COUNTRY	Min (kWh/m^2)	Max (kWh/m^2)	Average (kWh/m^2)
Belize	1,757	2,094	1,926
Costa Rica	1,537	2,222	1,880
El Salvador	2,206	2,206	2,206
Guatemala	1,778	2,355	2,067
Honduras	1,789	2,181	1,985
Nicaragua	1,621	2,387	2,004
Panama	1,523	1,921	1,722
Central American Average	**1,744**	**2,195**	**1,970**

Full Load Hours

Assumption: *PR of 80% as per section 4.4.2.1*

COUNTRY	Min (hours)	Max (hours)	Average (hours)
Belize	1,406	1,675	1,540
Costa Rica	1,230	1,778	1,504
El Salvador	1,765	1,765	1,765
Guatemala	1,422	1,884	1,653
Honduras	1,431	1,745	1,588
Nicaragua	1,297	1,910	1,603
Panama	1,218	1,537	1,378
Central American Average	**1,396**	**1,756**	**1,576**

[187] Robin, D. (2012): p.9

Calculation results based on source data above:

Annual Electricity Produced (kWh): Installed Capacity 1.5 W_p

COUNTRY	Min (kWh)	Max (kWh)	Average (kWh)
Belize	2.1	2.5	2.3
Costa Rica	1.8	2.7	2.3
El Salvador	2.6	2.6	2.6
Guatemala	2.1	2.8	2.5
Honduras	2.1	2.6	2.4
Nicaragua	1.9	2.9	2.4
Panama	1.8	2.3	2.1
Central American Average	**2.1**	**2.6**	**2.4**

Annual Electricity Produced (kWh): Installed Capacity 10 W_p

COUNTRY	Min (kWh)	Max (kWh)	Average (kWh)
Belize	14.1	16.8	15.4
Costa Rica	12.3	17.8	15.0
El Salvador	17.6	17.6	17.6
Guatemala	14.2	18.8	16.5
Honduras	14.3	17.4	15.9
Nicaragua	13.0	19.1	16.0
Panama	12.2	15.4	13.8
Central American Average	**14.0**	**17.6**	**15.8**

Annual Electricity Produced (kWh): Installed Capacity 50 W_p

COUNTRY	Min (kWh)	Max (kWh)	Average (kWh)
Belize	70.3	83.8	77.0
Costa Rica	61.5	88.9	75.2
El Salvador	88.2	88.2	88.2
Guatemala	71.1	94.2	82.7
Honduras	71.6	87.2	79.4
Nicaragua	64.8	95.5	80.2
Panama	60.9	76.8	68.9
Central American Average	**69.8**	**87.8**	**78.8**

Annex F

Calculations Underlying the Ecological Assessment

Calculation of annual CO_2 and Black Carbon emissions for a daily usage of 4 hours:

Emissions for 3.5 hours of usage: Mills, E. (2003) & Lam, N. et. al. (2012)

Light source	Light output (lm)	Kerosene consumed per year (liters)	CO_2 Emissions per year (kg)	g BC/ kg of kerosene	Black Carbon Emissions per year (kg)
Simple wick lamp	7.8	13	33	90	0.96
Hurrican lamp	45	38	98	5	0.16
Source:	*Mills, E.*	*Mills, E. (2003)*	*Mills, E. (2003)*	*Lam, N. et. al.*	*Own calculation*

Emissions for 4 hours of usage: Own calculation based on data above

Light source	Light output (lm)	Kerosene consumed per year (liters)	CO_2 Emissions per year (kg)	g BC/ kg of kerosene	Black Carbon Emissions per year (kg)
Simple wick lamp	7.8	15	38	90	1.10
Hurrican lamp	45	43	112	5	0.18

Calculation of potential annual CO_2 and Black Carbon emission savings:

Data Sources:		*Units*	*Source:*
Households served by off-grid energy solutions	981	*('000)*	*Analysis as per Annex C*
Off-grid households using kerosene:	86%	*%*	ENEE (2005)
Kerosene (weight/volume)	0.82	*kg/liter*	*Mills, E.*

ECOLOGICAL ASSESSEMENT

		Units	*Source:*
Off-grid households using kerosene	844	*('000)*	*Own calculation based on data above*
Rural households: BOP 500 - 1000	377	*('000)*	*Analysis as per Annex C*
Rural households: BOP 1500 - 2000	310	*('000)*	*Analysis as per Annex C*
Rural households: BOP 2500 - 3000	157	*('000)*	*Analysis as per Annex C*
Number of simple wick kerosene lamps per household	1	*units*	*Assumption as per section 4.6.2.1*
Number of simple hurricane kerosene lamps per household	1	*units*	*Assumption as per section 4.6.2.1*
Number of simple hurricane kerosene lamps per household	3	*units*	*Assumption as per section 4.6.2.1*
Number of simple wick kerosene lamps	377	*('000)*	*Own calculation based on data above*
Number of simple hurricane kerosene lamps	780	*('000)*	*Own calculation based on data above*
Annual kerosene usage for wick kerosene lamps	5,604	*('000 liters)*	*Own calculation based on data above*
Annual kerosene usage for hurricane lamps	33,866	*('000 liters)*	*Own calculation based on data above*
CO_2 Emissions			
Simple Wick	14,227	*tons*	*Own calculation based on data above*
Hurricane Lamp	87,340	*tons*	*Own calculation based on data above*
Total CO_2 Emissions	**101,566**	***tons***	*Own calculation based on data above*
BC Emissions			
Simple Wick	414	*tons*	*Own calculation based on data above*
Hurricane Lamp	139	*tons*	*Own calculation based on data above*
Total BC Emissions	**552**	***tons***	*Own calculation based on data above*

Annex G

The Financial Implications of Introducing PV Systems to BOP Households: Sample Calculation

The following sample calculation demonstrates the methodology applied for the financial analysis of section 4.7.4. This sample, chosen for demonstration purposes, represents the case of microcredit financing of a Solar Kit with a nominal power of 10W$_p$, one of the scenarios laid out for *Basic Level* of Expenditure households (section 4.7.4.4).

Assumptions:

		Units	*Source:*
Peak capacity of PV System	10	*W_p*	*As per Table 4.7*
Price of equipment	100	*US$*	*As per section 4.7.4.1*
Down payment	10%	*%*	*As per section 4.7.4.1*
Loan amount	90	*US$*	*(=price of equipment - downpayment)*
Interest Rate	30%	*%*	*As per section 4.7.4.1*
Tenor months	12	*months*	*As per section 4.7.4.4*
Equipment insurance	0.7%	*%*	*As per section 4.7.4.1*

Calculation:

Month	Quota (Amortization + Interest) (US$)	Interest (US$)	Amortization (US$)	Outstanding Principal Amount (US$)	Equipment Insurance (US$)	Total Quota for Client (US$)
0	8.8			90.0	0.7	9.5
1	8.8	2.3	6.5	83.5	0.7	9.5
2	8.8	2.1	6.7	76.8	0.7	9.5
3	8.8	1.9	6.9	69.9	0.7	9.5
4	8.8	1.7	7.0	62.9	0.7	9.5
5	8.8	1.6	7.2	55.7	0.7	9.5
6	8.8	1.4	7.4	48.3	0.7	9.5
7	8.8	1.2	7.6	40.8	0.7	9.5
8	8.8	1.0	7.8	33.0	0.7	9.5
9	8.8	0.8	7.9	25.1	0.7	9.5
10	8.8	0.6	8.1	16.9	0.7	9.5
11	8.8	0.4	8.4	8.6	0.7	9.5
12	8.8	0.2	8.6	(0.0)	0.7	9.5
13	-	-	-	-	-	-

Graphical Representation: