ALTERNATIVE ENERGY SYSTEMS

for Lower Income Communities in El Salvador

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To God and my Father

TABLE OF CONTENTS

Chapter Two: Literature Review

Chapter Three: Case Studies / Alternative Energy

ABSTRACT

Currently, human societies are depending on fossil fuels at a time of constant growing demand which has required societies an immense environmental and economic cost. In El Salvador, as in most developing countries, this reality is also true in low-income groups since they rely on fossil fuel combustion for their energy consumption. The imposing high energy rates in El Salvador have put at risk their economic stability leading these communities to several social concerns. Currently, architects and engineers propose new concepts of design and technology in order to have clean energy for an affordable price. These ideas are charting a course toward true energy autonomy using renewable sources of energy.

This research focuses on sustainable energy for low-income communities. The main focus will be an analysis of the different renewable energy technologies and design strategies used by designers in housing located in tropical areas. The analysis of income level, housing type, climate factors and topography of these low-income settlements will define which alternative energy technologies and design solutions can be adopted.

The answer lies with communities and public participation given the ability to create a healthy energy saving culture. Therefore, to ensure the future sustainability of low income communities, the suggested practices must be adopted as an integral part of their lives. This report contributes to sustainable development by examining how low-income community redefine their overall approach to sustainable energy systems and thus discover successful alternative strategies. The strategies suggested in this research are designed to benefit the public and private housing sector as a way to integrate excluded urban areas into sustainable development in El Salvador. In other words, a strategic action plan is necessary to convert deprived communities into sustainable ones that can stand on their own feet and adapt to the changing demands of today's social and environmental aspects.

RÉSUMÉ

Lovins, Amory B. "Souhaitez-vous mieux mourir du réchauffement climatique, guerre du pétrole, ou d'une catastrophe nucléaire?"

La communauté mondiale doit affronter une réalité émergente: le réchauffement de la planète suivit d’une crise énergétique mondiale. À l’El Salvador, comme dans la plupart des pays en développement, cette réalité affecte grandement les groupes à faible revenu tels que les communautés marginales qui comptent essentiellement sur les combustibles fossiles. Aujourd'hui, les architectes et les urbanistes proposent de nouveaux concepts en design et en technologie afin de répondre à ce problème. Ces nouvelles idées sont en train de tracer une voie vers l'autonomie énergétique en utilisant des vraies sources d'énergie renouvelables.

Cette recherche se concentre sur la croissance de communautés plus saines fondées sur l'utilisation d'énergie durable et la conception des logements. L'analyse de différente technologie d'énergie renouvelable et des stratégies de design de logement utilisés par les concepteurs dans les zones tropicales est la mise au point. L'analyse du niveau de revenu, type de logement, les facteurs climatiques et la topographie de ces agglomérations de faible revenu vont définir quelles technologies d’énergie alternative et des solutions de conception peuvent être adoptées.

La réponse se trouve avec les communautés et la participation du public pour créer une culture saine d'énergie économique. Pour assurer la durabilité des communautés à faible revenu, la pratique doit être adoptée de manière intégrale dans leur vie. La thèse contribue au développement durable en examinant comment une communauté exclut peut aider à recadrer l’approche globale et donc trouver des stratégies alternatives efficaces. Les suggestions de conception de cette recherche ont le propos de bénéficier le secteur du logement public et privé comme un moyen d'intégrer les zones urbaines exclues dans le développement durable à l’El Salvador. Autrement dit, un plan d'action stratégique est nécessaire pour convertir les communautés défavorisées en communautés durables qui peuvent se lever sur leurs propres pieds et s'adapter aux demandes changeantes des aspects sociaux et environnementaux d'aujourd'hui.

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In addition, I thank McGill University and its School of Architecture for providing me all the comfort, moral support and tools I needed and for enriching my professional career as an architect despite all the hardship I faced this year. Their libraries and staff truly create the required environment for creative excellence.

Shalom.

LIST OF FIGURES

Chapter One

Chapter Two

Chapter Three

Chapter Four

LIST OF TABLES

Chapter One

Chapter Two

Chapter Three

Chapter One

Introduction

1.1. Introduction

Since the mid-1980s, the term “*sustainable development*” has been included in many debates and discussions of international environmental forums. In 1983, the Brundtland Commission authored a report called *Our Common Future* that proposed long-term environmental strategies to achieve sustainable development by the year 2000 and beyond. As a result, many international organizations and governments made commitments towards sustainability and this soon became a challenge to the conventional forms of development. This new approach seeks to reconcile the ecological, social and economic aspects of progress, now and in the coming decades (Kasemir, 2003).

Currently society faces great challenges such as climate change, unprecedented population growth and fossil fuel depletion. All of these factors have created ecological and social interest among governments to develop and implement strong policies especially in relation to housing and efficient energy sources. As in other developing countries, El Salvador has encountered new consequences of this emergent situation. In the 1990s, rural-urban migration began to overcrowd cities, which resulted in these cities losing their capacity of population absorption (Abel and Lewis, 2002). Consequently, a lack of employment and public services favoured the emergence of communities that have since come to be excluded from society. Many are presently excluded from health services, adequate housing in seismic regions and alternative renewable energy systems. These deprived low-income groups rely mostly on fossil fuel combustion and, are therefore, the most vulnerable to oil price increases (UNDP, 2010).

Achieving a transition to sustainability in our modern times is a challenging task. However, involving citizens in climate policies and the use of energy resources is necessary because such endeavours require their consent. Without integrating public participation and considering their points of views on environmental issues, any transition to sustainability is put at risk (Kasemir, 2003).

1.2. General aspects of El Salvador

After four decades of dictatorships and military succession governments, twelve years of civil war, and two massive earthquakes, El Salvador has stood since 2010 in the top 10 Human Development progress places within Latin American countries.

Geographic aspects of the Republic of El Salvador	
Capital	San Salvador
Territorial Division	14 departments, 262 municipalities
Total Area	21,040 km²
Population	6.19 million (2010)
Density	341.5/km² (884.4/sq mi)
Currency	U.S. dollar
GDP (nominal) 2011 estimate	
Total	$22.76 billion
Income per capita	$7,600.00 U.S. dollars

Table 1-1| Geographic aspects of the Republic of El Salvador (Source: https://www.cia.gov/library/publications/the-world-factbook/geos/es.html).

1.2.1. **Geography**

The central region of El Salvador is dominated by a mountainous landscape that is made primarily of a line of volcanoes, some still active, which cross the center of the country. These volcanoes are separated by a series of 'plateaus' located between 1,000 and 1,500 meters which are made of fertile volcanic earth. To the south lies a narrow coastal plain with altitudes ranging from 30 to 150 m (Fig. 1-1).

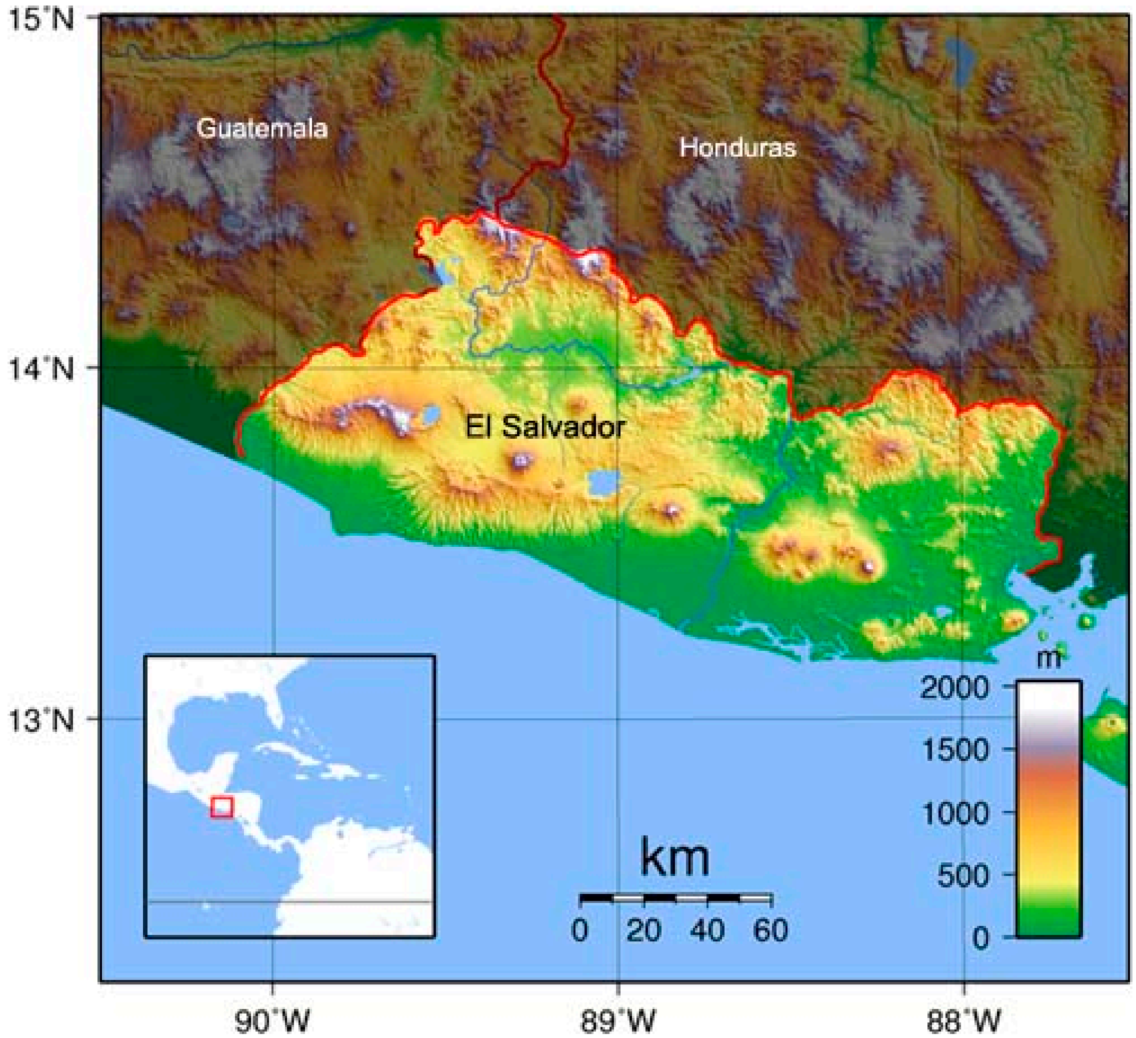


Figure 1-1| El Salvador's topography (Source: http://en.wikipedia.org/wiki/File:El_Salvador_Topography.png).

1.2.2. **Climate**

In general, the climate in El Salvador is tropical. The temperature varies between 15˚C and 23˚C. The rainy season lasts from May to October. However, there is considerable variation in the different climatic areas within the country. The lowlands on the Pacific coast and the lower parts of the *Lempa* River Valley are characterized by average temperatures of between 25˚C and 29˚C. In San Salvador, the average maximum temperature is aproximately 34˚C (usually in March) with a minimum of 17˚C (usually in January). In areas located more than 1,500 meters above sea level, average temperatures vary between 17˚C and 22˚C. The annual rainfall in the Pacific plains averages 1,700 mm per year, but rainfall is higher (1,800 to 2,500 mm per year) in mountaineous areas. In the valleys and the plateaus, this figure ranges between 1,100 and 1,500 mm per year. The rivers of El Salvador are divided into 58 basins that flow into the Pacific Ocean (SNET, 2011).

1.2.3. **Potential for renewable sources**

According to the 2010 meeting of the Economic Commission for Latin America and the Caribbean (CEPAL), it was estimated that El Salvador has a high potential for the implementation of renewable energy such as hydroelectric and geothermal power (Table 1-2).

Type of Source	Potential MW	Installed MW	% Installed of the identified
Hydroelectric	2,165	486.0	22.45
Geothermal	333	204.4	61.3
Eolic	-	-	-
Biomass	-	103.5	-

Table 1-2| Available potential of renewable energy generation in megawatts (MW) (Source: CEPAL, 2010).

Since 2010 El Salvador has been initiating studies to evaluate the possibility of implementing eolic energy fields (wind aerogenerators) and the expansion of energy production from biomasses (CEPAL, 2010).

The path to sustainable energy development has led El Salvador to look to the sun, with a suggestion of solar power for electricity and heat, which would complement the national grid. According to the government-owned electric utility *Comision Ejecutiva Hidroelectrica del Rio Lempa* (CEL), it is planning to set up the Central American nation's first utility-scale solar and wind projects to diversify its energy sources. In 2013, CEL made known in the Salvadoran media, it plans to implement a 14.2-megawatt solar farm and a 42-megawatt wind farm in 2014. El Salvador's quest for alternatives to fossil fuels has led the country to lookout at other options. With the concern of generating electricity by renewable energy sources, El Salvador is considering wind and solar energy the most suited (CEPAL, 2010).

1.3. Rationale of the study

In recent years, more and more countries and international institutions have become concerned with the vulnerability of low-income groups*. Favelas, marginales* and *tugurios* are some of the names given to these informal urban settlements, where housing conditions are at very low levels. Furthermore, according to data from the Central Bank of the Reserve (BCR), more than 40,000 jobs were lost in El Salvador due to the 2008 financial crisis (http://staging-cadata-trunk.centralamericadata-admin.com/es/article/home/El_Salvador_5000_empleos_perdidos_en_4_meses). This contributed to an increase in poverty and deprived communities. With energy consumption as their major housing expense, it is imperative that people have access to renewable energy sources at affordable prices, or even free. Therefore, such communities must rely on alternative and renewable energy efficiency systems. At a 2009 Latin American energy efficiency convention, it was stated that 63 percent of El Salvador's energy resources are obtained through fossil fuel combustion in the locations where most marginalized communities live (Fig. 1-2). Therefore, due to the low incomes and high energy rates of such communities, their capital is invested in meeting the basic needs for survival; on many occasions, they sacrifice educational opportunities by sending their children to work at an early age. If these energy systems are implemented cost-free, low-income groups could gain access to more capital. They could then use this money to encourage a healthy dietary regimen and focus on their children's education as well as their own. In short, it could enhance the possibility of overcoming extreme poverty (UNDP, 2010).

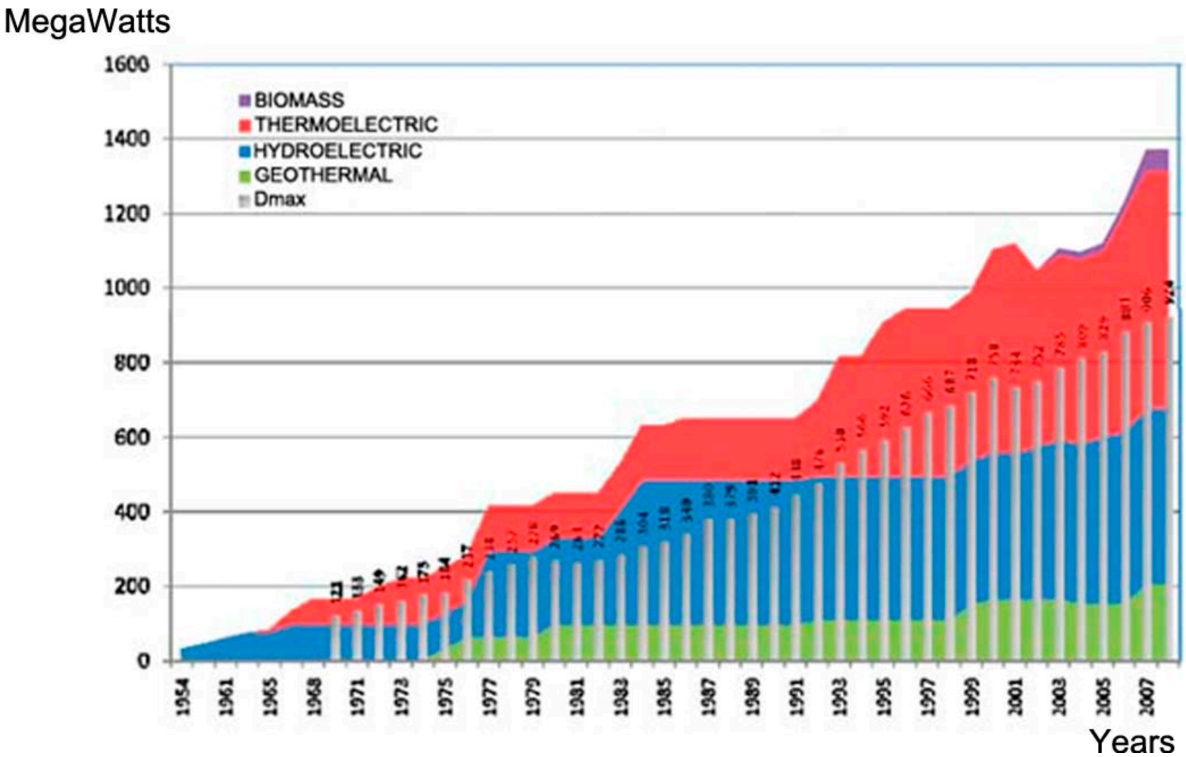


Figure 1-2| Progress (MW) and maximum demand (Dmax) of the power capacity installed (Source: Reyes, 2009).

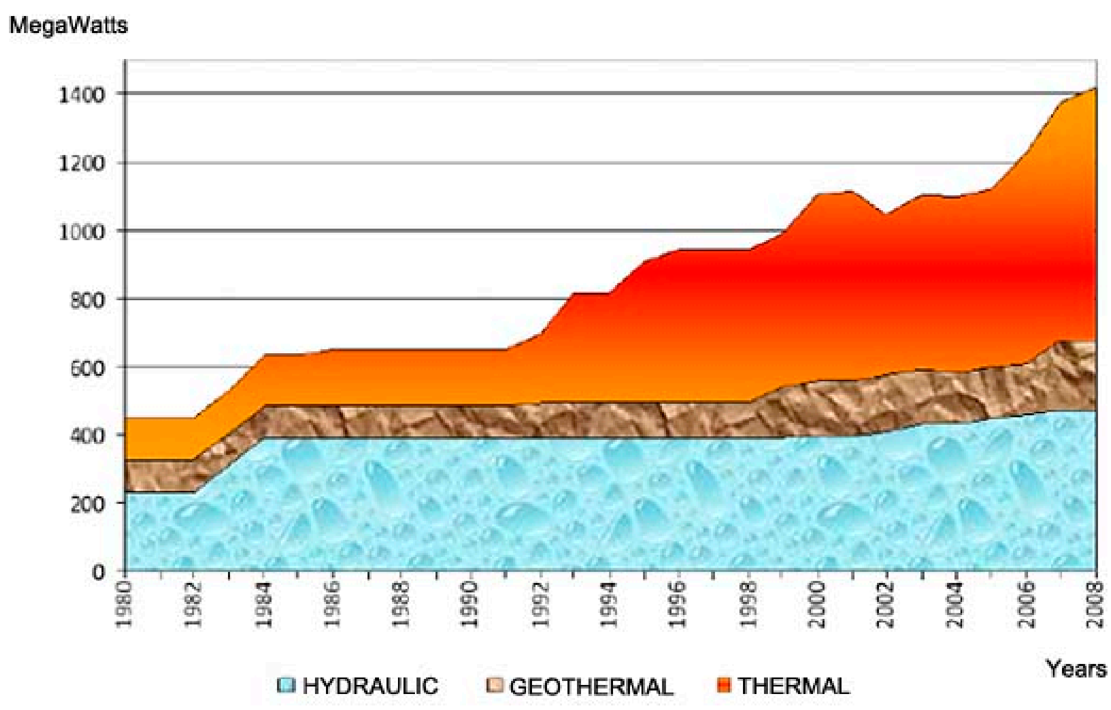


Figure 1-3| El Salvador's power potential by resource type (Source: Reyes, 2009).

In the early 1980’s, El Salvador stopped investing in hydraulic and geothermal power. Instead, investments were mostly made in thermal power plants (fossil-fuel based) that were subsequently exposed to the volatility of fuel prices. As the chart shows (Fig. 1-3), the 1990s was the beginning of the growth of, and dependency on, thermal power generation.

Annual Average Price of MRS	
Year	**$/MWh**
2001	66.2
2002	64.9
2003	70.6
2004	68.0
2005	77.0
2006	88.4
2007	93.3
2008	128.9

*****The market regulator system (MRS) is the private institution authorized by El Salvador’s government to fix energy rates.

Table 1-3| El Salvador’s energy rates in the market regulator system (MRS) (Source: Reyes, 2009).

MRS rates have increased hand in hand with the price of a barrel of oil and therefore the price of the derivatives. Year after year, the energy rate has growns, especially during 2008 (Tab. 1-3.) when the economic crisis had a major impact on the MRS, reaching $ 128.9 U.S. per Megawatt-hour in El Salvador. Afterwards, the MRS rate was transferred to the consumer through the cost of electrical consumption.

Year	Electric Generation by Resource (GWh)			Emissions
	Hydropower	Geothermal	Thermoelectric	Ton Co²
2000	1,740,417	738,851	1,415,798	1,342,733
2001	1,158,487	906,857	1,691,268	1,378,794
2002	1,133,500	936,379	1,909,402	1,550,969
2003	1,460,384	966,209	1,784,919	1,442,079
2004	1,382,448	948,085	1,987,402	1,585,786
2005	1,664,426	985,184	1,938,070	1,522,908
2006	1,956,610	1,069,580	2,358,410	1,849,777
2007	1,734,190	1,293,038	2,463,648	2,188,109

Table 1-4| Greenhouse Emissions Gases in electrical generation (Source: Reyes, 2009).

The visible increase in carbon dioxide emissions is due to this increased investment in oil-based power plants. By 2007, the energy figures showed higher emissions, which were due to reduced hydroelectric generation (Table 1-4).

This study aims to address the different concerns related to alternative renewable energy systems that can be implemented in precarious urban settlements (PUS). Developers and institutions in the field of housing and designers (architects, planners, etc.) have not yet realized the great importance of the problem. Extreme poverty and vulnerability are highly complex issues that are difficult to eradicate, or often even address, in developing countries. However, some innovative strategies can be implemented to confront this reality using a different approach.

1.4. Research questions

This study aims to pursue the contemporary and conscious efforts of architects and planners to design energy efficient communities. The key research question of this study is:

What renewable energy efficient systems can be implemented for low-income communities in El Salvador?

Some other questions for this research are:

- What alternative renewable energy systems are available in the Central America market?
- How will these renewable energy systems redefine the urban morphology of excluded communities?
- What strategies can be implemented to help the residents of these deprived communities to maintain the new energy systems?
- Are affordable renewable energy systems available that can improve their communities?

1.5. Goals and objectives

This report studies design strategies that will serve as guidelines or models for architects, planners, engineers and builders who want to design sustainable urban settlements that use affordable energy sources for low-income groups in Central America. A list of different and innovative technology systems for energy efficiency must be developed to ensure that sustainable development is a realistic goal. Low-income groups within excluded communities have been deeply studied and much has been said on this topic. However, in El Salvador, some of these communities are still growing and are greatly affected by oil prices. Therefore, this investigation aims to provide some design strategies that will allow communities to rely on renewable energy systems. In addition, Chapter Three will present a detailed study of their morphology and characteristics.

The main objective of this investigation is to propose viable low-cost alternative energy production technologies to low-income communities in El Salvador. To accomplish this objective, it is necessary to generate the following sub-objectives, which will establish the path that will take this research to its final stage:

- Identify low-income communities in El Salvador with geographic and climatic needs that are potentially suited to alternative low-cost technology implementation.
- Identify availability of renewable energy systems in the region.
- Identify adequate types of alternative energy systems that are suitable for those populations.

1.6. Methodology

This investigation has gathered information mostly on the housing characteristics of excluded communities in El Salvador and the various types of alternative renewable energy systems. Chapter Two starts with a literature review that studies the relevant information found in books and articles. The findings of the study are presented in the last three chapters. The references are chosen works by researchers in the field of energy efficiency, passive and active energy technologies, Latin American housing and public participation. In Chapter Three, an analysis is conducted using photographs, local government surveys and site maps of low-income communities. Therefore, the research is realized through an in-depth investigation of the available information. This method will allow the author to gain a better understanding of the challenge. Finally, the last chapter offers a list of design guidelines detailing how alternative renewable energy systems can be implemented.

1.7. Intended readers

The target audience for this report is primarily architects who want to thoroughly understand the context of deprived communities in Central America. They will be able to use this learned knowledge in their firms or their projects to design energy-efficient communities. Engineers who work in the field of residential development and with architects to create effective solutions that can meet sustainable goals are other target readers. Finally, policy-makers, researchers, designers, and governmental or non-governmental organizations that are interested in creating sustainable communities and eradicating extreme poverty in general are intended readers.

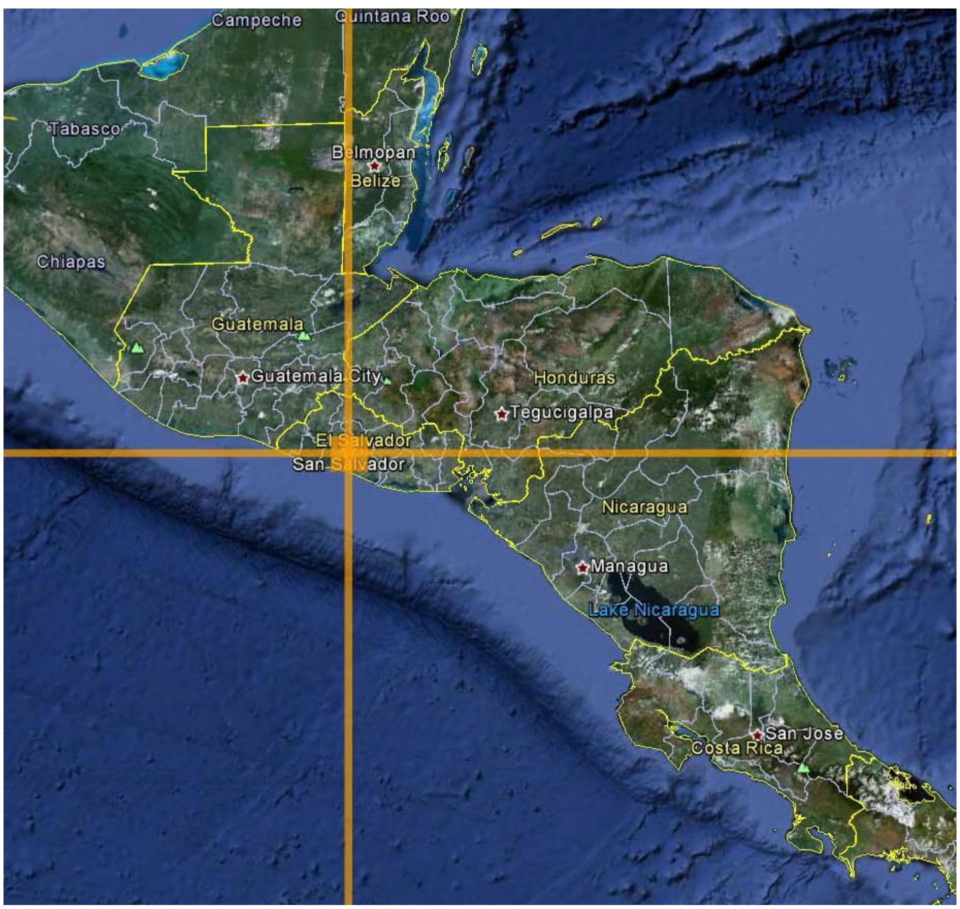


Figure 1-4| Location of San Salvador, El Salvador (Source: http//:www.earth.google.com).

1.8. Scope of the study

Local climatic conditions such as wind, sun movement and water precipitation play a very important role in defining which type of energy system is more adequate than another. This investigation aims to provide guidelines on, and a proposal for, deprived urban settlements that are each designed to reduce dependency on fossil fuel and rely instead on renewable energy systems. The report also studies how dwellings of Salvadoran low-income groups can rely on natural and renewable energy sources in order to foster a healthy and sustainable lifestyle.

1.9. Structure of the report

The following a detailed description of each chapter:

Chapter 1: Introduction

This research is divided into four main chapters. Chapter One provides information about the conceptual path, such as the rationale of the study, and the research questions, goals and objectives. Additionally, the target audience and the scope of the study are outlined in this section. This chapter explains the importance of the topic and serves as a foundation to support the investigation.

Chapter 2: Theoretical Framework

The second chapter presents a study of the different research that has been conducted in the field of low-income urban settlements in El Salvador and on the different energy efficiency technologies that can be implemented in housing at a low cost. In other words, the literature review mainly uses books and articles that concern the field of energy sustainability and mechanical engineering. In addition, in order to fully understand the characteristics and locations of these urban settlements, this chapter will also rely on certain sociology texts and Latin American studies that relate to housing conditions. As a result, all of the aforementioned references will help to generate the theoretical background needed for the second chapter of this research.

Chapter 3: Case Studies of Alternative Energy

The third chapter is the most important. It analyzes three case studies of potential alternative energy systems. These case studies will define the cost and applicability to El Salvador. In addition, they discuss architectural design approaches that designers have considered in order to achieve energy efficiency at a low cost.

Chapter 4: Conclusion and Design Strategies

The fourth and final chapter concludes the report. This chapter presents suggestions of what should be done to introduce alternative energy at a minimum cost. Secondly, a list of guidelines will be formulated that are based on the analysis carried out in Chapter Three.

Chapter Two

Literature Review

2.1. Introduction

Currently, the use of energy is an essential factor for an economic and social development of human societies. Energy powers industries and allows residential and social services to be provided. Unfortunately, if the tendency of fossil fuel consumption continues, the world could face a climatic catastrophe and the exhaustion of certain natural resources. This menace is caused by the industrialized world's fossil fuel consumption. However, a developing country such as El Salvador also forms part of this fossil fuel consumption trend, as a result of its recent rapid increases in energy costs. How to eradicate poverty without polluting the planet or worsening climate change is one of the fundamental challenges that the world is facing. In low-income neighborhoods, energy consumption is mainly used for lighting and electrical appliances like televisions and radios, whereas gas is mostly used for cooking because of its very low cost. On the other hand, people excluded from the power grid also have to use kerosene lamps and candles, which provide poor lighting and lead to inadequate working conditions at night.

As societies grow and evolve, new types of housing settlements are emerging that face different daily challenges. In this sense, low-income groups in El Salvador show certain peculiarities compared to common "marginal areas" or slums. In order to define what types of energy technology are more suitable for their needs, it is necessary to know in what conditions they exist. In what type of dwellings do El Salvadorans live? Such questions set the groundwork as to whether one particular energy system would be more adequate than another.

2.2. Housing situation of lower income communities in El Salvador

Walls in poor condition or fences made of plants serve as limits to single-family detached homes that are built in cities, or on its margins, that have no access to all of the different public services such as a proper sewage system. These are poor urban spaces with a strong lack of aesthetic that are built without any professional assistance. Their inhabitants collect any worthless or unwanted material such as cardboard, sheets or pieces of recycled wood to build or repair their homes. In other words, members of these communities live in houses that are well below any acceptable standard for shelter, comfort and safety. These urban settlements also strongly lack a consistency of public service, and the inhabitants endure multiple kinds of housing conditions and socioeconomic characteristics. Most of the precarious urban settlements (PUS) include families who have insufficient income to buy a home in the formal market (UNDP, 2009).

2.2.1. **Precarious urban settlements (PUS)**

PUS are part of a spatial agglomeration with clear deficiencies in living conditions. These shortcomings are observed in terms of structural materials or in the quality of access to basic urban services. In other words, PUS homes lack access to basic needs, such as building materials that are not suitable for home safety, have low access to urban services commodities, including a potable water and sewage system, endure the absence of a road network and pedestrian access, and are subject to inadequate housing space according to the number of people living in the dwelling (UNDP, 2009).

In El Salvador, precarious urban settlements are generally known as marginal communities with illegal subdivisions. The proposed definition by the Salvadoran Foundation for Development and Minimum Housing (FUNDASAL, 2009) states that:

> "The *comunidad* is a group of marginal houses with high population density that are located in semi-centric lands and are not always linked to the urban city and its public services".

FUNDASAL (2009) also identifies a second type of PUS in El Salvador: locations with an illegal subdivision of land. These settings are commonly seen in the peripheral areas of a large extension; they are divided into regular lots, which are acquired by contract purchase without legal protection. Even though the actual houses are relatively adequate, they have very poor accessibility to public services.

These definitions reveal certain differences and similarities between these two types of urban settlements (*comunidad* and illegal subdivision of land). At the same time, they highlight how difficult it is to precisely characterize PUS due to the dynamism of the growth processes within cities. On the other hand, Abel and Lewis (2002) express that there is a necessity to extend these definitions in order to evaluate the other types of precarious housing agglomerations that are present today or that may emerge in the future, regardless of the rationality of their construction. Given their characteristics, PUS are considered to be territorial expressions of urban poverty. The poor, in terms of income, tend to live in homes that have multiple basic needs. Table 2-1 shows that a significant proportion of poor households in the Metropolitan Area of San Salvador (AMSS) face housing shortages. More than half live in overcrowded conditions (three or more people sharing the same room). Additionally, four out of ten of these households live in dwellings with dirt floors, a metallic laminated roof, with waste material present and no indoor water service pipe.

Housing Shortages	Poor Households with Housing Shortages	Percentage of the Total Households in Monetary Poverty
Old laminated roof or other waste material	40,462	44.3
Wall material of low quality	9,857	10.8
Floor made of dirt	39, 689	43.5
Restroom is not exclusive or isn't connected to sewers	29, 805	32.6
No water service through a pipe inside the house	38, 815	42.5
Overcrowding of three or more persons per room	48, 742	53.4

Table 2-1| Poor households in San Salvador by housing shortages (Source: http://www.digestyc.gob.sv/servers/redatam/htdocs/CPV2007P/index.html).

Not all of the residents who live in these settlements are considered to be low-income. Some of those who live in PUS do not earn incomes below the established monetary poverty line, but the PUS do have the highest proportion of precarious dwellings. For this reason, they should be recognized as spatial agglomerations of homes with a high probability of maintaining a very low-income status in relation to the rest of the homes in the town in which they are integrated.

2.2.2. **The emergence of PUS**

According to Abel and Lewis (2002), many factors favoured the emergence of PUS and are explained as follows:

> “on one hand the natural population growth of cities, migration to urban areas […] and furthermore, the non-existent or inadequate planning urban and social policy responses by the State".

The growth of PUS in Latin America is associated with the industrial modernization and urban transformation that took place between 1950-1960 in countries with late industrialization. In essence, these formations are directly linked with the population’s rural-urban migration, which converted them into a surplus of population (Abel and Lewis, 2011).

However, the later industrialization of these households could have been integrated if the urban economy had managed to develop the minimum credentials required by the markets. In El Salvador, the emergence of marginalized communities appeared in the 1950s and intensified between the 1970s and 1980s. The main reasons for this are the incapacity of the agrarian structure to maintain the workforce in the field, combined with the start of armed conflict in 1979. Other possible reasons are the high concentration of the urban population in AMSS (Metropolitan Area of San Salvador) since the 1950s, the scarcity of urban land and its constant price increases, and the earthquakes of 1965 and 1986, which destroyed a large proportion of San Salvador’s traditional housing (FUNDASAL, 1995).

Table 2-2 shows that the dwellings in excluded areas are divided into two types in the most relevant cities of El Salvador: communities and rooming houses. The term “*comunidad”* is understood to be an urban settlement of many improvised dwellings in precarious conditions with no public services (i.e. water supply, sewage system, streets and sidewalks). Rooming houses, on the other hand, come from the term “*mesón”* in

Spanish, which refers to a house with several rooms that multiple families share (Fig. 2-1).

MUNICIPALITY	1971				1974				1989			
	COMMUNITIES		ROOMING HOUSE		COMMUNITIES		ROOMING HOUSE		COMUNIDADES		ROOMING HOUSE	
	Number	Houses	Number	Houses	Number	Houses	Number	Houses	Number	Houses	Number	Houses
Santa Tecla	6	492	UN*	3,102	UN	519	UN	3,765	14	1,945	183	1,872
Antiguo Cuscatlan	3	108	UN	141	UN	81	UN	11	7	352	19	140
Soyapango	5	934	UN	1,513	UN	3,439	UN	1,837	36	5,005	517	3,479
Ilopango	8	173	UN	340	UN	1,210	UN	413	13	1,437	189	1,109
Ciudad Delgado	14	426	UN	2,894	UN	3,510	UN	3,512	22	1,130	317	2,225
Cuscatancingo	1	12	UN	806	UN	2,220	UN	978	7	242	150	840
Ayutuxtepeque	1	5	UN	168	UN	550	UN	204	2	65	28	159
San Marcos	0	0	UN	738	UN	3,827	UN	895	10	1,094	137	767
Mejicanos	12	578	UN	2,665	UN	5,370	UN	3,235	28	1,946	414	2,516
San Salvador	90	6,874	UN	21,752	UN	11,347	UN	26,402	164	15,812	1,552	11,056
Total	140	9,602	UN	34,119	UN	32,073	UN	41,252	303	29,028	3,506	24,163

*Unavailable

Table 2-2| Social urban housing in AMSS by type of settlement and number, 1971-89 (Source: FUNDASAL, 1995).

Figure 2-1| A *Meson* in the City of Aguilares (Source: Castro, http://www.panoramio.com/photo/15611906).

2.2.3**. Housing policy in El Salvador**

Millions of families throughout the country, and in Latin America in general, are facing severe problems in terms of their housing conditions and accessibility to basic public services such as a power grid and potable water. Most of them live in houses that do not match their hopes and needs, and they still have difficulty paying rent. One hypothesis to explain the poor housing conditions where most deprived communities live is that Latin American governments, such as that of El Salvador, have not made housing a main priority in their annual budget because it is not considered to be a social issue like education and healthcare (Table 2-3). Thus, economic and social planners have neglected the issue of housing (Abel and Lewis, 2009):

> "The problem with housing is that it was comprehensive, everyone needed a house. There might occasionally be a special housing programme to remove slums but it was exceptional" (Abel and Lewis, 2002).

Percentage of GDP	Country (period)
Above 2%	Costa Rica (1986-94:3.2% in 1989), Mexico (1992-94), Dominican Republic (1987-92), Venezuela (1980-2).
1-2%	Argentina, Brazil (1980-92), Chile (twice went lower), Ecuador, México (1984-91), Nicaragua (1981-85), Panama (1980-84), Venezuela (1983-90).
0.5-1%	Colombia only twice went over 1%, Costa Rica (1980-85), Guatemala (1993-95), Honduras (1983-89), Mexico (1980-83), Nicaragua (1986-7), Panama (1985-94).
0.2-0.5%	El Salvador (1980-84), Honduras (1981-2, 1990-95), Paraguay, Dominican Republic (1980-86), Uruguay.
Less than 0.2%	Bolivia, **El Salvador (1985-94),** Guatemala (1980-92), Nicaragua (1990-95), Peru (1981-90)

Table 2-3| Public spending on housing by country, 1980-95 (Source: Abel and Lewis, 2002).

The housing problem cannot be easily solved, given the persistence of poverty, and perhaps cannot even be substantially reduced. Indeed, Salvadoran governments still face a major challenge to improve the lives of their citizens. The rapid pace of urbanization in recent decades, and the territorial concentration of economic opportunities in El Salvador, has reconfigured the distribution of poverty, converting it into a predominantly urban phenomenon. It is necessary to encourage and foster the social inclusion of individuals living in poverty who are located in hazardous urban areas if the country is unable to solve the problems related to their basic services and needs, such as low-cost energy and a lack of potable water. In this sense, innovative approaches must be developed, not only to understand poverty and measure its many dimensions, but also to focus on its dynamics of location and concentration in urban spaces.

2.2.4. **Sustainable energy systems**

The different types of PUS mentioned previously hold a constant concern: accessibility. Being deprived of most public services puts the health and continuous progress of a society at risk. It is here where renewable energy options become an attractive option that have the strong potential to revitalize these off-grid areas.

Electricity can allow for improvements in quality of life through their household applications. Therefore, the productive use of energy could increase incomes and provide development benefits to low-income groups. Electricity that is wisely used is closely related to the promotion of microbusiness, which can create employment and introduce income-generating activities. This could be a possible process to transform PUS. The transformation process would lead to a long-term strategy that would allow these PUS sites to be reintegrated into cities.

As incomes increase, these urban settlements will then become better able to afford greater levels of energy service, which allows for even greater use of renewable energy. The productive uses of renewable energy could even extend beyond the households themselves and benefit outer spaces for the community through activities such as drinking potable water and facilities such as street lighting.

The question remains of how to identify the most appropriate alternative energy sources for PUS. Reviewing, identifying and selecting technologies that can decentralize massive energy production into mini-grid energy systems might be the key.

2.3. Alternative energy sources

Since the beginning of human civilization, energy utilization has charted an irregular process and revealed enormous variations in energy sources (Stein and Powers, 2011). Presently, the principal sources of energy in the world are fossil fuels and El Salvador is no exception. More than 63 percent of El Salvador's energy resources are obtained from a fossil fuel combustion where most marginalized communities are included (Reyes, 2009).

This part of the chapter discusses a range of alternative energy sources that are starting to be considered for housing purposes. From small-scale energy systems to architectural passive designs, this chapter presents an overview of the potential design strategies that can be utilized to obtain energy efficiency.

2.3.1. **Energy efficiency**

Thomas (2006) divides energy into two forms: *heat* and *work*. These are calculated under the same measuring unit which permits comparison of the energy efficiency between different energy technologies. In terms of differences, some are more important than others, such as electricity, which can easily be transformed into heat and work. Fossil fuels on the other hand, can be transformed into heat but only a certain percentage can be turned into work. The surplus is lost in cooling circuits and friction.

Full energy efficiency converting heat into work is calculated with the following formula:

$$\text{Efficiency} = \frac{\text{Work extracted}}{\text{Heat availale}} = 1 - \frac{T\text{cold}}{T\text{hot}}$$

“where T_{cold} is the temperature of the cooling source and T_{hot} is the temperature of the source of heat, both in degrees Kelvin (the temperature in degrees Kelvin equals the temperature in degrees centigrade plus 273)” (Thomas, 2006).

2.3.2. **Solar energy**

According to Stein and Powers (2011), “the energy falling on the Earth from the Sun is more than enough to supply the world’s energy needs”.

The sun is a constant and consistent power source and its rays can generate electricity through the use of photovoltaic (PV) cells. On a bright sunny day, the sun expels approximately 1,000 watts of energy per square meter of the planet's surface. If we could collect all of that energy, we could easily power our homes and offices for free (Fig. 2-2 and Fig. 2-3). The success of solar power depends on technology advances and possible cost reduction, which may require regulatory changes to be enacted. It is unlikely that solar power will completely replace fossil fuel for now, but it may supply 10 to 30 percent of the world’s energy needs in the near future (Stein and Powers, 2011).

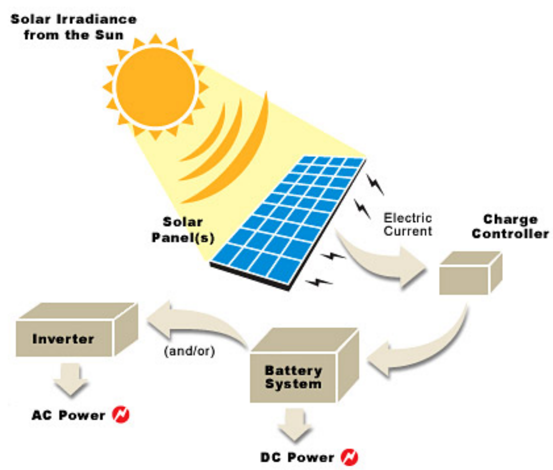


Figure 2-2| Solar panel system (Source: http://www.alternative-energy-news.info/technology/solar-power/).

Figure 2-3| Solar panels installed on a rooftop (Source: http://msquire.wordpress.com/2009/11/17/solar-energy-for-community-associations-%E2%80%93-funding/).

According to Hawkes (2002), photovoltaic systems are defined as follows:

> "Photovoltaic (PV) installations often consist of an array of PV modules and the associated wiring and control equipment. The modules are made up of cells. A typical crystalline cell might be 100 mm by 100mm; module sizes might be 0.3 m^2 or larger".

Fig. 2-4 shows the electricity generated per watt in standard conditions, which is also known as the 'spectral responsivity' for a monocrystalline silicon cell. According to Thomas (2006), the dimension of monocrystalline silicon cells that range between 400 and 700mm are more energy efficient. The objective of identifying the right dimension range for PV cells is to maximize the productivity of solar radiation for the lowest cost possible.

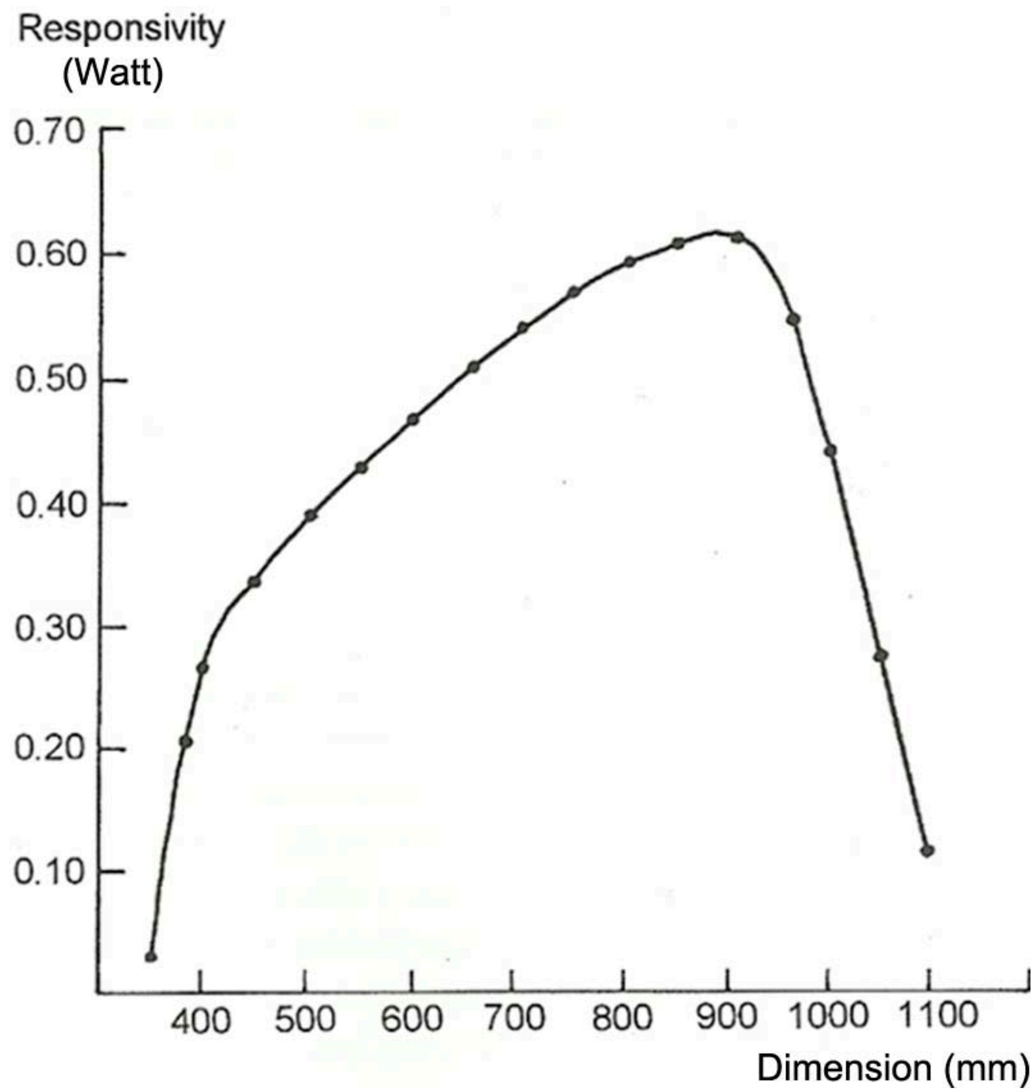


Figure 2-4| Spectral responsivity of a monocrystalline silicon cell (Source: Thomas, 2006).

Type	Approximate Cell Efficiency[a] (%)	Approximate Module efficiency[a] (%)	Approximate Installed Cost (£/Wp)[b]	Construction
Monocrystalline silicon	13 -17	12-15	10[c]	Single silicon crystal
Polycrystalline silicon	12-15	11-14	5.8-6.9[d]	Cast ingots of many crystals
Thin-film silicon	5	4.5-4.9	5.8[e]	Stack of series of p-n layers, responsive to large band of wavelengths
Triple junction thin-film silicon	6-8	5-7	5.8-10[f]	Three amorphous layers with different band gaps
Heterojunction with intrinsic thin layer (HIT)	17-19	14-16	6.9-7.5[g]	Monocrystalline layer in a thin-film amorphous sandwich

[a] Efficiencies determined by testing under standard conditions for a solar irradiance of 1,000 W/m² with a spectrum corresponding to air mass 1.5 and a cell temperature of 25˚C.
[b] Note these are indicative installed cost for systems between 20 and 50 Wp based on south-facing arrays with 30˚ tilt. Costs have not been reduced for funds, grants, etc. Conversion based on mid-market figures 11/02/05.
[c] Building integrated monocrystalline SunSlates.
[d] Buiding mounted Sharp polycrystalline modules.
[e] Building mounted Kaneka amorphous silicon module.
[f] Building integrated Unisolar shingles and Unisolar solar metal roof.
[g] Building mounted Sanyo hybridcrystalline and amorphous modules.

Table 2-4| PV cell and module data (Source: Thomas, 2006).

Photovoltaic design not only regards the maximum use of solar radiations but also meets the needs of affordability. Nowadays, the efficiency of photovoltaic design is increasing due to new and improved cells and module designs. Even more, costs have been reduced in many constituents of the photovoltaic modules and also in their installation. Table 2-4 shows an example of costs in the UK that are falling due to mass-market development.

Solar radiation

Between 1977 and 1979, the public started paying attention to passive solar designs, following the oil crisis. Previously, large solar collectors had not been well integrated aesthetically into house design and came to be gradually rejected by communities. However, passive solar design offered a much more satisfactory architectural result because it integrated collectors and thermal storage into the structure (Borasi, 2007). The sun is a valuable source of heat energy. Similar to light, the sun's natural heat may be wanted or unwanted, depending on location. Tropical countries such as El Salvador do not want excessive heating from the sun. The orientation of a building as well as the structural elements used in its design play an active role in controlling the sun's heat. In the northern hemisphere, it would be appropriate to use a sunscreen on the southern facade, closely spaced with vertical louvers orientated towards the north on the eastern and western facades, and widely spaced vertical louvres positioned at a normal angle to the northern facade (Harkness, 1978).

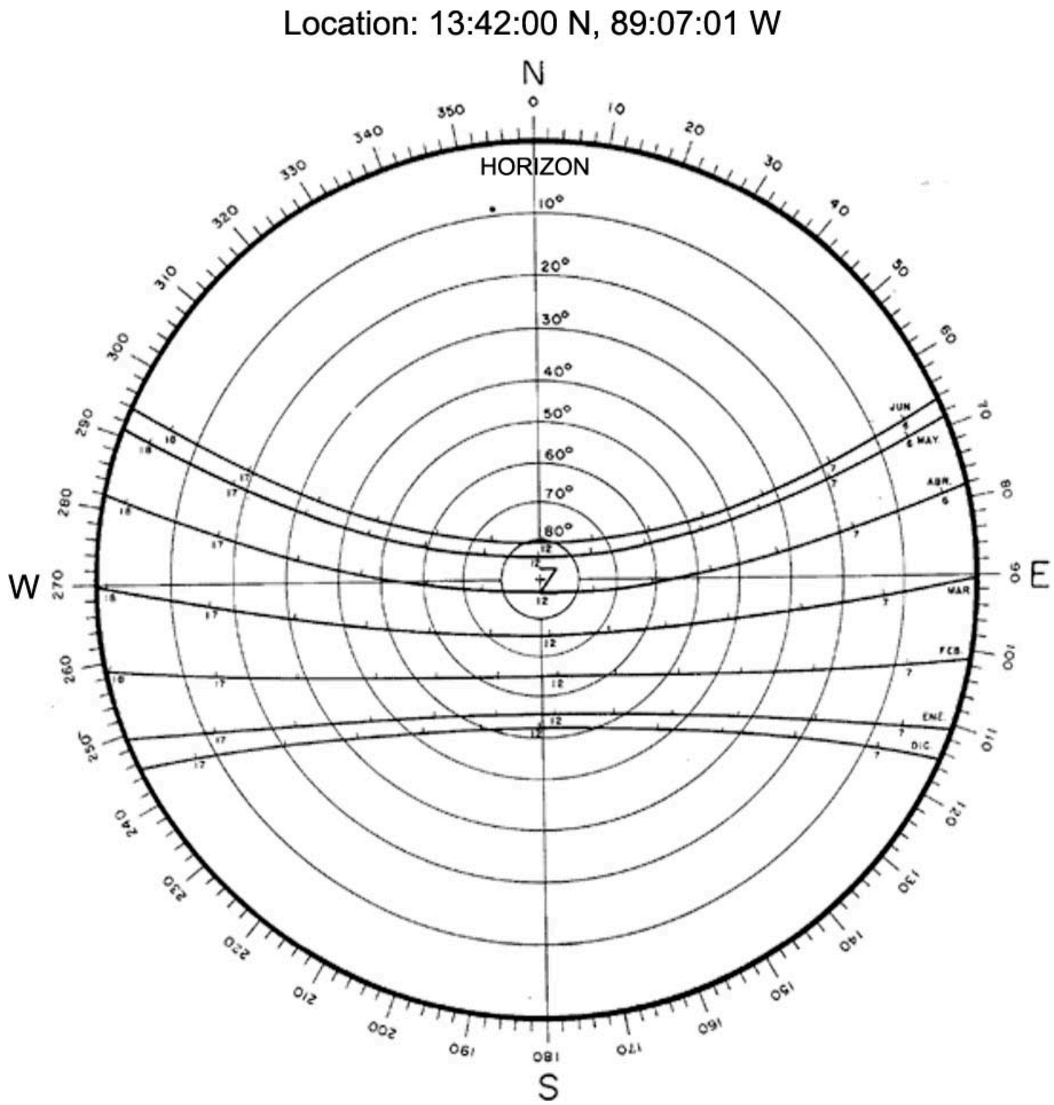


Figure 2-5| Solar diagram of San Salvador (Source: http://www.heliodon.net/downloads/Beckers_2004_Ir_El_diagrama_solar.pdf).

Furthermore, in the northern hemisphere, it is important to consider that vertical surfaces or walls facing east and west sides receive equal amounts of daily solar radiation. Therefore, it is more important to insulate the western walls. The reason is that when the sun rises and its rays hit the eastern wall, the outdoor temperature becomes lower following a cool night (Harkness, 1978).

2.3.3. **Wind energy**

According to Stein and Powers (2011), wind is formed by the "unequal heating of the atmosphere by the sun, so the wind's energy really comes from the sun".

Air motion requires energy. The sun and the rotation of the earth provide the energy to move large air masses, thus producing wind, and this wind energy can turn a windmill to pump water or grind flour, or, more recently, generate electricity. Essentially, the air over land areas warms more during the day than that over water. The heated air is less dense and rises so the cooler air moves in to replace it (Fig. 2-6). At night, the land cools more rapidly, so the direction of the wind reverses and comes off the land. It is recommended for houses that benefit from a sea breeze to use wind turbines systems (Fig. 2-7).

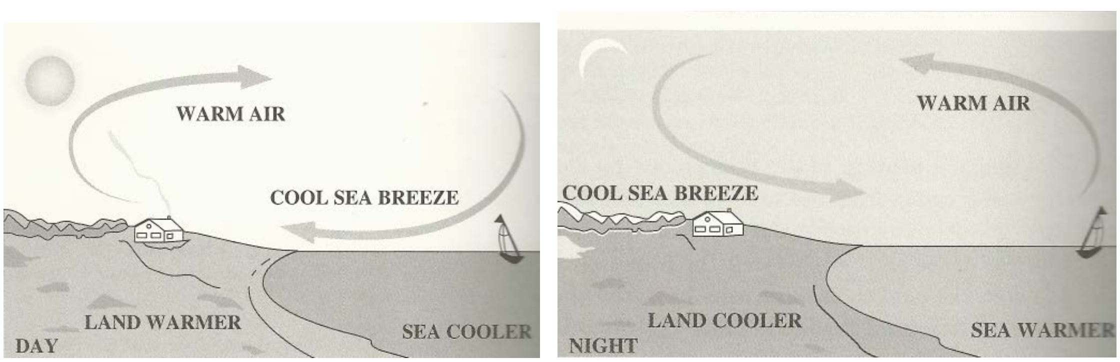


Figure 2-6| Wind generation (Source: Stein and Powers, 2011).

Figure 2-7| Wind turbines system for a home (Source: http://householdwindturbines.com/).

Randall Thomas (2006) proposes an equation to calculate the maximum power that can be derived from a wind turbine:

P= η x o.35 x (*A* x u^3)

> “where P is power output (*W*), n is the plant efficiency which is in the range of 50 to 70% to account for mechanical and electrical losses, *A* is the area swept by the wind turbine blades (m^2), and *u* is the wind speed (m/s)” (Thomas, 2006).

In order to make wind energy accessible to a large number of people who are off the grid of the major power companies in their region, *Windworks* (USA) designed a light-weight wind generator (Fig. 2-8) that can easily be transported and quickly assembled (Borasi, 2007).

Figure 2-8| Windworks lightweight wind generator (Source: http://www.solarelectricinc.com/WindWorks-Off-grid-Wind-Power-Systems-300-Watt-24Vdc-WM-300-24.htm).

2.3.4. **Geothermal energy**

The proposed definition of geothermal energy by Stein and Powers (2011states that:

"Geothermal energy results from heat stored in rock by the earth's natural heat flow which is highly concentrated in 'high-enthalpy' regions at volcanically active plate margins".

In other words, geothermal energy uses the earth's heat as a heating or cooling engine. In El Salvador, which is located in a volcanic area, it is appropriate to use this type of system, since it is a renewable energy source. For small-scale use, several geothermal-based systems were developed such as the heat pump.

Geothermal heat pumps retrieve heat from the earth using its ground loops (Fig. 2-9 and Fig. 2-10). As the geothermal pump retrieves heat from the ground loop, the heat is dispersed afterwards into the duct system of the house (Fig.2-11).

On the other hand, the process for heating is inverted when the user decides to switch the system to the cooling mode. Instead of withdrawing heat from the ground loops, heat is taken from the dwelling's indoor air. It is then either returned into the ground loop, or used for other appliances such as preheating water in the hot water tank (Stein and Powers, 2011).

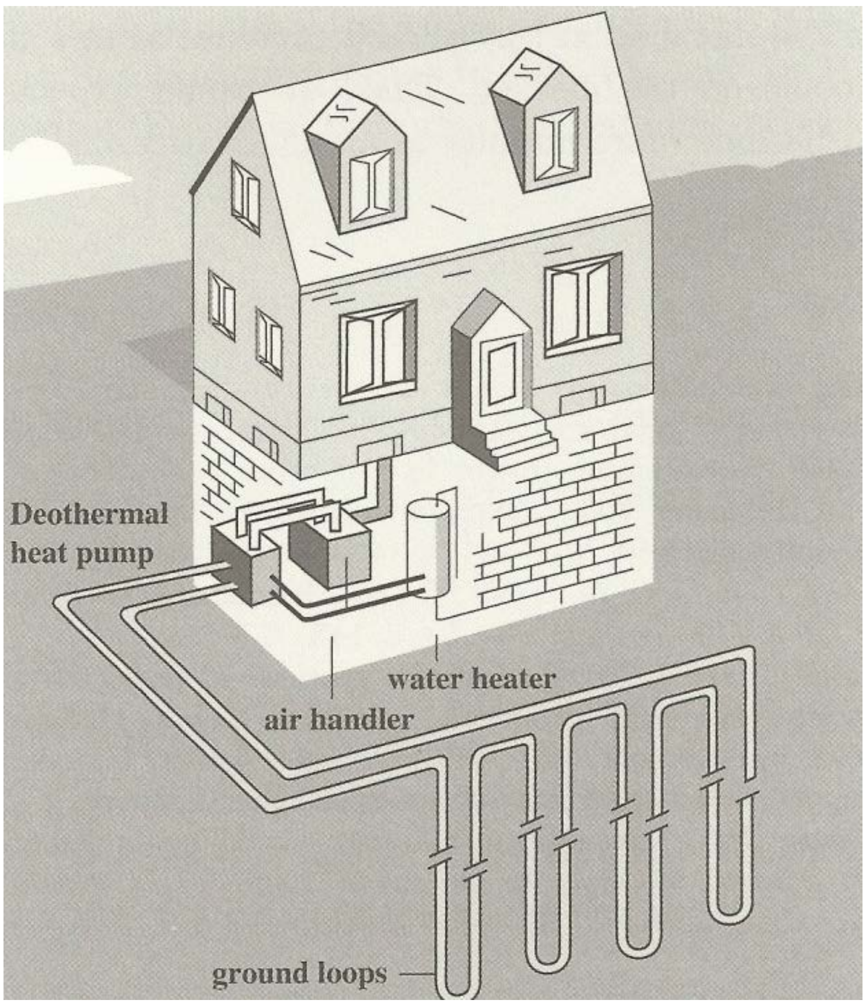
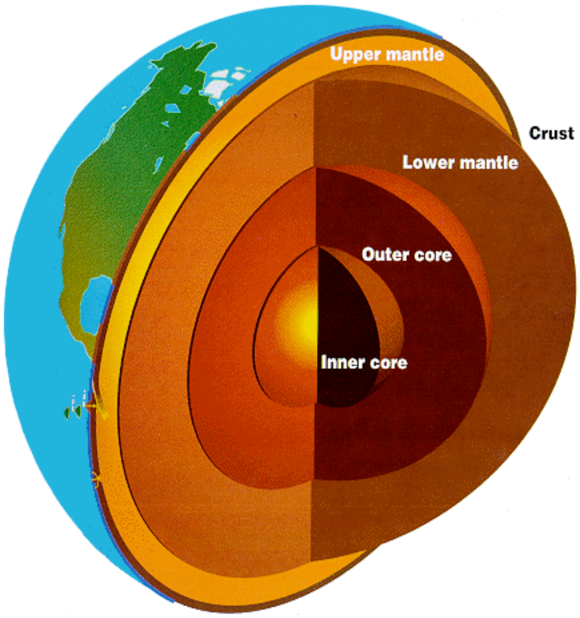


Figure 2-9| Thermal control of a small facility using ground loops (Source: Stein and Powers, 2011).



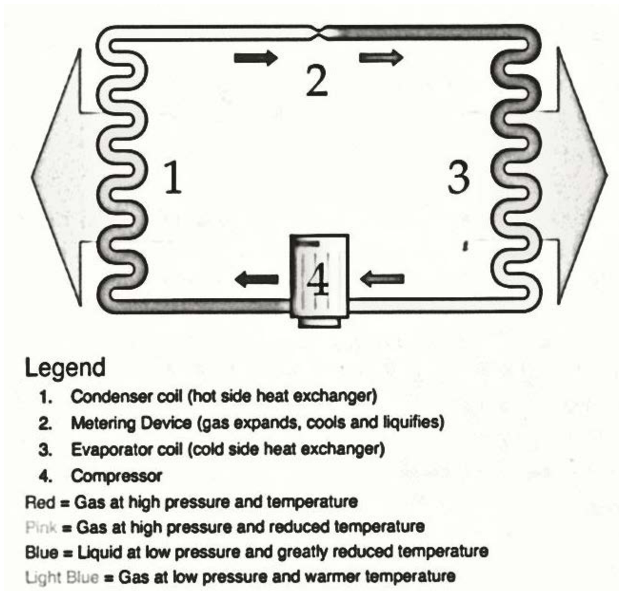


Figure 2-10| Cross-section of the Earth (Source: http://gtalumni.org/Publications /magazine/win98/earthsci.html).

Figure 2-11| Diagram of a heat pump (Source: Stein and Powers, 2011).

2.3.5. **Small scale hydro**

According to Smith (2005), the required flow velocity of rivers must be at least 0.75 meters per second for an efficient small-scale hydro energy system.

> "Many rivers have a flow rate in excess of 0.75 m per second which makes them eligible to power so-called run of river generators. The conventional method is to create a dedicated channel which accommodates a cross-flow generator which is a modern version of a water wheel or a 'Kaplan' turbine which has variable blades".

Renewable energy systems have approximately 30 times less impact on the environment than fossil-based energy with one kWh produced by small-scale hydro (Fig. 2-12 and Fig. 2-13) polluting 300 times less than the dirtiest of them all, lignite (often referred to as brown coal). Another method of comparison is to award *ecopoints* (see Table 2-5) to the various technologies, which are points of environmental penalty and are based according to many criteria such as the greenhouse emission, ozone depletion, acidification, eutrophication of water and heavy metal pollution (Smith, 2005).

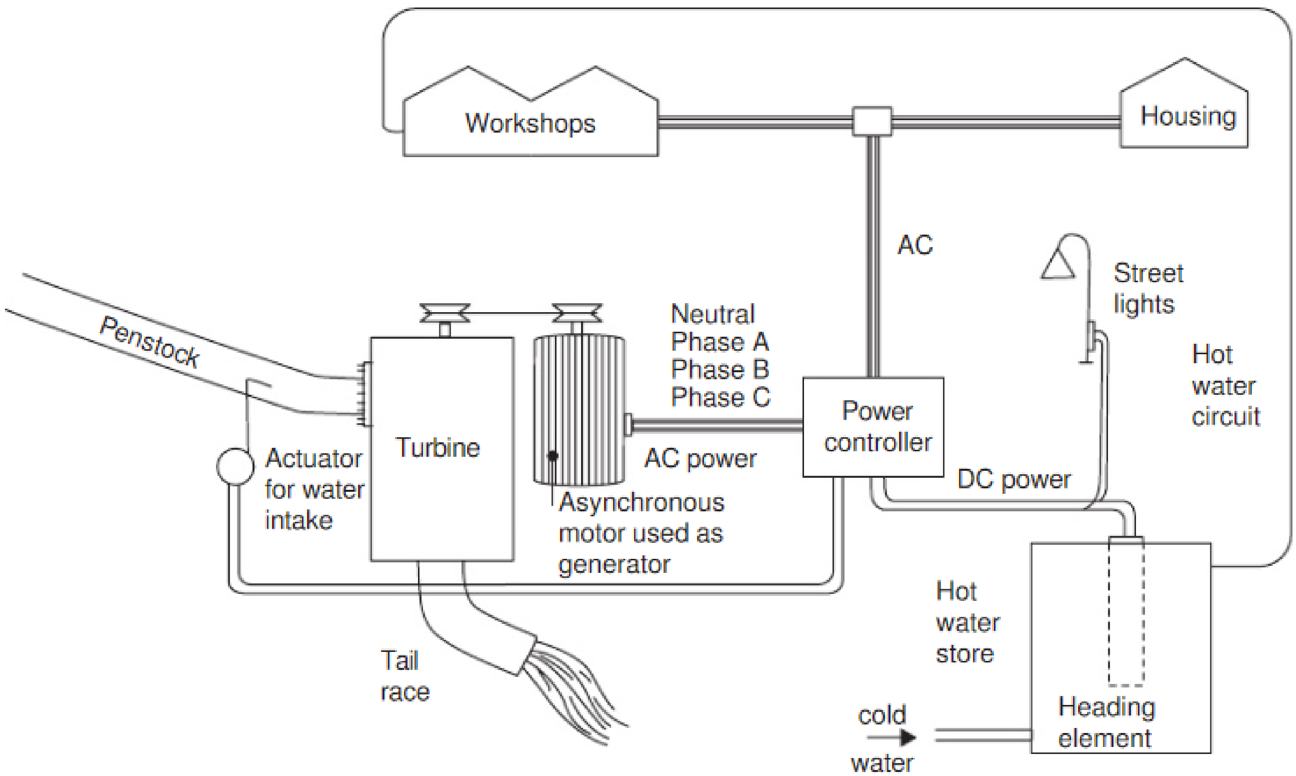


Figure 2-12| Typical village system with power controller (Source: Smith, 2005).

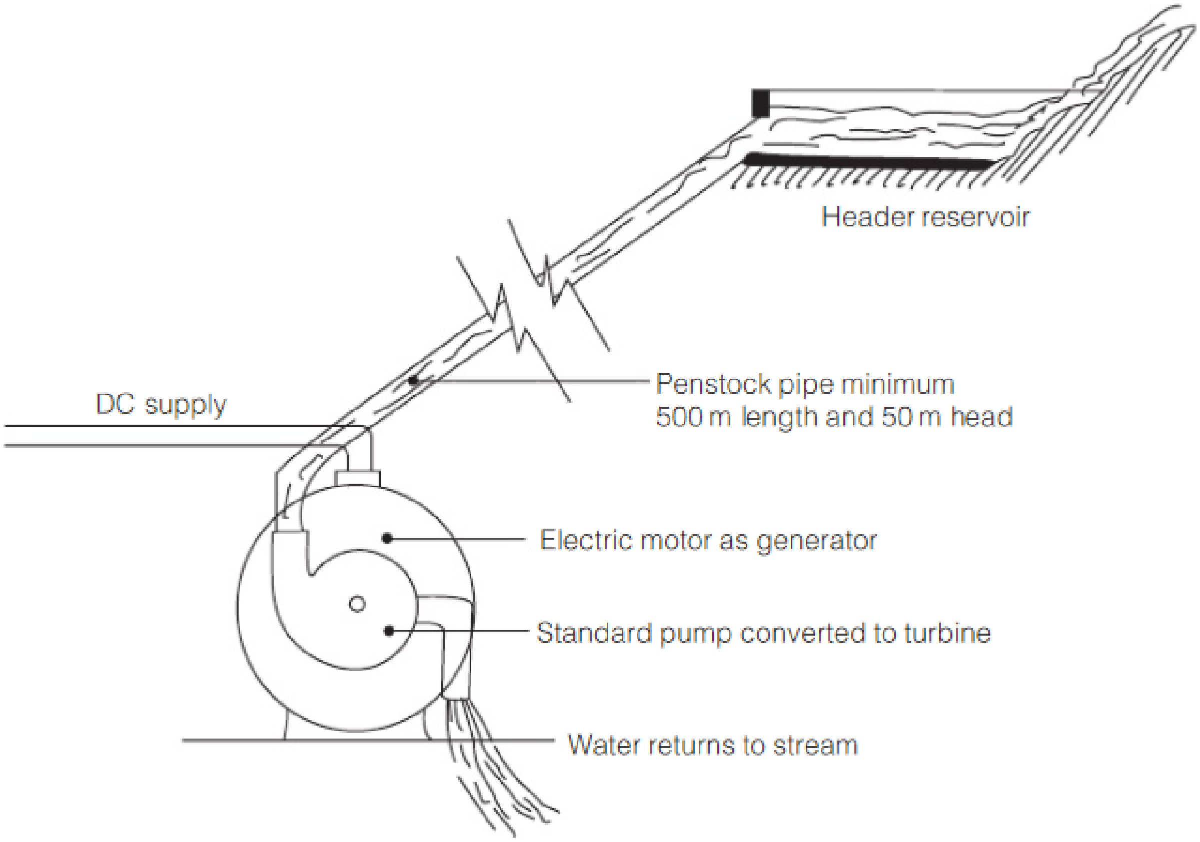


Figure 2-13| Improvised micro-hydro with a converted electric motor as a generator (Source: Smith, 2005).

Fuel	**Ecopoints**
Fuel oil	1398
Coal	1356
Nuclear	672
Natural gas	267
Small hydro	5

Table 2-5| APPA (Spain) study on environmental impact of electricity production (Source: Smith, 2005).

Until now, there were only two possible ways of creating energy from small-scale hydro. Both depend on geographical and geological characteristics, and the location of a suitable water source.

1) In mountainous countries. This area provides a high hydraulic head of water, which makes a high-speed impulse turbine.
2) In river valleys. These usually create opportunities for a low head of water, which generally less than 20 meters in height.

The essential components of a small scale hydro system are:

- An adequate rainfall catchment area.
- A weir or dam to provide a suitable head of water.
- A river with an adequate slope which will allow water to be lead into a turbine at the right velocity.
- A turbine, generator and electrical connection.
- A tailrace to return water to the river**.**

2.3.6. **Tidal energy**

According to Boyle (1996), tidal energy is defined as follows:

> “Tidal energy, as we shall see, is the result of the interaction of the gravitational pull of the moon and, to a lesser extent, the sun, on the seas”.

Tidal energy is another form of hydropower based on the principle that low water is retained to create a sufficient ‘head of water’ in order to rotate the turbine (Fig. 2-14)..

Power generation is obviously intermittent but the spread of tide times around the coast helps to even out the contribution to the grid.

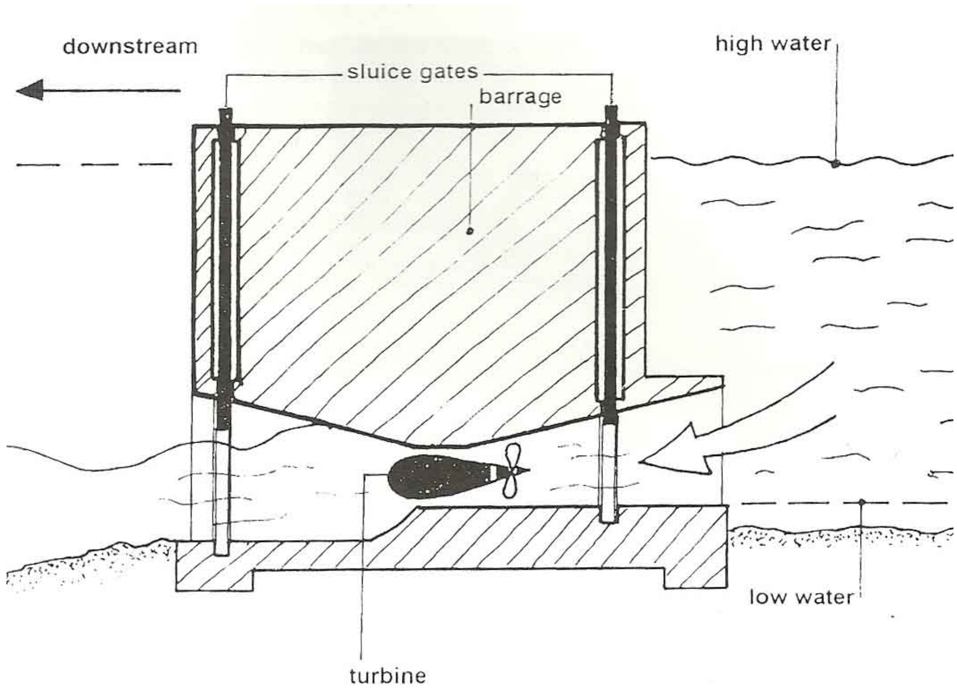
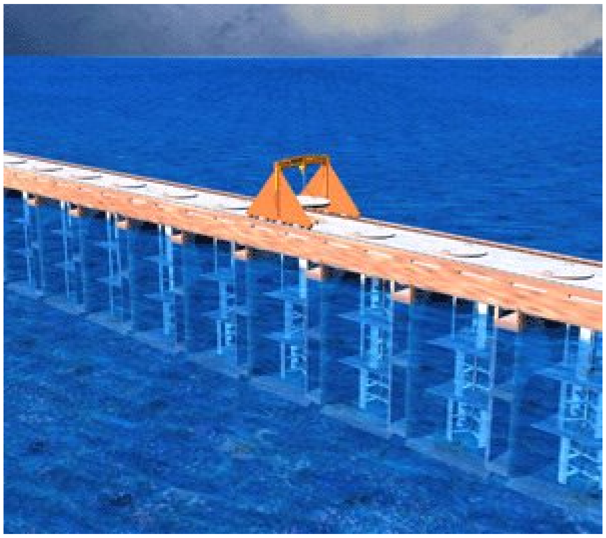


Figure 2-14| Basic tidal barrage (Source: Smith, 2005).

There are three types of tidal systems that can exploit energy, offering reliable and renewable electricity in the multi-gigawatt range.

1) The tidal barrage (Fig. 2-14)
2) The tidal fence or bridge (Fig. 2-15 and Fig. 2-16)
3) Tidal mills (Fig. 2-17)



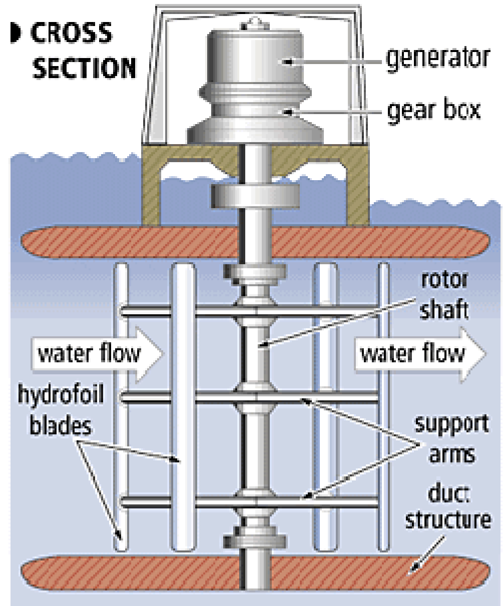


Figure 2-15| Blue energy tidal fence concept (Source: http://arewegreenyet.blogspot.ca/ 2008/03/earths-tide-as-power-source.html).

Figure 2-16| Cross section of tidal fence (Source: http://peswiki.com/index.php /Directory:Blue_Energy).

According to Smith (2005), tidal fences can be understood as an open barrage. This energy system produces electricity as long as the water flow passes through the free stream turbines submerged into the water. Unlike common hydro power turbines, these free stream turbines are installed on vertical axis, and are located between the piers of the bridge. Also, tidal fences offer the possibility to be implemented in deeper water or rapid currents. However, environmental impact is less harmful than common gated barrages.

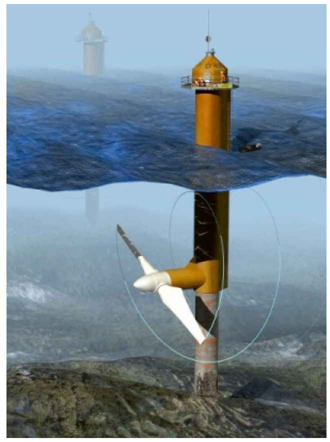


Figure 2-17| Basic tidal mills (Source: Smith, 2005).

Smith (2005) affirms that tidals mills are high energy efficient systems, and can produce much more power than conventional wind turbines.

“tidal mills are characterized by turbines placed on a horizontal axis. It is the same concept as wind turbines but that of water instead. However, the energy density is four times greater than air. For example, a rotor of 15 meters in diameter will produce equal power to a wind turbine of 60 meter diameter” (Smith, 2005).

2.3.7. **Alternative energy systems as a response to fight PUS**

It is important to state that an important number of measures do exist and have been adopted throughout the world to fight PUS. Every decade, researchers are developing new energy systems. Unfortunately, on many occasions, the total success of an energy system depends strongly on the conditions of the country where it will be implemented, the technology used, local norms and other factors. Nevertheless, choosing the right technology in many cases could enhance the quality of life in PUS.

Chapter Three

Case Studies / Alternative Energy

3.1. Introduction

As society is aware of the costs and risks of conserving today's world fossil fuel-based energy system, several leading actions such as the Kyoto Protocol, proposed to diminish substantially the consequences of the atmospheric emissions of greenhouse gases. National governments are approving public policies that are aimed to promote the use of renewable energy sources and recycling of materials, in order to reduce the negative effects of our dependency on fossil fuels. Thus, scientific and technological advances are essential to promote progressive change, prevent another oil crisis and create a more sustainable future (Baker, 2006). After an analysis of various renewable energy sources, CEL (Executive Hydroelectric Commission of the *Lempa* river) indicates that biomass, wind and solar energy are promising power generation in El Salvador (NCE, 2011). These alternatives show that, small-scale hydropower plants are also important for electricity. These systems can supply energy to isolated communities such as the PUS that are located in regions not yet connected to the national electricity grid. Even more, in November 2007, the El Salvador government sanctioned a fiscal incentives law to encourage renewable energy. A 10-year tax exemption for projects that generate 10 megawatts or lower is one of the many incentives included in this recent legal structure (SIGET, 2011). In regard to the financial situation, a new System for the Promotion of Renewable Energy (SIFER) contemplates the creation of a Revolving Fund for the Promotion of Renewable Energy (FOFER), which would provide loans, guarantees and assistance to the financing of feasibility studies for these types of projects (SIGET, 2011b).

After the in-depth review of the different available renewable energy technologies worldwide, in the previous chapter, and considering the conditions of PUS, a list of criteria is shown below to determine the most suitable energy system for El Salvador:

- Availability and abundance of a natural resource
- Cost of product
- Availability of product in the region

Considering these criteria, Table 3-1 suggests 7 potential energy systems and highlights that the first 3 of them are the most suitable and convenient for PUS.

Ranking[a]	**Alternative Energy System**	**Rational**
1	**Solar (Photovoltaic panels)**	El Salvador is known for its abundance of sun throughout its 14 States. Its availability is found within the country and the costs are affordable.
2	**Eolian (Wind turbines)**	Geographically, El Salvador is a coastal nation on the Pacific side and therefore possesses a great amount of wind throughout the whole year.
3	**Geothermal (Cooling pumps)**	A volcano line (22 in total) crosses the country from east to west. Earth heat in El Salvador is very high, ideal for geothermal systems (http://en.wikipedia.org/wiki/List_of_volcanoes_in_El Salvador).
4	**Hydroelectric (Small scale hydro)**	This system is very cost effective but PUS are not commonly located near creeks or rivers. These systems require the dwellings to be nearby a river.
5	**Tidal barrage**	These three systems are relatively new. These are cost efficient in large projects but are not suitable for small scale developments. These systems are very expensive and require specialized personnel to maintain them.
6	**Tidal fence**	
7	**Tidal mills**	

[a] Ranking's range is from 1 to 7, being 1 considered as the most suited and 7 the less suited.

Table 3-1| Alternative energy selection.

This chapter describes three technologies that can transform natural resources into useful forms of energy. It also presents the cost of these technologies in El Salvador including their applicability to the different housing settlements. The renewable energy technologies included in this analysis are: solar, wind and geothermal. These energy sources are the most relevant for the region in terms of their potential and availability. Therefore, certain renewable energy systems such as biomass and tidal energy (all forms) are not presented in this Chapter.

3.2. Solar energy

Solar energy can be used directly for heating, cooling, lighting homes, and domestic needs such as hot water. The sun's radiant energy can be used to improve public safety through lighting and refrigeration. It can also be used to produce potable water from seawater or pumped water for irrigation systems. It can even be used in solar cooking stoves, replacing the endless task of collecting firewood (which falls mainly on the shoulders of women), which in turn deforests ecosystems and contaminates the air in low-income households. This wide range of possibilities makes solar power a very attractive option, and the Salvadoran region is known for its abundance of solar radiation. In most of the territory, the average solar radiation is over 5 $kWh/m^2/day$ (Ayala, 2005). In addition, some months of the year, such as March, show higher levels of solar radiation, with values of 6.2 $kWh/m^2/day$. However, despite the abundance of solar radiation and its many benefits, the application of solar energy has been very limited in El Salvador thus far (NCE, 2011).

3.2.1. **Potential of solar energy**

In the 1980s, a meteorological team called SWERA-El Salvador studied the local solar radiation and wind patterns with the purpose of determining renewable energy potentials throughout the region. The investigation consisted on locating several database stations to capture meteorological information, and fulfill the following activities (CEPAL, 2010):

- Digitization of existing data.
- Elaboration of an inventory of climate registries.
- Elaboration of a database system to capture solar radiation data.
- Utilization of GIS technologies .
- Utilization of software to estimate wind potential.

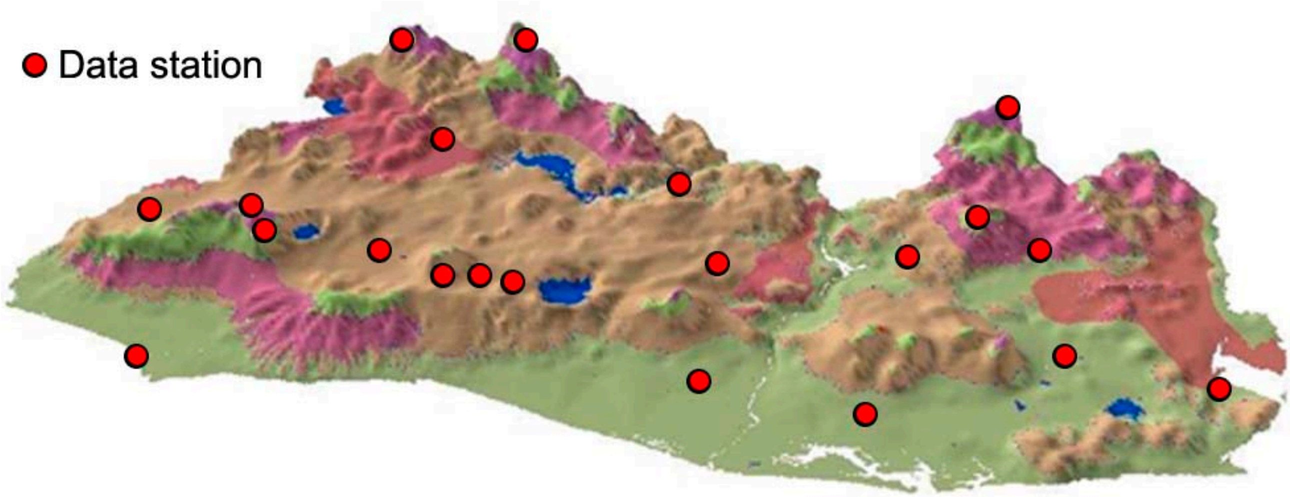


Figure 3-1| Location of solar/wind data stations (Source: Ayala, 2005).

Tables 3-2 and 3-3 show the different ranges of solar radiation throughout the year in 10 different data stations across the country. These stations were located in strategic points throughout the country in order to attain the best comprehension of the wind behavior in Salvadoran territories. According to SNET (2012), these stations have collected data since 1969, even though digital information was only implemented in 1984 during the civil war.

Code	*Station*	*Department*	*Period*	*Sub-total*
A31	Montecristo	Santa Ana	1984-1985, 2000, 2002	120
H8	Ahuachapan	Ahuachapan	1984-1990, 1992	255
G3	Nueva Concepción	Chalatenango	1984-2000, 2002	882
G13	Las Pilas	Chalatenango	1984-1987, 1989-2000, 2002	602
S5	Observatorio	San Salvador	1984-1986, 1996-1998	215
S27	Estación Matriz	San Salvador	1984	26
Z4	La Galera	Morazan	1984	7
N15	La Unión	La Unión	1984, 1986-2000, 2002	556
			Total	*2663*

Table 3-2| Number of digitalized solar radiation bands, 1984-2002 (Source: Ayala, 2005).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
a31	4.9	5.2	5.0	4.5	3.6	4.1	5.2	4.7	3.8	4.4	4.6	4.6
g13	4.6	5.0	5.6	5.3	5.1	5.0	5.5	5.5	4.8	4.7	4.3	4.3
g3	4.9	5.4	5.7	5.5	5.2	5.2	5.4	5.4	5.0	4.9	4.7	4.6
h8	5.0	5.4	5.7	5.5	5.0	4.7	5.2	5.0	4.3	4.5	4.6	4.5
n15	4.7	5.1	5.4	5.3	4.8	5.0	5.2	5.2	4.8	4.7	4.5	4.4
s27	5.1	5.6	6.2	5.9	5.2	5.3	5.9	5.6	4.9	4.8	5.0	4.8
s5	4.9	5.4	5.7	5.4	4.9	5.1	5.5	5.2	4.6	4.8	4.8	4.8
u11	4.9	5.4	5.5	5.2	4.8	4.8	5.4	5.4	5.0	4.8	4.8	4.7
v13	4.6	5.2	5.3	5.1	4.8	4.7	5.1	5.1	4.6	4.5	4.6	4.4
z4	4.4	4.9	5.1	4.8	4.1	4.0	4.5	4.3	3.5	3.7	3.7	3.9

Table 3-3| Solar radiation in kWh/m²/day, 1969-2002 (Source: Ayala, 2005).

According to these charts, the months with more kWh productivity are February, March and April consecutively with another rise in solar radiation in July and August. On the other hand, the months of September to January are less productive. The capital city, San Salvador, has the highest record of 6.2 kWh/m² in the month of March and the northern east city of *La Galera* has the lowest record with 3.5 kWh/m2 in the month of September. Overall, in most months, the average solar radiation is above 5 kWh/m² which is ideal for PV solar energy generation.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a18	6.9	7.8	8.2	7.6	5.5	4.7	6.7	6.0	4.3	4.6	5.4	5.8
a31	8.7	8.5	8.1	7.1	5.0	4.8	6.7	6.2	4.0	5.9	7.7	8.0
a35	7.7	7.5	6.9	5.9	5.1	4.7	7.6	7.2	4.6	5.2	7.0	7.5
b10	8.9	9.0	9.4	8.5	7.0	6.7	8.1	8.0	6.2	7.3	8.3	8.7
g13	8.2	8.0	8.6	7.6	7.1	7.2	8.4	8.2	6.8	7.1	7.1	7.6
g3	9.1	9.6	9.2	8.5	7.5	6.8	7.9	7.4	6.3	7.3	8.2	8.1
h8	9.1	9.4	9.4	9.0	7.4	6.6	8.2	7.4	5.9	7.1	8.6	9.4
l4	9.2	9.2	8.8	8.0	6.8	6.4	8.1	7.4	5.7	6.7	8.3	8.9
l8	9.8	9.8	9.5	8.1	6.7	6.0	8.0	7.4	5.9	6.6	8.6	9.5
m18	9.6	10.0	9.7	8.6	7.3	7.0	8.3	7.6	6.3	7.0	8.4	9.2
m23	8.0	8.6	8.4	6.2	4.5	4.7	7.2	6.6	5.3	5.5	6.9	7.0
m6	9.4	9.8	9.7	8.9	7.7	7.3	8.6	8.6	7.2	7.8	8.5	9.3
n15	9.8	10.0	9.7	8.9	7.4	7.4	8.8	8.5	7.2	8.1	9.1	9.7
s27	8.5	9.1	9.2	8.5	6.4	6.4	8.2	7.7	5.9	6.9	7.9	8.2
s5	9.1	8.7	9.2	7.5	5.6	5.5	7.6	7.3	5.6	7.3	8.3	9.0
t6	9.8	9.9	9.6	8.6	7.3	6.8	8.2	7.7	6.7	7.3	8.9	9.4
u11	9.7	9.9	9.7	8.6	7.0	6.9	8.2	8.2	7.0	7.3	8.9	9.5
u6	9.1	9.4	9.1	7.9	6.5	5.6	7.8	7.5	5.5	6.2	7.9	8.9
v13	9.8	10.0	9.5	8.5	6.9	6.5	8.1	8.0	6.6	7.2	8.9	9.7
v6	9.4	9.7	9.5	8.5	7.4	6.9	8.3	8.2	6.8	7.4	8.5	9.4
z2	9.4	9.8	9.4	8.5	7.0	7.0	8.2	8.0	6.9	7.6	8.6	9.2
z4	7.0	7.9	7.9	7.1	5.6	5.1	7.1	6.2	4.6	4.7	5.7	6.2

Table 3-4| Solar brightness map (available sunlight hours) (Source: Ayala, 2005).

Table 3-4 shows the large and constant amount of time of sunlight in the country. This is very important, since it determines the applicability of solar panels, which are viable and suitable almost in every corner of the nation. In other words, solar energy is probably the most reliable natural resource for generating renewable energy in off-grid settlements as in the case of PUS that are located in rural areas. However, in most cases, it refers to those in urban areas. The orange frame in Fig. 3-2 highlights the region of San Salvador and its capital city. As shown in Fig. 3-2 and 3-3, San Salvador, where most of the country is concentrated has the highest levels of solar radiation and some of the longest daylight hours. Therefore, implementing solar panel systems for low-income groups located in San Salvador are highly cost-effective.

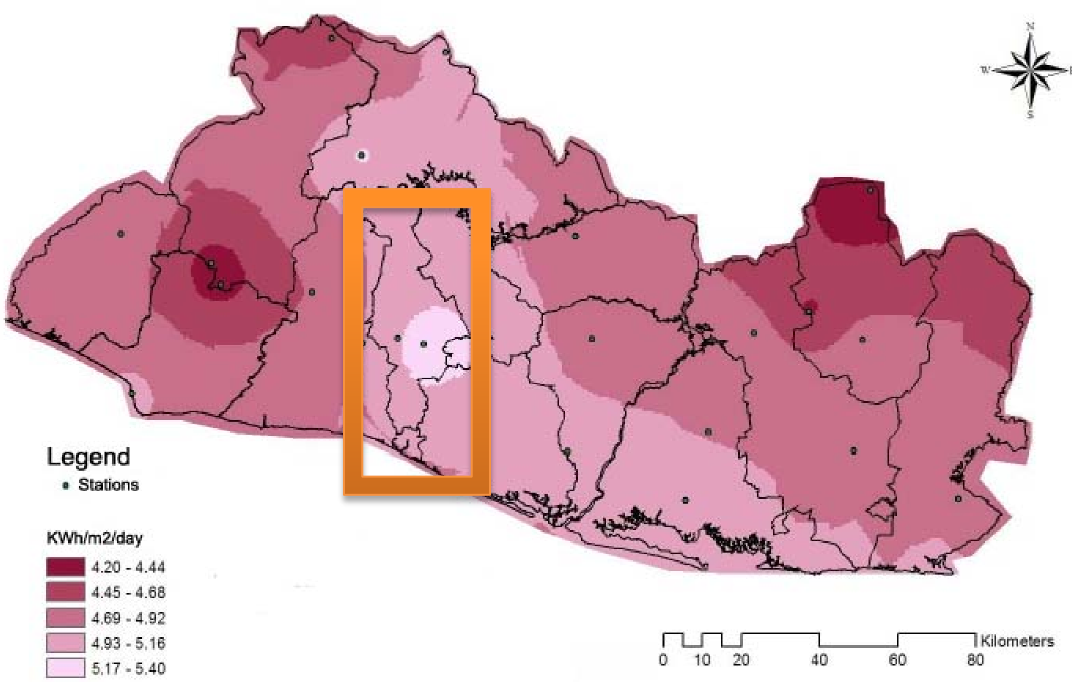


Figure 3-2| Radiation map (annual average) in kWh/m²/day for El Salvador (Source: http://www.temasactuales.com/tools/solarmaps.php).

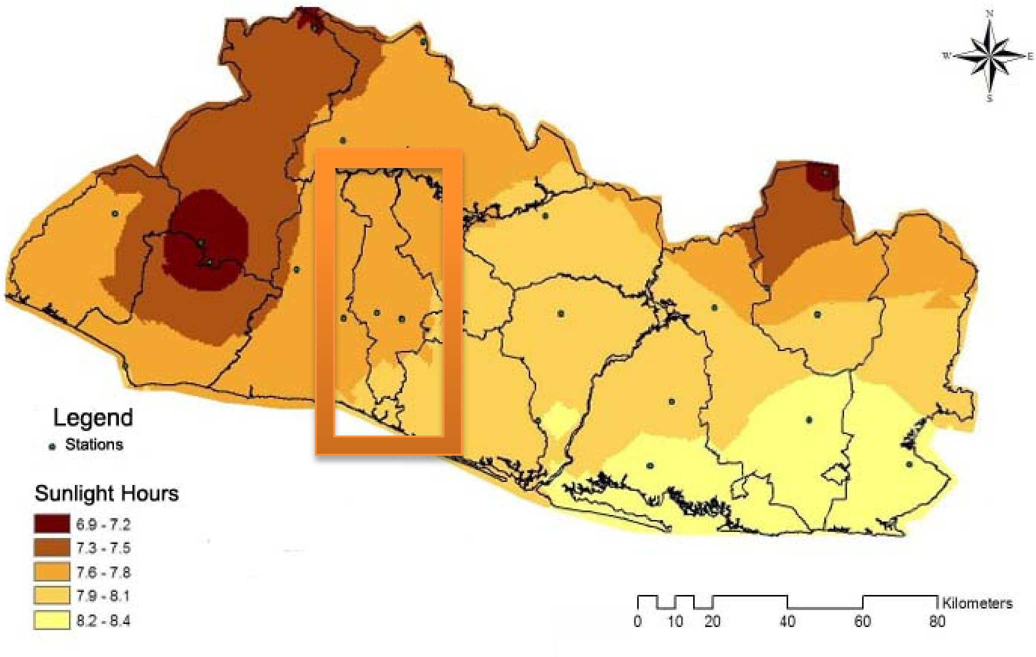


Figure 3-3| Radiation map (annual average) in kWh/m²/day for El Salvador (Source: http://www.temasactuales.com/tools/solarmaps.php).

3.2.2. **Power supply costs**

Electricity prices are regulated by the *Superintendencia General de Electricidad y Telecomunicaciones* (SIGET). In 2011, the average electrical tariff for residencies in El Salvador was $ 0.171 U.S. per kWh, which is above the $ 0.105 U.S. per kWh average for the rest of Latin America (Table 3-5) (CEPAL, 2010). The electricity prices vary significantly from one company to other. Consumers of a smaller amount of electricity have the highest rates, in contrast to larger consumers (industries such as manufacturing), who benefit from low rates. This is an indication that the rates in El Salvador for the national power grid are costlier for low-income groups than other countries.

Electric Rates Effective on April 12, 2011		CAESS	DEL SUR	AES-CLESA	EEO	DEUSEM	EDESAL	B&D	ABRUZZO
LOW TENSION									
Residential	≤ 99kWh								
		1-R	1-R	1-R	1-R	1-R	1-R	1-R	1-R
Marketing Fee:									
Fixed charge	$ / User	0.767096	0.967705	0.767096	0.767096	0.767096	0.756047	0.754195	0.799957
Consumption Charge:									
Variable charge	$ / kWh	0.175741	0.178461	0.178543	0.178543	0.178675	0.174773	0.173026	0.170432
Network Usage Charge:									
Variable Charge	$ / kWh	0.04312	0.061005	0.069317	0.069223	0.068808	0.049321	0.02238	0.035486
Residential	> 99 kWh								
Block 1: first 99 kWh									
		1-R	1-R	1-R	1-R	1-R	1-R	1-R	1-R
Marketing Fee:									
Fixed charge	$ / User	0.813531	0.967705	0.879995	0.86499	1.021556	0.756047	0.754195	0.799957
Consumption Charge:									
Variable charge	$ / kWh	0.172614	0.17006	0.171038	0.171658	0.169176	0.170773	0.173026	0.170432
Network Usage Charge:									
Variable Charge	$ / kWh	0.023168	0.044442	0.043942	0.055315	0.059613	0.049321	0.02238	0.035486
Block 2: 100 kWh ≤ x ≤ 199 kWh									
		1-R	1-R	1-R	1-R	1-R	1-R	1-R	1-R
Marketing Fee:									
Fixed charge	$ / User	0.813531	0.967705	0.879995	0.86499	1.021556	0.756047	0.754195	0.799957
Consumption Charge:									
Variable charge	$ / kWh	0.171974	0.169411	0.170356	0.170476	0.168543	0.175697	0.175377	0.169781
Network Usage Charge:									
Variable Charge	$ / kWh	0.046854	0.053178	0.059401	0.061387	0.064555	0.5071	0.024009	0.038841
Block 3: ≥200 kWh									
		1-R	1-R	1-R	1-R	1-R	1-R	1-R	1-R
Marketing Fee:									
Fixed charge	$ / User	0.813531	0.967705	0.879995	0.86499	1.021556	0.756047	0.754195	0.799957
Consumption Charge:									
Variable charge	$ / kWh	0.171503	0.169158	0.169827	0.169358	0.167834	0.176434	0.178454	0.169525
Network Usage Charge:									
Variable Charge	$ / kWh	0.06854	0.059186	0.064141	0.065951	0.066662	0.052101	0.025928	0.040434

Table 3-5| Electric rates in El Salvador (Source: SIGET, 2011).

All 8 of the power industries have high electricity rates ranging from $0.167 U.S. to $0.178 U.S. per kWh. The rates vary due to the different natural resources of the power industry. Most of the Salvadoran power industries rely on fossil fuels or hydropower.

Subsidies

The Ministry of the Economy reveals data where users beneficiaries below a consumption of 300 kWh number approximately 1.25 million (Table 3-6). Nevertheless, even with government subsidies, electric power rates still remain among the highest in Latin America (SIGET, 2011a).

RPC: Residential power consumption (0 ≤ kW ≤ x)	Average of clients	Percentage	Percentage per Group
RPC = 0	11,509	**0.87%**	**65.24%**
RPC ≤ 49 kWh	367,360	**27.91%**	
RPC ≥ 50 ≤ 99 kWh	479,947	**36.46%**	
RPC ≥ 100 ≤ 199 kWh	319,174	**24.26%**	**30.13%**
RPC ≥ 200 ≤ 300 kWh	77,280	**5.87%**	
RPC ≥ 301 kWh	60,940	**4.63%**	**4.63%**
Total	**1,316,210**	**100%**	**100%**

Table 3-6| Governmental subsidies of residential power consumption (Source: http://www.minec.gob.sv/index.php?option=com_content&view=article &id=408:subsidioenergiaelectrica&catid=51:avisos&Itemid=76).

3.2.3. **Applicability to El Salvador**

The applicability of implementing PV cells in El Salvador as a strong cost-efficient energy option can be debated. Studies show the viability of this system is due to the amount of sun and location of the country. Unfortunately, very few projects have been realized and the availability of PV cells is limited. The University of Jose Simeon Canas (UCA) is a pioneer in developing and adapting PVs for El Salvador. Using these PV cells, the Faculty of Architecture is self-powered by solar radiation (Fig. 3-4). Today a new challenge can be resolved: the affordability and efficiency of PV cells for PUS.

Figure 3-4| Solar plant in the Martin-Baro Building (UCA) (Source: Menjivar, http://www.uca.edu.sv/virtual/comunica/archivo/may192006/notas/nota13.htm)

The private sector has worked for several years on the evolution of solar energy systems. In an effort to improve the performance of these solar systems, the private sector in El Salvador has recently developed a system that is capable of multiplying the power they supply. Such is the case of PSI (the solar panel industry) with its hybrid system. It is a multiplier bridge that uses solar energy as a primary source, the power consumption as a catalyst. The system combines the power stored in the batteries with an initial booster in order to generate an exponential electrical reaction. Table 3-7 shows a list of the variety of PV cells are available in El Salvador (Data provided by Eng. Calderon of PSI):

Medium/High kWh production					
Model	Code	Voltage	Total Watts	Prices per watts-USD	Total Price (USD)
CSI CS6P-235PX 235W Solar Panel,24 Unidades	P2011CSI1	20	5,640.00	1.40	$ 7,905.59
CSI CS6X-290M 290W 24 Unidades	P2011CSI2	24	6,960.00	1.44	$ 10,053.72
Kyocera KD235GX-LPB, 235W Pallet 20	P2011K1	20	4,700.00	1.71	$ 8,046.40
Kyocera KD135SX-UPU, 135W Pallet 20	P2011K2	12	2,700.00	2.61	$ 7,049.16
LG LG235M, 235W Pallet 22	P2011LG1	20	5,170.00	1.70	$ 8,795.72
Low kWh production					
Model	Code	Voltage	Total of Watts	Price per watts-USD	Total Price USD
Kyocera KD135SX-UPU, 135W	K2011135	12	135.00	3.45	$ 465.75
LG LG235M, 235W	LG2011235	20	235.00	3.00	$ 705.00
LG LD135R9W, 135W	LG2011135R	12	134.00	3.20	$ 428.80
LG LD130R9W, 130W	LG2011130R	12	130.00	3.20	$ 416.00
LG LD125R9W, 1235W	LG2011125R	12	125.00	3.20	$ 400.00

Table 3-7| Available PV models in El Salvador (Source: http://psipty.com/category/solar-fotovoltaicaelectricidad/).

This facilitates the installation of large solar systems, and substantially reduces the need for large batteries. As a result, it offers cost-efficient electricity generation. This system of continuous power generates no noises or smoke, minimizes the extensive use of many solar panels. Furthermore, it does not use gasoline, diesel, water or oil.

In the case of the low-income groups in El Salvador, whose monthly income per household ranges between $597.11 U.S. in urban areas and $303.88 U.S. in rural areas, low kWh production PV cells are more economically reachable if users can pay with their own capital (MINEC, 2009). Although the energy generated by these PV cells will not necessarily cover all of the kWh consumption, it will significantly lower their energy bill. On the other hand, if financing can be found either through the government or foreign investors, medium/high kWh production is much more attractive in terms of self-powering houses. For example, the *Kyocera KD135SX-UPU, 135W Pallet 20* model generates 3240 kWh per year, giving a total of $554.04 U.S. in savings per year (Fig. 3-5). Within the next 13 years, this savings would pay off its initial cost.

1.	Solar Panel
2.	Controller box
3.	Solar charge control
4.	Inverter
5.	Battery
6.	Control accessories
7.	Consumer (rechargeable) 8 to 12 hours daily
8.	Satellite exit only for refrigeration/24 hours

Figure 3-5| Hybrid solar energy systems (Source: http://psipty.com/wp/wp-content/uploads/2010/12/Diagrama-de-Conexion-11.jpg).

Solar energy in rural areas

The use of solar energy in rural homes is easier to implement than elsewhere. Usually, people living in these areas do not have large energy consumption needs because they do not use all of the appliances that are used in urban areas. It is important to highlight that the largest consumption of rural households is lighting (CEPAL, 2010). Air conditioning, microwaves, electric heaters, toasters and other appliances are not used due to a lack of electricity and cultural habits. All of these factors make the system more affordable and efficient.

However, some solutions in the market can provide the requirements for almost all of the appliances in these houses. The use of 12 volt lights, radios, televisions, blenders and other low-voltage systems are very inexpensive pieces of equipment. For this reason, the solar systems installed in these homes usually produce a low kWh level, and are thus more affordable. A high percentage of the cost is due to the transportation of such energy systems to areas that have limited access to vehicles.

Figure 3-6| Solar plant in rural areas (Source: http://europa.eu/abc/12lessons/lesson_5/index_es.htm).

3.3. Wind power

Wind is generated by the irregular heating of the earth's surface produced by the sun's radiation heat. This air movement is then captured by wind turbines and transformed into energy. In the Central American region, meteorologists have recognized several prevailing winds throughout the country. The most frequent ones are the trade winds. Sea-land and mountain-valley breezes are also found near Salvadoran coastal areas (SNET, 2012). According to Fig. 3-7, the highest velocities (gusts) registered by the data stations of the country correspond to the 5.6 to 7.8 meter per second ranging from type-2 to type-5, that is, to marginal and excellent winds according to the Beaufort wind speed scale (Table 3-8) (http://www.nrel.gov/wind/pdfs/el_ salvador.pdf). In general, common wind velocities registered by the SWERA-El Salvador project range between 1.12 and 3.91 meter per second, which correspond to type 1 up to type 3 winds, that is, light to moderate winds (Ayala, 2005).

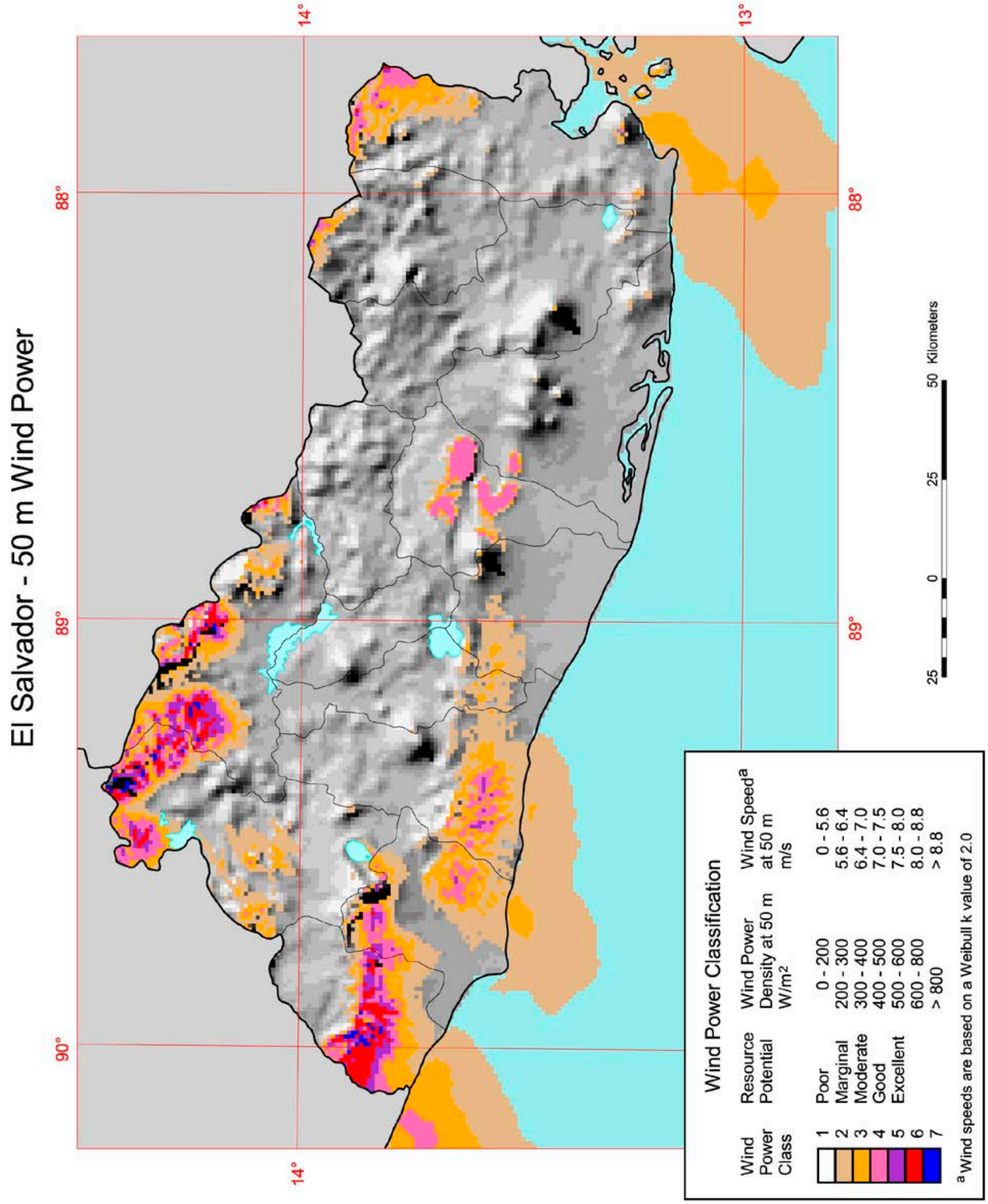


Figure 3-7| Range of wind velocities in El Salvador (Source: http://www.nrel.gov/wind/pdfs/el_salvador.pdf).

Specifications and equivalent speeds									
Beaufort wind scale	Mean Wind Speed		Limits of wind speed		Wind descriptive terms	Probable wave height in metres*	Probable maximum wave height in metres*	Seastate	Sea descriptive terms
	Knots	ms^{-1}	Knots	ms^{-1}					
0	0	0	<1	<1	Calm	-	-	**0**	Calm (glassy)
1	2	1	1–3	1-2	Light air	0.1	0.1	**1**	Calm (rippled)
2	5	3	4–6	2-3	Light breeze	0.2	0.3	**2**	Smooth (wavelets)
3	9	5	7–10	4-5	Gentle breeze	0.6	1.0	**3**	Slight
4	13	7	11–16	6-8	Moderate breeze	1.0	1.5	**3–4**	Slight–Moderate
5	19	10	17–21	9-11	Fresh breeze	2.0	2.5	**4**	Moderate
6	24	12	22–27	11-14	Strong breeze	3.0	4.0	**5**	Rough
7	30	15	28–33	14-17	Near gale	4.0	5.5	**5–6**	Rough–Very rough
8	37	19	34–40	17-21	Gale	5.5	7.5	**6–7**	Very rough–High
9	44	23	41–47	21-24	Severe gale	7.0	10.0	**7**	High
10	52	27	48–55	25-28	Storm	9.0	12.5	**8**	Very High
11	60	31	56–63	29-32	Violent storm	11.5	16.0	**8**	Very High
12	-	-	64+	33+	Hurricane	14+	-	**9**	Phenomenal

* 1. These values refer to well-developed wind waves of the open sea.

2. The lag effect between the wind getting up and the sea increasing should be borne in mind.

3. To convert knots to mph multiply by 1.15, for m/s multiply by 0.514.

Table 3-8| Beaufort wind speed scale (Source: http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html).

From the analysis of the previous charts and figures, it is evident that there is strong potential for the development of small wind energy generation systems in El Salvador. Small off-grid wind energy generation plants have many benefits, for example, avoiding the high costs of power when covering remote locations in rural areas. They also avoid temporary power failure and are an endless source of energy that causes no harm to nature. Furthermore, the sound created by the wind turbines ranges from 52 to 55 decibels (Boyle, 1996), which is less than an average refrigerator. Wind turbines are a kinetic energy-based system. In other words, they transform wind velocity into mechanical power.

3.3.1. **Cost**

Wind energy projects are competitively more difficult to place within the market and are often purchased through subsidies. Although technology has advanced significantly, the problem is the low utilization factor, which is due to the inconsistency of wind resources. It is common to find wind farm projects with plant factors of 25 and 30 percent production (Stein and Powers, 2011). Nonetheless, Eng. Calderón of *Proyectos Solares e Instalaciones* (PSI) from El Salvador states that some wind systems are ideal for a single home with moderate electrical usage. In 2012, PSI developed a 5 kW aerogenerator for $11,200 U.S. per unit (Fig. 3-8 and Table 3-9). He also affirms that, depending on the number of wind turbines required, the cost per unit can be lower. For example, a dozen 5 kW aerogenerators would cost $10,150 U.S. instead of $11,200 U.S.

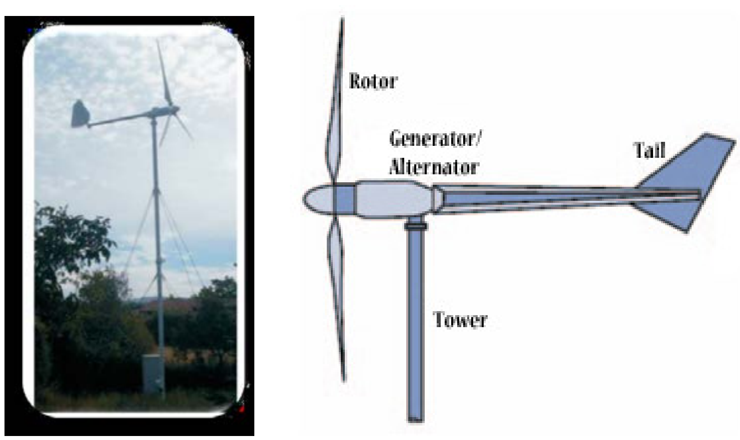


Figure 3-8| 5 kW aerogenerator model (Source: http://www.smallwindtips.com/tag/vertical-axis-wind-turbine/).

Model No. 5000x	
Rated power	5000W
Maximum power	7000W
Voltage	220V
Start wind speed	3m/s
Rated wind speed	9 m/s
Security wind speed	40m/s
Weight	186kg
Wind wheel diameter	6.0m
Brake	Electromagnetic brake
Blade number	3
Tower height	9m
Blade material	CFRP
Control system	Electromagnetic
Generator	Three-phase permanent magnet synchronous generator

Table 3-9| Characteristics of a 5 kW wind turbine (Source: http://www.smallwindtips.com/tag/vertical-axis-wind-turbine/).

In normal conditions, the aerogenerator would produce 5000 watts per year. Meaning that it would save $855 U.S. per year (5000 W x $0.171 U.S.) as long as the house doesn't exceed 416 kWh per month. If only one unit is bought, it would take not more than 14 years to pay back its initial cost. If a dozen would be implemented for a community, for example, it would take less than 12 years. However, this aerogenerator requires a high amount of money for low-income groups. Financing would definitely be a must. This being said, the market also proposes a much more affordable product for very small scale power generation called the 'Whisper 100' (Fig. 3-9).

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Figure 3-9| Whisper 100 for small-scale energy generator (Source: http://www.sonigate.com/pt/product/show_details/41849/Aerogerador-Whisper-100-900W).

With a 2.10 meter diameter of the blade, the Whisper 100 is designed for locations with medium wind speeds (5.4 meters per second at least). The small turbine alternator possesses a permanent magnet, which combined with its high efficiency blade design produces 1,500 watts. The Whisper 100 produces 4.2 kWh/day in winds with an average speed of 5.4 meters per second, and its total cost in the Salvadoran market is $2,875 U.S. (http://www.enalmex.com/paginas/eolicos/whih40.htm).

As in the case of the Whisper 100, wind turbines are commonly designed on a horizontal axis and possess two or three blades made of fiberglass. In most cases, wind turbine models are constituted of 3 parts: the rotor, the generator and the tail. Depending on the rotor diameter, the level of electrical productivity will vary. The tail keeps the turbine aligned with the wind. Since the wind velocity increases with height, the turbine is mounted on a tower. In general, the higher the tower is, the more power the wind system produces (Jha, 2011).

The function of the tower is to keep the turbine above the turbulent airflow that exists close to the ground surface. This turbulence is due to obstructions such as mountains, buildings and trees. Many engineers specialized in this field suggest to implement wind energy systems on a high structure so that a height difference exists between any obstacles. This height difference will favour to obtain a continuous wind flow, and therefore will maximize the power generated by the wind turbine. Moving a 10 kW generator from an 18 meter to a 30 meter tower implies an increment of 10 percent of the original cost of the system. However, this change also implies a 29 percent increment in the produced power (Jha, 2011).

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3.3.2. **Applicability of wind turbines in El Salvador**

Table 3-10 shows the required wind turbine power depending on the purpose required for the house. For reference, a normal house uses approximately 4000 kWh annually, whereas a large consumer may utilize approximately 6000 or 8000 kWh. In terms of wind speeds, an average of 5 meters per second is considered sufficient to install a wind turbine (Ayala, 2005).

Purpose	Required Power
Save energy	1.5 or 3.5 kW
Self-sufficiency for normal home	3.5 or 7.5 kW
Self-sufficiency for home with high electricity consumption	7.5 or 15 kW
Energy savings for small business or farm	1.5, 3.5, 7.5 or 15 kW

Table 3-10| Required power for total or partial energy savings (Source: Ayala, 2005).

In theory, a wind turbine works better with fewer obstacles in the wind flow. Buildings, trees and other obstacles have almost no influence on the performance of the turbine, which must be placed at twice the height of any barriers located very close to it (Fig. 3-10). Wind turbines are designed to last for more than 20 years. This is due to their robust design, high-quality material, and corrosion treatments, with a fully sealed design preventing moisture and other foreign particles from entering the system. Many professionals in this field, such as Eng. Calderon of PSI, suggest that small wind turbines are the perfect choice for individuals, communities or small businesses that want to generate their own energy. The characteristics of the chosen site (average wind speed, location and topography) determine the size and type of the wind turbine used in each case.

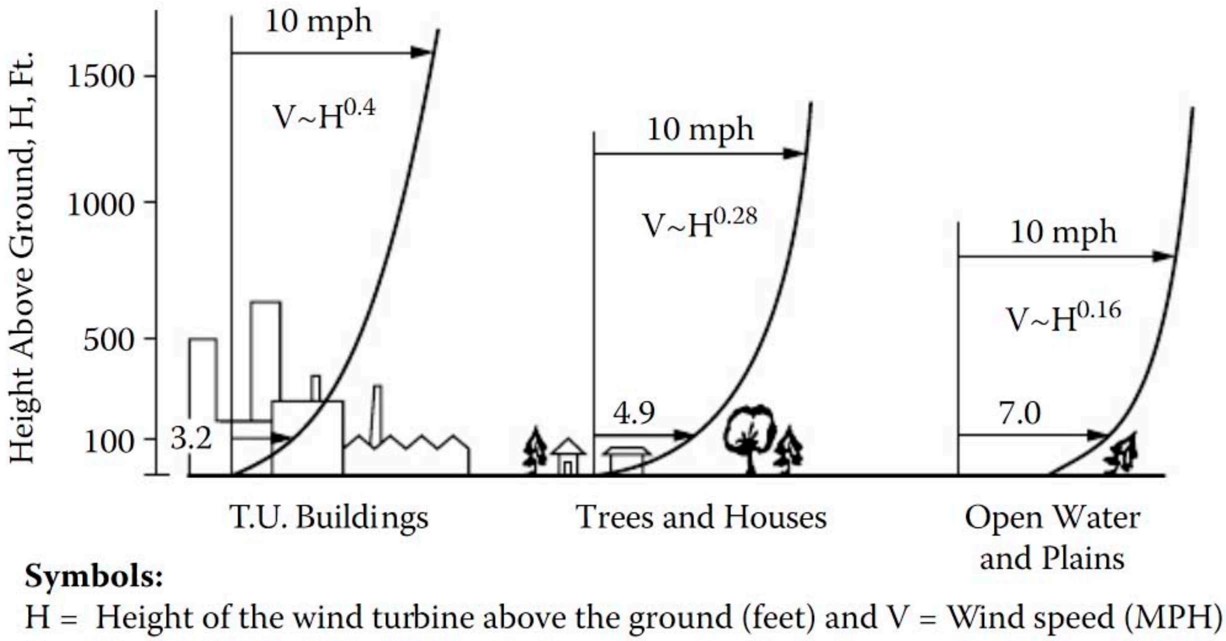

Figure 3-10| Obstacle effects on the wind velocity at a given site (Source: Jha, 2011).

Note that the turbine blades are positioned at a convenient height in order to avoid the effects of turbulence. For a given wind site, if the heights above the ground level of the towers increase, then the wind velocities also increase. This phenomenon is known in the wind industry as "windshear". It represents a good opportunity to improve the financial perspectives of any wind investment, simply by installing the wind turbines on higher towers (Smith, 2005).

Power ranges for wind turbines

Small turbines correspond to the 20 W to 100 KW range. Microturbines (10 to 500 watts) are used for a variety of applications such as charging the batteries of recreational vehicles and boats (Smith, 2005). Turbines ranging from 1 to 10 KW are commonly installed for water pumping applications. Turbines for residential use vary from 400 W to 100 KW depending on the amount of electrical power needed. In other words, a 4 KW wind turbine would fulfill the power needs of a house that requires not more than 340 KWh per month which is the average energy consumption by most low-income groups of El Salvador (CEPAL, 2010). The manufacturer provides information about the maximum allowed velocity for proper turbine operation. Wind power (in watts per square meter) is the fundamental parameter that determines the success of a wind project.

Wind maps to determine the viability of wind power

According to Jha (2011), the class of wind power is determined by the wind power density range (in watts per square meter of the area swept by the rotor, that is, the area perpendicular to the wind flow), at a given height above ground level (Table 3-11).

Class	Resource potential	Velocity of the wind (m/s) 30 m height	Wind power density W/m^2 30 m height	Wind velocity (m/s) 50 m height	Wind Power density (W/m^2) 50 m height
1	Poor	0.0 - 5.1	0 - 160	0 – 5.6	0 – 200
2	Marginal	5.1 – 5.9	160 – 240	5.6 – 6.4	200 – 300
3	Considerable	5.9 – 6.5	240 – 320	6.4 – 7.0	300 – 400
4	Good	6.5 – 7.0	320 – 400	7.0 - 7.5	400 – 500
5	-	7.0 – 7.4	400 – 480	7.5 – 8.0	500 – 600
6	-	7.4 – 8.2	480 – 640	8.0 – 8.8	600 – 800
7	-	8.2 – 11.0	640 – 1600	8.8 – 11.9	800 - 2000

Table 3-11| Classification of wind power (Source: Ayala, 2005).

El Salvador's wind power potential is considerable given the fact that average wind velocity is between class 2 and 3. The wattage varies between 160 W to 400 W, which is just enough for self-sufficiency in low-income groups' houses. Table 3-12 shows which months of the year are more productive: February, July, and October to December. February is the most kWh productive (241 watts per square meter).

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
A	5		3.3	3.8	2.5	2.8	5.6	4.4	4	4.7	5.7	6
K	1.46	1.26	1.21	1.24	1.22	1.1	2.04	1.61	1.83	1.4	1.6	1.59
U	4.55	4.76	3.09	3.55	2.35	2.67	5	3.95	3.55	4.28	5.08	5.38
P	163	241	71	103	31	56	143	93	58	145	200	238

*Parameters: A, scale factor; K, form factor; U, velocity (m/s); P, power (W/m2)

Table 3-12| Wind power potential in watts per meter square (Source: Ayala, 2005).

The SWERA team has developed a GIS eolic map of El Salvador (Fig. 3-11). This map shows the areas that have more potential for the implementation of eolic energy plants. As such, the Southwest region of the country along the coast is calculated to have the best climatic conditions for wind turbines. Consequently, it is suggested that the low-income groups located in these areas use eolic energy systems.

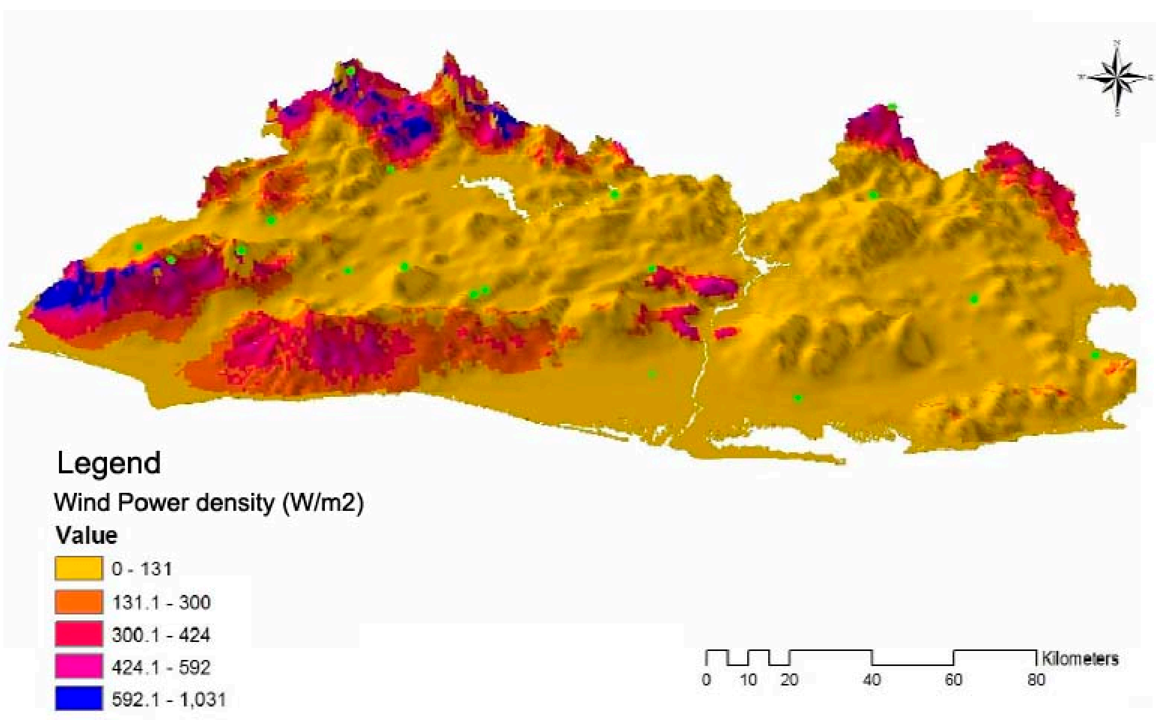

Figure 3-11| Eolic map of El Salvador in 2004 (Source: Ayala, 2005).

3.4. Geothermal Energy

El Salvador is characterized by widespread volcanic activity and its earthquake's frequency. These geographical conditions are due because of the tectonic instability throughout all Central America. More specifically, it is the direct effect caused by the friction between the Caribbean and Cocos plates. The speed in which these plates move is approximately 10 meters per century. Since both plates (Cocos and Caribbean) are constantly rubbing themselves, seismic activity have done more damage than most volcanic eruptions in El Salvador's history (SNET, 2011). Because of this, Central American countries such as El Salvador, is characterized with a mountainous topography and a high density of volcanoes (Figs.3-12 and 3-13). Most of these volcanoes are located near the Pacific coast. El Salvador has one the highest volcanic densities in the region (about 22 volcanoes of the 40 in the region) (SNET, 2011).

Figure 3-12| Active volcano called *Izalco* (Source: http://www.snet.gob.sv/Geologia/Vulcanologia/paginas/volcanesactivos.htm).

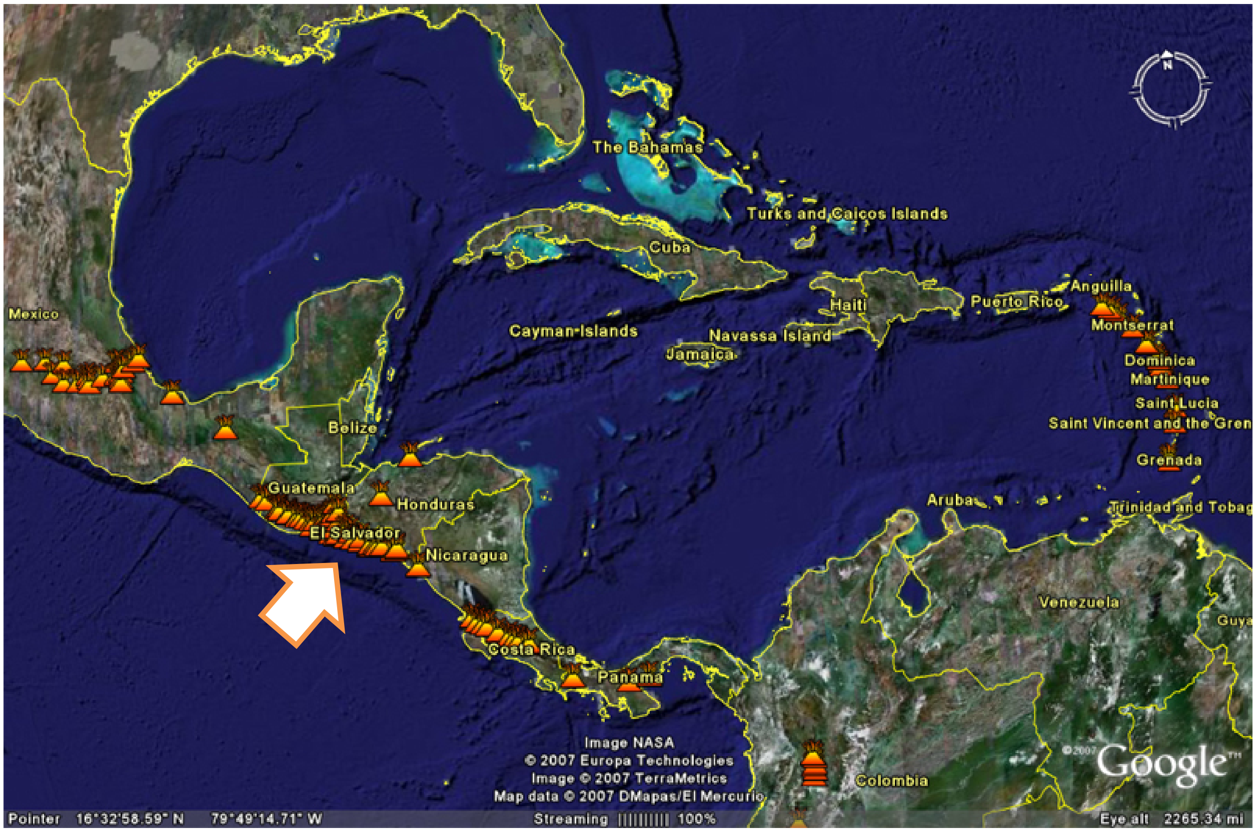

Figure 3-13| Volcanic map on Cocos tectonic plate (Source:http://geology.fullerton.edu/whenderson/f2007201/tectoniccocos/images/centralamericagoogleearth2.jpg).

Geothermal power is a renewable energy source. It is retrieved from the Earth's underground heat. Regions with a high density of volcanic activity are the most suitable for this type of energy system. Under these terms, El Salvador is rich in geothermal resources due to its high volcanic activity. Worldwide electricity generation from geothermal sources qualifies as clean renewable energy when compared to other sources of energy such as fossil fuels, which are responsible for releasing the gases that are causing global warming (SNET, 2011).

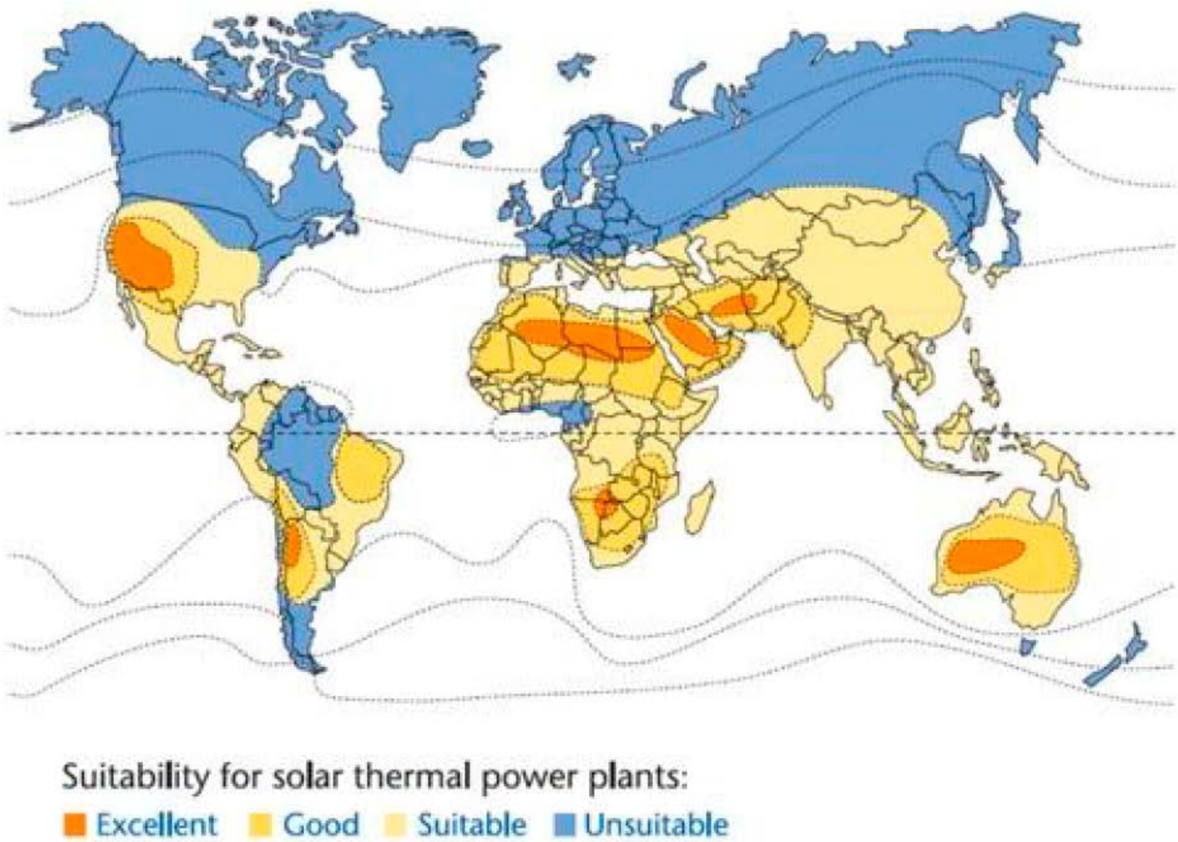

Figure 3-14| World suitability for solar thermal power plants (Source: Huacuz, 2012).

Low concentrations of gases emitted into the atmosphere during power generation from geothermal resources are less significant than those detected in the emanations of natural areas of volcanic origin in El Salvador. Fig. 3-14 locates El Salvador in a 'good' area for geothermal energy. The nation is a world leader in terms of percentage of electricity production from sustainable geothermal resources: approximately 25 percent. According to a report by the Intergovernmental Panel on Climate Change (IPCC), El Salvador is in the top 10 for high MW potential in geothermal energy (Huacuz, 2012).

COUNTRY	MW
1. United States of America	3,093.5
2. The Philippines	1,904.0
3. Indonesia	1,197.3
4. Mexico	958.0
5. Italy	842.5
6. New Zealand	628.0
7. Iceland	574.6
8. Japan	536.0
9. El Salvador	**204.4**
10. Kenya	167.0
11. Costa Rica	165.5
12. Nicaragua	87.5
13. Russia	81.9
14. Turkey	81.6
15. Papúa-New Guinea	56.0
16. Guatemala	52.0
17. Portugal	28.5
18. China	24.2
19. France	16.2
20. Ethiopia	7.3
21. Germany	6.6
22. Austria	1.4
23. Thailand	0.3
24. Australia	0.1
TOTAL	10,715.4

Table 3-13| Geothermal energy potential in megawatt (MW) (Source: Gutierrez, 2011).

3.4.1. **Cost and durability of geothermal heat pumps**

To determine the total cost of this system, many elements play a significant role. The heat pump brand, energy efficiency rating, and other factors (e.g. location, size, orientation) define the prices which usually range from $1,500 U.S. to $7,500 U.S. per purchase. Geothermal heat pumps pull heat from the ground and are therefore more reliable and more efficient. Ground heat with high level of stability is also available continuously throughout the year. In total, these systems including installation usually cost somewhere between $9,000 U.S. and $23,000 U.S., depending on the geological evaluation conducted by the manufacturer's dealer (http://www.energysavers.gov/your _home/space_heating_cooling/index.cfm/mytopic=12610).

Figure 3-15| Geothermal drilling (Source: http://www.hydroresources.com/capabilitiesGD.html).

In addition, clients must consider the cost of drilling in relation to the total cost of the project. It will mainly depend on how the drilling will be held. The total cost will vary according to the drilling axis: vertically (costlier) or horizontally (cheaper). For example, ground loops installed on a horizontal fashion would reduce the cost considerably due to the shorter distance to drill below ground. Other factors may also affect the total cost such as the consistency of the earth where the drilling will be held. (http://www.hydroresources.com/ capabilitiesGD.html).

On the other hand, in terms of maintenance, geothermal energy is much more durable and therefore more economic. Its components are easily accessed which favours the rapid and quick maintenance. Also, manufacturers of geothermal heat pumps usually offer long-term guarantees ranging from 25 to 50 years depending of the geological conditions of the earth. Another benefit of geothermal energy is its low level of noise since they don't require outside devices like solar power of wind turbines. Most of its components are located beneath the earth's surface, and thus guarded from deterioration caused by external factors.

Geothermal heat pumps offer a high efficiency and run at low operating cost. They can save homeowners from 30 to 70 percent on heating and 20 to 50 percent on cooling costs over conventional systems. Reports by builders who monitor their in-place systems indicate heating and cooling savings between $358 U.S. and $1,475 U.S. annually (http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12610).

3.4.2. **Applicability of the Geothermal Energy System**

In an excavation where the stability of the surrounding land is compromised, or because the soil does not have sufficient strength to resist the weight of a structure, piles are used with the possibility of adding ground screens, retaining walls or slabs made of concrete assembly. These are built into the ground usually between a 10 and 40 meter depth (Fig. 3-16) (Smith, 2005).

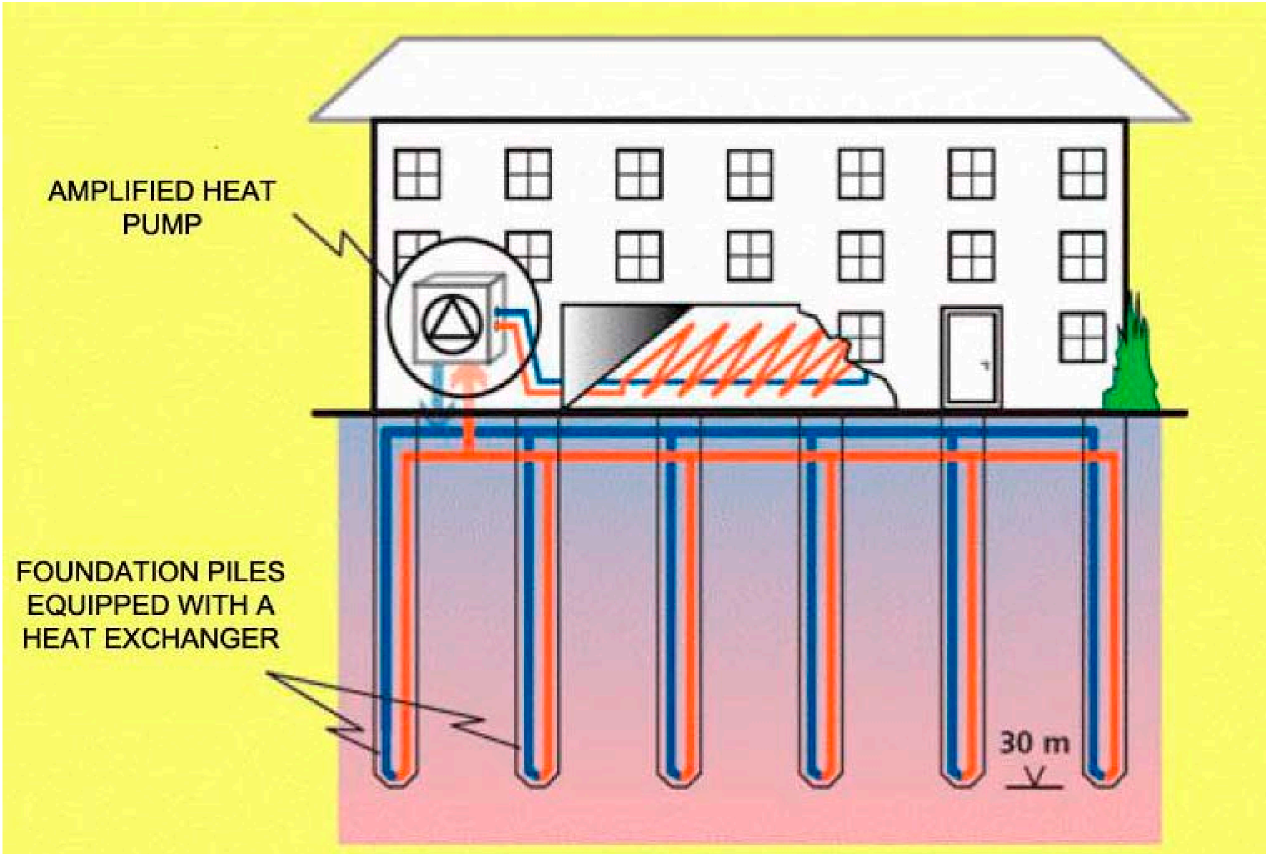

Figure 3-16| System energy piles for heating and cooling (Source: http://www.uponor.com/en/solutions/indoor-climate-solutions/ground-energy/energy-piles.aspx).

Acording to Smith (2005), prior to the implementation of a geothermal installation, it is important to consider the following:

- Geotechnical properties of subsurface strata in which the foundations will be implemented.
- Level of the phreatic surface, annual oscillations, direction and flow velocity.
- Site characteristics necessary to define the geothermal potential: volumetric heat capacity, thermal conductivity and permeability.
- Existence of nearby wellsprings or underground constructions that would deviate groundwater.

- Subsurface temperature range (maximum, minimum and annual mean).
- Monthly and weekly distribution of energy consumption for heating and cooling.

The design of a heating and cooling system using geothermal foundations should be designed at an early stage, since the foundation piles are placed on site prior to the installation of the heating and cooling system. It is also very important from the beginning of the construction to have a constant dialogue with architects, geologists, engineers, construction supervisors and other professionals involved in the project. As a result, the company implementing the heat pump can proceed with its calculation and simulation in three dimensions of the different parameters. This will influence and determine the performance of the geothermal system (Figs. 3-17 and 3-18) (Smith, 2005).

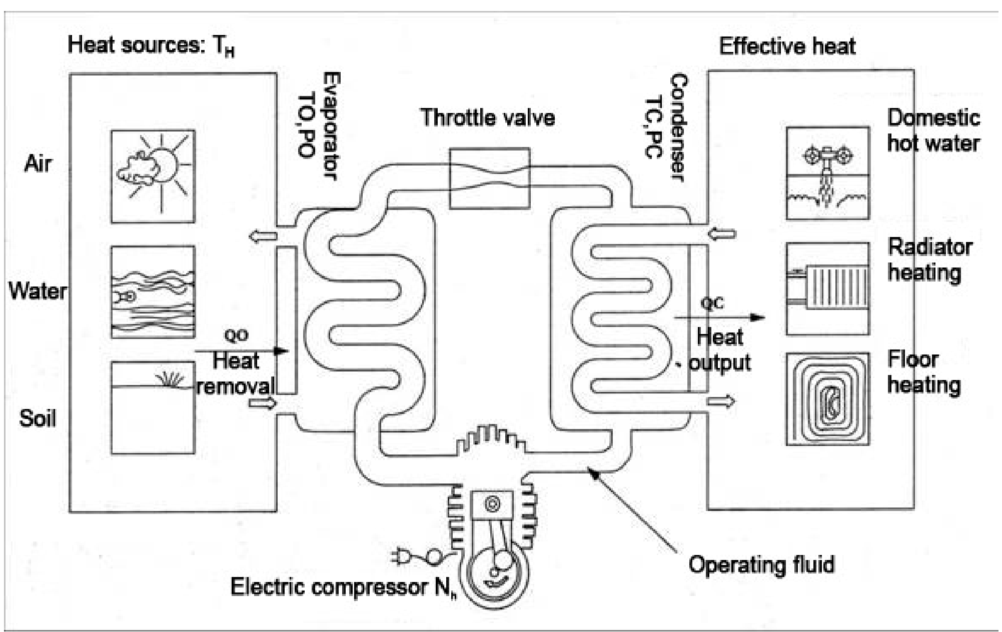

Figure 3-17| Technology schematic of heat pumps (Source: https://www.educate-sustainability.eu/portal/index. php?q=img_assist/popup/2401).

Figure 3-18| Schematic of a heating system (Source: https://www.educate-sustainability.eu/portal/content/heat-pumps).

Types of geothermal systems for houses

Different types of geothermal systems are available depending on the arrangement of the ducts that are intended to absorb the heat. A classification of geothermal systems is shown as follows:

Closed pump loop

This type of geothermal system is recommended for land with a small surface area (Fig. 3-19). The ground loops are built into the ground from 50 to 150 meters depth. On the other hand, this system requires a drilling for its ground loops, which increases the total cost.

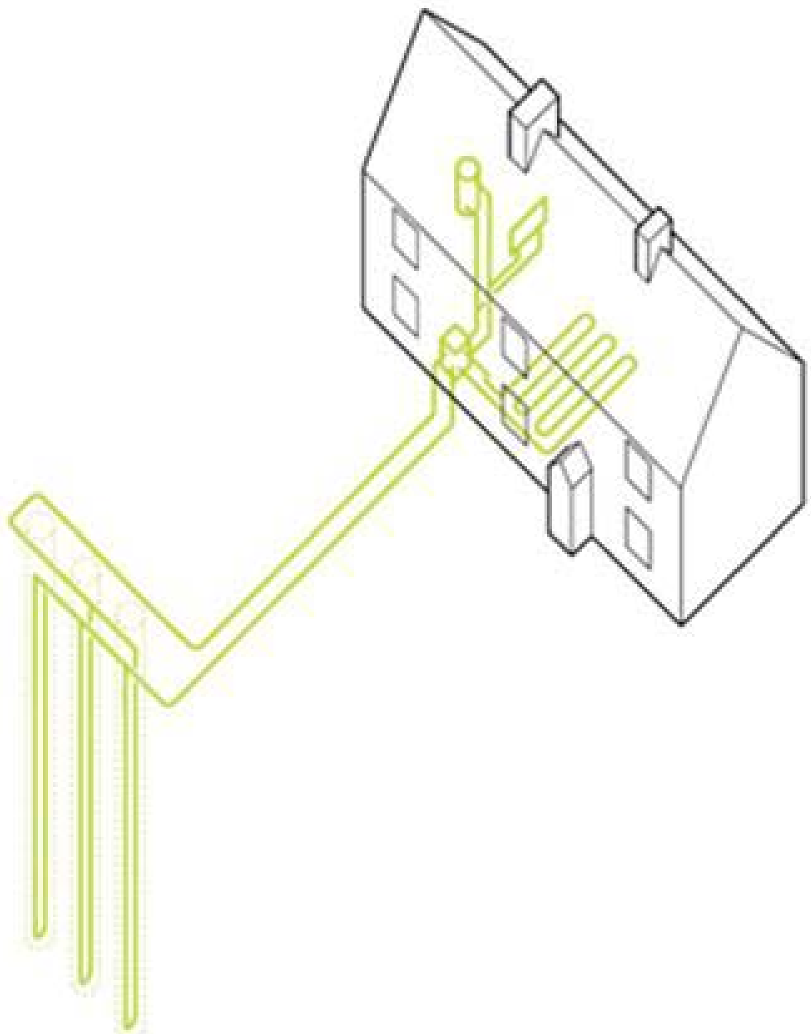

Figure 3-19| Diagram of a closed pump loop (Source: http//:www.giesp.es)

Horizontal pump system

These systems are often seen where a large land area is available. The tubes are placed in trenches that range from 30m to 120m in length (Fig. 3-20). This type of system also benefits from a low cost of drilling since the ground loops don't go deeply in the surface.

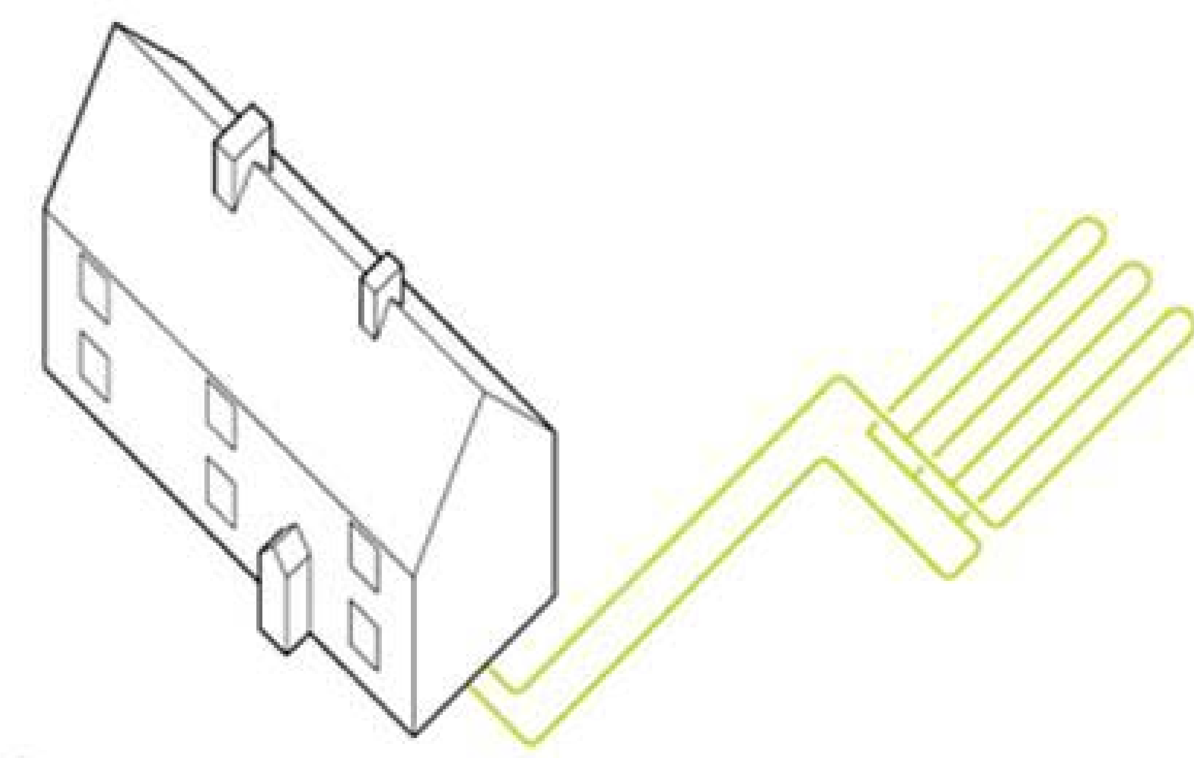

Figure 3-20| Schematic of a horizontal pump system (Source: http//:www.giesp.es).

Open pump system

Open circuits use groundwater as a source of energy. Ideally, an open system may be the most affordable (Fig. 3-21).

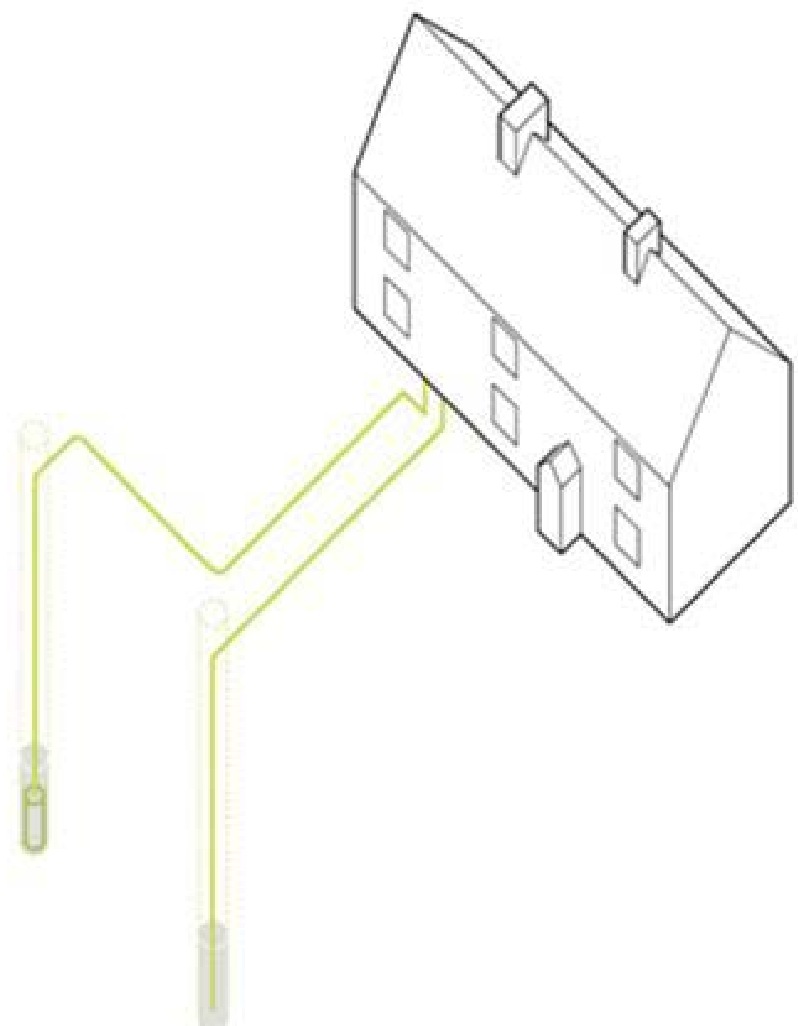

Figure 3-21| Schematic of an open pump system (Source: http//:www.giesp.es.).

Ponds pump system

These are highly economical where a body of water is available, because excavation costs are very low. Coils of pipe are simply placed in the bottom of the pond (Fig. 3-22).

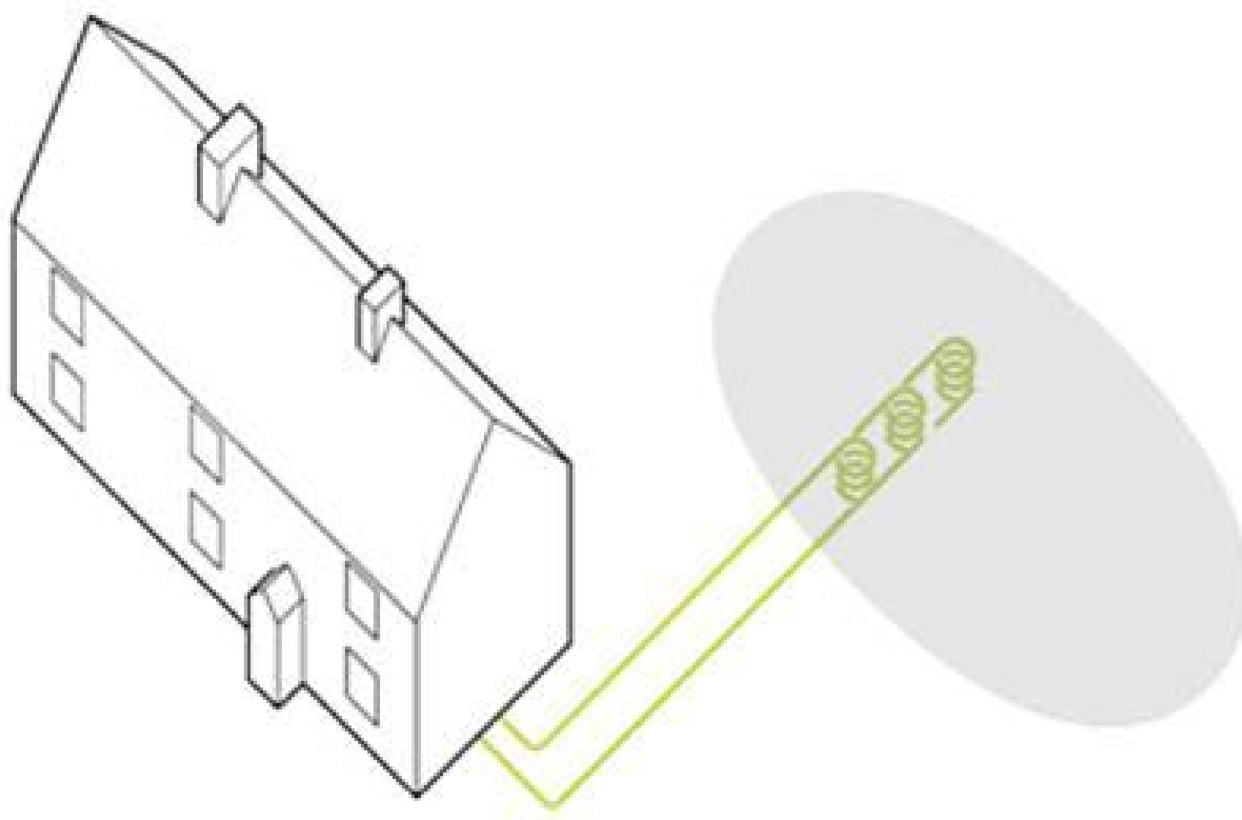

Figure 3-22| Schematic of a pond pump system (Source: www.giesp.es).

3.4.3. **Challenges**

In sum, a variety of geothermal heat pumps are currently available in the North American market. However, geothermal systems for residencies are very limited in Latin America. Therefore, their availability has to rely on importation from foreign countries, which, in this case, would be the U.S., since it is geographically nearest. As such, El Salvador shows high potential for geothermal applications in households or low-income groups. In terms of feasibility, the implementation of these applications would also require financing for the drilling and transportation of the manufacturing equipment (e.g. the U.S., Canada, China or Spain) to the site in question. This issue compromises the feasibility of introducing geothermal systems to low-income groups. Nonetheless, this option should not be discarded, since it is a 100 percent renewable energy source with great abundance in El Salvador. Salvadoran engineers are very familiar with studying and dealing with geothermal energy on a broad scale. In this sense, it is necessary to pay attention to the many alternatives an energy source has to offer, especially when 'plugging in' off-grid communities. If broad electric plants are unable to completely resolve the energy problem in El Salvador, small-scale energy systems might be the key. Hopefully, in the coming decades, alternative energy sources can be diversified within the Salvadoran market, allowing for a wider range of possibilities.

Chapter Four

Conclusion

4.1. Renewable energy systems for low-income groups: an opportunity or a challenge?

Designers and architects in El Salvador need to take clear and effective approaches to the issue of sustainable energy supply. If they are to become a part of the solution to the current energy crisis, they must address the entire sector of alternative energy sources. Although much can be done at a design stage, the key challenge is the social choices and behavior patterns of low-income groups. The ideas must remain true to the energetic aims of development. If designers in the private or public sectors are truly committed to these types of projects being used by energy/sustainable communities, it is important that they offer some sort of education or awareness to the affected residents.

Furthermore, the integration of renewable energy systems into these settlements is a natural response of a society that needs and wants to fight greenhouse emissions and global warming. Low-income groups also form part of a very large percentage of the Latin American population, and therefore have a strong impact on their local environment. The purpose of this new alternative energy integration is not only to use clean energy, but also to use it as an asset to integrate these low-income groups into society; the aim is to ‘push’ them towards a better quality of life by giving such populations more capital for education and food.

The challenges are also related to the capital costs of these systems that return operating savings. However, in El Salvador, energy prices are expected to rise at a greater rate than the cost of living, challenging the budgeting efforts of low-income families even further. In this sense, there is also an opportunity to take a leadership position over this situation and invest in its potential outcomes through the use of sponsors, who can position themselves alongside these initiatives.

4.2. Challenges of alternative energy systems in low-income groups

4.2.1. **Climate**

El Salvador has various types of climates within the country. The temperature variations range between 30°C and 12°C (see Fig. 4-1), which is directly linked to the altitude of the area, since higher grounds have a cooler climate. From mountainous to tropical and dry climates (tropical deserts), low-income groups throughout the nation encounter many types of environments, thus advantaging certain energy systems. For example, solar energy systems would logically be more appropriate for the groups that are located in a dry climate, such as the regional departments located on the western coast (Departments: Usulután, San Miguel, La Union). In addition, low-income groups located near coastal or mountainous areas benefit from stronger wind speeds and therefore should use wind turbines (Departments: La Union, La Paz, Sonsonate and Ahuachapán). Finally, settlements near volcanic activity can use geothermal energy (Departments: San Ana, San Salvador and San Vicente). In other words, the geographical location of low-income will be suitable for one or many energy systems while eliminating others. Climate is a crucial factor to determine which alternative energy system is more suitable to specific areas.

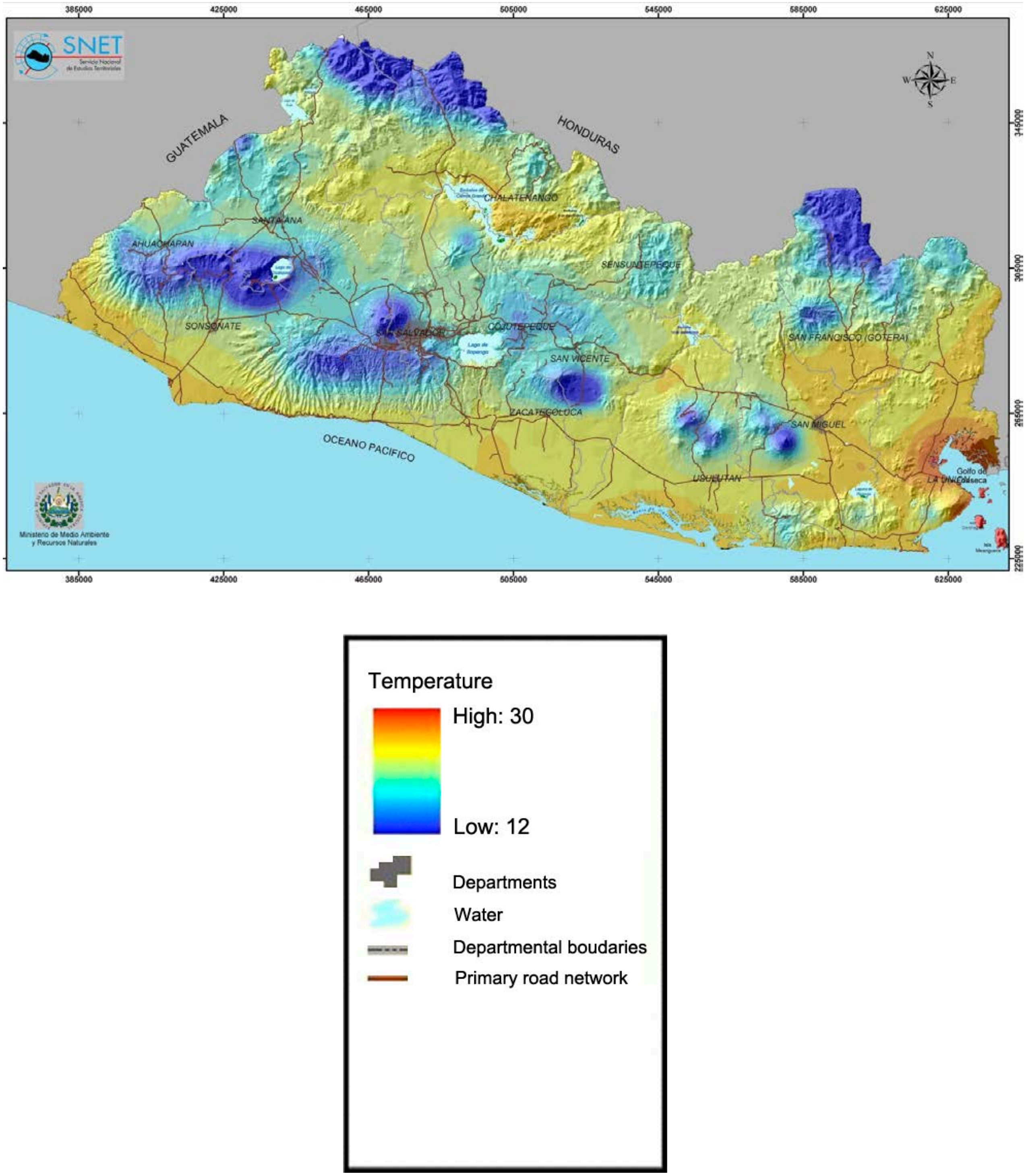

Figure 4-1. Climate map of El Salvador (Source: SNET, 2011).

4.2.2. **Housing conditions of PUS and suitable energy systems**

As Chapter 2 explained, the complexity of characterizing these urban settlements (PUS) with precision and classifying the 'informality' of their construction is problematic when choosing the proper energy system structure for them. The reason is that makeshift walls and improvised concrete foundations are commonly found in these settlements. Consequently, the most adequate energy systems are probably the ones that require simple and rapid installation. PV panels and wind turbines are systems that can be installed quickly and do not require complex housing foundations, unlike geothermal energy. However, geothermal solutions would not be the most suitable because of all the different procedures required to install them (drilling or foundation piles). As such, while solar panels and aerogenerators are locally available in the Salvadoran market at an affordable cost, small-scale geothermal technologies would have to be imported from North America, Europe or China. Nonetheless, as a long-term project, geothermal energy might be viable for low-income groups as the Salvadoran market diversifies in the coming decades.

4.2.3. **Future of alternative energy systems in El Salvador**

The use of new energy technology in El Salvador is ongoing. Although the market is still very limited, its growth will mean new economic diversity, and therefore new jobs. This growth should not only include the creation of new companies that produce alternative energy systems, but also the design of new power plants and housing. By slowly introducing a concept of comprehensive sustainability into the market, El Salvador and other developing countries can be part of that revolution. For that to happen, political vision and an action plan will need to be implemented nationwide. It will also be necessary to renovate the thinking of Salvadoran society concerning energy consumption from its current notion to a more realistic one. This will require the implementation of energy-saving measures and a persuasive educational effort.

Currently, El Salvador needs more public policies and better leadership in order to promote the widespread use of grid systems that are based on renewable sources. The incentives provided by El Salvador for this type of project are in line with those of other countries in the region. These inducements are designed to foster the low incorporation of new renewable systems, the source of which can be explained by the complex approval and licensing mechanisms that directly affect the availability of certain energy systems in the region.

Obviously, the technology and the economy will improve over time. Nonetheless, both are sufficiently advanced to encourage wider participation among local governments and the private sector in order to bring about major energy infrastructure within Salvadoran society. Furthermore, it is important to set specific goals based on the assumption that the next 50 years will involve significant improvements in energy efficiency; these will be coupled with an increase in renewable energy (especially solar and wind power) applications.

4.3. Recommendations

4.3.1. Political scale

Any success in implementing alternative energy sources to low-income groups will require the participation and collaboration of multiple investors across all relevant sectors of society: governments, businesses, and civil society organizations, all of whom have important and complementary roles to play. How they participate will vary according to their different scopes, since they should be able to represent the multiple types of engagement expected from each investor group.

El Salvador must create economic conditions that enable growth by establishing a clear vision, national goals, policies, regulations, a normative approach, and incentives that bond energy efficiency to development. Attracting private investment should definitely be a primary target, since it would contribute greatly to the success of alternative energy systems. This could be reached through the implementation of an institutional framework, which should be to ensure transparency and a high degree of predictability. The country should also extend the existing national plan beyond the actual governmental party in power, by giving access and promoting energy efficiency as a sustainable politic that responds to national concerns.

An energy efficiency politic to integrate these urban expressions (PUS) into Salvadoran society in order to eradicate extreme poverty might be the answer. For example, one regulation might require the improvement of precarious housing conditions by using affordable, locally found, low-impact materials such as adobe, while another might commit to enabling the development of off-grid solar/wind/geothermal power.

Regulations can also provide public capital for technical assistance to support pilot projects or demonstrations, or fund instruments that reduce the risk to the private sector. All of these strategies can be used to spur political action that can and should support sustainable development in El Salvador.

National and local governments are crucial players that can contribute to the creation of energy-efficient houses for low-income groups. According to Abel and Lewis (2002), rural-urban migration is one of the main reasons why Latin America and El Salvador have large and deprived communities spread out in so many different locations. Current trends show that residents of city populations will be increasingly living in urban areas in the coming decades. In this context, regional and local governments, urban planners, designers and architects can have a considerable influence on the future of energetic sustainability in El Salvador. They can design policies and foster investment in order to encourage greater use of mini-scale off-grid systems for rural areas. This will reverse the trend of rural-urban migration by implementing educational programs that examine energy consumption consciousness.

4.3.2. **Broadcasting of technology**

Action on the discussion and adoption of renewable energy sources needs to involve all sectors of society. These actions can be approached in many ways. For example, they could promote the funding of panel discussions and technology diffusion through large-scale activities such as conferences, seminars, workshops and technical meetings for professionals and private sector representatives. The participation of both public and private sectors could encourage the generation and use of renewable energy systems on small and large scales across El Salvador. Subsequently, the development and demonstration of prototypes that show the feasibility and affordability of these types of projects could be implemented. Finally, a plan for promoting knowledge at the academic level is definitely another priority, since those in education represent the next ideal of future designers. This level should be reached by funding science fairs that provide demonstration activities on renewable energy in different undergraduate architectural schools. These actions will certainly create a strong and positive amount of energy consciousness among the public and private sectors.

4.3.3. **Addressing renewable energy financing**

Financing is a major issue for these types of projects and should be addressed by enabling a discussion of the long-term feasibility of alternative energy systems in low-income groups. The combination of efforts must be supported both by local government and major investors such as the World Bank, the IMF, and the International Finance Corporation. Private foundations should such as the Rockefeller Foundation and the Fulbright Foundation should also be courted, as they are renowned for funding renewable energy projects across the globe. Additionally, development agencies such as the International Bank for Reconstruction and Development (IBRD) also run programs that offer viable financing options.

4.3.4. **Energy consciousness**

Energy consciousness introduces all residents and parties involved directly or indirectly to the use of alternative energy systems. With the increase in living standards year after year, household energy consumption is progressively rising. In this context, energy conservation through appropriate construction, use and maintenance practices assumes prime importance. Users play an important role in ensuring the success of these alternative energy sources. Well-cultured consumers who have a strong notion of energy utilization can greatly contribute to these types of projects. Therefore, if designers want to ensure the success of these developments, they must offer an energy consciousness program that will give users at least some basic knowledge of how to use these systems properly.

4.3.5. **Self-sufficient housing**

Self-sufficient housing has become the goal of many professionals and architects. This is an extensive field of study that not only takes energy efficiency into account, but also seeks to respond to all of the other human activities that occur within a household, such as providing potable water, food, security and low-impact materials. This research only covers the energy efficiency field as it relates to groups with low budgets who are facing many kinds of social problems. Nonetheless, it serves as a guideline and is a first attempt to hopefully bring about self-sufficient housing in El Salvador in the near future.

4.3.6. **Off-grid housing**

Accessibility is probably the main issue in most PUS. As a result, some of these settlements are located far from the public grid or are in vulnerable geographical areas. It would cost a lot if these settlements were to be connected to the rest of the cities in which they reside. Therefore, some electricity distribution solutions must be developed. First of all, providing access to electricity through off-grid, micro- and mini-grid solutions is a possible and affordable option. Clean energy through mini-grid solutions for rural or isolated areas using renewable sources would not only respond to the energy demand but also contribute to lower greenhouse emissions.

Furthermore, providing the appropriate regulatory framework would incentivize and support the distribution of off-grid renewable energy systems, for example, in the case of solar lighting through a self-contained system that can provide uninterrupted power if the grid fails. This is an excellent approach for communities that are characterized by a large quantity of rainfall, which commonly causes temporary shutdowns in the public grid. In the case of solar power, this system not only provides electricity for lighting or domestic appliances but can also be used to pump water to the surface. Finally, examining the energy efficiency of off-grid low-income groups will support the development of comprehensive research on the performance of these unique types of households.

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