MSc Program
Environmental Technology & International Affairs

Zero Fossil Fuels for the Galápagos Archipelago: Sustainability Assessment of the Island Strategy towards a 100% Renewable Energy System

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

supervised by
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Vienna, 05.08.2014

Affidavit

I, **KATHARINA PROESTLER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ZERO FOSSIL FUELS FOR THE GALÁPAGOS ARCHIPELAGO – SUSTAINABILITY ASSESSMENT OF THE ISLAND STRATEGY TOWARDS A 100% RENEWABLE ENERGY SYSTEM", 236 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

The delicate ecosystem of the Galápagos archipelago, a world natural heritage because of its unique biodiversity, appreciated by virtue of Charles Darwin's research, is under threat. Flourishing tourism, a growing population and economic development have increased fossil fuel consumption and dependence. The supply of energy has primarily been based on diesel; while during the last ten years, there have been several initiatives to implement renewable energies (REs) on Galápagos. These have been receiving international support after the accident of the oil tanker Jessica in 2001 showed the possible damage oil spills can cause to the delicate ecosystem. In 2007, the Ecuadorian government emphasized the goal to change the energy matrix by announcing the "Zero Fossil Fuel Program for Galápagos". Since then, some of the fossil fuels have been successfully replaced through the implementation of wind energy on San Cristóbal and vegetable oil on Floreana. Additional initiatives plan to repower the solar park on Floreana, to install wind turbines on Baltra, and solar photovoltaic on Santa Cruz, Isabella and Baltra. The goal of this thesis is to assess the sustainability of the current strategy towards a 100% RE-System and to find out why despite these efforts, fossil fuels have not yet been completely removed. For this purpose, adequate sustainability criteria are defined from the outset and are organized around the four major dimensions: technological feasibility, energy security, socio-economic energy equity and environmental sustainability. Based on these the sustainability of the electricity systems of all four of the populated islands are analyzed. This research found that the deployment of RE technologies could not only support the global combat against climate change by reducing CO_2 emissions and mitigate other negative effects connected to fossil fuel combustion, but additionally could also increase socio-economic energy equity by promoting prosperity, increasing affordability and improving quality of life. From this comprehensive analysis, a set of recommendations are formulated and these suggestions aim at providing an inspiration to reconsider and reformulate the Zero Fossil Fuel Program for the Galápagos with a view towards creating a reliable, affordable, environmentally friendly and socially inclusive energy system.

Keywords: Renewable Energy Sources, Galápagos, Sustainability Assessment, Zero Fossil Fuels, 100% Renewables, Hybrid Systems, Sustainable Energy Development Trend

Resumen

El archipiélago de Galápagos, un patrimonio cultural de la humanidad debido a su ecosistema único y de la biodiversidad, apreciado en virtud de las investigaciones de Charles Darwin, está bajo amenaza. Turismo floreciente, aumento de la población y el desarrollo económico han provocado constantemente el aumento del consumo de combustibles fósiles y la dependencia de ellos. El suministro de energía se ha basado principalmente en el diesel; mientras que durante los últimos diez años se plantearon varias iniciativas para la aplicación de las energías renovables, en Galápagos. Estos han recibido apoyo internacional después del accidente del tanque petrolero Jessica en 2001 ha mostrado que los posibles derrames de petróleo pueden causar graves daños al delicado ecosistema. En 2007 el gobierno ecuatoriano destacó el objetivo de cambiar la matriz energética, al anunciar el "Programa Cero Combustibles Fósiles para Galápagos". Desde entonces algunos de los combustibles fósiles se han sustituido con éxito a través de la implantación de la energía eólica en San Cristóbal y aceite vegetal en Floreana. Esfuerzos adicionales prevén realimentar el Parque Solar en Floreana, instalar aerogeneradores en Baltra, y paneles fotovoltaicos en Santa Cruz, Isabela y Baltra. A pesar de estos esfuerzos, sin embargo, los combustibles fósiles aún no se han eliminado por completo, ni se ha desarrollado un concepto integral y sostenible para el sistema de energía. Por tanto, el objetivo de esta tesis es evaluar la sostenibilidad de la estrategia actual hacia un sistema de 100% RE. Para este propósito inicialmente un conjunto de criterios de sostenibilidad adecuados se definen, organizados en torno a cuatro dimensiones: la viabilidad tecnológica, la seguridad energética, la equidad socio-económica de la energía, y de sostenibilidad ambiental. Sobre la base de estas la sostenibilidad de los sistemas eléctricos de las cuatro islas pobladas son analizados. Se ha encontrado que el despliegue de tecnologías de energía renovable no sólo podría apoyar la lucha mundial contra el cambio climático reduciendo las emisiones de CO_2 y mitigar otros efectos negativos derivados de la combustión de combustibles fósiles. También pueden aumentar la equidad socio-económica de energía mediante la promoción de prosperidad, el aumento de accesibilidad y la mejora de calidad de vida. Sobre la base de este análisis global se formulan una serie de recomendaciones. Estas sugerencias tienen por objetivo proporcionar una fuente de inspiración para reconsiderar y reformular el Programa Cero Combustibles Fósiles para las Galápagos, con miras a crear un sistema energético fiable, asequible, respetuoso del medio ambiente y socialmente inclusivo.

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List of Acronyms

%	Percent
ACSR	Aluminium Conductor Steel Reinforced
ADB	Asian Development Bank
AECID	*Agencia Española de Cooperación para el Desarrollo*; English: Spanish Agency for International Cooperation and Development
AGR	Annual population growth rate
ANDES	*Agencia de Noticias del Ecuador y Sudamérica*; English: Agency for News of Ecuador and South America
AOSIS	Alliance of Small Island States
ASC	Aluminium Stranded Conductor
BMU	*Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit*; English: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BP	British Petroleum
BtL	Biomass to liquid fuels
BWE	*Bundesverband Windenergie e.V.*; English: German Federal Organisation for Wind Energy
CCS	Carbon capture and storage
CDF	Charles Darwin Foundation
CDM	Clean Development Mechanism
CdTe	Cadmium telluride
CEER	Council of European Energy Regulators
CELEC	*Corporación Eléctrica del Ecuador*; English: Electricity Corporation of Ecuador
CENACE	*Centro Nacional de Control de Energía*; English: National Energy Control Centre Ecuador
CGREG	*Consejo de Gobierno Regional de Galápagos (former INGALA);* English: Governing Council of Galápagos
CLEWS Nexus	Climate – land-use – energy – water systems Nexus
CNEL	*Corporación Nacional de Electricidad*; English: National Electricity Company
CO	Carbon monoxide
CO_2	Carbon dioxide
CONELEC	*Consejo Nacional de Electricidad*
CSP	Concentrating solar power
CxHx	Some amount of carbon and hydrogen
DC	Direct current
DED	*Deutscher Entwicklungsdienst*; English: German Development Service
DLR	*Deutschen Zentrums für Luft- und Raumfahrt*; English: German aeronautics and space research centre
DSM	Demand Side Management
ECF	European Climate Forum
EIA	Energy Information Administration
EIA	Environmental Impact Assessment
ElecGalápagos	*Empresa Eléctrica Galápagos*; English: Public Electricity Utility
ENERGAL	*Energías Renovables Galápagos*; English: Renewable Energies Galápagos

EnerNOC	Energy Network Operations Centre
ENSO	El Niño-Southern Oscillation
EOLICSA	*Corporación Eólica San Cristóbal S.A.*; English: Wind Energy Corporation San Cristóbal
EPI	Environmental Policies Index
EREC	European Renewable Energy Council
ERGAL	*Energías Renovables para Galápagos*; English: Renewable Energies for Galápagos
et al.	et alii
EWEA	European Wind Energy Association
FAO	Food and Agriculture Organization of the United Nations
FCD	*Fundación Charles Darwin*; English: Charles Darwin Foundation
FEEM	*Fondazione Eni Enrico Mattei*; English: Eni Enrico Mattei Foundation
FERUM	*Programa De Energización Rural Y Electrificación Urbano-Marginal*; English: Rural and Urban Marginal Electrification Fund
FiT	Feed-in Tariffs
GC	Galápagos Conservancy
GDP	Gross Domestic Product
GEA	Global Energy Assessment
GEF	Global Environment Facility
GENI	Global Energy Network Institute
GHG	Greenhouse Gases
GHP	Geothermal heat pump
GIZ (former DED)	German development organization
GNI	Gross national income
GSEP	Global Sustainable Electricity Partnership
GWEC	Global Wind Energy Council
H2	Hydrogen
ha	Hectare
HCFC	Hydrochlorofluorocarbon
HH	Household
i.e.	id est; which means
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEA-RETD	IEA Renewable Energy Technology Deployment
Ifeu	Institute for Energy and Environmental Research
IIASA	International Institute for Applied Systems Analysis
IICA	Inter-American Institute for Cooperation on Agriculture
INEC	*Instituto Nacional de Estadística y Censos*; English: Ecuadorian National Institute for Statistics and Census
INER	*Instituto Nacional de Eficiencia Energética y Energías Renovables*; English: Ecuadorian National Institute for Energy Efficiency and Renewable Energies
INIAP	*Instituto Nacional de Investigaciones Agropecuarias*; English: Ecuadorian National Agricultural Research Institute
INOCAR	*Instituto Oceanográfico de la Armada del Ecuador*; English: Ecuadorian Naval Oceanographic Institute

IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Provider
IRENA	International Renewable Energy Agency
ISED	Indicators for sustainable energy development
JICA	Japan International Cooperation Agency
KfW	*Kreditanstalt für Wiederaufbau*; English: Reconstruction Credit Institute
kg	Kilogram
km	Kilometer
KOICA	Korean Cooperation Agency
KP	Kyoto Protocol
kV	Kilovolts
kW	Kilowatt
kWh	Kilowatt-hours
kW_{peak}	Kilowatt peak
Li-Ion	Lithium-Ion battery
LOREG	*Ley de Régimen Especial para la Conservación y Desarrollo Sustentable de la Provincia Galápagos*; English: Organic Law of the Special Regime for the Conservation and Sustainable Development of the province of Galápagos
LPG	Liquefied petroleum gas
LRSE	*Ley de Régimen del Sector Eléctrico*; English: Electricity Sector Regime Law
LUC	Land Use Change
m	Meters
m/s	Meters per second
m^3	Cubic meter
MAE	*Ministerio del Medio Ambiente Ecuador*; English: Ministry of the Environment
MAGAP	*Ministerio de Agricultura, Ganadería, Aquacultura y Pesca*; English: Ministry of Livestock, Agriculture, Aquacultur and Fisheries
Mbtu	British thermal units
mc-Si	Multicrystalline silicon
MCPEC	*Ministerio Coordinador de Producción, Empleo y Competividad*; English: Ministry for the Coordination of Production, Employment and Competitiveness
MDGs	Millennium Development Goals
MEER	*Ministerio de Electricidad y Energía Renovable*; English: Ministry of Electricity and Renewable Energy
MEM	*Ministerio de Energía y Minas*; English: Ecuadorian Ministry of Energy and Mines
mg	Milligrams
MICSE	*Ministerio Coordinador de Sectores Estratégicos*; English: Ministry for the Coordination of Strategic Sectors
MINTUR	*Ministerio de Turismo*; English: Ministry of Tourism
MIPRO	*Ministerio de Industrias y Productividad*; English: Ministry of Industry and Productivity
MRNNR	*Ministerio de Recursos Naturales No Renovables*; English: Ecuadorian Ministry of Non-Renewable Natural Resources
MTOP	*Ministerio de Transporte y Obras Públicas*; English: Ministry of Transportation and Public Works
MW	Megawatt
MWh	Megawatt hour

MW_{peak}	Megawatt peak
N_2O	Nitrous oxide
NBI	Basic unsatisfied necessities (index)
NCSL	National Conference of State Legislatures
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
Nox	Mono-nitrogen oxides NO and NO2 (nitric oxide and nitrogen dioxide)
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OLADE	*Organización Latinoamericana de Energía*; English: Latin American Energy Organization
PAH	Polycyclic aromatic hydrocarbons
PB	Planetary Boundary
PBL	*Planbureau voor de Leefomgeving*; English: Netherlands Environmental Assessment Agency
PetroEcuador	*Empresa Estatal Petróleos del Ecuador; Empresa Pública Petroecuador*; English: Public Petroleum Enterprise of Ecuador
PIK	Potsdam Institute for Climate Impact Research
PM	Particulate Matter
PME	*Plan Maestro de Electrificación*; English: Master Plan for Electrification
PNBV	*Plan Nacional del Buen Vivir*; English: National Development Plan
PNG	*Parque Nacional Galápagos*; English: Galápagos National Park
PNUD	UNDP; United Nations Development Program
poly-Si	Polycrystalline silicon
pp.	Pages
PR	Performance ratio
PV	Photovoltaic
PVPP	Photovoltaic Power Plant
PwC	PricewaterhouseCoopers LLP
QOL	Quality of Life
R.O.	*Registro Official*; English: Official Register
R&D	Research and Development
RCREEE	Regional Centre for Renewable Energy and Energy Efficiency
RE	Renewable Energy
Reg.	Regulation
REN21	Renewable Energy Policy Network for the 21st Century
RE	Renewable Energy
RES	Renewable Energy Sources
RES-E	Electricity from Renewable Energy Sources
Res.	Resolution
RET	Renewable Energy Technology
RITE	Research Institute of Innovative Technology for the Earth

ROI	Return on investment
SCADA	Supervisory Control and Data Acquisition
SD	Sustainable Development
Se4all	Sustainable Energy for All initiative
SEI	Stockholm Environmental Institute
SENAGUA	*Secretaría Nacional del Agua*; English: National Water Secretariat
SENESCYT	*Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación*; English: National Secretariat for Higher Education, Science, Technology and Innovation
SENPLADES	*Secretaría Nacional de Planificación y Desarrollo*; English: National Secretariat of Planning and Development
SETECI	*Secretaría Técnica de Cooperación Internacional*; English: Ecuadorian Secretariat for International Cooperation
SIDS	Small Island Developing States
SIEE-OLADE	*Sistema de Información Económica Energética*; English: Energy-Economic Information System of the Latin American Energy Organization (OLADE)
SO_2	Sulfur dioxide
SPNG	*Servicio Parque Nacional Galápagos*; English: Galápagos National Park Service
TBL	Triple bottom line
toe	Tons of oil equivalent
UK	United Kingdom
UN-DESA	Department of Economic and Social Affairs of the United Nations Secretariat
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNF	United Nations Foundation
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
USD	United States dollar
VAT	Value-added tax
WCED	World Commission on Environment and Development
WCMC	World Conservation Monitoring Centre
WEC	World Energy Council
WEF Nexus	Water-Energy-Food Nexus
WELMM	Water, Energy, Land, Materials and Manpower
WHC	World Heritage Convention
WHO	World Health Organization
WWF	World Wildlife Fund of Nature
WTG	Wind Turbine Generator

Acknowledgements

> *"Galápagos es diferente. No es Hawaii ni Canarias, no es Guayaquil ni Quito y tampoco es Miami. Es un lugar único en el planeta. Es un lugar muy especial, y por lo tanto vivir en él también requiere de un modo de vida especial."* (PNG, 2007: I)

This master thesis is the conclusive work of a journey that started two years ago and took place within the realms of the Master of Science in Environmental Technologies and International Affairs at the Diplomatic Academy and the University of Technology in Vienna. It would not have been possible without the help, encouragement, unconditional love and support of my parents and family, who have always supported me and believed in my dreams and ambitions. My greatest gratitude goes to Rafael who has encouraged me at every step I have taken and has been a source of inspiration.

Moreover, I would like to express my profound gratitude and sincere appreciation to my thesis supervisor Professor Dr. Günther Brauner for his precious guidance and creative suggestions as an expert in renewable energies and for his continuous support and encouragement. In addition, I am very grateful to Professor Dr. Hans Puxbaum who supported my research and gave me the unique possibility to discover an exciting, fascinating and challenging aspect of Ecuador.

I am greatly thankful to Marcelo Neira and his successor Eduardo Noboa and his team at the Institute of Energy Efficiency and Renewable Energies of Ecuador as well as Marco Salao and his team from ElecGalápagos. In particular, I would like to thank Elsy Parodi, Andrés Montero and Andrea Eras for supporting me with patience and valuable information without which this master thesis would not have been possible. Furthermore, these institutions and the kind support of their staff made it possible for me to spend an unforgettable and enjoyable research period in Quito and the fascinating Galápagos Islands. Moreover, I thank all the interviewees from ENERGAL, EOLICSA, ERGAL, GIZ, JICA, KOICA, UNDP and several public companies and ministries, such as MEER, MICSE, Yachay, and MAGAP for their valuable information and insights.

I wholeheartedly thank my dear friends and ETIA colleagues, for the many joys shared, challenges overcome and the memorable times we have spent together.

Katharina Proestler
August 2014, Vienna, Austria

1. Introduction

This introductory chapter provides the motivation for this Master thesis focusing on the renewable energy systems on the Galápagos Islands. The chapter states the research question and hypothesis, delineates the scope and describes the methodology. Finally, the conceptual framework is presented and lays down the structure of the thesis.

1.1. Motivation

> *"[E]nergy is the golden thread that weaves together economic growth, social equity, and environmental sustainability". United Nations Secretary-General Ban Ki-moon* (WEC, 2013: 10).

Internationally, mitigating climate change and maintaining our world's biodiversity for current and future civilizations has become increasingly important. There is growing acceptance and acknowledgement that the world's dependence on fossil fuels has negative implications for the climate, the environment and human and animal health as well as for energy security (IPCC, 2007; WEC, 2010: 368; OECD/ IEA, 2012; IPCC, 2012). For instance, notwithstanding the existing uncertainty about the Earth's climate in general, many scientific institutions (UN, 1992; UN, 1998; US National Academy of Sciences, 2010; IPCC, 2013; Royal Society - UK National Academy of Science, 2014) have progressively recognized the link between climate change and anthropogenic influence through the consumption of fossil fuels. For instance the Working Group I to the Fifth IPCC report has confirmed with 95% certainty that human activity is the reason for observed global warming (IPCC, 2013: 96). The rate of change is unprecedented and humans are not only altering the atmosphere, but effects are also observable in other abiotic factors as well as terrestrial and aquatic biota such as oceans, lakes, rivers, flora, fauna and animals (Nebel and Wright, 1993: 18ff.). The Galápagos Islands are particularly vulnerable to small changes of the Earth's climate and their ability to adapt is uncertain (Di Carlo and d'Ozouville, 2012). In this regard, scientists warn that once human activity has passed certain "planetary boundaries", often referred to as thresholds or tipping points, there is a risk of abrupt and irreversible environmental change (UN Secretary-General's High-Level Panel on Global Sustainability, 2012: 22).

While the demand for energy is growing continuously, the supply of these exhaustible resources is increasingly endangered. Despite the evidence that fossil resources are scarce and that oil reserves are reaching their limits and may soon peak (Hubbert, 1956; Campbell, 1997; Campbell and Laherrère, 1998; Deffeyes, 2005; EIA, 2011; OECD/ IEA, 2012; Post Carbon Institute/ Energy Policy Forum/ Earthworks, 2013), today, more than 80% of the global energy supply is linked to fossil fuels such as coal, oil and gas (OECD/ IEA, 2012). While energy is the motor of our modern global economy[1] (Sari et al., 2008; Das et al., 2012), oil is still the key source of energy. It therefore remains the most important raw material in the world in both domestic and global as well as economic and political terms (OECD/ IEA, 2012). Also, on the Galápagos Islands, the consumption of fossil fuels has been rising steadily – growing population, increasing tourism, higher available income and the subsequent modernization driven by the desire for a higher standard of living, have increased the dependence on diesel and gasoline for electricity production and transport.

Aside from accelerating climate change and tightening of energy supplies, other negative impacts of fossil fuel use persist. From a socio-economic point of view, fossil fuel extraction and use deepen energy poverty and strengthen petro-dictatorship. In addition, not only do environmental impacts are numerous and often cause a risk to human health but also accelerate the extinction of plants and animals. The unique biodiversity[2] of the Galápagos makes its ecosystem especially vulnerable not only to climate change, but also to emissions of any kind, as well as to other pressures on natural resources and land. Many of these social and modern economic pressures are related to energy consumption (Kassels, 2003). For instance, the risk caused by the transport of fossil fuels to, and their use on, the islands has become visible through the oil spills of the yacht, Iguana, in 1988, or the oil tankers, Jessica and Taurus, in January 2001 and July 2002 respectively – although quantification of damages proved to be difficult (Sanderson et al., 2001; Lougheed et al., 2002; GEF/ UNDP, 2006). These incidents, along with the recent grounding of the freight ship, Galapaface, on 9th May 2014[3] (ANDES, 2014), show the risks that the already extremely vulnerable archipelago is facing.

One of the most reviewed possibilities to increase energy security and energy

[1] Causal Relationship between Energy Consumption and Economic Growth: Summary of Literature Review. More information in the review studies by Das et al. (2012) and Sari et al. (2008)

[2] The Galápagos is a World Heritage Site, a national park and the surrounding waters are a marine nature reserve. The islands are characterised by high levels of endemism. Species such as marine iguanas, Galápagos penguins and lava gulls are found nowhere else on the planet, whilst others such as Galápagos sea lions are distinct subspecies. Also many marine invertebrates and 17% of fish species are known to be endemic.

[3] Currently, the grounding of the freight ship Galapaface on 9th May 2014 raises attention as it could release 16,000 gallons of diesel into the delicate marine ecosystem (ANDES, 2014).

independence, as well as to protect the environment and human health, is the diversification and modification of the energy supply by using renewable energy sources (RESs) (GENI, 2011; Danish Ministry on Climate, Energy and Building, 2012; GENI, 2013; Institut dezentrale Energietechnologien, 2013; Go100Percent, 2013; IPCC, 2011; IRENA, 2013; Greenpeace/ EREC/ GWEC, 2012). On Galápagos, renewable energies (REs) already contribute to the electricity system and their share is expected to increase significantly in the future. In this context, the RE system shall not only be environmentally friendly and secure but also reliable, affordable and accessible. It is also essential to consider – apart from the technological feasibility of the RE system – the three dimensions of sustainability: environment, economy and society. However, there has not yet been a comprehensive assessment of the overall sustainability of the application of these technologies on the archipelago. Therefore, there is a need to determine whether the renewable energy technologies (RETs) chosen can support energy security, socio-economic energy equity and environmental sustainability.

1.2. Objective, Hypothesis, Research Question and Scope

The Galápagos archipelago, part of Ecuador and isolated in the Pacific Ocean, is a world natural heritage site because of its unique ecosystem explored in the research of Charles Darwin (Wyhe, 2002). Flourishing tourism, growing population, rising income and the subsequent modernization, driven by the wish for a higher standard of living, has caused constantly rising consumption and dependence on fossil fuels. The supply of energy has primarily been based on diesel, while during the last 10 years there have been several initiatives to implement REs on the Galápagos. These were initiated due to the oil spill in 2001 and emphasized by the "Zero Fossil Fuel Program for Galápagos" announced by the Ecuadorian Government in 2007[4] (MEM, 2007a; SENPLADES, 2007; La Insignia, 2007).

Objective

The overall motivation of the thesis is twofold. On the one side, it goes hand in hand with the idea of the governmental program that stresses the conservation of the unique biodiversity on the Galápagos Islands in harmony with the needs of the population. On the other hand, the thesis supports the idea that RETs promote sustainable development (SD) and the global combat against climate change. Nevertheless, since the Galápagos are too small to make any significant difference

[4] See Annex 1.

regarding things such as emissions, the aim is not so much on the quantitative side, but instead, acts as an inspiration and laboratory for sustainable RETs, such as wind, solar and geothermal energy. Accordingly, energy is seen as a central element of development and renewables as a key condition for SD.

Wind energy turbines have already replaced some fossil fuel usage on San Cristóbal and Jatropha oil is used on Floreana. Additional efforts are planned to repower the solar park in Floreana, install a solar park in Santa Cruz, Baltra and Isabella and install wind turbines in Baltra. Nevertheless, it appears that the "Zero Fossil Fuel" objective cannot yet be reached: despite the efforts to create an environmentally friendly initiative for the electricity sector on the archipelago, no comprehensive and sustainable concept for the energy system has been elaborated because each island differs regarding energy demand and renewables potential. Moreover, there seems to be limited scientific research on comprehensive sustainability assessments of decentralized energy system on islands. Regarding RE projects on Galápagos, numerous studies have been conducted concerning technical or economic feasibility or environmental impacts, but none of them considers the whole archipelago and all dimensions of sustainability. Therefore, the objective of this thesis is to assess the sustainability of the current and projected energy supply system of the Galápagos archipelago based on an extensive evaluation of existing primary data, initiatives and studies under consideration of the local circumstances. For this evaluation, it is necessary to first choose adequate criteria for the sustainability assessment based on an extensive literature review. The criteria must be appropriate to illustrate the impacts of the RETs on environmental, social and economic sustainability. Finally, policy recommendations shall be given to support the development of future scenarios to eliminate fossil fuels and reach the 100% renewables target. Therefore, this study will be an important contribution to the Zero Fossil Fuels Initiative for Galápagos, as it assesses the sustainability of the RE initiatives and indicates knowledge action gaps as well as the requirement for further action to reach a sustainable system. In addition, the criteria developed in this research could also be a potential starting point for continuously matching the planned actions against the status quo of the energy system in Galápagos. Finally, this study proposes and tests criteria for sustainability assessment of RE systems for islands, which could be used for evaluating other RE island systems. A useful by-product of the thesis is the facilitation of access to data for institutions, ministries and interested public.

Hypothesis

Different RETs exist that can decrease the share of fossil fuels on the Galápagos Islands and can help to reach the *Zero Fossil Fuels goal*. Furthermore, studies confirm that the credibility of 100% coverage of electricity demand with renewables increases (Delucchi and Jacobsen, 2011; GENI, 2011; GENI, 2013; Go100Percent, 2013; EREC, 2010; REN21/ ISEP, 2013) and is feasible for islands (IRENA, 2013; EU SEW, 2014). However, to reach an environmentally sound, socially acceptable and economically feasible solution, the transformation of the islands needs to be sustainable. In other words, the energy system needs to be reliable, affordable, accessible, secure and environmentally friendly. The scenarios to reach these goals depend on many variables such as time, money, governance, social acceptance, environmental impact, and energy demand and efficiency improvements. For instance, the transformation can only be successful if the needs of the population and the islands' unique biodiversity are adequately and carefully considered, if the concepts are well planned, and if they consider technological, economical, environmental and social aspects. The transformation to an energy system that mitigates reliance on fossil fuels reduces environmental risks, boosts resource efficiency and can make the Galápagos more resilient to future increases in global energy and commodity prices. Therefore, the criteria used in this thesis for the sustainability assessment are the following: technological feasibility, energy security, socio-economic energy equity, and environmental sustainability.

Research Questions

In order to underline the above-mentioned hypothesis, the following research questions have been defined:

- ⇨ Which aspects affect the sustainability of the RE system on Galápagos?
- ⇨ How sustainable is the Zero Fossil Fuel Program and the existing, as well as planned, energy systems on the islands of the Galápagos archipelago from an environmental, social and economic point of view? In other words, how do the implemented and planned projects on each island impact energy security, socio-economic energy equity and environmental sustainability?

Scope

This Master thesis will investigate the sustainability of the Zero Fossil Fuels Initiative on Galápagos by assessing the sustainability of the RE system on each island of the archipelago. Therefore, it is not within the scope of the thesis to consider alternative carbon avoidance technologies such as end-of-pipe pollution control, change of raw material to gas or process-integrated emission control. In addition, the assessment of the technologies' sustainability will be based on existing studies such as environmental impact assessments or sustainability assessments for other locations. Due to time constraints, the execution of new assessments to analyse the lifecycle GHG emissions based on primary data of the technologies used on the Galápagos was not within the scope of this thesis. Furthermore, the thesis does not consider comprehensively all technologies and subcategories, such as differentiating between solar panels based on mono- and polycrystalline technologies because of the sheer number of new inventions. Therefore, the evaluation is based on the main technologies for producing electricity from sun, wind, water and geothermal energy potential that are planned for implementation on Galápagos.

Concerning the representativeness of the interviews it must be noted that it was not possible to contact all experts, as some were not available. However, in view of the fact that numerous experts have been interviewed[5], covering all different institutions and stakeholder groups, it can be assumed that all relevant aspects have been considered and documents collected. It cannot be excluded, though, that some experts were biased while answering questions and providing suggestions.

1.3. Structure

The aim of this study is to examine the sustainability of the energy system on the Galápagos Islands in light of the Zero Fossil Fuel Program and the relevant implemented RET projects or those under execution. Therefore, this paper is divided into six sections. The first chapter presents motivation, hypothesis, research question and scope of this Master thesis, and lays down the research methodology. The background of and the motivation for the Zero Fossil Fuel Program are explained in the second chapter. The third chapter contains the theoretical and conceptual framework of the sustainability assessment based on a state-of-the-art literature review. This section carves out adequate criteria to assess the sustainability of the energy system on Galápagos. The fourth chapter describes in detail the chosen criteria for the sustainability assessment while providing an overview of the energy system on Galápagos. In chapter five, the criteria are applied to the sustainability assessment of the energy systems of the four populated islands.

[5] See Annex 3 for a list of interviewed experts and stakeholder on all four populated islands of the Galápagos archipelago and in Quito between July and September 2013.

In the fourth and fifth chapter official primary data from Ecuadorian governmental authorities as well as secondary literature are used. Finally, the sustainability assessments of the single islands are united and an attempt is made to provide an outlook on the prognostic sustainability by associating the current RE concepts on the Galápagos Islands with future drivers of demand. The thesis concludes with recommendations for a more sustainable transformation of the energy sector on the archipelago.

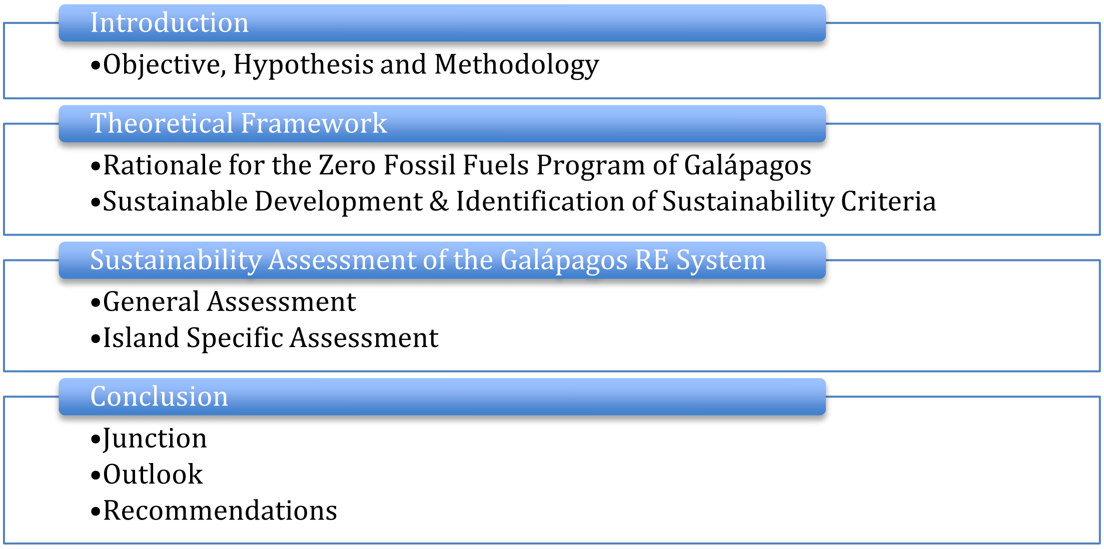


Figure 1: Outline of the thesis
Source: Own elaboration

1.4. Methodology

The complexity of a sustainability assessment requires the application of both empirical and theoretical concepts. Hence, this study uses a combination of different theories and approaches – also called triangulation. As the research method chosen for the thesis is the case study, the objective of the triangulation is to create a more comprehensive picture and understanding of the case. At the same time, a case study uses the complexity of a real-life context to investigate a single entity or phenomenon (Yin, 2009: 4), "the case" that is bound by time and activity (Creswell, 1994). Moreover, a case study concentrates on any phenomena, adds Thomas (2011: 3), that for example, could be a country, region, event, institution, person, group, a period in time, a company or relationship. The uniqueness of the subject and its completeness are central to the case.

While the first research question could be answered by doing a survey, the answer to the question “how” requires the implementation of a case study (Yin, 2009: 10). In this thesis, the Galápagos archipelago is the case study allowing for the examination of "how" sustainable the RE systems implemented under the Zero Fossil Fuels strategy are. To achieve more sustainable and balanced results, it is necessary to consider various angles and to create a three-dimensional picture of the case. Therefore, the case study relies on multiple sources, such as quantitative and qualitative evidence, and interviews, as well as direct observations (Hulme, 2007: 1; Yin, 2009). The combination of quantitative and qualitative approaches, also called Q-squared, is used as it offers benefits in terms of data quality and depth of understanding (Hulme, 2007). Consequently, to deal with the complexity of the subject, the empirical research part of this thesis is based on a variety of data collection techniques including expert interviews[6], field visits and assessment of primary data sources, as well as a state-of-the-art project and literature review. A field research visit to Ecuador and the Galápagos Islands was undertaken from July to September 2013 to conduct expert interviews and site visits. In addition, several observations[7] of sociological behaviour were made, primarily regarding cultural and social aspects such as the population's acceptance of REs, their consumption priorities, lifestyle, fears, needs and their expectations. Furthermore, a quantitative approach is applied based on primary data. For example, statistics on energy generation, fossil fuels supply and REs have been collected from the state-owned oil company, *PetroEcuador*, the electrical utility, *ElecGalápagos* (*Empresa Eléctrica de Galápagos)*, and the wind park corporation, *EOLICSA (Corporación Eólica San Cristóbal)*. In addition, a qualitative approach is used when conducting semi-structured interviews with experts or examining documents, such as maps. Generally, the research approach is interdisciplinary and multimodal in order to cover all relevant aspects of REs and sustainability (Jewitt, 2009).

Regarding the sampling in the thesis, it is no coincidence that the Galápagos archipelago has been chosen as "sample", as the "case". Firstly, according to Johnson and Marian (2009: 2234):

> *"An Island serves as an excellent location for a holistic approach and for innovative solutions to improving the sustainability of the energy sector: the boundaries are distinct and the points of entry for imports are few and easily tracked".*

[6] Concerning expert interview it is crucial to choose the "best" persons, where "best" means those that "best help us understand the case". Therefore, all the interview persons were experts in their area and were chosen based on their occupation and their relevance to the field of study. For this purpose, the "snow-ball" sampling has been used.

[7] According to Nebel and Wright (1993; 6) all scientific information is based on observation and is subject to objective verification.

Secondly, there are high demands on water, energy, transport and goods – especially during the peak season, when large numbers of tourists visit the islands (Smink et al., 2010: 2). Thirdly, the archipelago is a conspicuously good case, as it receives a significant degree of attention due to its status as World Natural Heritage site. Fourthly, it is not a typical case but an "outlier case" that is atypical or extreme. It can, therefore, offer an unusual, interesting and particularly revealing set of circumstances. A case such as this might allow disclosing more information than the potentially representative case. Nevertheless, the above-mentioned special features and particularities imply that the case cannot serve as a blueprint for other locations because it is about the particular rather than the general. According to Thomas (2011), no generalization from a single case study is possible. In addition, the unique ecosystem, the endemic[8] species and the isolated location of the Galápagos do not only elevate the visibility of sustainable activities but also constrain the possible solutions.

In addition to empirical principles, theoretical approaches are used. First, in order to structure the thesis, the SWOT Energy Analysis Tool developed by the Aalborg University is applied (Smink et al., 2010). The steps they suggest are inspired by Sorensen and Vidal (1999: 26) and can conveniently be aligned with the case study sequences according to Yin (2009: 5). These include the following: Background, Status, Analysis, Planning I, Planning II and Action. Accordingly, the background of the Galápagos is examined and case study evidence collected while developing the criteria for the sustainability assessment. The status will describe the current situation of the energy system in general, and for each island in particular. The analysis is covered by examining the RE systems' sustainability. It considers the efforts in the framework of the Zero Fossil Fuel Program that have already been made or are currently under development in order to reduce the use of fossil fuels. The thesis concludes by considering Planning I and providing a junction of the sustainability assessments as well as an outlook for whether or not the islands move into the "right" direction, i.e. if the initiatives chosen are sustainable. Planning II is briefly represented through the recommendations given in the conclusion. These might provide an inspiration for reconsidering and reformulating the Zero Fossil Fuel Program for the Galápagos archipelago with a more pronounced focus on sustainability. Based on the planning, "actions" are necessary. However, the additional research, communication and cooperation required to develop the next

[8] An endemic species is natural to or characteristic native or indigenous of a specific place. It belongs exclusively or is confined to a particular place.

steps lie beyond the scope of this thesis.

Second, IRENA (2013: 2) points out the importance of “sustainable energy systems design, modelling and planning as an integrated and comprehensive approach towards the transition to a renewables-based energy future”. The aim is to reach an optimal solution in terms of cost, social acceptance, technical feasibility, and environmental protection. For this reason, the sustainability approach as defined by the Brundtland Commission (WCED/ UN, 1987) is used to analyse the Zero Fossil Fuels Initiative of the Galápagos. This triangular approach to sustainability takes into account the social, environmental and economic dimension (The World Bank, 1995; OECD, 2008a; OECD, 2008b).

Third, the Energy Service Approach is taken into account since it enhances the chance of a sustainable use of energy. This approach has two advantages: it can create a greater sense of satisfaction amongst beneficiaries that their needs are met and it considers affordability. It is an end-use oriented and demand-driven approach that focuses on what people actually want and need. In order to do so, it also considers changes in energy demand such as changes in energy efficiency and a shift to modern energy carriers. It contrasts purely supply-side planning, which focuses on the provision of energy sources and appropriate conversion technologies (UNDP, 2000; Skutsch et al., 2005; Miller and Birkeland, 2011; Kaygusuz and Toklu, 2012).

2. Zero Fossil Fuels on Galápagos

> *"More than 230 islands, islets and rocks born of volcanoes make up the archipelago. Their isolation, during million years, has created ecosystems, unique, on Earth. Today, these ecosystems are sustenance of the local people and visitors who come, and benefit from them."* (PNG, 2014a)

2.1. Development of the Zero Fossil Fuel Program on Galápagos

The idea to implement REs on Galápagos is not new. In 1995, with the support of the United Nations (UN), the Ecuadorian government examined the barriers for the installation of RETs (ERGAL/ KfW/ Lahmeyer, 2001). However, it took until 2001 to initiate concrete, RET-based, project ideas with the goal of auto-sufficiency for the electricity sector. Subsequently, on 20th February 2002, the Ecuadorian Ministry of Energy and Mines (MEM), the Ecuadorian Ministry of the Environment (MAE) and United Nations Development Program (UNDP) signed a Memorandum of Understanding aiming at partially repowering the islands with REs. For this purpose, the Ecuadorian government and UNDP signed an agreement in April 2003 to establish "ERGAL" as umbrella for the execution of the project "Ecuador: Renewable Energy for Electricity Generation – Renewable Electrification of the Galápagos Islands" (*Ecuador: Energía Renovable para la Generación de Electricidad – Electrificación Renovable de las Islas Galápagos*) (ERGAL, 2014). Although the Ecuadorian government, UNDP, and GEF initially agreed on objectives and on a number of projects to reach 60% electricity from renewable energy sources (RES-E) on the islands, each of them has to be agreed on and executed separately (ERGAL/ KfW/ Lahmeyer, 2001: 13). In 2007, the initiative was reinforced and extended by the Ecuadorian government announcing the "Zero Fossil Fuel Program of Galápagos" (*Programa Cero Combustibles Fósiles en Galápagos*) (MEM, 2007a; SENPLADES, 2007; La Insignia, 2007; GEF/ UNDP, 2006).

Figure 2 demonstrates the current and expected electricity demand, as well as the share of fuels used. It suggests that a combination of REs and energy efficiency measures shall help eliminate fossil fuels in the electricity sector until 2015 (ERGAL/ DED/ MEER, 2008: 9). In addition, the "Energy Agenda 2007-2011" of the MEM substantiates the Zero Fossil Fuel Program with the warning that fossil fuel consumption on the islands is increasing by 10% per year, augmenting risks of negative environmental impacts. Furthermore, it refers to the "Executive Decree No. 270 from 10.4.2007" declaring the conservation of Galápagos a national priority (República del Ecuador, 2007). Therefore, the aim is to eradicate fossil fuels on the archipelago in the electricity, as well as subsequently in the maritime and terrestrial transport sectors. This shall be reached by implementing RETs for electricity generation and heating, replacing fossil fuels with biofuels and by introducing electrical and hybrid cars (MEM, 2007a: 98; Alvear and Lewis, 2013).

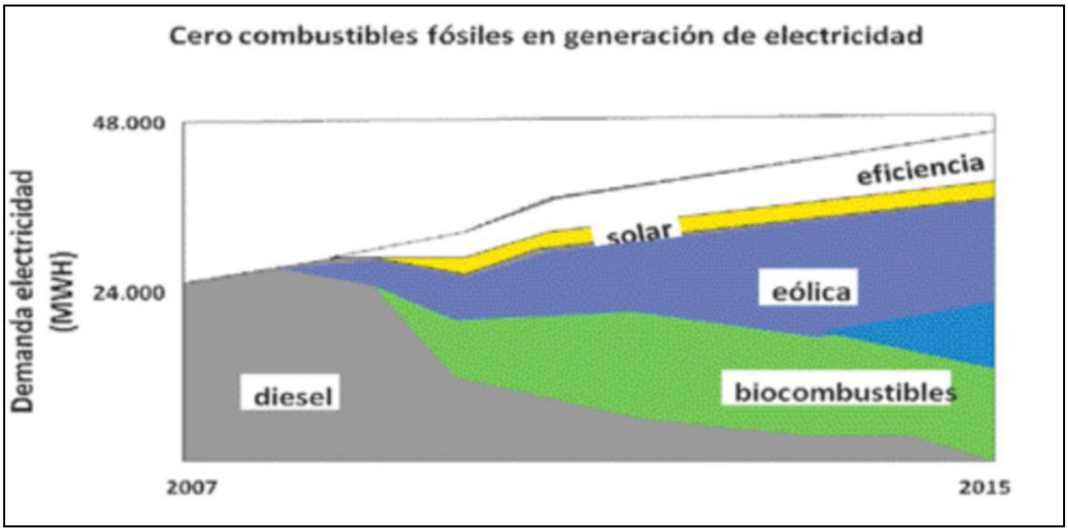


Figure 2: Expected Demand of Electrical Energy in Galápagos (MWh/ year)
Source: (ERGAL/ DED/ MEER, 2008: 9)

Currently, hybrid systems or multi-source systems are planned for most of the islands. With the aim to deliver stable and affordable energy, these systems combine the benefits of different RETs to leverage their respective strengths. They had been developed by Lahmeyer International (2001) and selected in 2006 by GEF and UNDP (2006: 23) primarily due to economic viability. In all cases, the diesel generators will either remain in place or will be replaced by new thermal units to meet back-up requirements. Such RE systems can provide reliable electricity 24 hours a day 7 days a week if they are properly designed (IEA-RETD, 2012: 41).

2.2. Rationale for Renewable Energies on Galápagos

On Galápagos, the consumption of fossil fuels and the dependence on them has been rising since the first settlers arrived. This is due to increasing population, flourishing tourism, the growing economy, higher income and subsequent modernization driven by the wish for a higher standard of living. The improved quality of life has become possible thanks to the unique and pristine ecosystem the

Galápagos Islands offer. Therefore, the aim is to maintain this natural paradise by avoiding environmental risks due to fossil fuel consumption and transport. The declared objectives of the Zero Fossil Fuel Program are to foster independence from fossil fuels and to protect the biodiversity on Galápagos not only with respect to the risks associated with transportation and transfer of fuel but also to reduce GHG emissions (GEF/ UNDP, 2006; MEM, 2007b; CONELEC/ MEER, 2012: 91).

The risks connected to the current energy supply are numerous. Firstly, the energy demand is exclusively met through imports, as the archipelago has no own fossil fuel resources. In view of the small storage capacity on the islands, frequent deliveries from continental Ecuador are necessary (GEF/ UNDP, 2006). This creates a strong dependence of the islands on the mainland. In light of declining oil and gas resources in Ecuador[9], the difficulties connected to this dependence may be aggravated in the future (Oxilia and Luna, 2011: 14; OLADE, 2012). Moreover, possible interruptions in the supply chain – as those frequently occurring with LPG that is used for cooking – could leave the islands without energy, resulting in high social and economic costs (ERGAL, 2008a: 5). Secondly, as nearly all fuel is imported via maritime vessels, possible contamination occurs not only during combustion of fossil fuels but also during transit (CONELEC, 2007; ElecGalápagos/ PSI/ PNG, 2011; Molina, 2012: 78). Although the unique biodiversity on Galápagos makes its ecosystem especially vulnerable to emissions and other pressures on natural resources, several smaller oil spills have already occurred, such as the ones by the vessels Iguana or Taurus in 1988 and 2002 respectively (Sanderson et al., 2001; Lougheed et al., 2002; GEF/ UNDP, 2006). The possible risk to biodiversity through oil spills could also be seen in 2001, when the oil tanker Jessica ran aground on Shiavioni Reef at the entrance of Wreck Bay on San Cristóbal Island (European Commission, 2001). Due to the accident, of the 240,000 gallons the ship was carrying, 180,000–200,000 gallons of diesel and intermediate fuel oil escaped and dispersed within the islands causing the death of around 10,000 marine iguanas and other species (Sanderson et al., 2001; Lougheed et al., 2002; GEF/ UNDP, 2006). The costs of this accident included not only USD 9-10 million for compensatory restoration measures, but also a loss of biodiversity and diminished number of tourists because of the adverse publicity caused by the spill (GEF/ UNDP, 2006; ERGAL/ DED/ MEER, 2008). Although an overall quantification of the costs caused by the oil spill is difficult because of the large size of the marine environment, this incident showed the extreme vulnerability of the islands and the

[9] Oil resources in Ecuador are expected to only last for approximately 36 more years (OLADE, 2012).

potential costs connected to accidents. To date, oil deliveries take place twice per month with a new oil tanker bringing diesel and gasoline to the islands exposing them to the danger of a potentially repeated accident. Thirdly, fossil fuels use is inherently connected to combustion technology that causes combustion products such as CO_2, aerosols, CO, SO_2 and NOx. These pollutants are released into the atmosphere, which has a negative impact on human health or induces a climate effect (IPCC, 2011; GEA, 2012; OECD/ IEA, 2012; Keeling, 1978).

Aside from the aim to mitigate risks and reduce dependence, the Zero Fossil Fuel Program is in line with the country's overall aim of "living well" in harmony with nature without exploiting natural resources, as laid down in the Ecuadorian constitution and in the national Plan for Well-Living (República del Ecuador, 2008; SENPLADES, 2013). To eliminate fossil fuels, the utilization of RES-E state-of-the-art hybrid systems shall be establised on each of the four islands. These systems shall demonstrate the sustainable use of RETs in an ecologically fragile and remote area, encourage the adoption of these technologies and serve as replicable framework for future projects that could also be pursued in continental Ecuador and other islands (GEF/ UNDP, 2006).

3. Sustainability Assessment: Concepts and Framework

In this chapter, the basic concepts used for sustainability assessment are described with a specific focus on the Galápagos Islands. Key criteria and indicators are identified for the assessment of the renewable energy systems.

3.1. Defining Sustainability and Sustainable Development

"Sustainable development is the imperative of the 21st century. Protecting our planet, lifting people out of poverty, advancing economic growth – these are different aspects of the same fight. (…) We will not achieve any of these goals without energy – sustainable energy for all." (Ban Ki-moon/ UN/ Se4All, 2011: 3)

Long before our current generation, civilizations tried to live their life in balance with nature, its resources and variations. The term *sustainability* appeared for the first time with respect to the management of forests in Germany in order to stop deforestation[10]. In his "Limits of Growth" (1972), Dennis Meadow evoked the worldwide debate on the issue of sustainable use of limited natural resources and the need for decoupling economic growth and environmental impact. In light of the ensuing oil crisis of 1973 and several chemical accidents, the World Wide Fund for Nature (WWF), Greenpeace, green political parties, the Stockholm Declaration, the United Nations Environment Program (UNEP), the United Nations Framework Convention on Climate Change (UNFCCC), the Montreal Protocol and many more emerged. Academic and political discussions about sustainability intensified during the 1980s, culminating in the Brundtland Report "Our Common Future" by the World Commission on Environment and Development (WCED). This report laid out the concept of SD, defining it as:

"… development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED/ UN, 1987).

This report was an important milestone. It gave the impetus to the Earth Summit held in Rio de Janeiro in 1992, which in turn, lead to the *Rio Declaration* and the *Agenda 21*. In 2000, the UN formulated *Millennium Development Goals* (MDGs) with the aim to reduce poverty, meet basic needs of the poor and to ensure environmental sustainability. In 2002, the World Summit on SD (Rio+10) was held in Johannesburg and in 2012, the Rio+20 Conference on SD, held again in Rio de

[10] Sustainability has been mentioned in a publication of Carl von Carlowitz (1645-1714).

Janeiro, resulted in the outcome document *The Future we Want* (UN, 2012). From the first formulation of SD until today, the concept has developed from a one-dimensional triangular approach based on three pillars – as defined by the Brundtland Commission – to a complex system of inter-linkages. Emphasis has shifted towards a balanced use of resources and to a collaborative and participative approach for the benefit of the people and the planet (Khatiwada, 2013). Nevertheless, it can still be traced back to the three dimensions as illustrated in Figure 3.

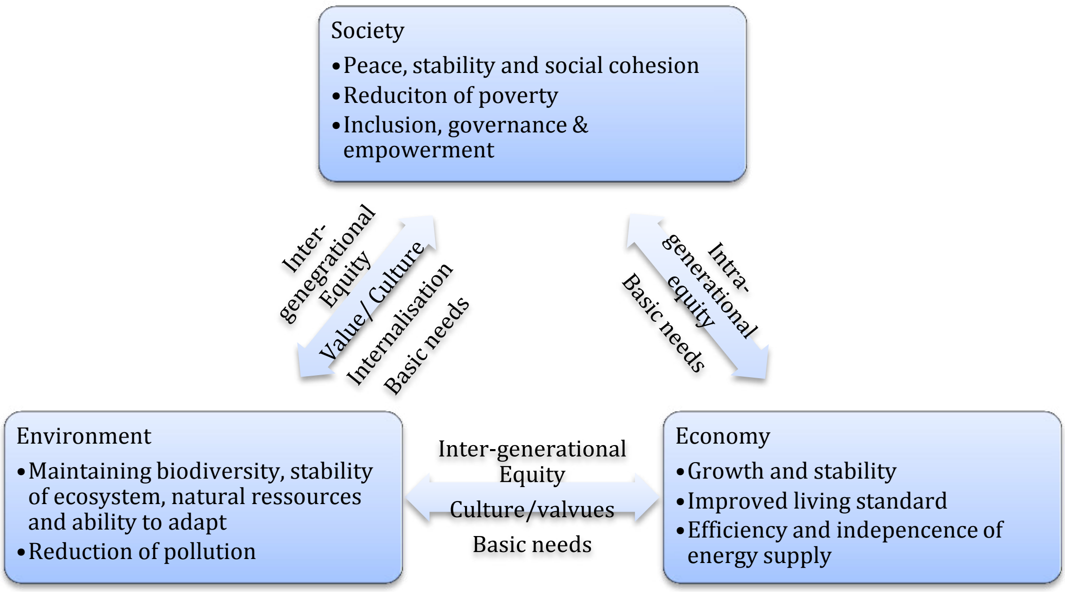


Figure 3: Dimensions of Sustainability and their Interrelationships
Source: Adapted from (The World Bank, 1995; OECD, 2008a; OECD, 2008b)

Generally, sustainability covers the realm of society, economy, and environment, or in other words: people, prosperity and the planet. SD means that the environment, comprised of the earth, its biodiversity and ecosystems, scarce resources and cultures, needs to be sustained, while society (states, regions, social capital, institutions), economy (wealth distribution, consumption), and people (education, equity, equality, life expectancy, survival) need to be developed (Kates et al., 2005; Khatiwada, 2013). This is summarized in Table 1.

According to many scholars, the concept of SD, its underlying three pillars and the aforementioned SD goals have become important for verifying the sustainability of energy systems (IAEA/ UNDESA/ IEA/ EEA, 2005; Kemmler and Spreng, 2007; Waheed et al., 2009; Khatiwada, 2013; WEC, 2013). In other words, a sustainable energy system should support and not threaten the attainability of these goals.

Table 1: Sustainable Development Goals
Source: Adapted from Kates et al. (2005) and UN DESA (2013: 113)

What is to be sustained?	What is to be developed?
S1) Nature: Earth, Biodiversity, Ecosystems	D1) People: Child survival, Life Expectancy, Education, Equity and Equal Opportunity, Human Security
S2) Life Support: Ecosystem services, Resources, Environment	D2) Economy: Wealth, Productive Sectors, Consumption
S3) Community: Peace, Cultures, Groups, Places	D3) Society: Institutions, Social Capital, States, Regions

In order to determine how sustainable an energy system is, it is important to consider the environmental, economic and social systems not only in isolation, but also with respect to their interrelations. Since environmental integrity, social development and economic prosperity are very well interconnected, synergies as well as trade-offs appear (UNDESA, 2013). Because they reinforce each other, it is not possible to deal with each pillar in isolation (Hediger, 2000). For instance, environmental protection involves economic costs and has an effect on social equity, as most often, the poor are more adversely affected by environmental pollution. Nevertheless, they do not have the financial means to pay for pollution abatement. As another example, an energy intervention using REs can positively impact health while imposing a financial burden if the affordability of the system is not considered sufficiently. This shows that focusing on only one of the three dimensions may result in merely shifting burdens instead of an overall decrease in burdens (Waheed et al., 2009).

In summary, sustainability and SD are among the most debated approaches of our time[11]. Nevertheless, reaching sustainable conditions in the environmental, economic, and social sphere is one of the most desirable developments.

3.2. Integrated Systems Approach for the Sustainability Assessment of a Renewable Energy System

Energy is a core element of development and is closely linked to human history. Its configuration and application influences all three dimensions of sustainability due to its interconnections with the environment, society and economy. Sustainable development implies the transformation of the energy system in a way that it can

[11] At present, sustainability is often criticized as a "buzz word". Nevertheless, most scholars and politicians agree with Coleman (2012a) since "even if you are sick of hearing the word "sustainability" there is something to its allure. The word evokes debate, critical thinking, and personal reflection within individuals' attempts to realize a better lifestyle and for society at-large and as a generation attempting to find its foothold amid financial turmoil and on-going geopolitical uncertainty."

promote social equity, economic development and environmental protection. Conventional energy systems based on burning fossil fuels have adverse impacts on the attainment of SD goals. For instance, they foster climate change and thereby pose a threat to biodiversity and human health, manifested by incessant droughts, storms and floods (Mukoni, 2013; Roehrl, 2013). According to Colombo et al. (2014), RETs are considered a solution for mitigating these risks while also fighting poverty and keeping up the quality of energy supply with local resources. However, if RETs shall have a positive influence, the nexus between sustainability and energy needs to be considered carefully. Due to the interrelations, synergies and trade-offs that characterize SD scenarios (Roehrl, 2013), this assessment, however, is complex (Liu, 2014). For instance, the socio-economic benefits of bioenergy are closely linked to social challenges and environmental burdens such as the conflict over natural resources and food security. Energy generation – especially biofuels and fossil fuels – requires large amounts of water, so an increase in energy consumption to achieve universal access to energy would directly result in an increased demand for water (PBL, 2012: 50; Roehrl, 2013: 36; 46). An integrated approach is needed to deal with this complexity (Khatiwada, 2013).

Furthermore, the aim of SD is to maintain the balance of the overall system. Therefore, the energy system on the Galápagos archipelago also needs to be balanced between the needs of the population, the requirements of conservation and the techno-economic feasibility. This is essential to reach social acceptance and satisfaction of local inhabitants and foreign visitors, as well as to assure its long-term success. Balancing the three dimensions, however, does not mean that there is no change at all. The world and nature itself are in a constant state of flux (Coleman, 2012b: xxiii). In addition, as the energy system and society are not static, the sustainability assessment requires an understanding of the relative merits of different options and a continued adjustment in response to changing priorities, conditions and knowledge (Dale et al., 2013). Its evolution depends on local conditions, socio-economic structures, and the priorities of the respective stakeholders. For instance, the sustainability assessment on Galápagos has to take into consideration the special interest in, as well as requirements for, conserving and protecting the unique and delicate biodiversity of the islands' marine and terrestrial biotas. Contrary to this, the sustainability assessment in a city like London, New York or Rio de Janeiro would have to consider large industries and criminality, which are insignificant on Galápagos. Therefore, summing up these passages results in the observation that there is the need for an integrated systems approach. This approach does not only consider the three dimensions of sustainability, their interconnections, synergies and trade-offs but also the specific local conditions and changing priorities.

3.3. Approaches for the Sustainability Assessment of Renewable Energy Systems

There are several approaches, conceptual frameworks and methodologies that can be used for assessing the sustainability of an energy system. Although, they vary greatly in terms of methodology and scope, most of them rely on sustainability indicators to assess the RE system (Liu, 2014). The following sub-chapter provides a review of relevant literature. This overview is not necessarily exhaustive, however, it is certainly representative to develop criteria for the assessment of the RE system on Galápagos.

Classification of Sustainability Indices

Sustainability indicators "are increasingly recognised as a useful tool for policy making and public communication in conveying information on countries and corporate performance in fields such as environment, economy, society, or technological improvement (Singh et al., 2009: 189). Although sustainability assessment is an emerging concept Waheed et al (2009) provide an extensive overview of sustainability indices, classified into six categories: (1) objective-based, e.g. strategic environmental assessment; (2) impact-based, e.g. environmental impact assessment (EIA); (3) influence-based; (4) process-based or stakeholder-based; (5) material flow accounting and life cycle assessment; (6) linkages-based, e.g. pressure-state-response (PSR). Based on this classification, the sustainability assessment of the energy system on Galápagos can most closely be related to an objective-based framework, as it aims to ensure that a particular initiative contributes to a defined state of sustainability. This approach is objective-based and proactive in nature; the defined state of sustainability, however, is rather vague: it would be the islands' situation in the case of eliminating fossil fuels. Although it can generally be expected that a 100% RES-E system on the islands would make them "better off" from an environmental, social and economic point of view, it is not defined what this outcome would look like. Nevertheless, Waheed et al. (2009) also point out that various engineering disciplines apply the impact-based framework. EIA and SIA are typical examples that usually focus on the sustainability of a particular system that may have both positive and negative impacts on one or more of the three dimensions. They refer to that as the "triple bottom line (TBL)", presented in Table 2, and claim that for any engineering project the following performance assessment criteria can be of importance:

Table 2: Sustainability Matrix – an example in terms of TBL objectives
Source: (Waheed et al., 2009)

Performance Assessment Criteria	Objectives		
	Environment	Economics	Society
Health	X		X
Safety	X		X
Economic Development	X	X	X
Social Equity		X	X
Environmental Quality	X	X	X
Ecology	X		
Technical Feasibility		X	X

The benefits of using *environmental impact assessments (EIA)* and *strategic impact assessments (SIA)* to identify the environmental and to a lesser extent also social and economic impacts of projects, plans, programs, and systems have also been acknowledged by Khatiwada (2013) or Carrera and Mack (2010). Especially environmental and social sustainability indicators are closely linked to EIA and SIA (Carrera and Mack, 2010). In the context of analysing the sustainability of the energy system on Galápagos it is worthwhile to consider these studies, in particular since environmental impacts have an outstanding significance for these islands.

Integrated Assessment Models: Nexus Models

Another type of model that can be useful for the evaluation of the sustainability of energy systems is the nexus model. These kinds of integrated assessment models embrace the water-energy-food nexus (WEF) or the climate-land-use-energy-water-systems nexus (CLEWS), which analyse the interdependencies and interactions between the different key resources (Baziliana et al., 2011). For instance, the study by Welsch et al. (2014) provides new insights into Mauritius' energy system and its interdependencies and illustrates the importance of capturing interconnections between CLEWS when designing strategies for SD. Baziliana et al (2011), however, point out that the scope and focus of integrated assessment models can vary widely and that they contain certain limitations. For instance, there is a fragmentation of analytical, decision- and policy-making tools[12] that are used to support decision-making concerning most water, energy and land use planning. Most tools and

[12] Among the common tools and models used for water system planning are the Water Evaluation and Planning system (WEAP), for water scarcity and food security planning, the Global Policy Dialogue Model (PODIUM), for energy system analysis MESSAGE, MARKAL and LEAP are applied. Nonetheless, these and other models lack the methodological components and data essential to conduct an integrated assessment.

models focus on only one resource – ignoring the inter-linkages between other resources; have overly simplified spatial representations; are policy "research" rather than short term applied "policy" decision support models; or analyse scenarios, which are impractically long-term (Baziliana et al., 2011).

Goals of Sustainable Development Scenarios

A report published by UN DESA (2013) gives a comprehensive overview of global SD scenarios, their goals, visions, and characteristics. All of these scenarios consider energy in one way or another, demonstrating that it is an essential part of SD. This fact and the general goals and indicators used in the scenarios inspired the development of criteria for the sustainability assessment of the energy system on Galápagos. Therefore, they are reviewed briefly in the next paragraphs.

The IIASA´s *Global Energy Assessment (GEA) for Rio+20* (Riahi et al., 2012: 1217; GEA, 2012; McCollum et al., 2012) provides four targets that a sustainable energy system shall promote: (1) improve energy access; (2) reduce air pollution and improve human health; (3) avoid dangerous climate change; and (4) enhance energy security.

The Netherlands' Environmental Assessment Agency (PBL[13]) with contributions from the British Overseas Development Institute and the Agricultural Economics Research Institute created the *PBL Sustainable Development Scenarios for Rio+20*. The approach is broader than IIASA's, as it considers more issues and sectors but has a lower technology resolution (Roehrl, 2013: 37). The goals presented in the scenarios embrace (1) human development (such as ensuring universal access to modern energy); (2) prevent climate change; (3) conservation of biodiversity, sustainable use of its components, and fair and equitable benefit sharing; (4) ensure sustainable use of water resources; (5) avoid acidification and eutrophication by avoiding interference with P and N cycles; and (6) reduce environmental health threats. Furthermore, for the energy sector, four main challenges were identified (Roehrl, 2013: 40; PBL, 2012): (1) provide sufficient energy to meet increasing demand; (2) ensure access to modern energy for all; (3) reduce environmental impact of the energy system; and (4) improve energy security. In addition, the authors point out specific synergies and trade offs. For example, universal access to energy requires affordability – while mitigating climate change causes higher costs. Moreover, using biofuels to reduce GHG emissions could threaten the goal of halting biodiversity loss, since additional land would likely need to be dedicated to

[13] Dutch: Planbureau voor de Leefomgeving (PBL).

growing bio-energy crops. Similarly, clean water needs might be compromised by universal access to energy as power generation – especially when it is based on fossil fuels – requires large amounts of water (Roehrl, 2013).

The Research Institute of Innovative Technology for the Earth (RITE) created *Alternative Pathways toward Sustainable Development and Climate Stabilization* referred to as RITE's ALPS scenarios for RIO+20 (Roehrl, 2013: 49ff; Akimoto et al., 2012). The main SD goals coalesce around: (1) poverty reduction; (2) energy efficiency; (3) energy and food security; (4) reduction of water stress, air pollution, land degradation and fossil fuel use; and (5) the limitation of dangerous climate change.

The OECD's green growth scenarios within the *Environmental Outlook for 2050* defined the following key environmental challenges (Roehrl, 2013: 55ff.): climate change, biodiversity, water, health and environment. Energy, however, is only considered indirectly as input factor.

The Stockholm Environmental Institute (SEI) developed sustainable energy scenarios for Rio+20 based on the scenarios of IIASA and PBL with its Long-range Energy Alternative Modelling System (LEAP) (Nilsson et al., 2012; Roehrl, 2013: 60ff.). Their four main goals are the following: (1) elimination of poverty; (2) improved energy access; (3) creation of a "global middle-class" through income convergence; and (4) avoidance of dangerous climate change by keeping global average temperature under 2°C.

The Italian foundation *Fondazione Eni Enrico Mattei* developed SD targets with the WITCH model including: (1) reduction of GHG emissions through limitation of the energy use[14]; (2) implementation of clean energy[15]; and (3) increase of energy efficiency; boosted by (4) innovative policy and increased research and development expenditure (Roehrl, 2013: 64ff.).

In summary, there is an impressively strong consensus on the broad direction of trends and major sustainability issues (Roehrl, 2013). In addition, the following "must haves" for a sustainable energy system were identified: (1) improvement in energy intensity and end-use efficiency; (2) shift from traditional biomass to cleaner and more flexible energy sources; (3) use of low carbon sources; (4) electrification of the transport sector; (5) reducing wasteful use of energy in buildings, transport and industry; and (6) decisive policies to support an energy system transformation (Riahi et al., 2012: 1260; Roehrl, 2013; GEA, 2012).

[14] Less than 70 GJ per capita by 2050.
[15] Spend at least 0.09% of GDP.

Indicators for tracking the Sustainability of an Energy System

In addition to the aforementioned scenarios, there are studies that specifically focus on assessing the sustainability of energy systems. For instance, the IAEA together with UN DESA, IEA and EEA, developed a set of 30 indicators for sustainable energy development (ISED) classified into three dimensions (IAEA/ UNDESA/ IEA/ EEA, 2005). However, they point out that there are numerous inter-linkages, which allows the classification of some indicators into more than one dimension. Their classification, subdivisions and indicators are visualized in the Figure 4.

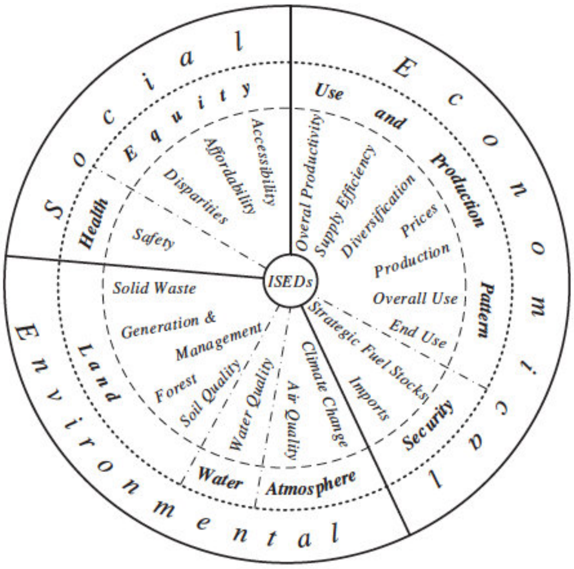


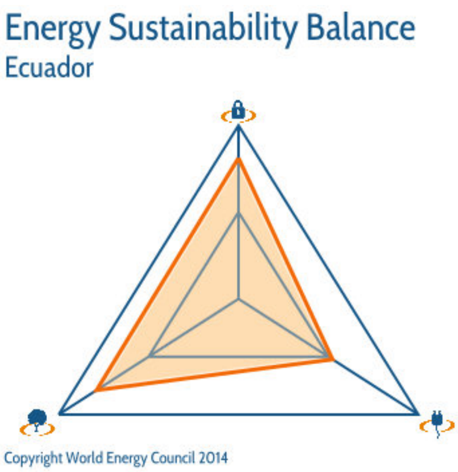
Figure 4: Proposed ISEDs by IAEA,
Source: Visualisation in (Meyer-Naimi and Vaez-Zadeh, 2012: 353) based on (IAEA/ UNDESA/ IEA/ EEA, 2005)

Moreover, also Kemmler and Spreng (2007) from the Swiss Federal Institute of Technology, developed indicators for tracking the sustainability of energy systems. While they also chose their indicators around the three sustainability dimensions, they focused on energy systems in developing countries. They highlight that the sustainability discussion in these countries considers poverty and equity as equally important as environmental issues. Contrarily, developed countries emphasize environmental aspects. They chose the following indicators: (1) economy: economic activity, efficiency and energy resource stock; (2) environment: climate change, local, regional and indoor air pollution; and (3) social: poverty and equity.

The World Energy Council (WEC) published an *Energy Sustainability Index* (ESI) aiming at creating a common understanding of what energy sustainability is. They claim that although energy systems around the world remain at vastly different stages of development all countries share one common problem: “They are far away from achieving sustainable energy systems.” (WEC, 2012; WEC, 2013). According to them, such a system is necessary to support sustainable economic and social development. The WEC uses the following three energy performance dimensions:

- ⇨ Energy security: “The effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand”.
- ⇨ Energy equity (in 2012: social equity): “The accessibility and affordability of energy supply across the population.”
- ⇨ Environmental sustainability (in 2012: environmental impact mitigation): “The achievement of supply- and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.”

They argue that a development of a stable, affordable and environmentally sensitive energy system cannot be reached with simple solutions since the three goals constitute a “trilemma”. Their argumentation is in accordance with many other scholars mentioned before and coalesces around the “complex interwoven links between public and private actors, governments and regulators, economic and social factors, national resources, environmental concerns, and individual behaviour” (WEC, 2012: 3)[16]. In addition, they defined three contextual performance dimensions: political strength, societal strength, and economic strength. Figure 5 illustrates the energy sustainability balance of Ecuador. This country, to which Galápagos belongs, improved its overall score in the WEC´s ESI from the 45th rank in 2011 to the 35th rank in 2013 (out of 129 countries).



ENERGY SUSTAINABILITY INDEX RANKINGS

Ecuador

	2011	2012	2013	TREND
ENERGY PERFORMANCE	24	20	23	↓
Energy Security	27	23	25	↓
Social Equity	71	65	62	↑
Environmental Impact Mitigation	25	27	28	↓
CONTEXTUAL PERFORMANCE	87	79	78	↑
Political Strength	117	112	109	↑
Societal Strength	102	89	89	→
Economic Strength	47	36	30	↑
OVERALL RANK	45	40	35	↑

Figure 5: Energy Sustainability of Ecuador
Source: (WEC, 2013)

[16] Therefore, a “balance score” was added in the 2013 version that shall reflect “how well a country manages the trade-offs between the three competing dimensions” (WEC, 2013: 12).

It is noteworthy that many small developing island states, such as Madagascar, Jamaica and the Dominican Republic have relatively poor ranks in the ESI. Energy security is especially difficult to reach for them, as it seems that the index does not consider REs to contribute positively to that dimension. For instance, Mauritius has a RES-E share of 25% but it comes last in energy security.

In general, however, the benefits of RES for the sustainability of an energy system have been recognized (Colombo et al., 2014). The most recent initiative in this respect is the *Sustainable Energy for All* initiative, which has the aim to encourage a positive transformation of the world´s energy system focusing on: (1) energy access, (2) energy efficiency, and (3) RES (Se4all, 2013). It is inspired by the benefits RETs can create, including strengthened economic growth, expanded social equity, and a cleaner environment[17].

Indicators for Assessing the Sustainability of a RE System

Environmental, social and economic impacts of RE systems and of each RET vary. This is because they use different kinds of natural sources, they have different sizes, visual impacts, and emissions such as noise and smell. Therefore, studies have been conducted to assess the sustainability of a specific technology, a group of technologies such as biofuels or a specific combination of technologies in a system.

Kassels (2003) provides a case study on RES to generate electricity for an environmental education centre on Isabela and Santa Cruz in the Galápagos archipelago. He stresses the importance of the social dimension of sustainability and mentions that education on RES can contribute to raise awareness for environmental conservation.

Cramer et al. (2007) outline a framework for assessing the sustainability of biomass. The project group distinguishes six relevant themes: (1) GHG emissions; (2) competition with food, land and material; (3) biodiversity; (4) environment; (5) prosperity; and (6) social well-being. They describe the first three criteria as biomass specific while the latter three in line with the “Triple-P”: people, planet and profit.

Begic and Afghan (2007) performed multi-criteria sustainability assessments of

[17] This initiative has eleven action areas. These are grouped into two categories: sectoral and enabling. The seven sectoral action areas address both power generation and the principle sectors of energy consumption. They include: modern cooking appliances and fuels; distributed electricity solutions; grid infrastructure and supply efficiency; large scale renewable power; industrial and agricultural processes; transportation; and buildings and appliances. The four enabling action areas characterize cross-cutting mechanisms designed to support effective sectoral action and address existing obstacles. They include: energy planning and policies; business model and technology innovation; finance and risk management; capacity building and knowledge sharing (Se4all, 2013).

various options for energy power systems such as thermal power units; combined cycle gas turbine plants; hydropower plants; power plants based on solar energy; wind turbines; and biomass power plants. For the evaluation they chose the following sustainability indicator: (1) resource indicator e.g. fuel and steel; (2) environmental indicator e.g. CO_2, SO_2, NOx; (3) economic indicator e.g. energy costs and efficiency; and (4) social indicator e.g. jobs and diversity (Begic and Afghan, 2007: 1981). By means of a multi-criteria assessment of potential options, decision-makers are able to evaluate various options and to select the optimal new power plant capacity.

The *RenewIslands methodology* was developed by Chen et al. (2007) and applied by Duic et al. (2008) to analyse the SD of three islands. It focuses on technically, environmentally and economically viable energy solutions. In addition, Duic et al. (2008: 1034) claim the methodology could serve as a complement to sustainability assessments and strategic design of energy systems.

Jaramillo-Nieves and del Río (2010) provide an overview of the literature and a research agenda regarding the contribution of RES to the SD of islands. They found that most studies focus on the economic dimension, while the social and environmental dimensions do not receive enough attention. They also criticise that most studies deal with islands in the Mediterranean region. In addition, virtually all papers focus on electricity and heat supply and do not take cooling or transport systems into account.

Dale et at. (2013) identify 16 socioeconomic indicators for assessing the sustainability of bioenergy systems. The minimum list of practical measures regarding bioenergy sustainability coalesces around the following six main areas: (1) social well-being: employment, household income, work days lost due to injury; (2) energy security: fuel price volatility; (3) external trade: trade volume that capture for example the profitability of the biofuel; (4) profitability: net present value that reflects for instance global market prices and soil properties; (5) resource conservation: depletion of non-renewable energy resources and fossil energy return on investment; and (6) social acceptability: public opinion, transparency.

For Demirtas (2013) sustainable energy production is environmentally, technically, economically and socially sustainable and in the long run it should be reliable, adequate and affordable. He suggests the following evaluation criteria for sustainable energy planning: (1) technical: energy production capacity, technological maturity, reliability, safety; (2) environment: impact on ecosystem, CO_2-emissions; and (3) social: social benefits, social acceptance.

Liu (2014) provides an overview of methods regarding selection, quantification, evaluation and weighting of sustainability indicators for RE systems. In addition, a framework for general sustainability indicators (GSIs) for RE systems is presented suggesting the following basic sustainability indicators (BSIs): (1) environmental indicators: CO_2-emissions, NOx-emissions, SO_2-emissions, renewable fraction, and energy efficiency or exergy efficiency; (2) economic indicators: costs, return on investment, and payback time; and (3) social indicators: job creation and benefitted residents.

3.4. Sustainability Assessment Matrix for the Renewable Energy System on Galápagos

After having briefly reviewed current concepts of SD, sustainability assessment and respective indicators, it is possible to choose sustainability indictors for assessing the Zero Fossil Fuels Strategy and the corresponding RE systems on Galápagos. Although the overview of relevant literature is not necessarily exhaustive, it is certainly representative to develop indictors for Galápagos. The motivation for the development of a modelling framework for Galápagos is based on the idea that indicators are values that provide information about the situation of a system and its targets. They facilitate orientation in a complex world by condensing large amounts of information into a recognizable pattern (Kemmler and Spreng, 2007). The preceding literature review has shown that the development of scenarios and the analysis of individual systems, such as energy or water systems are undertaken routinely. However, they often focus only on a single resource or are applied on an aggregated scale for use at regional or global levels and, typically, over long time periods. Therefore, it is necessary to choose adequate indicators for assessing the energy systems on the Galápagos Islands. The indicators should be measurable whenever possible. However, as many aspects are rather ambiguous and vague, they have been provided with a linguistic representation. The attempt has been made to translate them into numbers from 0 to 5 by using fuzzy logic[18]. The aim was to allow for a consistent treatment in a condition where ambiguity and vagueness of the criteria cannot be reduced.

Table 3 summarizes the research findings and reveals that four dimensions have been chosen for Galápagos: technological feasibility, energy security, socio-economic energy equity and environmental sustainability. This framework covers all

[18] In fuzzy logic – also referred to as diffuse logic – there are not just two alternatives but a whole continuum of true values for logical propositions.

three dimensions of sustainability, complemented by a contextual parameter focusing on technology. These dimensions are further divided into indicators, which contribute to the respective goals: the creation of a reliable, secure, affordable and environmentally friendly energy system.

Table 3: Sustainability Assessment Matrix for Galápagos
Source: Own elaboration

Sustainability Evaluation				
Dimension		**Indicators**		**Explanation**
Context 25%	**Technolo-gical Feasibility**	25%	Technological Feasibility	The technology decides whether an energy project is feasible and economically viable. The decisive factor for all RETs is the energy potential at a certain location, such as wind speed or solar irradiation.
Energy perfor-mance (75%)	**Energy Security**	25%		
			Energy Independence (33%)	The dependence on imports of energy sources can be reduced through a higher share of indigenous RES.
			Reliability of the energy supply (33%)	Reliability of supply means, that an energy source is able to provide energy where and when it is needed.
			Investment Security (33%)	A stable regulatory framework is vital for stimulating private investment, which is required for a large scale RET deployment.
	Socio-Economic Energy Equity	25%		
			Accessibility and Affordability of an adequate Electricity Supply (28.5%)	This can be expressed in three dimensions: general energy access, affordability on the demand side depending on available income, and profitability on the supply side.
			Quality of Life & Social Well-Being (43%)	
			Prosperity	Prosperity includes the creation of jobs and economic opportunities.
			Quality of Life	QOL concerns a person´s physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of his or her environment. RES can improve the QOL if they are clean, affordable, reliable and socially inclusive.
			Employee Health & Safety	Health is a state of complete physical, mental, and social well being not merely the absence of disease (WHO, 1997).
			Public/ Social Acceptance (28.5%)	Public acceptance implies "that a certain policy or a certain concrete measure is clearly or tacitly supported by members of the public who may be affected, positively or negatively, by its implementation." (IAEA, 2007: 5)
	Environ-mental Sustain-ability	25%		
			Climate Change, CO^2 and GHG Emissions	Due to the link between climate change and the consumption of fossil fuels, the deployment of RETs may reduce climate change by reducing GHG emissions.

			Freshwater Use/ Water Quality (33%)	Water is a key aspect of SD and especially crucial on islands. Water availability and quality is closely interconnected with energy.
			Land Use (33%)	Energy generation through mining, petroleum extraction, and also, bioenergy, are important drivers for LUC. REs require space for their conversion into electrical energy.
			Other Environmental Impacts (33%)	
			Ocean Acidification	Ocean acidification is closely connected with CO^2 emissions.
			Stratosph-eric Ozone Depletion	Currently, N_2O is the most relevant pollutant responsible for stratospheric ozone depletion since CFCs have been strongly reduced. Main sources of N_2O are agricultural and soil, but also fossil fuel activities.
			Biogeo-chemical Cycles	Disturbances of the nitrogen and phosphorous cycle have been identified as critical sustainability concerns since biogeochemical cycles are responsible for many life-sustaining processes on our planet.
			Biodiversity	Biodiversity loss is unacceptable for ethical reasons and – since current knowledge is incomplete – can have unexpected consequences for the functioning of the ecosystem. Biodiversity is a particularly important for the Galápagos Islands. Furthermore, there is a close interconnection with the other PBs.
			Atmospheric Aerosols (Air Pollution/ Quality)	Atmospheric Aerosols, e.g. particulate matter (PM), tropospheric ozone, as well as oxides of nitrogen and sulphur, have an adverse effect on human health and crops at both global and regional level.
			Chemical Pollution	Substances causing chemical pollution include heavy metals, radioactive compounds and organic compounds, which adversely affect human and ecosystem health, such as persistent organic pollutants, plastics or endocrine disrupters.

4. Criteria for the Sustainability Assessment of the Galápagos Energy System

In this chapter, the four dimensions of the sustainability assessment and the respective sustainability indicators are described while focusing on the energy systems on the Galápagos Islands.

4.1. Technological Feasibility

The technology and the available resources decide whether an energy project is feasible and able to meet the demand (Johnson and Chertow, 2009: 2234). Riahi et al. (2012: 1236) have defined technical feasibility as the ability of the supply side to deliver the useful energy demand. For RETs, the decisive factor generally is the energy potential[19] at a certain location, such as wind speed, solar irradiation or geothermal heat. The only exception is bio-energy, since biomass such as crops or wood, can be transported like fossil fuels. Another crucial aspect affecting the technological feasibility is the possibility of RE integration and the transport of electricity through the existing energy generation and distribution system. According to Riahi et al. (2012: 1234), due to their intermittency, systems integration of RES is the most important rationale for restrictions of renewables. Additionally, technicians require adequate knowledge and training about installing, operating and maintaining the RE system. Moreover, the quality of the equipment is relevant. It influences, for instance, energy conversion efficiency, standstills and lifetime, since the equipment has to stand the climatic and environmental conditions in which the plant is operating. All of these aspects strongly influence the so-called “technical potential”. This potential, however, needs to be considered in a dynamic context since technology is advancing rapidly, increasing the technical potential (EREC, 2010: 16). Due to the fact that the globalization of manufacturers continues, the cost-performance-ratios between wind turbines (WTGs) and solar photovoltaic (PV) panels produced in different countries are decreasing continuously, though uncertainty over turbine quality and bankability of Chinese suppliers exists (IPCC, 2011; U.S. Department of Energy, 2013). For these reasons, generally no details are given about the exact technology or manufacturer in this study.

[19] Generally, three types of potentials are differentiated: theoretical (upper limit), technical (considers conversion efficiency, technical limitations, availability of raw material) and economic (economically competitive) potential. All three are estimated based on current scientific knowledge.

4.1.1. Background Information about the Energy System on Galápagos

Ecuador is currently one of the fastest-growing economies in the region[20], which leads to dramatic reductions of poverty and inequality but also to increasing energy demand (McKeigue, 2013; CONELEC/ MEER, 2013). Despite this trend, energy consumption remains low in the country. On Galápagos the per capita consumption increased from 1.67 tons of oil equivalent (toe) in 2010 to 2.02 toe in 2012. This is still low as compared with the 2010 demand in OECD states with an average 5 toe per capita, the US with 7.04 toe per capita, or the EU with 3.41 toe per capita. Nevertheless, it is higher than the Latin American average of around 1 toe per capita (OECD/ IEA, 2012; Ramos Malo, 2012; Enerdata, 2013; PetroEcuador, 2013).

4.1.1.1. Energy Demand and Supply on Galápagos

The total primary energy demand in the Galápagos archipelago has constantly been growing during the last decade – with a small decline after the 2008-2009 financial crisis[21]. Figure 6 reveals that the energy demand nearly tripled from 2000 to 2012, growing around 170% (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013). The drivers for the increasing demand are numerous. On the one hand, the local population grew by around 35% during this time, while on the other, the number of tourists rose by more than 150%. In 2012, the total primary energy demand on the archipelago amounted to 15.8 million gallons of diesel and gasoline, corresponding to 55,122 toe supplying around 27,200 residents (INEC, 2010b; Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013). The graph reveals a clear upward trend and raises the expectation of a continuously growing energy demand in the future as well (OLADE, 2011: 6). This tendency is coupled to economic progression as well as sustained population growth and flourishing tourism.

[20] Recently the Ecuadorian government was able to increase investments in infrastructure and social spending without generating a budget deficit through expanding taxes significantly (Becker, 2012: 2). This has boosted economic growth. Even during the financial crisis in 2008-2009, the Ecuadorian government carried out comprehensive financial reforms, took control over the central bank and forced it to bring back about $2bn of reserves held abroad. These were used for increasing public spending such as for infrastructure and agriculture. Together with other reforms, this helped Ecuador to overcome the crisis very fast and emerge strong.

[21] Data received from PetroEcuador, ElecGalápagos and MEER are not fully consistent. The reason could be the different accounting methods for delivery, stock and consumption. In addition, responsibility for one gasoline station (Isabela) has only recently been transferred to PetroEcuador and no reliable data has been made available for the past. The decline after 2008 can be partially explained with the financial crisis. An additional factor could be a surcharge applied to fossil fuels consumed by tourist vessels. This price premium has been passed on to the tourists, discouraging on-board travel and favouring land-based stays on the islands (Metropolitan Touring, 2008).

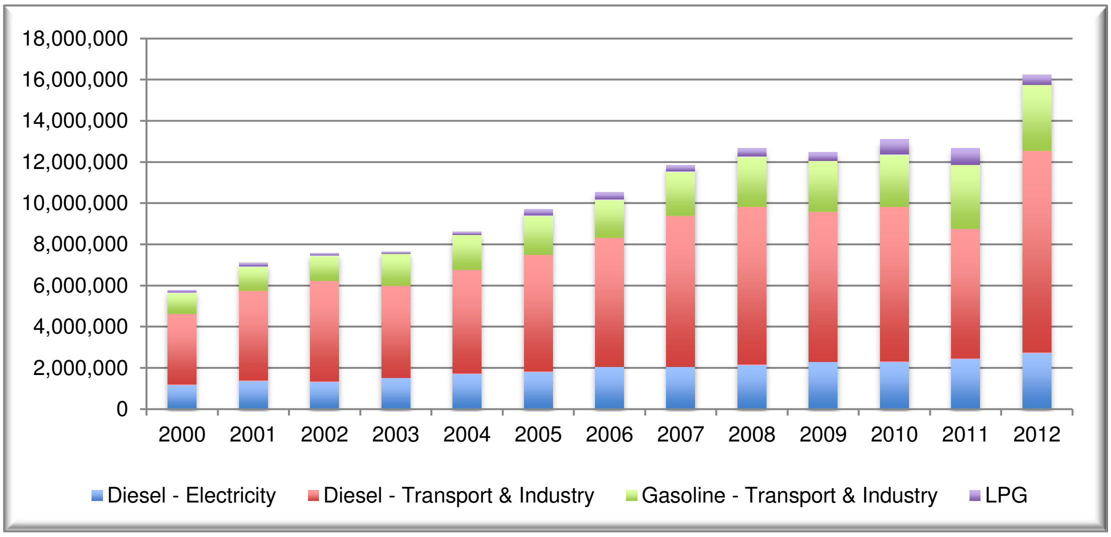


Figure 6: Consumption of fossil fuels on Galápagos (gallons)
Source: Own elaboration based on: (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013)[22]

In this context it is worthwhile to consider the types of fossil fuels consumed on the islands and the respective shares. As illustrated in Figure 6, there are three main types of fossil fuels consumed on Galápagos: diesel, gasoline and liquefied petroleum gas (LPG). Diesel accounts for the largest share (80%), and is mainly used for transport (62%) and to a lesser extent for electricity generation (18%). Gasoline has a share of around 20% and is nearly exclusively used for transport purposes. LPG only accounts for approximately 3% and is mainly used for cooking and unofficially for water heating (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013). It becomes apparent that the main driver for fossil fuel consumption is the transport sector as illustrated in Figure 7. Maritime and terrestrial transport together account for 75% of the fossil fuel demand; electricity generation represents 21% and industry 3%.

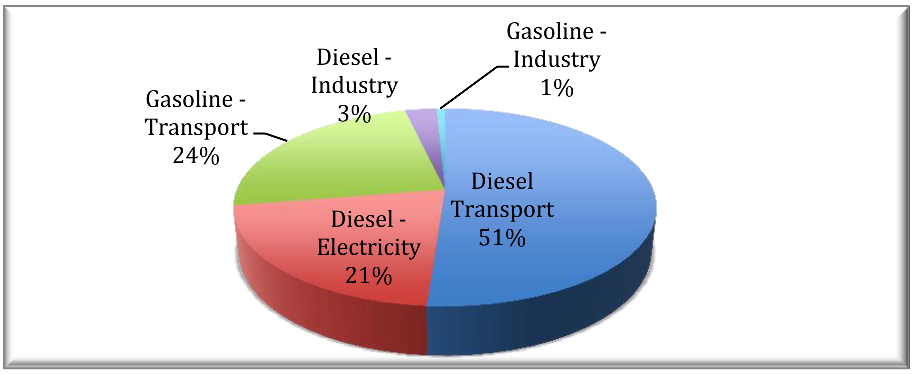


Figure 7: Consumption of diesel and gasoline by fuel and sector 2012
Source: Own elaboration based on (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013)

[22] No data was available for LPG consumption in 2010, 2011 and 2012.

These shares are unusual and dissimilar to the global average primary energy demand (as illustrated in Figure 8) where transport typically accounts for approximately 30%. Nevertheless, the energy consumption pattern on Galápagos is comparable to those of other small islands where typically transport accounts for the highest proportion of fossil fuel demand and industrial activities are negligible (IRENA, 2013; Secretariat of the Convention on Biological Diversity, 2014).

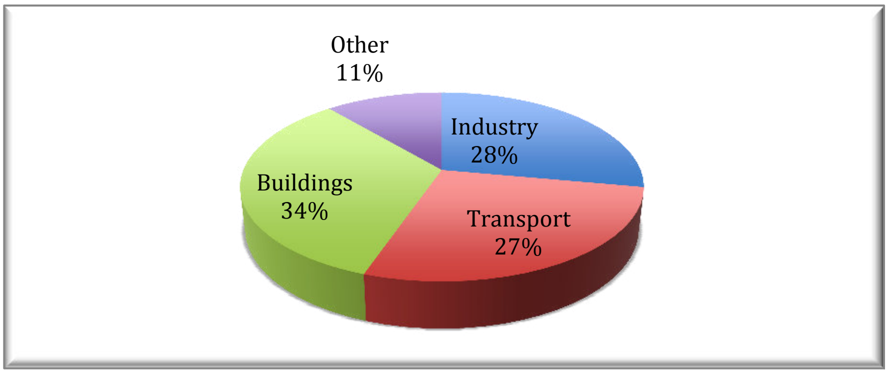


Figure 8: Global Primary Energy Demand by Sector in 2010
Source: Own elaboration based on data from (OECD/ IEA, 2012)

Analysing the usage patterns of diesel and gasoline fuels on Galápagos in more detail, it becomes apparent that they diverge (see Figure 9). Whereas 93% of the gasoline is used for terrestrial transport, such as cars, mopeds or motorbikes, larger vehicles, such as buses, use only 9% of the diesel. The largest share of the diesel is demanded by the maritime transport sector with 59%. This comprises 52% for touristic naval activities and only 7% for traditional fishery.

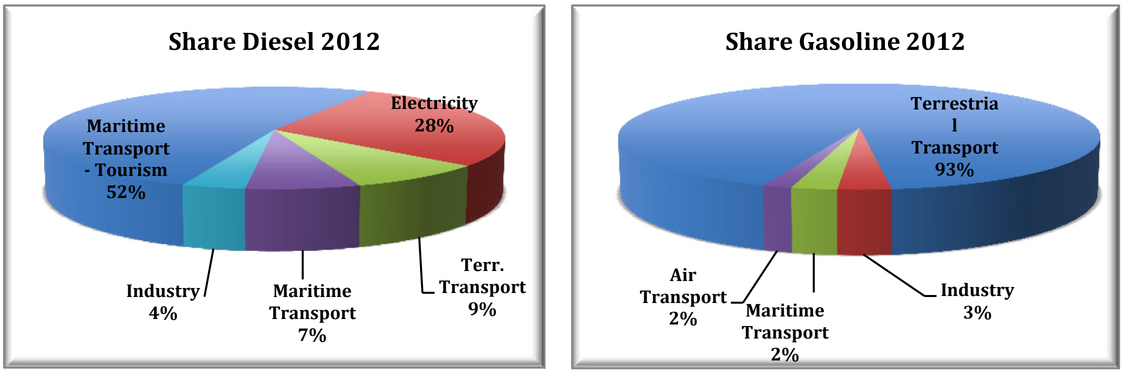


Figure 9: Share of fossil fuel by Sector for Diesel (left) and Gasoline (right) in 2012
Source: Own elaboration based on data from (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013)

Balancing these data, it can be seen that tourism is the most important driver for fossil fuel demand in which maritime transport is the largest consumer of fossil fuels. It becomes clear that transforming the transport sector on Galápagos is a basic condition for a phasing out of fossil fuels. A vital and indispensible step towards eliminating fossil fuel usage is a concept for transforming the electricity sector to reduce the use of conventional fuels as much as possible by replacing them with RES. It is an essential pre-condition for adapting the transport sector, since it lays the basis for including low carbon technologies for mobility, such as electrical cars or buses.

4.1.1.2. Electricity Demand and Supply on Galápagos

Similar to primary energy demand, electricity demand on the Galápagos archipelago has been increasing continuously with an average growth rate of 9%, doubling the demand from 3.4 MW in 1998 to currently around 7 MW (CONELEC, 2007; CONELEC/ MEER, 2012). As illustrated in Figure 10, the residential sector accounts for the highest demand with a consumption that nearly tripled from around 5,100 MWh in 1999, to nearly 15,000 MWh in 2012. Similarly, demand by the commercial sector augmented from around 3,000 MWh in 1999, to nearly 12,000 MWh in 2012. Industry as well as public lightning[23] play minor roles (ElecGalápagos, 2013c).

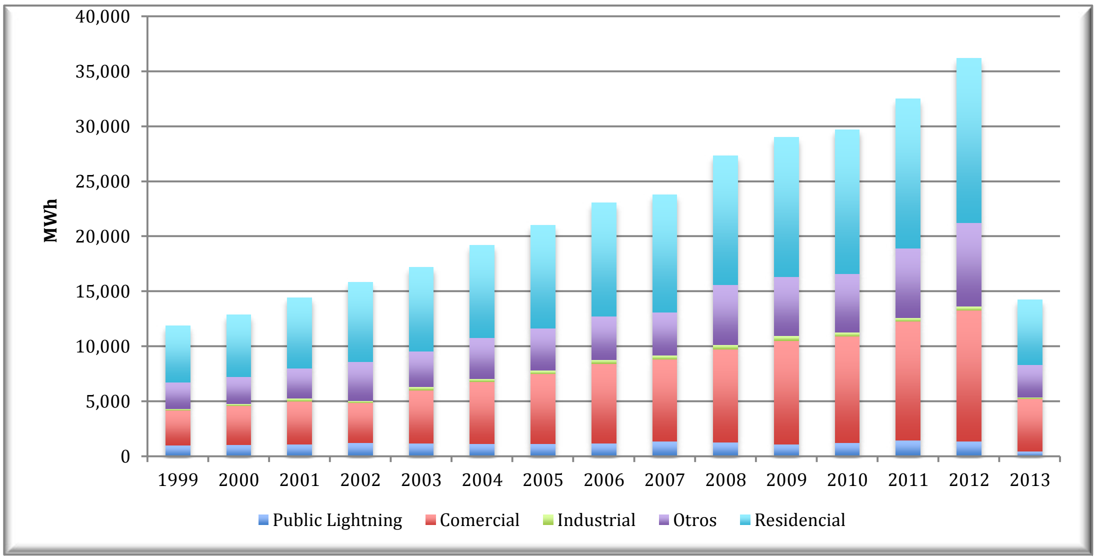


Figure 10: Electricity consumption in MWh by sector from 1999 to 2013
Note: Data available until 30.4.2013
Source: Own elaboration based on data from (ElecGalápagos, 2013c)

The analysis of the energy statistics additionally suggests that not only the total electricity consumption increased but also the relative average annual electricity consumption per capita. The latter nearly doubled between 2001 and 2012 from 774

[23] Public illumination is composed of a mixture of different lightning technologies: sodium, mercury, LED, induction and fluorescent (ElecGalápagos, 2013d).

kWh per capita to 1,326 kWh per capita. This average annual electricity consumption is high compared with Africa and Asia at around 500 kWh and 800 kWh respectively in 2010, but remains low compared to the Latin American average with 1,800 kWh per capita, China with 2,600 kWh per capita, or the OECD average of 7,800 kWh per capita (GEA, 2012: 1626; OECD/ IEA, 2012: 537). In this context, it is important to emphasize that the electricity demand on the four populated islands is not uniform by virtue of diverging population density. As illustrated in Table 4, in 2012, Santa Cruz Island had the highest annual electricity consumption with 22,466 MWh, followed by San Cristóbal with 10,213 MWh, and by Isabela 3,211 MWh. The inhabitants of the least populated island, Floreana, consume only 322 MWh (ElecGalápagos, 2014a).

Table 4: Electricity consumption per island in 2012
Source: Data adapted from (ElecGalápagos, 2014a)

Name of the canton	Invoiced electricity 2012 (MWh)	Inhabitants 2012	Invoiced electricity 2013 (MWh)	Inhabitants 2013
Santa Cruz	22,466	16,725	25,173	17,169
San Cristóbal	10,213	8,095	11,086	8,293
Isabela	3,211	2,464	3,683	2,538
Floreana	322	145	348	n/a

Monthly Electricity Demand Curve

The energy demand per month shows a similar and clearly seasonal trend for all islands as depicted in Figure 11 (ElecGalápagos, 2014c). In line with the climatic conditions, energy demand in the warmer months January to May is higher, mainly due to the use of air conditioning.

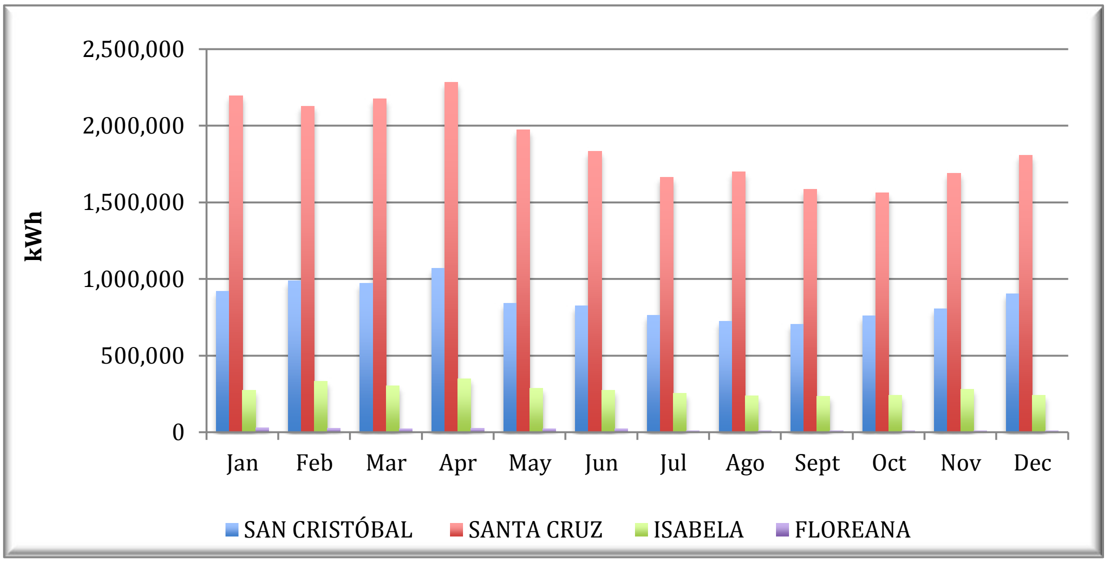


Figure 11: Seasonality of Electricity Consumption on Galápagos in 2013 (in kWh)
Source: Own elaboration based on data from (ElecGalápagos, 2014c)

The load curve on a monthly basis, in Figure 12, shows that the month of April has the highest load, where demand can be 13% higher than the average. The lowest load is in September, where the demand can be 10% lower than the average (Lahmeyer International/ MEER, 2012: 9).

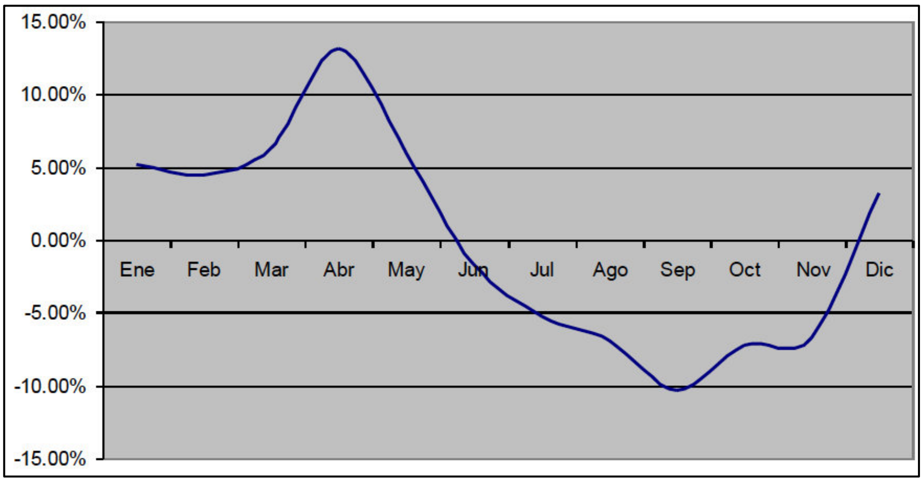
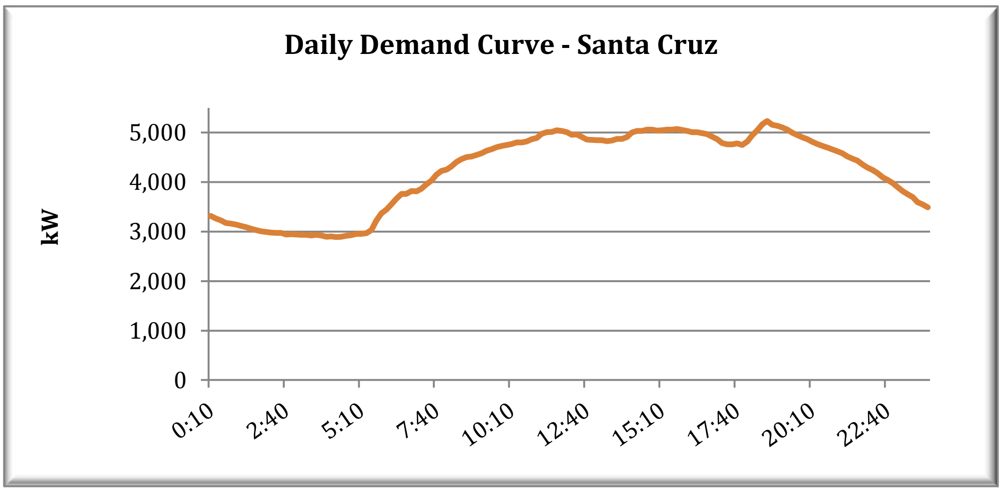


Figure 12: Seasonal Load Curve
Source: (Lahmeyer International/ MEER, 2012: 9)

Daily Electricity Demand Curves

The daily demand curves of the four islands have significant similarities as can be seen in the curves presented in Figure 13. All islands show a typical peak demand in the evening between 18:30 and 20:00, mainly caused by illumination and cooking chores. The lowest demand is from 1:00 to 5:00 (ElecGalápagos, 2013d). Due to the fact that there is no significant industrial load there is no large difference between daily demand patterns of working days and weekends (ERGAL/ KfW/ Lahmeyer, 2001).



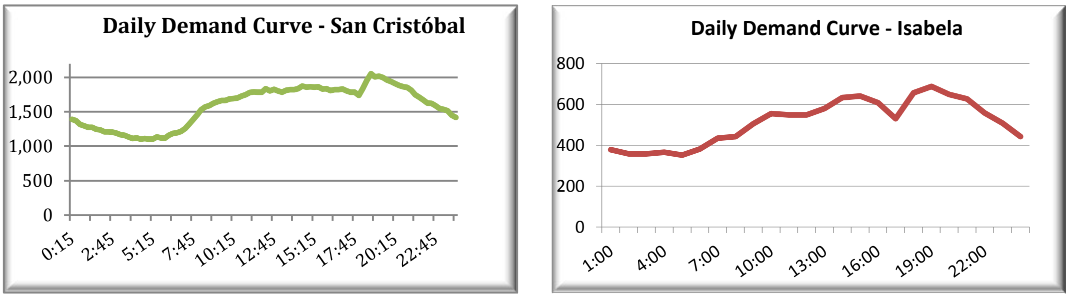


Figure 13: Daily Demand Curves for Galápagos in 2013
Source: Own elaboration based on data from (ElecGalápagos, 2013d)

This information about monthly and daily demand is important to design adequate RE systems. For instance, according to Lahmeyer and MEER (2012), neither the touristic nor the residential sector is susceptible for modification based on 24h. Hence, this implies that a shift of demand from peak times to times of less demand might not easily be possible, requiring other solutions such as storage to be included.

Electricity Generation

The current electrical system on Galápagos is providing electricity on all four islands 24 hours a day, and has a frequency of 60 Hz (ERGAL/ KfW/ Lahmeyer, 2001). Demand is mainly met by thermal fossil fuel power plants, based on small diesel generators. The total nominal installed thermal capacity on the whole archipelago is 15.068 MW and effective 11.882 MW (ElecGalápagos, 2013a). This conventional capacity is complemented by around 2.5 MW RES-E capacity.

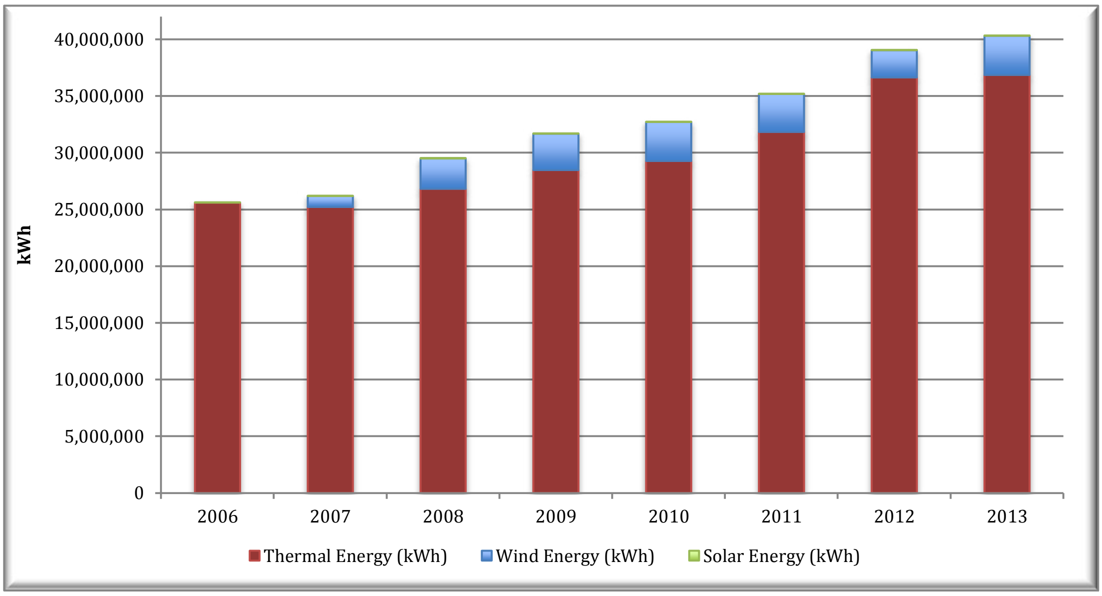


Figure 14: Electricity Generation on Galápagos by Source from 2006 to 2013 in kWh
Source: Own elaboration based on data from (ElecGalápagos, 2014a)

Statistics from ElecGalápagos demonstrate that despite the increasing integration of RES the even faster growing demand offsets these efforts. Figure 14 illustrates that thermal electricity generation therefore remains the most important source, while the share of electricity generated by wind was 8.5%, and that by PV 0,04% in 2013 (ElecGalápagos, 2014c). A later subsection revisits the issue of electricity generation per island in more detail.

Electricity Transmission and Distribution on Galápagos

Electricity consumers on Galápagos are connected through a low voltage grid of 120 or 140 V. In addition, there is single-phase 7.62 kV available on San Cristóbal, Isabela and Floreana, or 7.96 kV on Santa Cruz. Moreover, there is three-phase on San Cristóbal, Isabela and Floreana with 13,2 kV and on Santa Cruz with 13,8 kV (ElecGalápagos, 2012; ElecGalápagos, 2013d). Figure 15 illustrates a typical overhead grid line on Galápagos. Furthermore, the first 34.5 kV transmission line is currently under construction to connect Baltra and Santa Cruz (ElecGalápagos, 2014b).

Figure 15: Grid on Galápagos
Source: (Lahmeyer International/ MEER, 2012: 30)

According to a report by ElecGalápagos (2013d), the primary electrical grid on all islands is a combination of both overhead and underground lines. They are generally reinforced by “Aluminium Conductor Steel Reinforced” (ACSR) and to a lesser extent by a bare “Aluminium Stranded Conductor” (ASC). The underground lines are made of cross-linked polyethylene (XLPE) insulated cables. The secondary overhead lines are composed of ACSR, ASC and pre-assembled aluminium cables. The secondary underground lines are composed of copper cables of the type TTU. The electricity connection to the houses consists mainly of overhead lines composed of pre-assembled aluminium and copper cables with anti-theft systems. The underground lines are of concentric copper.

4.1.2. Climate on Galápagos

The microclimate on Galápagos is the result of a complex interaction of ocean currents and winds. According to Wolff (2010), the main driver of inter-annual and inter-decadal variability of the climate on Galápagos may be the Humboldt Current system coupled with the El Niño Southern Oscillation. Due to its location in the Equatorial zone the Intertropical Convergence Zone (ITCZ) has a strong influence on the climate (ERGAL/ KfW/ Lahmeyer, 2001). Therefore, it is possible to differentiate two seasons, which are driven by the Southern Humboldt Current and the Eastern Cromwell Current. From December/January to May/June is the hot season influenced by the warm northern El Niño current and characterized by localized convective precipitation and a high variability in rainfall in relation to sea surface temperature. During this season, the islands receive large amounts of solar radiation, increasing potential for PV, while wind speeds strongly decrease, reducing the potential for wind energy. The period from May/June to November/December is the cold season, characterized by ground-level cloud cover, cold winds, occult precipitation, and misty conditions in the high lands on the windward side of the islands. In addition, this period is accompanied by horizontal precipitation with very fine droplets commonly referred to as “garúa”. During this season, solar potential is reduced while wind potential is higher (UNDP/ SPNG/ INGALA/ SESA-Galápagos/ FCD, 2006; Trueman and D’Ozouville, 2010; ERGAL/ KfW/ Lahmeyer, 2001: 44).

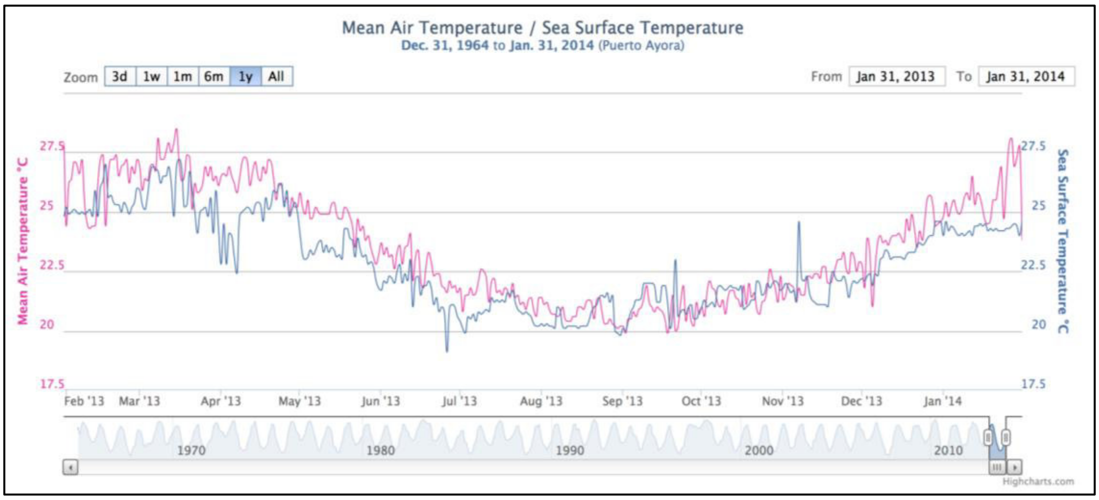


Figure 16: Mean Air and Sea Surface Temperature on Santa Cruz, Galápagos
Source: Chart created on 3. April 2014 on (Charles Darwin Foundation, 2014)

Figure 16 illustrates that both atmospheric and sea surface mean temperatures are between 20°C and 27°C. Nevertheless, during *el Niño/ la Niña* the climate changes considerably. For instance, temperature and precipitation are exceptionally high in El Niño phenomenon years, such as in 1998, favouring conditions for wind energy generation. By contrast, during la Niña precipitation is low, favouring solar energy conditions (ERGAL/ KfW/ Lahmeyer, 2001; Charles Darwin Foundation, 2014).
Knowledge about the climate is crucial for choosing the right combination of RETs to cover the respective demand. During the hot season, for example, energy demand is higher due to the use of air conditioning. Nevertheless, wind energy potential is low during that season whereas solar potential is high. In this context it is also important to include considerations about a potential climate change the Galápagos Islands are expected to experience during the next few decades. Although varying degrees of uncertainty exist, the future of the archipelago will most likely include continued ENSO[24] events, some of which may be intense. Moreover, increases in sea level, precipitation and surface ocean temperatures as well as acidity are expected (Sachs and Ladd, 2010). These factors might influence the RE potential as well as the consumers' demand patterns. In addition, the climatic conditions are also relevant for the wind or solar power plant construction and the transport phase of the equipment. For instance, during the cold, rainy season, civil construction projects face considerable difficulties.

4.1.3. Potential of Renewable Energy Technologies on Galápagos

According to EREC (2010) and IRENA (2013), nature offers numerous options for energy generation, which are freely available, clean, secure and affordable. Nevertheless, their theoretical, technical, economic and sustainable potential varies.

Wind Energy

Wind energy technology uses the kinetic energy of air in motion to produce electrical energy (Kleemann and Melіß, 1993; IPCC, 2011; BWE, 2013). Generally, a differentiation is possible between onshore and offshore wind energy turbine generators (WTGs). For onshore there are both large and small (<50kW) WTGs. Nearly all wind turbines are freestanding on industrial sites, mountains, agricultural areas and coastal sites. There is, however, only a small number of building-mounted WTGs, since in urban areas wind speeds are lower or unsuitable turbulences may occur. These turbines cannot pay back their embedded carbon emissions and have

[24] El Niño-Southern Oscillation

therefore not yet been successful (EWEA/ EC, 1997; IPCC, 2011; Carbon Trust, 2012). Electricity produced from wind is both variable and to some extent unpredictable. Nevertheless, experience has shown that the integration of wind energy usually poses no insoluble technical barriers (EWEA/ EC, 1997; IPCC, 2011).

In general, the technological and economic feasibility[25] of a wind energy project is strongly influenced by the specific wind regime at a certain site (BWE, 2014). The importance of the wind speed for the generated power output is captured in the power equation (Quaschnig, 2013: 263):

$$P = \frac{1}{2} * \rho * A * v^3 \qquad (4.1)$$

The available power (P) depends on air density (ρ), the area of the wind rotor (A), and the wind speed (v). The crucial importance of the wind speed is demonstrated in the equation, indicating that the wind turbine power output increases disproportionately with wind velocity. This equation can be adjusted by adding the power coefficient[26] (e) "being the efficiency of capturing the kinetic energy that exists in a unit area of intercepted wind" and the number of hours during which the power was captured (h) to get more exact results (Quaschnig, 2013: 263; SkyWindPower, 2006):

$$P = \frac{1}{2} * \rho * A * v^3 * e * h \qquad (4.2)$$

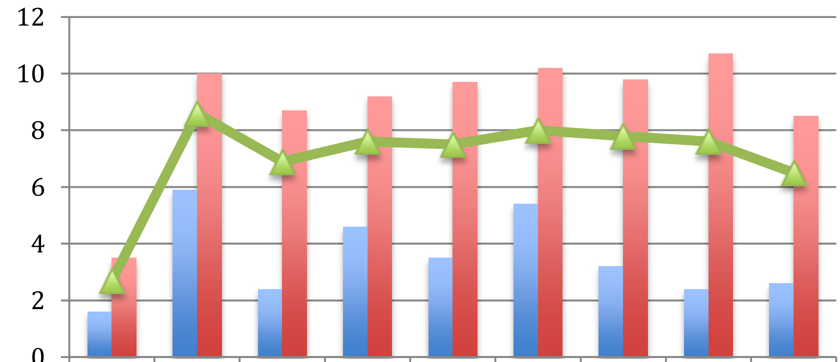
The specific energy output of a WTG depends additionally on the power performance curve of the respective turbine type. Generally, wind turbines start extracting energy from wind as from 2.5 to 4.5 m/s, also referred to as cut-in speed. Although WTGs increase power production with wind speed, at approximately 20 to 25 m/s most turbines stop producing energy, also referred to as cut-out wind speed. Through stall control or by pitching the blades the speed of the blades is reduced or the movement is prevented at al. This shall prevent damage of the WTG´s structural components. The point at which the rated power level is reached depends on the turbine type. Current technology allows the optimization of power generation by offering different WTG types, which can be chosen depending on the prevailing wind

[25] The economic aspects will be treated in a later chapter with focus on the affordability of the power supply. Generally, electricity generation costs are used to calculate the profitability of a wind energy project. They are calculated using investment costs, annual costs and the produced energy output of the WTGs (Kleemann and Meliß, 1993: 299).

[26] The maximum power coefficient was calculated by Betz and is at 0.593 (Kleemann and Meliß, 1993; Quaschnig, 2013).

regime (IPCC, 2011: 550; Quaschnig, 2013: 275ff.).

At first glance Galápagos enjoys a good wind regime with annual average wind speeds of 6 to 8 m/s as demonstrated in Figure 17. This is comparable to other good coastal wind regimes (Kleemann and Meliß, 1993: 246; Consulambiente, 2012: 169). Nevertheless, since WTGs operate not at 10m above the ground but at a hub height of 50 to 120m, this illustration is not representative for specific project sites on Galápagos and can only serve as a rough orientation.



	2000	2001	2002	2003	2004	2005	2006	2007	2008
Velocity (min)	1.6	5.9	2.4	4.6	3.5	5.4	3.2	2.4	2.6
Velocity (max)	3.5	10	8.7	9.2	9.7	10.2	9.8	10.7	8.5
Average	2.7	8.6	6.9	7.6	7.5	8	7.8	7.6	6.5

Figure 17: Variation of Wind Velocity from 2000 to 2008 on Galápagos measured at around 10m above the ground
Source: Own elaboration based on data from (Consulambiente, 2012: 169)

Figure 18 illustrates a recently by the MEER (2013b: 51) developed wind map based on additional wind measurements. It depicts that wind speeds at 80m above the ground are in the range of 4 to 6 m/s. The colour range demonstrates the different wind speeds indicating a rather modest wind regime. This confirms the statement by Kleemann and Meliß (1993: 244) that there is low wind energy potential in the equatorial zone and in very sunny regions.

However, information about the annual wind velocity is not sufficiently accurate to verify whether the wind energy potential is high enough to allow a technologically feasible harvest that would cover the electricity demand on Galápagos. It is therefore crucial to consider the wind regime in more detail and to analyse wind measurements for specific sites (Kleemann and Meliß, 1993: 246; BWE, 2014).

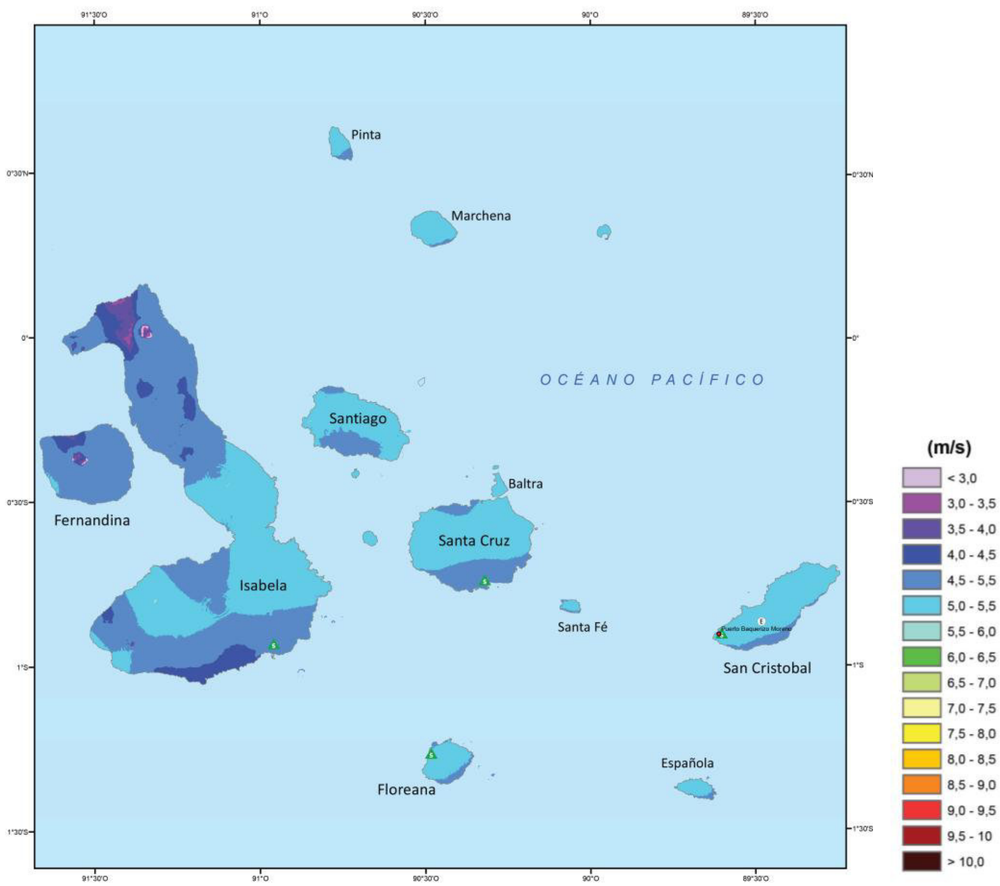


Figure 18: Average Annual Wind Speeds at 80m above the ground
Source: (MEER, 2013b: 51)

Table 5 depicts that the specific sites on the archipelago show average annual wind speeds ranging from 3 to 6.8 m/s. Specific site measurements indicate potentials, at the rotor height, of 6.8 m/s on San Cristóbal and also on Santa Cruz the site "Cerro Crocker" denote 7.35 m/s and Picacho 6.9 m/s; on Isabela the site "Cuatro Hermanos" shows 5.2 m/s (GEF/ UNDP, 2006; ERGAL/ KfW/ Lahmeyer, 2001).

Table 5: Average Monthly Wind Speeds in m/s, long-term corrected
Source: Adapted from (ERGAL/ KfW/ Lahmeyer, 2001: 45; Lahmeyer International/ UNDP, 2001)

Stat.	Site	Aug 99	Sep 99	Okt 99	Nov 99	Dez 99	Jan 00	Feb 00	Mar 00	Apr 00	May 00	Jun 00	July 00	Avg
Gal-1	Floreana; Coast	3.3	3.1	3.1	4.4	5.0	3.0	1.5	2.0	2.6	2.2	2.6	3.5	3.0
Gal-2	Isabela; Coast:	3.9	3.4	3.8	3.9	3.8	3.4	3.0	3.3	3.0	3.5	4.1	4.1	3.6
Gal-3	St.Cruz; Cerro:	5.2	5.2	4.6	6.5	6.9	5.5	2.2	2.5	2.0	3.3	3.8	5.4	4.4
Gal-5	S. Cristóbal; Coast	5.5	5.1	4.9	6.6	7.7	5.2	2.3	2.1	1.8	3.5	4.1	5.7	4.5
Gal-6	S. Cristóbal; Cerro	8.1	7.8	7.5	10.6	9.6	6.4	4.2	3.7	3.5	5.7	6.6	8.4	6.8
Gal-7	St.Cruz; Camote	3.4	3.4	3.2	4.3	4.3	3.1	2.3	2.8	2.2	2.4	2.7	3.6	3.1
Gal-8	St.Cruz; Coast:	3.9	3.9	3.8	3.4	2.8	2.7	2.8	3.0	2.7	3.2	3.7	4.0	3.3

Additional factors that influence the wind energy potential are the wind's daily and monthly variations due to climatic and geographic aspects, surface roughness and orography[27]. Due to their location in the ocean and the relatively small size of most islands, daily variations in wind speed and direction are primarily influenced by solar irradiation (ERGAL/ MEER/ UNDP, 2007: 27; Quaschnig, 2013: 257). The highest wind speeds occur during the day at 14:00 while lowest in the night around 2:00. Additionally, there are strong monthly variations, as can be seen in Table 5, with the lowest potential between February and April. These variations influence the energy production of the turbine and therefore also the possible full load hours during which a WTG can theoretically produce electricity. Consequently, it is necessary to put the energy production per year and the nominal installed power into relation in order to evaluate the wind energy potential. This is illustrated in the equation (Earnest and Wizelius, 2011: 59):

$$Full\ load\ hours = \frac{Production\ per\ year}{Nominal\ power}\ (hours) \qquad (4.3)$$

The average annual full load hours, and therefore the potential of a wind park at a certain site, can also be expressed in generation per unit of capacity (kWh/kW), also referred to as machine productivity (Earnest and Wizelius, 2011: 59; EWEA/ EC, 1997: 9):

$$Generation\ per\ unit\ of\ capacity = \frac{Production\ per\ year}{Nominal\ power}\ (kWh/kW) \qquad (4.4)$$

The fraction of the year the WTG is operating at rated (peak) power is referred to as capacity factor[28] (%). The capacity factor is based on both the characteristics of the site and the turbine characteristics (Earnest and Wizelius, 2011: 59; EWEA/ EC, 1997: 9; Kalmikov et al., 2011):

$$Capacity\ factor = \frac{Production\ per\ year}{Nominal\ power * 8760}\ (\%) \qquad (4.5)$$

For the Galápagos Islands, the local utility ElecGalápagos (2014d) estimates a capacity factor of 25%, resulting in a generation per unit of capacity of 2,190 kWh/kW, or 2,190 full load hours. This is in the range of recent estimations by experts (IEA, 2012; IEEE, 2012; IPCC, 2011; EWEA/ EC, 1997), which indicate

[27] For instance, plants, mountains or buildings are able to slow down wind velocity by increasing surface roughness, creating turbulences or wind shadow (Quaschnig, 2013: 261).
[28] "Capacity factor" should not be confused with "power coefficient", which is the proportion of energy actually captured compared to what would be captured if running at rated capacity full time.

capacity factors in Europe of 20–40% onshore and a global average of 21%[29]. The real capacity factor of the only wind power plant installed on Galápagos is 12–17%, which results in a generation per unit of capacity of 1,000–1,500 kWh/kW (ElecGalápagos, 2014a). Capacity factors can be increased through higher hub heights, advanced control methods and site-specific designs (Kalmikov et al., 2011). This is also referred to as *Micrositing*. The aim is to create an optimal park layout that also considers grid connection, shadowing and acoustic emissions (BWE, 2014) to make wind energy use technologically feasible and suitable for the islands.

Other factors influencing technical feasibility are the climatic and environmental conditions in which the plant is operating. The Galápagos Islands are characterized by a high salt content in the air due to the proximity to the ocean, by the strong irradiation and to a lesser extent by humidity (ElecGalápagos/ PSI/ PNG, 2011: 82; Lahmeyer International/ MEER, 2012: 19). This, as well as the wind gusts that partially reach 13 m/s, has to be considered in the design of the wind turbines (INOCAR, 2012: 172). Despite these gusts, no other storm risks have to be considered since the Galápagos are located in the inter-tropical convergence zone, and therefore they do not have hurricanes (NOAA, 2014). In spite of these promising wind potentials and favourable circumstances, so far only the identified potential on San Cristóbal has been realized (GEF/ UNDP, 2006; ERGAL/ KfW/ Lahmeyer, 2001).

Solar Energy

Theoretically, there is 10,000 times more energy globally coming from the sun than would be required for powering human civilization (Haefele, 1981; IPCC, 2011; Greenpeace/ EPIA, 2006: 10). However, the solar energy potential is not equally distributed worldwide, as can be seen in Figure 19, indicating that the tropical regions offer better resources compared to temperate latitudes. The solar radiation is important, since the quantity of electricity generated is larger if there is more available solar energy (Greenpeace/ EPIA, 2006: 10). For solar PV the global radiation is relevant including both direct and diffuse radiation (Kleemann and Melië, 1993: 34ff.).

[29] For offshore wind turbines the capacity factors are likely to be higher, with approximately 35–45%.

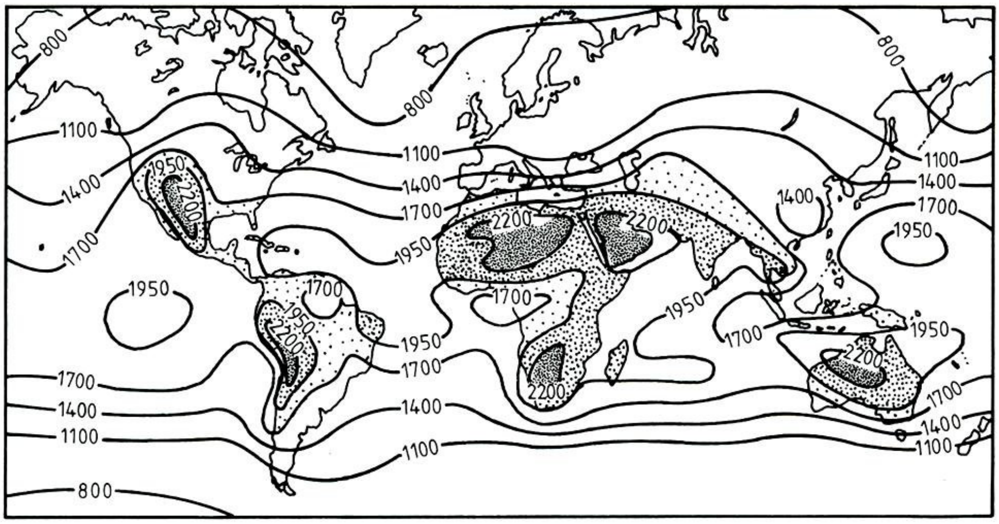


Figure 19: World global radiation map in kWh/m²/a
Source: Figure based on measured data from the World Meteorological Organization in (Kleemann and Meliß, 1993: 47)

Figure 20 shows the average monthly global radiation for Galápagos demonstrating monthly variations. Further, the measurements in the highlands indicate slightly lower insolation compared to the coastal sites.

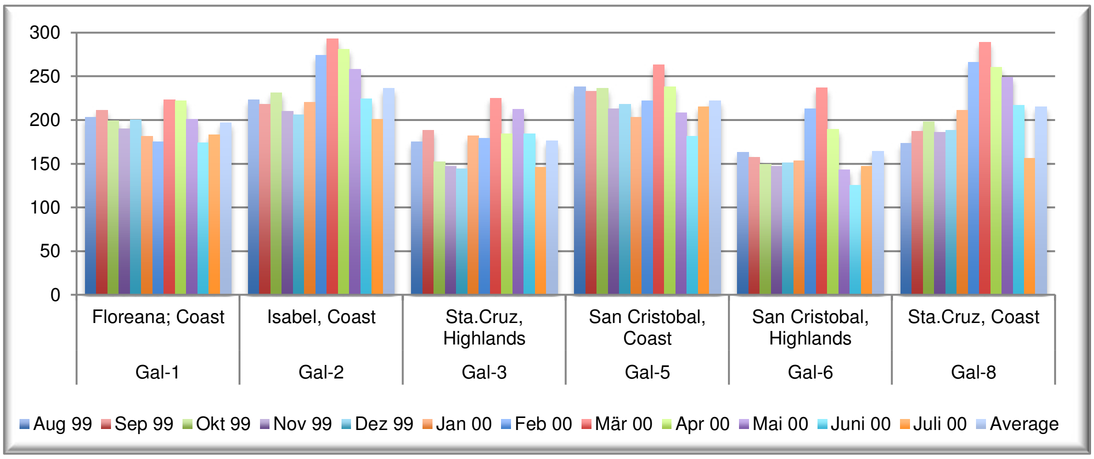


Figure 20: Average global radiation on Galápagos (W/m²)
Source: Own elaboration based on data from (Lahmeyer International/ UNDP, 2001: i-8)

Currently, a wide range of different solar energy conversion technologies exist, which are capable of meeting a variety of energy needs including heating, cooling and electricity generation (IPCC, 2011: 337). For instance, water heating through solar thermal collectors is a comparatively straightforward technology, since any material will absorb thermal heat if placed in the sun. Nevertheless, specific technologies, such as mirrors, coatings, and evacuated spaces, are required to maximize the absorbed energy and to store it (IPCC, 2011: 337). By way of another example, thermodynamic absorption or adsorption cycles can be driven by heat derived from solar radiation and can be used to cool buildings (IPCC, 2011: 337).

For the generation of electricity through solar radiation, it is necessary to use either photovoltaic (PV) or concentrating solar power (CSP) plants (IPCC, 2011: 337). The current costs for PV rooftop installations range from USD 0.22 to 0.44 kWh. The costs for utility-scale installations are estimated to lie between USD 0.20 and 30.7 kWh and between 0.19 and 0.20 for CSP, with expectations for both technologies to fall under 10 cents after 2030 (REN21/ ISEP, 2013: 56f.).

Regarding PV cells it can be argued that the “greater the intensity of the light, the greater the flow of electricity” (Greenpeace/ EPIA, 2006: 10). The flow refers to the photovoltaic effect on which the functioning of solar PV energy is based (see Figure 21). Generally, photons hit the solar panel and are absorbed by semiconducting materials, such as silicon. Consequently, in the solar cell negatively charged electrons are knocked loose from atoms, creating electron-hole pairs. These are spatially separated through the junction acting as an electrical field. Due to the specific composition of solar cells, the electrons are only moving in a single direction from the p-type to the n-type layer. The n-type layer is mixed with phosphorous and has many more free electrons, creating a negative charge. The p-type layer is mixed with boron, has deficient electrons and therefore creates a positive charge. Voltage is created through the charge separation; if an external load is connected, then the subsequent flowing of electrons from the n-type to the p-type layer through the circuit to the other side of the PV cell to cancel the electron imbalance creates direct current (DC). In this way electricity is generated that can be captured (IPCC, 2011: 351; Quaschnig, 2013: 172ff.; Greenpeace/ EREC/ GWEC, 2012; Kleemann and Melíß, 1993: 168f.).

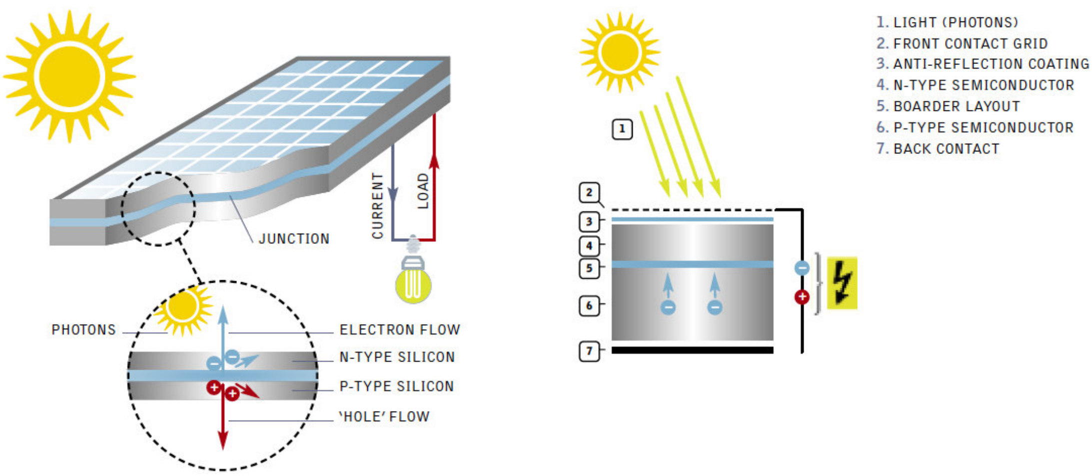


Figure 21: Generic schematic cross-section illustrating the operation of a solar cell
Source: (Greenpeace/ EREC/ GWEC, 2012: 235)

The capacity of a PV system is usually expressed through kilowatt peak (kW_{peak}) indicating the amount of electrical energy that can theoretically be produced when the sun stands directly horizontally above the panel on a clear day (Greenpeace/ EREC/ GWEC, 2012). The efficiency of a solar PV cell is expressed as the ratio between electrical power output and the irradiation on the array under standard conditions. The power output strongly depends on the material used. The prevalent material types used are monocrystalline silicon (c-Si) and polycrystalline silicon (poly-Si), also referred to as multicrystalline silicon (mc-Si). Monocrystalline silicon is most efficient at about 25% efficiency, but also most expensive and produces the largest amount of waste during manufacturing. Multicrystalline silicon has a lower efficiency of about 20% but also produces less waste. A relatively new technology is thin-film using, for instance, amorphous silicon (a-Si) with about 10% efficiency, cadmium telluride (CdTe) with 17% efficiency or gallium arsenide (GaAs) with around 40% efficiency. This technology reduces the amount of material used since the thin-film is sandwiched between two panes of glass. This causes a smaller ecological impact but also an efficiency decline. Moreover, there are multi-junction cells consisting of multiple thin-films using metal organic vapour phase epitaxy and no silicon (IPCC, 2011: 62). Generally, solar cells are mounted together and protected by layers of glass in units called "modules"[30]. Other key components include inverters, cabling, building structure and often storage systems such as batteries (Greenpeace/ EREC/ GWEC, 2012).

The fraction of the year during which the solar PV cell is operating at peak power is referred to as capacity factor. The main parameter influencing the capacity factor of a PV system is the actual solar irradiation at a given location in kWh/m^2 per day or per year (IPCC, 2011: 381). Therefore, the capacity factor is determined by the insolation at a certain site and the system performance ratio (PR)[31] (GEA, 2012: 828f.):

$$Capacity\ factor = \frac{N * PR}{8760} = \frac{Production\ per\ year\ (kWh/m2/a) * PR}{8760}\ (\%) \qquad (5.5)$$

Solar radiation varies between regions by a factor of three. While northern Europe reaches an insolation of 2 to 3 kWh/m^2 per day, in the tropics it is 5 to 6 kWh/m^2 per day, indicating a much higher potential. Due to the proximity of the Galápagos Islands to the equator, situated in the tropical zone, the islands enjoy a very good

[30] Module efficiencies are typically 50% to 80%.
[31] PR is defined as the average alternating-current (AC) system efficiency divided by the module efficiency under standard test conditions (STC).

solar regime with an average of 5.5 kWh/m^2 per day (GEF/ UNDP, 2006; Rosero and Chiliquinga, 2011: 20; ElecGalápagos/ PSI/ PNG, 2011) and daily sunshine hours are consistent throughout the year (Czisch, 2001; Kleemann and Melіß, 1993: 25). For the same reason, module inclinations have only a minor impact on the energy output. For the photovoltaic power plant (PVPP) on Isabela, calculations showed that the most suitable direction was east, but generally the differences between cardinal points are not significant (Lahmeyer International/ MEER, 2012: 129). On Galápagos the highest irradiation values can be found in March with around 6.4 kWh/m^2 per day; the lowest values occur in June with around 4.7 kWh/m^2 per day (Lahmeyer International/ UNDP, 2001: 20). This equals an annual energy output of about 1,980[32] kWh/m^2. ElecGalápagos (2014d) estimates a capacity factor of 16% for PV, resulting in a generation per unit of capacity of 1,402 kWh/ kW_{peak}. This is within the range of estimations by experts that mention capacity factors of currently 8-30% (IPCC, 2011: 381; IEEE, 2012; GEA, 2012: 829). Calculations by Lahmeyer for the planned PVPP on Isabela indicate a planned average annual yield per installed capacity over the life time of 25 years of 1,450 kWh/ kW_{peak} at an inclination of 10° (Lahmeyer International/ MEER, 2012: 124).

Apart from solar PV, electricity generation through solar energy is also possible through concentrated solar power (CSP). According to Rawlins and Ashcroft (2013: 18), “small-scale CSP in on-grid power generation application could be a valuable option for mini-grids or island grids where overall demand is limited”. They suggest that CSP systems between 1 and 2 MW could provide additional benefits over PV. Advantages of CSP include, primarily, the potential to store excess energy in various storage media such as molten salt or concrete. This can also reduce the cost for back-up capacity. Nevertheless, while this offers potential benefits in extending the time during which a system can provide energy, it is more expensive at small scale. Another benefit is the possible use of waste heat for other purposes and processes[33]. Nevertheless, the deployment of mini CSP faces barriers such as insufficient confidence that the technology works in local conditions, a lack of proven and optimized technology solutions for rural/ off-grid applications, and unattractive payback periods for potential investors (Rawlins and Ashcroft, 2013: 3). In addition, the first Micro CSP installed in 2009 on Hawaii with 2-2.2 MW[34] nominal installed capacity for electricity generation, shows that a large area of about 15,000 m^2 is

[32] Calculation: 364 days per year * 5.45 kWh/m^2 = 1983.8 kWh.
[33] Please see (Rawlins and Ashcroft, 2013) for a comparison of CSP against other RES.
[34] The plant is working with parabolic trough technology provided by the company Sopogy. This company has shut down its operation in 2014.

required for conversion of incoming solar radiation to useful electricity (Keahole Solar Power, 2014; NREL, 2014). Due to these reasons, and because there is no significant heat demand on Galápagos, it is not expected that this technology will play a relevant role in reaching the goals of the Zero Fossil Fuel Program.

In conclusion, it can be suggested that on the Galápagos Islands, solar heating and cooling, as well as PV on- and off-grid electricity generation have a remarkable potential (Rawlins and Ashcroft, 2013). Solar PV solutions have already been installed and will be reviewed for each island separately and more closely in chapter 5. In the future, a focus should also be put on solar energy for heating and cooling purposes to reduce the electricity demand (Lahmeyer International/ UNDP, 2001: 48). Moreover, especially rooftop-solar[35] power could be a valuable option, as it does not use any extra space and has no negative effect on the landscape. These could help to overcome the primary barrier for solar power on Galápagos, which is land requirement. This is critical since 98% of the islands surface is protected as national park and because there are no areas defined as zones for solar PVPPs. Regarding roof-top solar power, the missing financial incentives are a serious barrier as well as the building style, which consist of either corrugated metal or unfinished flat roofs.

Bioenergy

In principal, biomass is stored solar energy (EREC, 2010: 14). The Biomass Energy Centre (2014) defines biomass in a broader concept as “biological material derived from living, or recently living organisms” and therefore does not only include plant-based material but animal derived material as well. It is multifaceted, as bioenergy can be produced from a variety of biomass feedstock (forest, agricultural and livestock residues), short-rotation forest plantations, energy crops, organic component of municipal solid waste and other organic waste streams. Also the conversion processes are multiple and biomass can either be used directly to produce electricity or heat, or can be converted to gaseous, solid, or liquid fuels and then be used in the transport sector. In addition, applications allow for flexibility since they can be in centralized or decentralized settings. Nevertheless, not only bioenergy technologies, but also their technical maturity, vary substantially (PwC/ PIK/ IIASA/ ECF, 2010: 25; IPCC, 2011; Biomass Energy Centre, 2014).

In general, bioenergy can be separated in two categories: low-efficiency traditional

[35] These systems can be mounted on top of roofs, so called building adapted PV systems (BAPV), or integrated into the roof or building, known as building integrated PV systems (BIPV) (Greenpeace/ EREC/ GWEC, 2012).

biomass and high-efficiency modern biofuels (IPCC, 2011: 216 ff.). Traditional biomass is comprised of wood, charcoal, crop residues and animal dung, mainly used for heating and cooking (OECD/ IEA, 2012: 212; 648; IPCC, 2011). It is often used due to a lack of access to modern energy, and thereby indicating energy poverty[36] (PwC/ PIK/ IIASA/ ECF, 2010: 28; OECD/ IEA, 2011a; OECD/ IEA, 2011b). Traditional biomass is usually characterized by low efficiencies and associated with heavy workloads as well as significant emissions of aerosols and non-CO_2 GHG, such as CH_4, N_2O, CO (OECD/ IEA, 2012: 212; 648; GEA, 2012; IPCC, 2011; Greenpeace/ EREC/ GWEC, 2012: 64). Therefore, it is closely connected to serious negative impacts on environment, health and living conditions such as indoor-air pollution (Schirnding et al., 2002; Meisen and Krumpel, 2009: 21). Although the share of biomass in the Latin American energy matrix is generally high (Oxilia and Luna, 2011: 18-20), the use of traditional biomass on Galápagos is insignificant. Less than 1% of the population cooks with wood, carbon or other vegetable or animal residues (INEC, 2010a), and there is no relevant heating demand.

High efficiency modern biofuels come in multiple variants, though their technical maturity varies substantially (IPCC, 2011). So-called 1st generation biofuels that are commercially viable can be divided in two different forms depending upon their source material (House of Commons - Environmental Audit Committee, 2008: 5). On the one hand, there is bio-alcohol, such as ethanol, gained from the fermentation of sugar and starch, such as corn, sugar cane and potatoes (Geitmann, 2008: 84; IPCC, 2011). This fuel can be used in gasoline engines either pure, or mixed with mineral gasoline (Geitmann, 2008: 85). Bio-alcohol has significant negative side-effects since its production requires substantial energy input for the distillation process, limiting its potential to save CO_2 emissions (Geitmann, 2008: 87). Moreover, bio-alcohol energy crops are in competition with food production (IPCC, 2011: 273; House of Commons - Environmental Audit Committee, 2008; Greenpeace/ EREC/ GWEC, 2012). On the other hand, there is biodiesel from palm oil, and vegetable oils such as rapeseed or Jatropha (Geitmann, 2008: 62). These can be used in diesel engines and have emissions similar to diesel, but lower particulate matter (PM) emissions, and higher NO_x. Biodiesel can be used either pure or mixed with mineral diesel. Pure vegetable oil has a significant advantage over fossil fuels, as it is biodegradable and therefore, oil spills cause no danger to

[36] The drawbacks of traditional forms of biomass such as animal dung or firewood for cooking are the in-door and out-door air pollution with its subsequent negative effects on human health but as well the time necessary for the collection and utilization of the biomass (Schirnding et al., 2002).

the environment (Geitmann, 2008: 64). Negative aspects include potential competition with food production, soil degradation and creation of N_2O during cultivation, as well as the required resources such as water and fertilization (Geitmann, 2008; PwC/ PIK/ IIASA/ ECF, 2010: 25; IPCC, 2011).

So-called 2nd generation biofuels can be sun fuels or biomass to liquid fuels (BtL). These are synthetic fuels made from cellulosic biomass and have their origin in woody crop, agricultural residues or waste. Therefore, they avoid conflict with food production, and are developed with the aim of higher GHG reduction potential. Nevertheless, the generation process via synthetic gas is still complicated (GEA, 2012: 779; Greenpeace/ EREC/ GWEC, 2012; IPCC, 2011). Still more challenging is the use of so-called, 3rd generation biofuels such as liquid biofuel production from algae. This technology is still in the research and development phase and therefore any argument would be speculative (IPCC, 2011; GEA, 2012).

Generally, producing electricity or heat from biomass has the potential to offer a wide range of benefits compared to other energy sources. Firstly, it is argued that bioenergy is CO_2-neutral since it "absorbs the same amount of CO_2 during growth as it emits during use" (EREC, 2010: 14). Nonetheless, the actual climate impact of biomass depends strongly on the specific conditions. For instance, emissions associated with land clearing can lead to even higher net carbon emissions than fossil fuels (EREC, 2010: 14). Secondly, bioenergy has the significant advantage over wind and solar energy that it can be stored and transported. Thereby it does not pose intermittency challenges (GEA, 2012: 1237). Finally, bioenergy use improves security of supply, since it is usually locally available. Thus, it can increase prosperity by creating local business opportunities and support the rural economy (Biomass Energy Centre, 2014). Nevertheless, if bioenergy production and use is not conducted sustainably[37], despite the potential benefits, multiple adverse effects can occur (GEA, 2012: 1237). These include competition with food production, biodiversity loss, increasing emissions, water scarcity, soil degradation and creation of N_2O during cultivation (Geitmann, 2008; PwC/ PIK/ IIASA/ ECF, 2010: 25; IPCC, 2011).

Initially, for the Galápagos Islands, bioenergy has not been considered a valid option due to environmental concerns regarding invasive species (GEF/ UNDP, 2006). Moreover, later studies such as those conducted by ERGAL, DED in cooperation with MEER (2008) came to the conclusion that it is not viable to use

[37] For instance, the adequate crop type needs to be selected according to their requirements such as soil, water, nutrients, and climate. The Global Energy Assessment provides a good overview over the most important crops and their requirements (GEA, 2012).

biomass or crops grown on the archipelago. Firstly, they confirm the risk that introduced species could adversely affect the fragile equilibrium of the islands' ecosystem. Secondly, there is a danger of affecting food security of the islands negatively. Thirdly, a cultivation of biomass on the islands would require space and other resources on the islands. However, nearly 98% of the islands surface is protected, leaving little space for agricultural use, intensifying the competition of bioenergy crops with food (ERGAL/ DED/ MEER, 2008; MAGAP, 2013). These arguments are expected to outrank the advantages a local cultivation could have, such as saving transport time and fuel, the creation of jobs on Galápagos and an approximation towards auto-sufficiency (ERGAL/ DED/ MEER, 2008). Therefore, it has been decided to use biodiesel from vegetable oil, Jatropha, on Floreana[38] that is grown on the Ecuadorian mainland, since it is biodegradable and can be combined with diesel fuel in the generators to provide back-up energy. For the future of the Zero Fossil Fuel Program, bioenergy should be considered as an option for the Galápagos, since it could play an essential transitional role for transportation (GEA, 2012: 1244) and backup electricity generation. Nevertheless, it is important to take the precautionary approach for the evaluation and future use of bioenergy to assure a sustainable energy supply (Greenpeace/ EREC/ GWEC, 2012: 228).

Hydro Energy

Hydropower harnesses the kinetic energy from water that moves from a higher to a lower elevation and is primarily used to generate electricity (IPCC, 2011; EREC, 2010: 60; Greenpeace/ EREC/ GWEC, 2012). Variations include dam projects with reservoirs or pump storage hydropower, and run-of-river systems; each of them can have various dimensions from small to large scale. This RET is one of the oldest and most popular as it is efficient, has low O&M costs, generates no waste and provides a constant output, therefore providing reliable and stable energy. In addition, it can be combined with other power generation types to meet peak demand and to store energy in case of excess power generation such as generation by WTGs during night (IPCC, 2011). Therefore, hydro could be an essential part of a 100% renewable power network (PwC/ PIK/ IIASA/ ECF, 2010: 24). In addition, hydro energy is considered a mature technology with costs for electricity production between 3-9 cents/kWh and pumped-storage-energy costs at around 12 cents/kWh (REN21/ ISEP, 2013: 59).

However, Hydro energy has also significant drawbacks, which can be seen in the

[38] More information on the Jatropha oil project on Floreana can be found in chapter 5.2.

resistance against the 'Hidro Aysen' hydro energy power plant planned in Chile (REUTERS, 2013). Environmental concerns refer to the loss of land, habitat and the displacement of settlements due to the necessary flooding of large areas (PwC/ PIK/ IIASA/ ECF, 2010: 24; Greenpeace/ EREC/ GWEC, 2012). Conflicts exist due to interference with nature, especially in the case of large dams or when river systems are altered (Greenpeace/ EREC/ GWEC, 2012; GEA, 2012). This may cause environmental damage and social conflicts. In addition, there is a risk of energy shortage due to droughts (IPCC, 2011; GEA, 2012).

While on the Ecuadorian mainland, there are plans to increase the share of electricity produced through hydroelectric power plants from 58% in 2011 to more than 95% until 2016 (Albornoz, 2012: 15), on the Galápagos Islands, the situation is different. Water is generally scarce on the archipelago, the islands are relatively small and rivers do not exist. The only lake is on San Cristóbal. Despite this, a study executed by Lahmeyer International (2001) for the UNDP suggested a mini pump-storage hydropower plant of 400 kW nominal potential to be an interesting option for the hybrid system on San Cristóbal. Nonetheless, environmental protection is strict, and therefore, no studies have yet been conducted to evaluate the hydropower potential. Nevertheless, for the future this technology could become relevant for reaching the Zero Fossil Fuels goal and requires detailed assessment.

Geothermal Energy

Geothermal energy uses extractable heat from geothermal reservoirs in the Earth's interior. Depending on the available amount of heat, it is possible to generate electricity or directly use the heat for instance through geothermal heat pumps used in heating or cooling applications. Geothermal energy has the advantage that it offers a constant output that can provide reliable base-load or back-up energy (IPCC, 2011; Quaschnig, 2013: 331). Currently, geothermal energy is extracted using wells or other means that produce hot fluids from either hydrothermal reservoirs with naturally high permeability or engineered (enhanced) geothermal system (EGS) type reservoirs[39] with artificial fluid pathways (IPCC, 2011: 404; Geothermal Energy Association, 2012). However, maturity level and environmental impacts diverge according to the technology. Generally, it is considered a mature technology and a study by REN21 in cooperation with ISEP estimates current costs

[39] „Enhanced geothermal systems (EGS) refer to the creation of artificial conditions at a site where a reservoir has the potential to produce geothermal energy. ... EGS technologies enhance existing fracture networks in rock, introduce water or another working fluid, or otherwise build on a geothermal reservoir that would be difficult or impossible to derive energy from using only conventional technologies." (Geothermal Energy Association, 2012: 28).

at 6-11 eurocents/kWh (REN21/ ISEP, 2013: 59). Nevertheless, costs can vary and strongly depend on the conditions of the specific site, especially the required depth of the drilling (Quaschnig, 2013: 331).

In Latin America, geothermal energy is currently issued primarily in Argentina, Brazil, Costa Rica, El Salvador and Mexico (WEC, 2010: 465); while large potential is expected in Mexico, El Salvador, Nicaragua, Costa Rica, and Guatemala (WEC, 2010: 454; Oxilia and Luna, 2011: 17). At first glance, geothermal energy appears to be an obvious option for energy generation on the Galápagos because the islands have been created and shaped by on-going volcanic and seismic activity (Toulkidis, 2004; INGALA/ CDF/ Municipios de Galápagos, 2005). Currently, the hotspot forming the islands is located near the equator, beneath the Nazca plate but close to the Cocos Plate and the Pacific Plate, which make up the Galápagos Triple Junction[40] (Lonsdale, 1988; Geist et al., 1994; Mitchell et al., 2011; Smith et al., 2013).

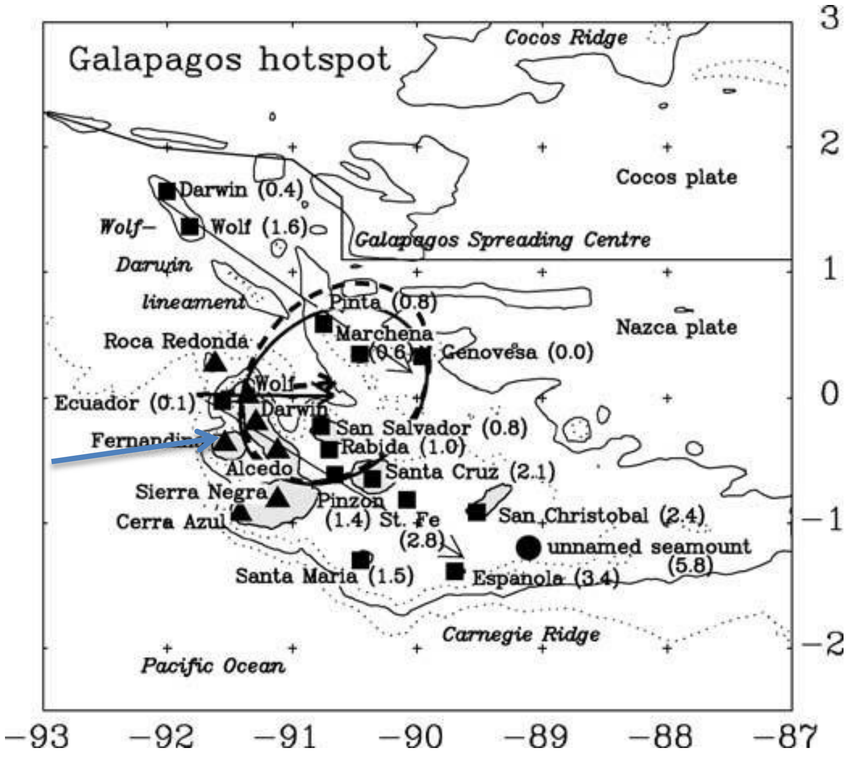


Figure 22: Bathymetric map of the Galápagos Islands.
Source: (Gripp and Gordon, 2002: 357)[41]

[40] This is the junction between the Cocos-Nazca Rift (CNR) and the East Pacific Rise (EPR). See for more details Annex 4.

[41] Note: Solid triangles, volcanoes with the non-numerical age of active; solid squares, volcanoes younger than 5million years; solid circle, a seamount older than 5million years. Angular curve is the approximate active plate boundary. Thin arrows show the observed Galápagos trends along the Carnegie Ridge and Wolf-Darwin lineament. Other arrows and 2-D 95 per cent confidence ellipses are scaled to show the displacement and corresponding uncertainty over 5.8million years. The thick arrow shows motion calculated from HS3-NUVEL1A. The dashed arrow shows motion predicted by removing

The archipelago is considered one of the most volcanically active areas in the world (European Commission, 2001: 2). Therefore, a high geothermal energy potential is expected. Nevertheless, plate tectonics and volcanism in this region is very complex, as visualized in Figure 22. First investigations are currently focusing on the Vulcan Alcedo on Isabela where high temperatures of 260°C to 320°C are expected (CONELEC/ MEER, 2012). Goff et al (2000) project this intra-caldera reservoir to produce up to 150 MWe.

Exploitation of geothermal energy, nevertheless, faces various barriers on the archipelago. Primarily, to be cost effective, a large installation would be necessary – but demands are relatively low (IEA-RETD, 2012: 75). Second, the identified geothermal potential is located inside the protected national park area, and therefore any initiative to explore and exploit it requires a permit and adherence to strict environmental regulations. In addition, water scarcity complicates drilling, exploitation and cooling where water is required[42]. Other limitations include the missing transmission line and general lack of infrastructure (Goff et al., 2000; Bernardo and Salgado, 2010; Quaschnig, 2013). In addition, geothermal energy would have a significant visual and environmental impact (Goff et al., 2004; Hall, 2014), with the potential to sensibly affect the image of the islands as untouched, pristine natural paradise. This could have negative implications for tourism. In addition, energy production through geothermal heat requires a large amount of water for cooling purposes, which is higher than that of any other RE technology (OECD/ IEA, 2012: 510). Although water demand is lower than for fossil fuels, it is a critical component of geothermal systems (Geothermal Energy Association, 2012). Other barriers include high costs, complex technology, risk of causing earthquakes, and potential requirement of new drillings after the cooling of the heat source[43] (Kleemann and Meliß,1993: 7; Quaschnig, 2013: 337f.; IPCC, 2011: 404).

Generally, it is suggested that geothermal energy is more interesting for heating than for electricity generation (Kleemann and Meliß, 1993: 7; Quaschnig, 2013: 337f.). Due to these reasons, the potential of geothermal energy for the Zero Fossil Fuel Program on Galápagos is not expected to be significant. Therefore, it will not be covered in more detail in this thesis.

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the Galápagos trend. The islands are shaded, even 1000m contours are solid, and odd 1000m contours are dotted.

[42] Water demand depends on the specific technology, such as thermal water resources from hot springs or drilling into a hot aquifer or hot-dry-rock-technology. Power plant technologies are flash power plants, dry steam power plants and binary power plants (Geothermal Energy Association, 2012).

[43] The IPCC (2011) special report on renewables mentions the possibility that heat sources are replenished by natural recharge if appropriately managed.

Nevertheless, lower temperature geothermal energy could be exploited through geothermal heat pump (GHP) technologies[44] for space and water heating as well as cooling purposes (IPCC, 2011: 413ff.). They could be a valuable option for reaching the Zero Fossil Fuel goal by reducing energy needs and fuel switching, for instance from fossil-fuel based electricity to geothermal or aero-thermal energy for space cooling (OECD/ IEA, 2012: 270). Their environmental impact depends on their efficiency but also on the emissions related to the production of the working energy that is required to drive the pump (Greenpeace/ EREC/ GWEC, 2012: 256). Therefore, attention needs to be paid to the specific technology but also the coolants play an important role (Quaschnig, 2013: 339ff.). For instance, Hydrochlorofluorocarbons (HCFCs)[45] used in compression heat pumps have a significant climate forcing potential since they are GHGs. In addition, also the use of ammonia in absorption heat pumps is critical as it is poisonous. Nevertheless, if a safe coolant is chosen and the heat pump is driven by RES-E, they have the potential to be very ecological (Quaschnig, 2013: 341; Greenpeace/ EREC/ GWEC, 2012: 256).

To evaluate the technical potential for the Galápagos, further research is necessary on available heat sources, as well as on heating and cooling demand. For instance, potential of hydrothermal and aero-thermal energy should also be considered (Greenpeace/ EREC/ GWEC, 2012: 254). Furthermore, prospects for technology improvements and innovation exist[46] (IPCC, 2011: 405) making a general evaluation of geothermal, hydrothermal and aero-thermal energy for the use on the Galápagos archipelago worthwhile at a later point in time.

Ocean Energy

Ocean energy harnesses the thermal, chemical, potential, and kinetic energy of seawater that can be converted to deliver electricity, thermal energy, or potable water. Currently available technologies are at the demonstration and pilot project phase and include a wide variety of technologies such as submarine turbines for tidal and ocean currents, devices to harness the energy of salinity gradients and waves, and heat exchangers for ocean thermal energy conversion (IPCC, 2011; Greenpeace/ EREC/ GWEC, 2012; OECD/ IEA, 2012). Ocean Energy is not

[44] Generally GHP systems circulate water or other liquids to pull heat from the earth through pipes in an open or closed continuous loop (Geothermal Energy Association, 2012). Two types of technologies are differentiated: compression heat pumps and thermally-driven heat pumps. Latter are driven by sorption processes – either adsorption of absorption.

[45] HCFCs have been phased out under the Montreal Protocol due to their impact on ozone depletion.

[46] For instance, reduction of costs, higher energy recovery, longer field and plant lifetimes, better reliability, and reducing the risk for seismic hazards (IPCC, 2011).

explored in further detail in this thesis, as most technologies are not yet mature[47]. In addition, the marine ecosystem on the Galápagos is delicate and it is assumed that the potential interventions due to ocean energy would not be viable due to the potential damage they may cause. Therefore, based on the precautionary principle, this technology will not be considered.

Conclusion and Technical Challenges

According to the state of current knowledge as presented, the RE potential on the Galápagos Islands is very good. The following Table 6 summarizes the potentials and demonstrates that wind and solar PV are the technologies that should be considered more closely since potential is high and the technology is mature.

Table 6: Overview of power generation and RES potential
Source: Own elaboration

Power Generation by Source 2013 – average annual penetration (%)			Renewable Energy Resource Potential					
Island	Fossil Fuel	RE	Solar	Wind	Biomass	Hydro	Geothermal	Ocean
Santa Cruz	100%	0%	+++	++	?	??	?	?
San Cristóbal	70%	30%	+++	++	?	+	?	?
Isabela	100%	0%	+++	+	?	??	++	?
Floreana	50%	50%	+++	+	?	??	?	?
*** - excellent, ** - good, + some potential; ? – definite potential but extent unknown; ?? none or unlikely potential								

Due to the fact that RES can be used through different processes and technologies, it is possible to cover a wide range of energy demand requirements such as electricity but also transport, water and room heating as well as cooling. This is illustrated in Table 7.

Table 7: Overview of RES, technology and main application
Source: Adapted from (EREC, 2010; Weisser, 2004; IPCC, 2011)

Energy Source	Technologies	Application
Solar	Solar thermal, PV, CSP	Water heating, Electricity, H2 Production (Transport)
Biomass/-gas	Cogeneration	Electricity (Biomass, Biogas), Transport (Bioethanol, -diesel, - gas), H2 Production
Wind	Turbines	Electricity, H2 Production, (Transport)
Hydro	Turbines	Electricity, H2 Production, (Transport)
Ocean	Turbines	Electricity, H2 Production, (Transport)
Geothermal	Turbines	Electricity, Water Heating, H2 Production, (Transport)
Geo-, hydro-, aero – thermal	Heat Pumps	Heating and Cooling

[47] Tidal barrage is the only exception presenting a mature technology using a dam like structure, tidal forces and hydropower turbines to generate electricity (IPCC, 2011).

One of the most critical issues concerning technical feasibility of RE projects is the volatile, intermittent and unpredictable nature of solar and wind energy. Such characteristics can substantially constrain ease of integration into energy systems, or may invoke additional system costs – especially when reaching higher shares of RES (IPCC, 2011). Although wind and sun are complementary, as wind often peaks at night and sun radiation during the day, there are doubts about whether they are a reliable source to provide "base load" energy[48]. Diversifying and combining RES as well as using storage systems to fill in gaps can solve this problem. Czisch (2001) promulgates the idea of "selecting the regions in order to get the best match of production and electricity consumption". This option is viable for Galápagos Islands despite their small size, due to the microclimate, though the framework is limited. According to the IEA-REDT (2012: 41), RES can provide reliable electricity 24-hours-a-day 7-days-a-week if they are properly designed. For instance, a hybrid system or multi-source system combines the benefits of different technologies to leverage their strengths with the aim to deliver stable and affordable energy. Such systems have been developed by Lahmeyer International (2001) for the Galápagos, differentiating scenarios for low, medium and high RE penetration. In 2006, GEF and UNDP (2006: 23) decided, which scenario is the most financially viable for each island. The status of the RET deployment is currently diverging and will be described in chapter 5 for each island separately. Nevertheless, in all cases the diesel generators will remain or be replaced by other thermal generators to meet back-up requirements.

4.2. Energy Security

According to the World Energy Council, Energy Security is (WEC, 2013: 5)*:*

> *"The effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand."*

The benefits of renewables in terms of security of supply are assumed in literature rather than measured (Jaramillo-Nieves and Río, 2010). The three criteria – *energy independence, reliability of energy supply and investment security* – intend to assess the relationship between energy security and RES for Galápagos.

[48] Base load energy is the minimum amount of energy that must be available to customers at any given hour of the day.

4.2.1. Energy Independence

Small islands often lack fossil fuel resources and have difficulties connecting the island grid to a larger network on the mainland, and therefore are highly dependent on energy source imports making them economically vulnerable (Jaramillo-Nieves and Río, 2010; IRENA/ RCREEE, 2013). The diversity of electricity generation influences energy dependence: the higher the diversity, the lower the dependence on one specific source (WEC, 2013: 17). In addition, the higher the fraction of indigenous RES, the lower the energy dependence on imports (Jaramillo-Nieves and Río, 2010). For instance, solar and wind energy can decrease energy dependency (Demirtas, 2013). The share of different RES can therefore indicate the diversity of electricity generation and energy independence. In this context, Liu (2014) points out that the renewable fraction has not yet often been applied as sustainability indicator, but some studies discussed this parameter for a hybrid system (Liu et al., 2011).

The Galápagos Islands are a special case in many aspects regarding energy dependence. As a small island, they do not only have to import fuel but also all required RE equipment and spare parts. Therefore, equipment and energy sources that require frequent imports increase dependence, and delays in delivery need to be considered (IEA-RETD, 2012: 101). That is true not only for fossil fuels, but also for bioenergy crops, since they cannot be cultivated on the islands due to restrictions by the Galápagos national park. For instance, vegetable oil from Jatropha pine nuts used in Floreana has to be imported, and therefore does not increase energy independence. Moreover, the fact that currently Jatropha oil still requires mixing with mineral diesel maintains fossil fuel dependence as well as import dependence. One must consider that the use of bioenergy crops could possibly even increase energy dependence since multiple climatic and social factors can influence the amount and quality of the pine nut oil provided (UNIDO, 2014). This could cause supply bottlenecks and aggravate the situation. In general, the complexity of removing fossil fuels causes doubts in Galápagos as it might only substitute dependency on fossil fuels with the dependency on foreign technology and expertise (IEA-RETD, 2012). This could enhance path dependence[49] and thereby hamper energy transition such as technology diffusion (GEA, 2012: 1748).

[49] Path dependence is the tendency for past practices and decisions to shape present choices.

4.2.2. Reliability of the Energy Supply

Reliability of supply means, that an energy source is able to provide energy where and when it is needed (Jaramillo-Nieves and Río, 2010). Reliability is one key characteristic of power quality (IEA-RETD, 2012: 215). Islands are especially vulnerable because the lack of interconnections with the mainland reinforces the risk of energy supply interruptions. On the one hand, fossil fuel supply shortages can occur through supply interruptions such as delays in transport. On the other hand, the small size of the islands and their energy systems limits the potential to balance interruptions caused by technical failures on an inter-island basis.

The integration of RES increases diversity of electricity generation, increasing energy reliability since diversity decreases dependence on one specific source. Nevertheless, most RES are intermittent and their volatility impedes the possibility to guarantee a specific energy supply at a given moment in time (Jaramillo-Nieves and Río, 2010; Curbelo, 2010). A combination of different RES, a so-called "hybridization" could contribute in this regard to increase predictability, and therefore manageability, of the energy system. This is particularly the case for wind and sun, since solar resources are available during day and the hot season, while wind speeds are higher during the cold season and at night on Galápagos (Jaramillo-Nieves and Río, 2010: 769; ERGAL/ KfW/ Lahmeyer, 2001). Nevertheless, intermittency is critical, especially in small territories, as it might not be possible to balance availabilities in different locations (Jaramillo-Nieves and Río, 2010: 794). Studies agree that the volatile nature of wind and solar energy makes back-up capacity unavoidable unless appropriate storage solutions are deployed (GEF/ UNDP, 2006; Jaramillo-Nieves and Río, 2010; IPCC, 2011; IEA-RETD, 2012; IRENA, 2012b; Boxleitner et al., 2010).

Besides the intermittent nature of REs, reliability of supply is also influenced by energy losses and power supply security. On Galápagos, the electricity generation is characterized not only by small diesel generators[50] and partially old equipment but also by relatively high losses (ERGAL, 2008a; ElecGalápagos, 2013a; ElecGalápagos, 2014a). Losses appear during transmission and distribution of the electricity through the grid from the generator to the consumer. In 2013, power transmission and distribution losses were about 9% on Galápagos (see Annex 8). This is relatively high compared with developed countries such as Germany,

[50] The system on Galápagos is not very efficient as it is equipped with low to medium speed diesel generators, most commonly used for electricity generation in small islands (IRENA, 2013). These reach their economic efficiency with increased scale. Full economies of scale are obtained with generators larger than 9,000kW rated output. The diesel systems on Galápagos, however, are between 69kW and 1,700kW (ElecGalápagos, 2013a).

Belgium, and Austria where losses are between 3–6 %. Nevertheless, it is rather good compared to continental Ecuador or other developing countries where losses are usually larger than 15–20% (CONELEC/ MEER, 2012: 120; The World Bank, 2013). The reason for this relatively good performance might be the locally restricted area in Galápagos with relatively short transmission distances.

Another important aspect of energy supply reliability refers to the performance of the power sector to provide electricity to the final consumer measuring frequency and duration of interruptions in electricity supply (GEA, 2012: 170). In other words, the number and duration of interruptions of the electricity supply influences the quality of the electrical grid, and therefore indicates its reliability. In 2012, on Galápagos, there have been 17.4 interruptions[51] amounting to 34.4 hours in total (CONELEC/ MEER, 2012). In comparison, most European countries had fewer than 3 interruptions per year in 2010, and the total duration of these interruptions was less than 3 hours (CEER, 2012). However, supply disruptions on the archipelago are low compared to other developing countries (Gelvin Electricity Initiative, 2011; GEA, 2012: 171). According to ERGAL (2008a), the lack of investment and maintenance of the existing electricity system together with old and inefficient equipment contributed to these expensive energy losses on Galápagos. Nevertheless, an unreliable electricity supply can have negative implications for the economy and should therefore be avoided.

In summary, the energy system on Galápagos has until recently been exclusively based on thermal diesel generators. This technology is technically feasible, well-known, and has been in operation for many decades. It is generally reliable despite the above-mentioned interruptions – although not overly efficient due to their small size (between 69 kW and 1,700 kW) (ElecGalápagos, 2013a; IRENA, 2013). Therefore, this section suggests that by implementing RETs, there is significant potential to improve the reliability of the electricity system if renewables are intelligently combined and complemented with storage options. In addition, a potential reduction in distribution losses would increase energy efficiency and reduce energy demand. Nevertheless, for these potentials to become effective it is necessary to overcome the lack of technical and operational human capacity[52] as well as the missing financial resources.

[51] This indicator is known as “SAIFI - system average interruption frequency index”.

[52] For instance, Curbelo (2010: 55f.) assumed that technicians of the electrical utility ElecGalápaogs are not in a condition and do not have the financial resources available that allow them to operate and maintain a complex hybrid system.

4.2.3. Investment Security

It has been widely recognized that private sector involvement is an indispensable condition to achieve the required scale of new investments necessary to reach high shares of REs. Studies conducted by Komendantova et al. (2009) identified barriers to investment in the particular context of RE development. The highest concerns are perceived in the area of regulation, politics and *force majeure*. Among these concerns, regulatory risks are of greatest concern and perceived as most likely to occur. These include complexity and corruption of bureaucratic procedures and instability of national regulations. Therefore, the following sub-chapters will describe the regulatory and institutional framework within which REs are developed on Galápagos. This includes, in particular, the legal context for energy supply, SD, and environmental protection with the aim to analyze the complexity and stability of national regulation. Hence, this section is organized in four dimensions presenting the local and international framework that concern a sustainable energy supply: 1) The underlying global structure; 2) the national regime of the state; 3) the decentralized regional administrative structure in Galápagos; and 4) the involvement of external governmental and non-governmental actors. In each section the most relevant conventions, laws and regulations for the Zero Fossil Fuel initiative will be mentioned and shortly described.

4.2.3.1. Global Political and Legal Aspects

Generally, states engage with the broader world system through international agreements. Numerous international agreements exist that try to protect certain environmental aspects. The first broad protection of biological diversity on the international level will be the Convention on Biological Diversity, which is supported by Ecuador, but not yet in force (Convention on Biological Diversity, 2013). Regarding climate change and energy related emissions, the most relevant are the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP) that has been signed and ratified by Ecuador as well as all 18 other Latin American states. Since Ecuador belongs to the Non-Annex 1 countries, it has no obligations to reduce GHG emissions. Nevertheless, it is committed to prepare reports, national strategies and GHG inventories in which it has to include Galápagos (UN, 1992; UN, 1998; Europeaid, 2009: 26; UNFCCC, 2013). In addition, development of RES-E will rely heavily on the availability of long-term funding mechanisms and partnerships (WEC, 2010: 290). Nevertheless, Ecuador has been characterized in the past by a weak financial base, relative high level of corruption and an illicit economy. Just as in other LA states, increasing protectionism, the "Socialism of the 21st century" with progressive nationalization of private property and restrictive entrepreneurial environment weaken property rights, marginalizing the private sector[53] (Klonsky et al., 2012; Heritage Foundation, 2013). This results in low foreign direct investment and the need for Ecuador to seek alternative investment while establishing a stable legal framework, strengthening property rights, fighting corruption and the illicit economy.

One of the most relevant frameworks to finance RE projects in developing countries is the Clean Development Mechanism (CDM) that is provided by the KP Art. 4. The purpose of the CDM is to help the Non-Annex I Parties to the UNFCCC achieve SD and to contribute to the convention's ultimate aim, as well as helping the parties that are included in Annex I to comply with their GHG emission reduction obligations as defined in the KP (UN, 1998; Europeaid, 2009: 33). There are two essential conditions: the CDM can only be used by the parties to the protocol, and the project is subject to the condition that the emission reduction achieved are additional to any that would have otherwise occurred. This means *in addition* to development aid and host country projects. Moreover, there are likely to be other incentive programs such as the Global Environmental Facility (GEF), the Clean Investment Funds and new mechanisms under the UNFCCC for countries that promote low-carbon development of their power sectors (Yépez-García et al., 2011: 23). Thus, currently, the main influence of the international legal sphere on the Zero Fossil Fuel Program is perceived in the financial area, in particular through the flexible mechanisms under the KP and the incentive programs under the UNFCCC. This has been confirmed by the registration of the San Cristóbal Wind Park under the CDM (ERGAL, 2008b; Rosero and Chiliquinga, 2011: 55).

4.2.3.2. Legal and Political Framework in Ecuador

On the national legal level, Ecuador shows remarkable environmental awareness and a strong intention to promote REs and sustainability. As of 2008, Ecuador's new constitution (República del Ecuador, 2008) not only rejects neoliberalism, expands

[53] As result of the financial crisis 1980s-1990s in Latin America, the states lost sovereignty over natural resources through reforms and the inflow of large amounts of international capital (Oxilia and Luna, 2011: 11). In recent years there has been a change in the direction of economic policies, most visible in Venezuela, Ecuador, Bolivia and Nicaragua, adhering to the "Socialism of the 21st century" (Emmerich, 2009: 6; 10) (Wolff, 2011: 5). International and local investors have been discouraged because of financial reforms, which intend to nationalize private property, for example oil industry (Becker, 2012: 2) (McKeigue, 2013). For many traditional liberal democracies, like Germany and the US, private property rights are a crucial element of the rule of law (Wolff, 2011: 21). Consequently, the nationalization of property is to them, a breech of law.

democratic participation and embraces increased resource allocation for healthcare, social service and education, but lays also down enforceable environmental rights – the rights of the nature also referred to as "*Pacha Mama*"[54]. Additionally, it embraces the "*suman kawsay*" the idea of "living well rather than living better" (República del Ecuador, 2008; Becker, 2012: 2). Furthermore, the Ecuadorian State has laid down the promotion of REs, energy efficiency, environmental projection and sustainability – not only in manifold legislation, such as the *National Plan for Well-Being*, but also in its constitution.

The following Articles of the *Ecuadorian Constitution* show the promotion of RES and sustainability (own translation):

> *Article 15 - The State shall promote within the public and private sector the use of **environmentally clean technologies** and low impact **clean alternative energy**. Energy sovereignty will not be achieved at the expense of food sovereignty, or affect the right to water.*
> *Article 313 - The **State** reserves the **right** to administrate, regulate, control and manage the **strategic sectors** in accordance with the principles of environmental **sustainability**, precaution, prevention and efficiency.*
> *Article 314 – The state is responsible for the provision of … electrical energy*
> *Article 315 – the state builds up public organizations to provide public services …*
> *Article 316 – the state can delegate this obligation to provide public services in the strategic sectors to mixed organizations only if the state has majority participation … Only in exceptional cases delegation to private initiatives or "economia popular y solidaria" when established by law*
> *Article 413 – the State shall **promote energy efficiency**, development and use of **environmentally clean** and **healthy technologies** and practices, as well as **renewable energies** that should be diversified, have a low-impact and be non-threatening to food sovereignty, to the ecological balance of the ecosystems and water rights.*
> *Article 414 – The Central Government adopts adequate transversal **mitigation** measures against **climate change** by **reducing the emissions** of green house gases, limiting deforestation and other atmospheric pollution; conservation of forests y vegetation, and protecting its population in risk.*
> *Article 415 – The Central Government and the decentralized autonomous governments will adopt comprehensive and participative urban land use planning policies... The decentralized autonomous governments will develop programs for rational use of water and waste reduction, recycling and proper treatment of solid and liquid wastes.*

In addition, the Government's National Development Plan entitled: *Plan Nacional del Buen Vivir (PNBV) - National Well-Living Plan 2013-2017* (SENPLADES, 2013) promotes the use of REs and energy efficiency, including (own translation):

> *Objective 3: improve the quality of life for the population*

[54] "Pacha Mama" is the Andean concept of the right of nature while "suman kawsay" is an Andean concept of living well rather than living better, thus favouring sustainability over material accumulation and the commodification of resources.

*Policy 3.9 d.: promote the construction of housing … which use efficiently natural resources and **alternative energy**.*

*Policy 3.12 b … promote non motorized **transport** modes that are **sustainable**, healthy and including; d. formulate mobility plans which give preference to sustainable public transport …*

Objective 5: strengthen the diverse identities, plurinationality and intercultural attitude

*Policy 5.1 v.: create an … **ecologically responsible transport***

*Objective 7: Ensuring the **rights of nature** and promoting a **sustainable** regional and global **environment**.*

Policy 7.2: Understand, value, conserve and manage sustainably natural patrimony and its terrestrial and maritime biodiversity with the just and equal access to its benefits

*Policy 7.7: Promote **efficiency** and increase the share of **renewable sustainable energies** to prevent environmental pollution.*

- *a. Promote **energy efficiency***
- *b. Promote investigation concerning **renewable energies** and **energy efficiency***
- *c. **Reduce** gradually the use of **fossil fuels** in transport, replace the conventional vehicles, promote sustainable mobility.*

*Policy 7.9: promote **conscious**, **sustainable** and **efficient consumption** considering the limits of our planet*

Policy 7.10: implement measures to mitigate and adapt to climate change to reduce economic and environmental vulnerability

*Policy 7.12: strengthen the environmental politic of the **Galápagos Archipelago** … and l. Consolidate the **cero use of fossil fuels** … with emphasis on sustainable terrestrial and maritime **mobility** through the use of **renewable** and **sustainable energies**, to promote a more healthy lifestyle.*

Objective 8: Consolidate in a sustainable way the economic and solidary economic system

Objective 10: Promote the transformation of the industrial sector

*10.9 e: articulate the actions and objectives of **clean energy** and **energy efficiency***

Objective 11: Assure the sovereignty and efficiency of the strategic sectors for an industrial and technological transformation

Policy 11.1: Restructure the energy mix considering … energy sovereignty and sustainability with an increased participation of renewable energies

*a … focus on **hydro** energy*

*b … exploit **bioenergy** without affecting food sovereignty and respecting the rights of the nature*

*d … promote **energy efficiency** and energy saving without affecting availability and quality of energy services*

*n … **optimize** the use of conventional **fossil fuels** by using efficient technologies*

*t … promote scientific investigation in the area of … **renewable energies** …*

Additionally, energy, the development of REs, improvement to access of public services and sustainable investment and project implementation are also mentioned in the intersectional guideline policies of the strategic sectors, such as energy (MICSE, 2014).

The Ministry of Energy and Mining (MEM) published the “Energy Agenda 2007-2011” in 2007, placing a special focus on REs and energy efficiency (MEM, 2007a). In addition, this strategic agenda is one of the first to officially mention the *Zero Fossil Fuels Program for Galápagos*. It substantiates the initiative with the warning that fossil fuel consumption is increasing with approximately 10% per year, and risks for negative environmental impacts are rising with it. In addition, it refers to the “Executive Decree No. 270 from 10.4.2007” declaring the conservation of Galápagos a national priority. Therefore fossil fuel use shall be eradicated from the archipelago in the electricity sector as well as in maritime and terrestrial transport. The latter shall be transformed by replacing fossil fuel diesel with biofuels and by introducing electrical and hybrid cars (MEM, 2007a: 98; Alvear and Lewis, 2013). Moreover, in 2008 the MEER developed the "Energy Policies of Ecuador from 2008 to 2020”, highlighting the energy sector’s SD related to REs (Rosero and Chiliquinga, 2011: 22):

> *“c) developing a model of **environmentally friendly energy technologies**.”;*
>
> *“d) formulating and carrying out a National Energy Plan, which defines the sector’s optimized expansion in the **sustainable development** context.”;*
>
> *“f) promoting the development of **sustainable energy resources** and fostering projects with **renewable** generation sources (hydropower, geothermal, solar and wind power), and new **efficient** electric generation...”;*
>
> *“n) reducing fuel consumption for transport and its substitution with compressed **natural gas** - CNG, electricity and the introduction of **hybrid technology**.”*

The Sub-secretary of the MEER responsible for REs and energy efficiency (*Subsecretaría de Energía Renovable y Eficiencia Energética*) is involved in the following plans based on the above-mentioned policies (MEER, 2014b):

- ⇨ In the context of biomass the production of Jatropha oil for electricity generation in Galápagos shall be promoted as well as the implementation of digesters for residues to generate biomass.
- ⇨ Concerning energy efficiency and REs the plans include intelligent public lightning and the exchange of light bulbs, increase of energy efficiency in the industry, implementation of new technologies in urban transport, and the program to replace energy inefficient household appliances such as fridges.

The CONELEC, as regulator of the electricity sector, formulates a “Master Plan for Electrification” (*Plan Maestro de Electrificación* – PME) each year in accordance with the MEER (CONELEC/ MEER, 2012; CONELEC/ MEER, 2013). Politics include the obligation of CONELEC to guarantee delivery of energy by considering renewable non-conventional energy sources such as solar, wind, geothermal, biomass, and ocean energy. In addition, CONELEC shall strengthen and adapt the transmission grids to the future supply and demand of electricity to allow for a gradually increasing share of REs. In agreement with the PNBV the energy politics shall not only consider changing the energy mix towards RES-E, but include energy efficiency as well. Programs contain five main plans:

- FERUM (Marginal Rural and Urban Electrification Fund): Program for rural and urban electrification, this also includes Galápagos
- PMD: Plan for improvement of the distribution system
- PLANREP: Plan for reduction of losses
- COCCION: Plan to replace natural gas based cooking facilities with electric kitchens.
- Plan de Soterramiento: Plan to bury the electricity grid underground

Their total investments as well as the share for Galápagos are depicted in the following Table 8.

Table 8: Total investment and the share for Galápagos for 2013–2022 in million USD
Source: (CONELEC/ MEER, 2013)

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total Galápagos
FERUM	$198,05	$0,12	$0,40	$0,18	$0,05	$0,08						$0,83
PMD	$883,93	$0,11	$0,20	$0,20	$0,20	$0,30	$0,30	$0,20	$0,23	$0,20	$0,26	$2,20
PLANREP	$365,49	$0,08	$0,09	$0,09	$0,09	$0,10	$0,10	$0,10	$0,11	$0,11	$0,12	$0,99
Cooking	$1.134,87	$0,35	$0,35	$0,35	$10,62	$10,44	$10,44	$10,44				$42,99
Plan for subsoil cable	$795,37			$4,47								$4,47
Sum	**$3.377,71**	**$0,66**	**$1,04**	**$5,29**	**$10,96**	**$10,92**	**$10,84**	**$10,74**	**$0,34**	**$0,31**	**$0,38**	**$51,48**

Additionally, there are specific laws in force within the electricity sector that support the promotion and development of REs (Rosero and Chiliquinga, 2011: 23-24):

- **The Electricity Sector Regime Law (LRSE – Ley de Régimen del Sector Eléctrico)** from 1996 defines the structure of the electricity sector, its functioning concerning generation, transmission, distribution, and the electricity market (Gobierno del Ecuador, 1996). This law also created the National Electricity Council (CONELEC). In addition, it lays down the opening of the electricity sector and its deregulation, creating the electricity market (MEM – Mercado Eléctrico Mayorista). Nevertheless, the constitution of 2008 considers electricity supply as strategic sector and electrical energy as a public good, thus the electricity sector remains nowadays mainly under public control. Furthermore, according to Article 63 LRSE, the state is committed to promote the development and use of unconventional energy resources. Article 67 LRSE[55]

[55] Art. 67: Waive the payment of fees, additional taxes and other charges affecting the importation of materials and equipment not produced in the country for research, production, manufacture and installation of systems for the use of solar, wind, geothermal, biomass and others. Waive the payment

includes benefits and tax exemptions to encourage REs such as solar, wind, geothermal, and biomass.

- ⇨ The CONELEC Regulation 008/08, lays down the procedures for qualifying FERUM projects[56]. In addition, there are several other regulations concerning the management of funds from **FERUM**, which define the purpose of the funds for new construction, expansion and improvement of distribution systems in rural and marginal urban areas, or for generating systems that use nonconventional REs in rural areas (CONELEC, 2008b).
- ⇨ Regulation CONELEC 003/11 determines the methodology for calculating the terms and referential prices for generation and self-generation projects developed by private initiatives, including those using renewable energy (CONELEC, 2011b).

To promote REs, Ecuador laid down a feed-in tariffs scheme, currently being the most common RE regulatory policy type in Latin American countries (UNEP, 2012: 14; REN21, 2012; Gipe, 2014). The development of the FiT in Ecuador started around 2000 and has been subject to continuous change as illustrated in Table 9.

Table 9: Evolution of the FiT in Ecuador
Source: Adapted from (Egüez Macías, 2012; CONELEC, 2012c; CONELEC, 2012c) and (CONELEC, 2013a)

Regulation No.	Date and Resolution	Due date eligibility criteria	Duration of tariff payment
CONELEC 000/08	Approved on September 27, 2000 (Resolution No. 161/00)	31.12.04	10 years
CONELEC 003/02	Approved on March 26, 2002 (Resolution No. 074/02)	31.12.04	10 years
CONELEC 004/04	Approved on December 24, 2004 (Resolution No. 280/04); in force since January 1, 2005.	31.12.06	12 years
CONELEC 009/06	Approved on December 19, 2006 (Resolution No. 292/06); in force since January 1, 2007.	31.12.08	12 years
CONELEC 004/11	Approved on April 14, 2011 (Resolution No. 023/11) and updated on January 12, 2012; (Resolution No. 017/12)	31.12.12	15 years
CONELEC 001/13	Approved on May 21, 2013 (Resolution No. 010/13)	31.12.2015	15 years

The most important regulations are the following: First, CONELEC Regulation 004/11 deals with energy produced with Renewable Non-Conventional Energy Resources including wind, biomass, biogas, photovoltaic, geo-thermal, and

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of income tax for five years from the time of its implementation to the companies that with their investment establish and operate electricity production plants using RE (Rosero und Chiliquinga 2011).

[56] It determines a reserve of 7.5% of the FERUM budget for border provinces, Amazon region and Galápagos. It also states that RE projects may be submitted to CONELEC by development agencies, provided that the project cannot be handled through networks, or considered by the Electricity Distribution Company in the area, as a non-RE project (Rosero und Chiliquinga 2011).

hydroelectric plants of maximum 50 MW of installed capacity. Under this regulation, parties interested in implementing a project using RES may request preferential treatment, and will have to submit the appropriate requirements to CONELEC. The preferential prices to be paid for energy are those indicated in Table 10. The prices established in this regulation are guaranteed for 15 years as of the signing date of the "Enabling Instrument" but have to be singed before 31.12.2012. CENACE is obliged to dispatch preferentially all electricity that plants using non-conventional REs deliver to the system, up to a ceiling of 6% of the total national installed and operational capacity of the National Interconnected System (NIS)[57] (Rosero and Chiliquinga, 2011: 23-24; CONELEC, 2011a).

Second, Resolution 017/12 reforms the FiT mentioned in the Regulation 004/11 and adds new types of technologies receiving a preferential tariff, such as marine ocean currents and solar thermal (CONELEC, 2012b).

Table 10: Prices for Renewable Energies (USD cent/kWh)
Source: Own elaboration

	Continental Territory			Galápagos Territory		
	Reg. 004/11 & Res. 017/12 Preferential Tariff	Reg. 001/13 Preferential Tariff	Reg. 001/13 Ordinary Tariff	Reg. 004/11 & Res. 017/12 Preferential Tariff	Reg. 001/13 Preferential Tariff	Reg. 001/13 Ordinary Tariff
Wind	9.13	(11.74)	2.39	10.04	(12.91)	2.62
PV	40.03		11.80	44.03		12.99
Solar Thermal	31.02	(25.77)	8.74	34.12	(28.34)	9.61
Ocean Currents	44.77	(32.43)	12.77	49.25	(35.67)	14.05
Biomass		9.67	2.38*		10.64	2.62*
Biogas		7.32	1.65*		8.05	1.82*
Biomass and Biogas < 5 MW	11.05	(11.08)	2.86	12.16	(12.19)	2.75
Biomass and Biogas > 5 MW	9.60		2.5	10.56		3.69
Geothermal	13.21	(13.81)	3.36	14.53	(15.19)	3.69
Hydro	6.21–7.17	(6.51–7.18)				
Hydro ($\leq 30MW$)		6.58				

Third, Regulation CONELEC 001/13 lays down the participation of electricity produced from renewable non-conventional resources. It reforms the preferential tariff and lays down that projects using biomass and biogas will receive the preferential tariff until a cap of 100 MW is reached. This cap does not include hydroelectricity. In addition, the regulation lays down the ordinary tariffs ("valor unitario") for the REs (CONELEC, 2013a). Values in brackets indicate the

[57] This is, however, not relevant for Galápagos since it is not connected to the NIS.

preferential tariffs, projects received, before the regulation was valid but after the validity of Regulation 004/11, which terminated 31.12.2012.

Fourth, Regulation CONELEC 002/13 lays down the simplified process for electricity generation units from REs with less than 1 MW and their treatment concerning commercial, technical and regulatory aspects. In addition, projects with less than 1 MW installed power do not fall under the 6% cap (CONELEC, 2013b).

In summary, this section shows that Ecuador is trying to promote REs and therefore has developed a legal framework. Nevertheless, as most countries in Latin America, Ecuador is also still criticized for being burdened with opaque policy frameworks, inefficiency and excessive red tape[58] (Yépez-García et al., 2011; IRENA, 2012a: 2f.). Market development of REs is impeded as Ecuador suffers from the lack of a clear, long-term policy framework (Yépez-García et al., 2011; GWEC, 2012: 36). Currently, the main obstacle to RE deployment is the absence of a reliable FiT scheme or renewable purchase obligations for RES-E. The FiT for solar, wind, geothermal and ocean currents energy was only available for approximately two years, which is a much too short timeframe to develop RES-E projects. Currently, a FiT scheme is only available for biomass, biogas and hydroelectricity. Nevertheless, there is a clear agreement that a reliable financial incentive scheme is essential to provide planning security for investors (Viebahn et al., 2010). Furthermore, there is a lack of legal framework for Independent Power Producers (IPPs), as the energy sector is mainly in public hands. Also, there are no comprehensive regulations on transmission access and interconnection requirements for renewables (Viebahn et al., 2010).

Nonetheless, it has to be mentioned, that not only in Ecuador do REs face obstacles. Barriers also exist in the RE pioneer states, such as in the EU or US, where RES-E flourishes – albeit the difficulties and varying degrees of success. For example, FiTs see a general downward trend in the EU. Cuts have been made in France, Germany, Italy, Greece, Slovakia and Switzerland while other states removed the support completely such as in Portugal, or have put it on hold such as in Spain (REN21, 2012: 67). In addition, when they are implemented, the average time to get permission for the construction and grid connection for a renewable power plant in the EU is about 30 months, with Ireland, Denmark, Spain and Sweden approaching or exceeding 50 months. Many countries have complicated permission procedures for the construction and grid connection of RE plants: in the

[58] Red tape is an idiom that refers to excessive regulation or rigid conformity to formal rules that is considered redundant or bureaucratic and hinders or prevents action or decision-making.

EU in average 5 different authorities, up to 40 in Hungary, are involved in the permission processes and 30% (in Hungary almost 100%) of all applications are rejected (PwC/ PIK/ IIASA/ ECF, 2010: 16). The fact that renewables in the EU increase despite these difficulties gives ground for optimism.

Another reason for being optimistic concerning RE deployment on Galápagos is the relatively high rank of Ecuador in the Environmental Policies Index (EPI). This is an indicator that tries to measure the attractiveness of a country for investment into REs. Ecuador reached a relatively high EPI score with 58.54 out of 100 – a rank of 53 out of 178 countries (Yale University, 2014). The EPI's points system[59] can help indicate the opportunity for environmentally oriented projects to be successful (Europeaid, 2009; Emerson et al., 2012). This justifies the hope that projects focusing on environmental conservation, such as implementing REs, could have substantial success in Galápagos.

4.2.3.3. Institutional Framework in Ecuador

Ecuador's institutional framework for a sustainable energy supply is based on various ministries, agencies and public companies as illustrated in Figure 23. The following are the most relevant public stakeholders for implementing RE projects and energy efficiency measures. Firstly, the energy sector is managed by two institutions: on the one hand, the Ministry for Electricity and Renewable Energies (MEER – *Ministerio de Electricidad y Energía Renovable*) is responsible for developing and implementing policies, programs and initiatives regarding electricity and REs. Its main task is to formulate national energy politics and administering projects (CONELEC, 2012a). On the other hand, the Ministry of Non-Renewable Natural Resources (MRNNR – *Ministerio de Recursos Naturales No Renovables*) exploits natural non-renewable resources sustainably and sovereignly. In addition it formulates and controls the politics, develops and investigates concerning fossil resources and mining. The execution is delegated, for example, to PetroEcuador.

[59] The Environmental Performance Index (EPI) was developed by the Yale Centre for Environmental Law and Policy and the Colombia University's Centre for International Earth Science Information Network, in collaboration with the Joint Research Centre. The EPI measures performance at a country level based on a common set of environmental policy goals that each country can be responsible for. The "Country Policy and Institutional Assessment" (CPIA) rates countries based on a set of 16 criteria grouped into four clusters: (a) economic management; (b) structural policies; (c) social inclusion and equity policy; and (d) management of the public sector and institutions. These environmental criteria estimate the extent to which environmental policies strengthen the protection and sustainable use of natural resources and pollution management. Multidimensional criteria are required to estimate environmental sustainability (e.g. for water, air, waste, the management of protected areas, the management of coastal areas and the management of natural resources). The CPIA index was created by the World Bank to ensure balanced assessments.

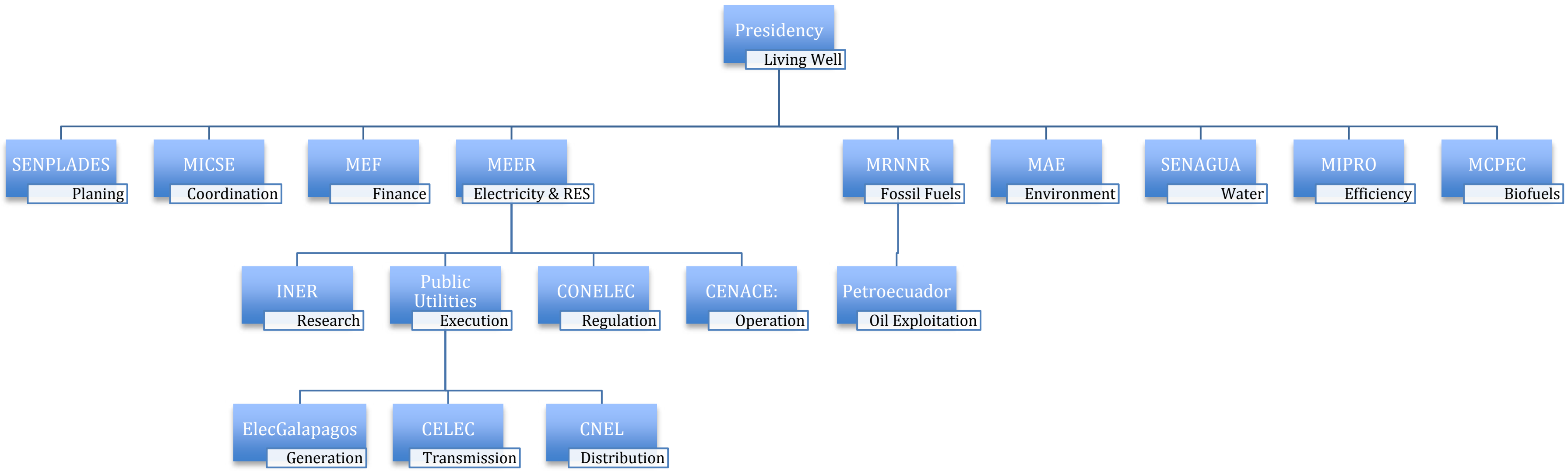

Figure 23: Structure of the Inter-Institutional Energy Framework in Ecuador
Source: Adapted from (MEER, 2014a)

Moreover, there is the National Secretariat of Planning and Development (SENPLADES – *Secretaría Nacional de Planificación y Desarrollo*) that is responsible for public investments to improve services such as the supply of electricity and water. SENPLADES supports, together with the MEER and the Ministry for Agriculture, Fisheries (MAGAP), the Jatropha oil project on Floreana; the sustainable mobility plan in cooperation with the local government; together with MEER the PV project in Baltra and the energy efficiency project in Galápagos; as well as the installation of energy efficient public lightning in Galápagos (SENPLADES, 2012).

The Coordinating Ministry for the Strategic Sectors (MICSE – *Ministerio Coordinador de Sectores Estratégicos)* guides the politics and actions of the institutions in the strategic sectors, such as energy (Gobierno del Ecuador, 2008).

The Ministry of Finance (MEF) is responsible for managing the public financial household. Energy is crucial for the MEF, since most of the public financial budget is based on fossil fuel profits produced by the public company PetroEcuador[60] (ILO, 2001; Petroecuador, 2010: 5). This money is then used to promote REs, energy efficiency and protection of the environment, as well as inclusive and sustainable development.

The Ministry of the Environment (MAE – *Ministerio del Ambiente*) is in place to execute efficiently and effectively environmental management, guaranteeing harmony between the economy, society and environment. Furthermore, it assures the sustainable use of the strategic natural resources. Its objectives involve the reduction of GHG, the decrease of resource consumption such as electricity, water and paper as well as subsequent waste (MAE, 2014).

The National Water Secretary (SENAGUA – *Secretaría Nacional del Agua*) acts as guardian of the water in Ecuador, developing policies, as well as norms, to allow for efficient control of water and use of this elemental resource. It is responsible for the distribution of water, its quality and quantity (SENAGUA, 2014).

The Ministry for Industry and Productivity (MIPRO – *Ministerio de Industrias y Productividad*) focuses more generally on cleaner production and efficient use of resources, including energy efficiency. Projects include "*Renova Refrigeradoras*" with the aim to change old refrigerators to more energy–efficient ones or "*Renova Cocina*" to change gas based kitchens to electric ones (MIPRO, 2014).

[60] Oil is one of the most important export products with 59% of total exports in 2010 a share of around 13% of the GDP that remained roughly constant since 1990 (ILO, 2001; Petroecuador, 2010: 5).

The Coordinating Ministry of Production, Employment and Competitiveness (MCPEC – *Ministerio Coordinador de Producción, Empleo y Competividad*) is the coordinating body for biofuel development. In charge is the 2007 founded National Biofuels Council (*Consejo Nacional de Biocombustibles*), which is responsible for defining the politics, programs and projects regarding production, management, and commercialization of biofuels. It is an inter-sectorial body bringing together various ministries, state companies and private sector representatives (Gobierno del Ecuador, 2007; Rosero and Chiliquinga, 2011). In the agenda for transforming the productive system of Ecuador, the "National Program for Biofuels" is mentioned as well as a proposed project in cooperation with SENACYT that shall consider electricity generation for domestic consumption using hydrogen (SENESCYT, 2013).

The MEER delegates specific aspects regarding electricity and REs to other institutions and public companies: CONELEC, CENACE, CELEC, CNEL, public utilities for energy generation, and the INER. The National Electricity Council (CONELEC – *Consejo Nacional de Electricidad*) is in charge of planning, regulation and control of the electricity sector in Ecuador. It is the main regulator of the electricity sector, sets energy prices and lays down the FiT for REs. It also defines technical regulations, and approves concessions for the exploitation of REs (Rosero and Chiliquinga, 2011; MEER, 2014a). The National Centre for Energy Control (CENACE – *Centro Nacional de Control de Energía*) is responsible for the technical management, and guarantees the operation of the sector (MEER, 2014a). It also administers the technical and financial transactions at the energy bourse (MEM – *Mercado Eléctrico Mayorista*) and its main responsibility is the sale of electricity. Furthermore, the MEER can delegate research issues to the National Institute for Energy Efficiency and Renewable Energies (INER – *Instituto Nacional de Eficiencia Energética y Energías Renovables*) (Gobierno del Ecuador, 2012).

Moreover, there are a number of public utilities in the electricity sector. Firstly, the National Company for Electricity (CELEC – *Corporación Eléctrica del Ecuador*) is responsible for providing the electricity services including generation, transmission, distribution, commercialization and the import and export of electrical energy. It has the aim to become a single company of the sector (MEER, 2014a). Until now it is fully responsible for the transmission and has additionally six electricity generation units. Secondly, the National Company for Electricity (CNEL – *Corporación Nacional de Electricidad*) is responsible, together with its operating units and ten other companies, for the distribution of electricity to the final consumer (MEER, 2014a).

Finally, electricity generation is also the responsibility of public companies, such as the electrical utility on Galápagos also referred to as ElecGalápagos – *Empresa Eléctrica de Galápagos* (MEER, 2014a).

Other relevant institutions for the development of the Zero Fossil Fuels initiative on Galápagos are the Ministry of Agriculture (MAPAG – *Ministerio de Agricultura, Ganadería, Aquacultura y Pesca*) because the development of biofuels concerns their fields of responsibilities. In addition, the Ministry of Urban Development and Housing (MIDUVI – *Ministerio de Desarrollo Urbano y Vivienda*) can influence energy efficiency of housing, as well as the delivery of public services such as water, that affect energy consumption. Moreover, the Ministry of Tourism (MINTUR – *Ministerio de Turismo*) can affect the elimination of fossil fuels since tourism is the most important economic sector of Galápagos. In the context of education, the National Secretary of Higher Education, Science, Technology and Innovation (SENECYT – *Secretaría Nacional de Educación Superior, Ciencia, Tecnología e Innovación*) can support the implementation of the Zero Fossil Fuel Program since it requires capacity building of human resources, education and increased public awareness. In addition, developing long-term strategies for maintaining and developing further technologies is vital, if the elimination of fossil fuels is to be sustainable in the long run.

This short overview of the governmental institutions on the national level reveals the extensive governmental apparatus and bureaucracy the Zero Fossil Fuel Program has to face. It is seen as critical that there is no single institution responsible for all matters concerning energy demand and supply. This complicates the success of the Zero Fossil Fuel Program.

4.2.3.4. Legal and Political Framework on Galápagos

The Galápagos archipelago has a special (and in Ecuador, a unique) administrative structure with a decentralized regional government, the '*Consejo de Gobierno Regional de Galápagos'* (CGREG) (Gobierno del Ecuador, 2010). The special status has been established in 1998 due to the specific requirements of the islands, such as their isolation, and because 97% of Galápagos surface is officially protected as national park (INGALA/ CDF/ Municipios de Galápagos, 2005). Therefore, a short overview shall be given with the aim to indicate governmental plans, policies and laws that affect sustainable RE application. Firstly, there is the Special Law for the Conservation and Sustainable Development of the Province Galápagos (LOREG – *Ley de Regimen Especial para la Conservacion y Desarollo Sustentable* *de la Provincia Galapgos*) (Gobierno del Ecuador, 1998) and the respective Regulation of the Special Law for the Conservation and Sustainable Development of the Province Galápagos (*Reglamento General de Aplicacion de la Ley de Regimen Especial para la Conservacion y Desarollo Sustentable de la Provincia de Galápagos*) (Gobierno del Ecuador, 2000). Their aim is to protect the ecosystems and biodiversity in Galápagos, and support SD of the islands in harmony with the unique nature. Therefore, it established the special status of Galápagos and acknowledged the authority of the Galápagos National Park and established the INGALA – the National Galapgos Institute, that has been replaced in 2008 by the CGREG, in its capacity to serve as the focal agency for development and conservation withing the province (República del Ecuador, 2008; GEF/ UNDP, 2006). In this context, it is important to emphisize that the Galápagos National Park has full authority over the protected areas, the CGREG only holds authority over the non-protected areas – consisting of around 2% of the surface. Secondly, there exists a number of regional plans. The Regional Plan for the Conservation and Sustainable Development of Galápagos (*Plan Regional para la Conservacion y el Desarollo Sustentable de Galápagos*) establishes guidelines for conservation and SD (Gobierno del Ecuador, 2003). In addition, the territorial development plans (PDOT – *Plan de Desarrollo y Ordenamiento Territorial*) provide an extensive collection of the actual situation on each island and provide guidelines or vague scenarios for the future development[61] (Gobierno de Galápagos, 2014). Currently, an island-unifying "Sustainable Development and Territorial Planning Plan for Galápagos" is under preparation. According to UNESCO (2012), it should have been finished by the end of 2011. However, no information is provided on the finalization of this plan. Finally, there is the "*Plan de Manejo del Parque National*" 2005 that embraces 97% of the provinces surface (INGALA/ CDF/ Municipios de Galápagos, 2005). It mentions that the "Parque Nacional Galápagos" (PNG) shall promote REs and energy efficiency and implement them in their operations, installations and equipment. In addition, the PNG shall act as example for efficient use of energy and water and support in educational projects in this area.

4.2.3.5. Institutional Framework on Galápagos

Currently, there are several governmental institutions that influence the development of REs on the Galápagos. The "*Consejo de Gobierno*" (CGREG,

[61] These plans exist for Isabella 2012-2017, Santa Cruz 2013-2027, and San Cristóbal 2012-2016.

former INGALA), the municipalities of Santa Cruz, Isabela, and San Cristóbal as well as the "*Parroquia Floreana*" are responsible for the general administration and planning on the islands. The key players regarding environmental protection are the Galápagos National Park (PNG – *Parque Nacional Galápagos*) that is run by the Ministry of Environment and responsible for protecting the national park for future generations; and the national marine represented by the "*Capitanía de los Puertos*" (SENPLADES, 2010).

In addition, there are two main governmental actors on Galápagos for RE development, execution and operation. Primarily, ElecGalápagos (*Empresa Eléctrica de Galápagos*), the electrical utility, is responsible for generation, transmission and distribution of electrical energy on the archipelago. It does the implementation support for all RE projects in Galápagos. However, the projects are executed by the Secretariat for Renewable Energy and Energy Efficiency of the MEER, to which the international cooperation partners and national implementers have to report the progress. The technical direction of the Secretariat maintains the register and controls the progress of the projects (ElecGalápagos, 2014b). Secondly, EOLICSA – *Eólica San Cristóbal* is the independent wind energy generation company of the wind park in San Cristóbal. Currently, EOLICSA is an independent company, however, it is in the process to be taken over by ElecGalápagos – likely during 2014 or 2015 – and would then become part of the public system.

4.2.3.6. External Governmental and Non-Governmental Actors

The international community is strongly represented on the Galápagos archipelago. Numerous development agencies from Germany (GIZ), South Korea (KOICA), Japan (JICA), and Spain (AECID) are involved mainly in biodiversity conservation[62]. Nonetheless, the most important and active institutions in the context of REs are ERGAL and ENERGAL. At first ERGAL – *Energías Renovables para Galápagos* is the umbrella for all RE projects on Galápagos. It is a Project Management Unit run

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[62] There are various existing activities concerning development assistance in Ecuador and Galápagos, but only some focus on REs for the Galápagos Islands. These are the following: Italy finances a multi-bilateral programme for the safeguard of Galápagos Islands. The total value is 2.2 million Euro, implemented by UNDP. By the end of the first year of activity it was decided to continue through direct management by the Development Co-operation Instrument (DCI). The new phase is currently being started (EUROPEAID, 2009: 98). Germany financed, through KfW, a "Feasibility studies RE Galápagos" concerning the electricity generation by REs in 2003 and made an investment 2007-2009 for REs there. In addition, Germany had a project through *Deutscher Entwicklungsdienst* concerning the introduction of Biofuels on Galápagos to substitute fossil fuel for the production of energy 2002-2008 (EUROPEAID, 2009: 93; 96). See Annex 5 for more details.

by the UNDP, as a joint initiative with the MEER and supported by the *e8*[63]. This organization shall coordinate and provide support to other RE projects. In addition, it is responsible for the execution of the wind power project in Baltra – San Cristóbal (ERGAL, 2013a; ERGAL, 2014). Further, ENERGAL – *Energías Renovables Galápagos* is the name of the framework and the RE initiative of the German development agency to support RE development on Galápagos that has a timeframe from January 2012 to February 2015. It includes the biofuel initiative and the repowering of the Solar PV Park on Floreana (GIZ, 2013; GIZ/ BMU, 2014).

Moreover, there are other actors of public, private and non-governmental form trying to support the SD and implementation of RES on the islands. For instance, the Charles Darwin Foundation (CDF) is the research institution that primarily supports the PNG (Gobierno Autónomo Descentralizado Santa Cruz, 2012b: 133). Additionally, there are independent local and international NGOs, such a WWF, Prince Charles Foundation, FundarGalápagos, and Galápagos Conservancy. When one considers the number of institutions, countries and executing organs[64] (SETECI, 2013b; SETECI, 2013c; SETECI, 2013d; Europeaid, 2009) present on the Galápagos it becomes evident, that the archipelago is a "playing ground" for international cooperation and NGOs. Nonetheless, this variety of parties involved requires substantial coordination if limited space and resources should be used efficiently and in the most effective way. Unfortunately, this seems not to be the case as the RES-E projects show in chapter 5 little cooperation and synergies as well as follow up of the projects.

4.3. Socio-Economic Energy Equity

Energy Equity is, according to the World Energy Council (2013: 5), "the accessibility and affordability of energy supply across the population". Energy equity therefore comprises socio-economic indicators that try to evaluate the effect of RES on economic development and social equity. In particular, it is assumed that RETs are used sustainably if they increase accessibility and affordability of energy, positively influence prosperity, quality of life and employee health and safety while there is high public acceptance. This subchapter briefly presents the most important aspects of the socio-economic background on the Galápagos Islands before the impacts of RETs, on the above-mentioned criteria, are analysed.

[63] American Electric Power (AEP) and Duke Energy (USA), Hydro Quebec (Canada), RWE (Germany), Electricité de France (France), ENEL (Italy), RusHydro (Russia), Tokyo Electric Power and Kansai Electric Power (Japan), Eskom (South Africa), Electrobras (Brazil), State Grid Corporation (China).

[64] See Annex 5.

4.3.1. Background on Socio-Economic Aspects on Galápagos

The human history in Galápagos is rather short, less than two centuries old and closely linked to the evolution of the modern world system and globalization (Grenier, 2013). Although, the archipelago consists of 19 main islands, only four of them are populated: Santa Cruz, San Cristóbal, Isabela and Floreana (SENPLADES, 2010; INEC, 2011a). A lesser-known fact is that the Galápagos Islands are home to 25,124 of Ecuador's total 14.4 million inhabitants according to the last population census in 2010 (INEC, 2011a). Nevertheless, population growth and flourishing tourism (see Figure 24) are putting increasing pressure on the islands ecosystem, its natural resources and its infrastructure (Walsh et al., 2010). Therefore, from 2007 to 2010 the archipelago has been on the list of "World Heritage in Danger". On the basis of substantial progress that the islands made to address the threats regarding invasive species, uncontrolled tourism and over-fishing the archipelago has been removed from the list in 2010 (UNESCO, 2010).

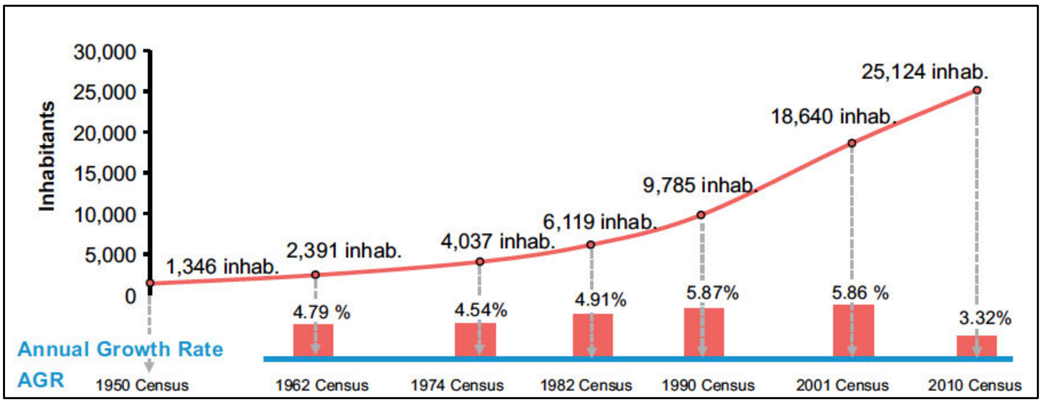

Figure 24: Annual rate of population growth in Galápagos from 1950 to 2010
Source: (León and Salazar, 2013)

As depicted in Table 11, the annual population growth rate (AGR) is currently around 2.6%. In the future, however, stricter immigration regulations are expected to slow down the population increase (INEC, 2010b).

Table 11: Projection of the population per calendar year and per region 2010-2020
Source: Data adapted from (INEC, 2010b)

Name of the canton	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
San Cristóbal	7,707	7,899	8,095	8,293	8,493	8,693	8,890	9,085	9,278	9,473	9,667
Isabela	2,321	2,392	2,464	2,538	2,614	2,690	2,765	2,842	2,918	2,995	3,073
Santa Cruz	15,856	16,285	16,725	17,169	17,619	18,070	18,517	18,963	19,404	19,852	20,302
Total	25,884	26,576	27,284	28,000	28,726	29,453	30,172	30,890	31,600	32,320	33,042
AGR (%)		2.67%	2.66%	2.62%	2.59%	2.53%	2.44%	2.38%	2.30%	2.28%	2.23%

Several aspects distinguish the *Galapageños*, residents living permanently on Galápagos, from the rest of the Ecuadorian population. Inhabitants of Galápagos are characterized by the lowest illiteracy and highest income. In addition, their age composition stands out prominently. In pursuance of the population pyramid (see Figure 25) young people between 15 and 25 do leave the islands for educational purpose. The majority of *Galapageños* is between the age of 5–10 or 25–35. On the Ecuadorian continent the pyramid has no kink and the majority of the population is in the age range of 5–25 (Villacís and Carrillo, 2012).

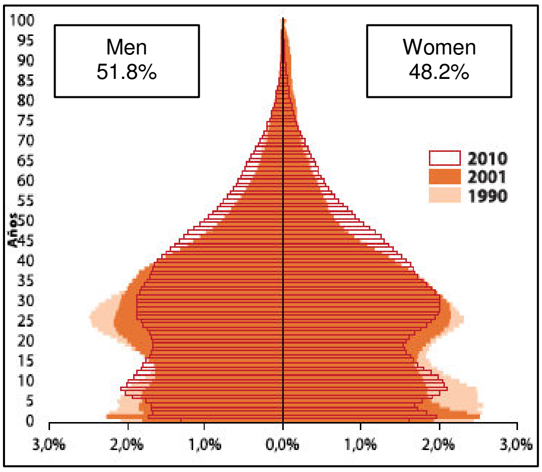

Figure 25: Population Pyramid Galápagos
Source: (Villacís and Carrillo, 2012: 71)

According to the Census in 2010 (INEC, 2010a), 7,236 households[65] (HH) and 9,119 housing units[66] (of these 8,979 individual) have been registered while 7,161 HH are connected to the public electricity services (CONELEC/ MEER, 2012; ElecGalápagos, 2013b). A further increase of HHs is expected for the future as demonstrated in Table 12.

Table 12: Number of households on Galápagos
Source: Data adapted from (INEC, 2010a) and own elaboration

HH	2010	2011	2012	2013	2014	2015e	2020e	2025e	2030e	2035e
Total	7,236	7,554	7,887	8,600	8,978	9,373	11,625	14,418	17,882	22,177

4.3.2. Accessibility and Affordability of an Adequate Electricity Supply

Lack of adequate energy services is a constraint to development since it limits the potential to meet basic needs such as health services (Jaramillo-Nieves and Río,

65 According to the regional government (Consejo de Gobierno Galápagos, 2013b: 10) around 8,600 households are expected for 2013. This makes a growth rate of around 4.4% per year.
66 Can be particular or collective such as hospitals, military, boarding schools, hotels, caserns, youth centres and the like (INEC, 2013a).

2010). Electricity is vital to deliver social services such as sanitation, water, health and education. Therefore, a sustainable energy supply implies that affordable, modern and adequate energy services are available (GEA, 2012; Greenpeace/ EREC/ GWEC, 2012; WEC, 2012; WEC, 2013; Se4all, 2013; Colombo et al., 2014). This can be expressed in three dimensions: general energy access, affordability from the demand side depending on available income and profitability from the supply side. The latter basically reflects the profitability of utilizing RES when the real electricity generation costs of all types of electricity are considered.

4.3.2.1. Energy Access

All four populated islands of the Galápagos archipelago are supplied by electricity through four separate autonomous systems operated by ElecGalápagos (ElecGalápagos, 2013d). Access to electricity on the archipelago is constantly improving and currently the best in Ecuador. Table 13 illustrates that while in the urban region 99.54% of the population has connection to the public electricity grid, in the rural area it is only slightly lower with 96.65% (CONELEC/ MEER, 2009). Hence, there does not remain significant improvement potential for RES. Nevertheless, in general, RETs are characterized by their modular nature and flexible size allowing for increasing access to modern electricity services (GEA, 2012: 822; Se4all, 2013; Colombo et al., 2014).

Table 13: Electrification Rate Galápagos
Source: Data adapted from (CONELEC/ MEER, 2009; CONELEC/ MEER, 2012)

Access to electricity	2001	2008	2010
Urban	97.6%	99.3%	99.54%
Rural	89.6%	98.5%	96.65%
Total average	93.6%	98.9%	99.09%

4.3.2.2. Affordability from Demand Side

Generally, whether energy services are affordable for the residents depends on both their income and expenses. Therefore, it is of importance to bear in mind that Galápagos is part of a developing country when assessing the sustainability in general and the affordability of the RE system in particular. Although, Ecuador's economy has been growing steadily since 2003 (see Table 14) with an annual growth rate of 5.1% from 2011 to 2012 and has reached a GNI of USD 9,490 per capita in 2012, it is still far away from the OECD countries with a GNI per capita of USD 42,948 (The World Bank, 2014b).

Table 14: Economic Development in Ecuador
Source: Data adapted from (The World Bank, 2014b)

	2003	2004	2011	2012
GNI per capita, PPP (current int. $)	5,840	6,340	9,010	9,490
Population (Total)	13,279,806	13,529,091	15,246,481	15,492,264
GDP (current US$) (in millions)	32,432.9	36,591.7	76,769.7	84,039.9
GDP growth (annual %)	2.7%	8.2%	7.8%	5.1%
Life expectancy at birth, total (years)	74.2	74.4	75.9	76.2

By contrast, 27.3% of the population in Ecuador live under the national poverty line[67] and 11.2% under extreme poverty according to the World Bank classification (2014a). In case the "basic insatisfied necessities index" (NBI)[68] is considered yet 60% live in poverty (Villacís and Carrillo, 2012: 29). The poverty threshold or poverty line for covering basic minimum alimentary necessities is in continental Ecuador USD 2,61 per person per day. Nevertheless, for Galápagos, the poverty line requires adjustment as drinking water has to be purchased, most of the goods need to be imported, transport situations are special, and the climatic sitution requires constant use of cooling for foodstuffs. Therefore, the province has an adjusted povery threshold of USD 5.79 per day and capita. According to this definition 8.11% of the *Galapageños* live in extreme poverty. However, if the poverty threshold of the continent of USD 2.61 per day and capita is used, then extreme poverty would be completely absent (León et al., 2013: 88). Nevertheless, in case the NBI us used, with its broader concept of "well being", then according to León et al. (2013: 85), 40.2% of the population in Galápagos live currently in poverty and 11.6% in extreme poverty.

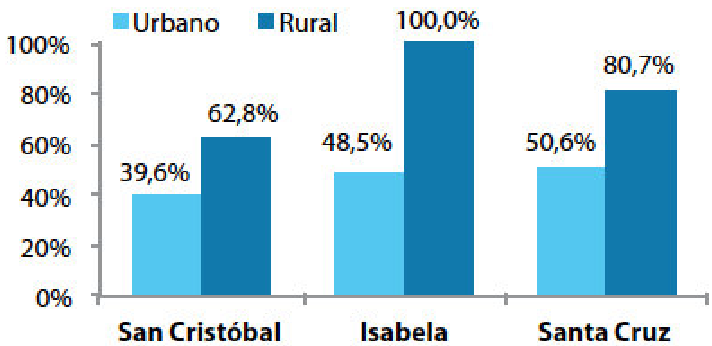

Figure 26: Poverty in Galápagos per island and rural versus urban
Source: (León et al., 2013: 87)

[67] National poverty rate is the percentage of the population living below the national poverty line. National estimates are based on population-weighted subgroup estimates from household surveys.
[68] "*Necesidades Básicas Insatisfechas* (NBI)": The Unsatisfied Basic Needs indicator considers well-being and access to basic needs such as adequate housing conditions, water and sewage, education, and income related indicators e.g. dependent employment.

Nevertheless, in this context it should be mentioned that poverty is not uniformly distributed over the islands as illustrated in Figure 26. On the one hand, there is a higher risk for poverty in rural areas compared to urban areas, while on the other, there are significant differences between the islands. Among the reasons for the strongly pronounced poverty using the NBI are grievances concerning basic necessities – mainly related to inadequate sanitary conditions. Improvements such as the installation of the missing connections to sewage systems and clean water, as well as in increase of space for living (as more than 3 people have to share one room) require not only monetary investment but also significant amounts of energy. Therefore, the enhancement of the electricity supply will also positively affect poverty reduction and improve the standard of living for more than 40% of the population (León et al., 2013: 86).

Income

A recent survey by the local government indicates that a household in Galápagos has in average USD 1,901 per month available and consists in average of 1.7 recipients of income[69] (Consejo de Gobierno Galápagos, 2013b: 10). Although the average available income per household seems to be relatively high compared with other developing countries, this is only an average. In fact, more than 40% of the population has an average salary of only USD 200–500 per person and month. Moreover, 35% of the population lives with less than USD 200 per person and month (Molina, 2012: 82).

According to INEC and CGREG (2010: 11), nevertheless, poverty and unemployment[70] rates on Galápagos are the lowest of Ecuador for two main reasons. Thanks to the special status of Galápagos, the minimum salaries are adjusted by a factor of 1.75 according to the law “Ley 67. RO/ 278 de 18 de Marzo 1998”. This means that in Galápagos, employees gain 75% more than on the continent. For the public sector, this results in a basic salary of USD 791.5, for the private sector USD 381.5 and for domestic employment USD 350[71] (INEC and CGREG, 2010). The second reason is the stable and successful economy that exists despite many barriers on the economic and political side, such as the socialism, nationalization of private property, corruption and low foreign direct investment (Emmerich, 2009: 6-10; Wolff, 2011: 5; Becker, 2012: 2; McKeigue,

[69] Of this income 81% reflects monetary and 19% non-monetary income. Latter contains e.g. social security, transport, education, scholarships, or any non-monetary service provided by the employer such as food and beverages.
[70] According to INEC and CGREG (2010: 11) the unemployment rate in Galápagos was 3.5% in 2009.
[71] See Indicators “Indicadores ECV - Galápagos” in (INEC and CGREG, 2010).

2013; Heritage Foundation, 2013). The reason for this is the pristine and unique nature and biodiversity, which attract tourists and researchers from all over the world. Statistics agree that the most important economic sectors are tourism and connected activities such as transport, construction and commerce. The second most important pillar is public administration, which includes conservation, science and research, such as the Galápagos National Park and the Charles Darwin Foundation (González, 2007: 13; INEC and CGREG, 2010: 11).

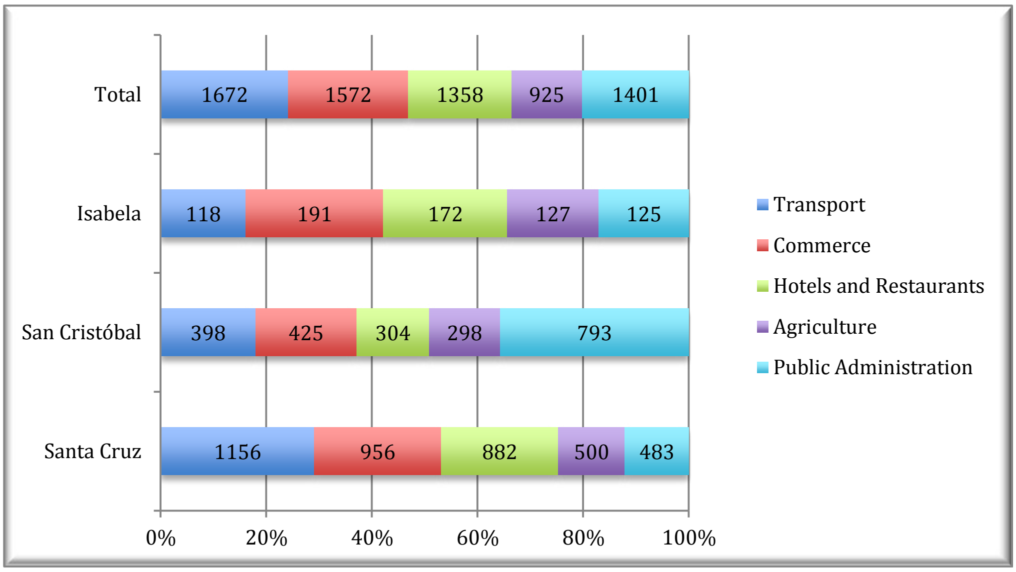

Figure 27: Economic Activities of the Population in Galápagos in 2009
Source: Own elaboration based on data from (INEC and CGREG, 2010: 12)

As illustrated in Figure 27, the most important single employer is the Ecuadorian government providing the primary source of income for 20% of the *Galapageños* and approximately 35% for residents on San Cristóbal (INEC, 2010a). Nevertheless, the main sector of employment on the archipelago providing either directly, or indirectly, jobs to most of the population is tourism (Walsh et al., 2010).

Tourism, however, is simultaneously the boon and bane of the islands. While it is responsible for most of the employment and approximately 23% of the regional GDP (González, 2007: 42), it is putting pressure on the islands ecosystem, its natural resources and its infrastructure (Walsh et al., 2010). Notwithstanding a small decline in 2009 and 2012, tourist arrivals and land-based visits have increased year after year since 1992[72] as depicted in Figure 28. In 2012, more than 180,000 tourists visited the islands, and in 2013 more than 200,000 (Consejo de Gobierno

[72] As the number of available beds on cruise ships has not increased for approximately 10 years, the increase in numbers is largely taken up by land-based visits. Efforts at regulating land-based tourism are on the rise, such as a campaign for the inventorying of all tourism establishments and ensuring they have the necessary permits and meet quality standards (UNESCO 2012).

Galápagos, 2013a: 2; PNG, 2014b). Considering the fact that around 130,000 were foreign tourists that have to pay a fee of USD 100 for the park entrance, this already makes an annual income of USD 13 Million. Nevertheless, flourishing tourism triggers rising fossil fuel consumption in the electrical sector and to an even larger extent, in the maritime transport, as most of the tourists visiting the Galápagos spend their time on cruise ships and motor yachts that consume large amounts of diesel fuel (Curbelo, 2011; Ramos Malo, 2012).

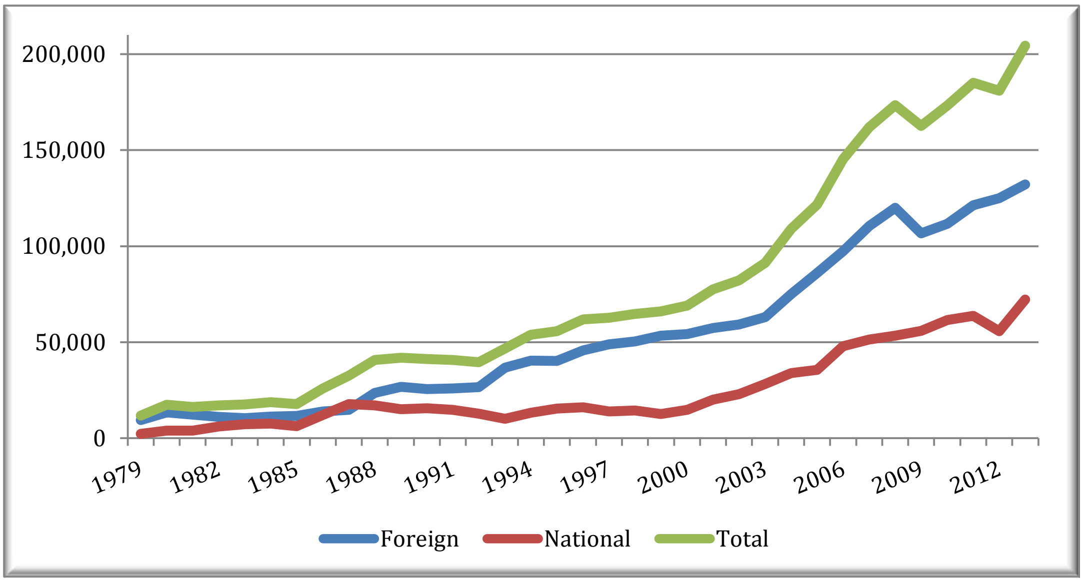

Figure 28: Visitors to the Galápagos National Park 1979–2013
Source: Own elaboration based on data from (PNG, 2014b)

In addition, the importance of tourism is increasing and supplanting traditional sectors such as fisheries, increasing the dependence on this sector (UNDP/ SPNG/ INGALA/ SESA-Galápagos/ FCD, 2006). Therefore, the imposition of a maximum number of visitors was considered impractical for the case of Galápagos. Due to the economic importance of the sector for the islands, improved tourism management has been suggested as the preferred approach (UNESCO, 2012). This is done by limiting the number of visitors and groups per visitor site with a focus on the impact of tourists on the physical and biological environment, as well as the perception of the tourists in experiencing the pristine nature (PNG, 2009a). There is a concerted effort by the authorities to encourage smaller-scale, lower-impact land-based tourism, and to introduce ecotourism obligatorily (UNESCO, 2012). In addition, a focus lays on education and raising awareness among the visitors such as in consuming as little energy and water as possible (PNG, 2009a). Currently, a study is in progress to define the impact of the number of tourists on the socio-ecological system of the islands with the aim to create scenarios for the islands' sustainability depending on the number of visiting tourists (Consejo de Gobierno Galápagos, 2013a: 2). The main objectives of maintaining tourism in Galápagos are to drive economic growth and social development by creating and maintaining jobs[73] (World Tourism Organization, 2010; Mitchell and Ashley, 2010; Winters, 2013). Additionally, tourists have the opportunity to experience pristine and unique nature. In this way, their awareness to protect the environment shall increase as well as their wish to support SD.

Expenses

The affordability of a RE system for a resident does not only depend on the available income of a household, but also on the respective expenses. To this end, it is necessary to point out that an average household income of USD 1,901 per month is matched by average monthly household expenses of USD 1,522[74] (Consejo de Gobierno Galápagos, 2014: 8-9). It is also worthwhile to mention that slightly more than 30% of the population does not have any capacity to save, since their income is not higher than their expenses.

Basic services, such as water and electricity, are in Galápagos not uniformly well covered[75], and their costs vary (INEC, 2010a). According to Guyot-Téphany et al. (2013), consumers pay less than USD 10 per month for tap water, except in Bellavista (Santa Cruz), where it costs USD 1.21 per cubic meter. The electricity tariffs have been set on a national level and depend on both voltage and the amount consumed, as illustrated in Annex 7 (CONELEC, 2013c). In Galápagos in 2012, the invoiced mean price for electricity was USD 8.8 cent/kWh, USD 9.13 cent/kWh for the residential and commercial sector, and USD 8.01 cent/kWh for the public sector[76] (INER, 2013; ElecGalápagos, 2013c). The average per capita consumption of electricity was in the same time approximately 1,200 kWh. Considering the average consumption by residential consumers of electricity of around 500 kWh per year and capita, the average expenses for electricity per capita amount to approximately USD 46 per year or around USD 12 per month and household[77] (ElecGalápagos, 2013c). Nevertheless, the real expenses per household can

[73] In case tourism is effectively harnessed, it can be a way for poverty alleviation (World Tourism Organization, 2010; Winters, 2013), although this is not yet empirically proven (Mitchell and Ashley, 2010).
[74] 15% of the expenses are dedicated to non-alcoholic beverages and food, 8.5% to transport, 7% to clothing, and 6.3% for hotels and restaurants. Furthermore, 96% of the money-spent stays inside the island where the person lives, 1% is spent on another island and 3% on the continent.
[75] While 99% of the population has connection to the public electricity grid, 96.5% have access to waste collection, 83.2% public water connection, 68.8% access to telephone services, but only 26.8% have access to a public sewage system (INEC, 2010a).
[76] See Annex 6 for more details.
[77] Calculation: 500 kWh per capita * USD 9.13 cent/kWh = 46 USD/ capita

deviate for several reasons: (a) different consumption patterns; (b) general gradually differentiated tariff depending on amount of consumption and use of electricity; or (c) a dignity tariff (*Tarifa de Dignidad)* of USD 4 cent/kWh applies for electricity consumption of up to 130 kWh[78] (CONELEC, 2008a).

Furthermore, in the context of expenses for energy, it is also worthwhile to mention the heating and transport sector. Currently, heating and cooling demand is mainly met by direct use of natural gas. De facto LPG is predominant for cooking and water heating in the residential sector as well as in hotels and restaurants. This is mainly due to the fact that gas is strongly subsidized and thus, the expenses for natural gas are, with USD 1.6 per 15 kg cylinder for domestic use, extremely low when compared with the international price of USD 10 to 24 (Rosero and Chiliquinga, 2011: 13; EP Petroecuador, 2014; ANDES, 2014; ARCH, 2014). In the meantime, the subsidized price is not any more valid for the commercial sector, so hotels and restaurants have to pay around USD 12.15 and are looking for alternatives (ARCH, 2014: 13). The subsidy will also be removed for the residential sector in 2016 (ANDES, 2014).

Expenses for transport are comparable with the mainland, as diesel and gasoline have nearly the same price at the petrol station on Galápagos (EP Petroecuador, 2014). For instance, diesel fuel costs approximately USD 1 per gallon (Alvear and Lewis, 2013; EP Petroecuador, 2014). This is extremely low compared to the international price of USD 4.5 per gallon (MEER/ GIZ, 2012)). However, there are two special aspects that differentiate energy costs for transport on Galápagos. Firstly, inter-island transport has a standard price of USD 35 per one-way trip. Secondly, cabs have standard price of USD 1 inside the city independent from time required. The latter strongly promotes the use of taxis, which is exacerbated by missing public transport.

In conclusion, it can be said that energy costs are very low on the archipelago, hence there seems to be some leeway for designing energy prices so that they are more sustainable. Nevertheless, in order to design a sustainable and appropriate scheme, it is necessary to carefully consider low-income and socially deprived households. Only if affordable energy services can be provided to the poorest 30% of the population will the scheme be appropriate and sustainable in avoiding negative repercussions.

[78] The dignity tariff (Spanish: Tarifa de Dignidad) of 4 USD cent/ kWh applies for electricity consumption of up to 130kWh in the coastal area, and up to 110kWh in the Andean region.

4.3.2.3. Affordability from Supply Side

The affordability from the supply side reflects the profitability of utilizing RES when the real electricity generation costs are considered. The hypothesis argues, RETs have the potential to undercut the cost of conventional modes of electricity generation, especially on islands, where RES are abundant and fossil-fuel-based electricity production is extremely expensive (Weisser, 2004: 127). This is important since the provision of adequate energy at a reasonable price remains a vital precondition for sustainable socio-economic development (Weisser, 2004: 129). In addition, economic and financial aspects are crucial for the realization of any project in the energy sector because private investors go where profit margins are largest – considering the security environment (Casillas, 2010; REN21/ ISEP, 2013: 63). This also applies to the Zero Fossil Fuel Program on Galápagos. Therefore, it is crucial to assess the sustainability of the RE system from an economic dimension with the aim to better understand the costs of electricity production from diesel generation and RETs in particular.

It is important to point out that each RE project is different and its economic sustainability depends on various specific characteristics influencing its investment costs and profitability. These aspects are primarily bound to a specific site location. For instance, they include the RE potential at the site, the remoteness and existing infrastructure but also requirements regarding environmental protection such as burying transmission lines to avoid disturbing the birds. Nevertheless, there are some economic aspects that are valid for all RE systems on the Galápagos or for Small Island Developing States (SIDS) in general. In particular, small islands such as Galápagos are characterized by dependence on imports, limited demand and diseconomies of scale (Weisser, 2004: 127). In other words, on islands, typically small-sized electricity systems without connection to the grid are used, which present a series of characteristics that complicate and raise the price of electricity supply in general because: (1) generation units are not big enough to reach economies of scale as absolute demand is low; (2) more reserve capacity needs to be maintained to ensure reliable energy supply; and (3) fuel transportation raises the costs of energy and risk for supply interruptions (Jaramillo-Nieves and Río, 2010). These factors result in an extremely expensive, unreliable and often-unsustainable power production (Weisser, 2004: 127). For instance, fuel imports impede SD since scarce financial resources are diverted from efforts to promote environmental protection, social or economic development (AOSIS, 2012). Due to these reasons and the usually available large indigenous RES potential on islands, studies agree that RETs are especially interesting for islands (Chen et al., 2007; Jaramillo-Nieves and Río, 2010; IEA-RETD, 2012). Nevertheless, in spite of this, RE deployment in Galápagos currently faces a difficult economic environment and several barriers that come both from within the region and from the nature of REs themselves. They include high investment costs, limited access to finance and distortions of the real electricity generation costs through subsidies and missing internalization of external costs such as noise and pollution.

Financial Challenges for RE Development on Galápagos

Costs and finance are important aspects for evaluating the sustainability of a RET since they influence the extent of investments and thereby the potential success or failure of implementing a 100% RES-E system[79] (Rawlins and Ashcroft, 2013; Liu, 2014). Most clean technologies face financial challenges since they are capital-intensive and pay back their high upfront investment costs only over time through lower energy and fuel consumption (GEA, 2012: 416; Haselip et al., 2011a; Greenpeace/ EREC/ GWEC, 2012). The incremental cost gap caused through generally high investment costs is one of the greatest obstacles to wide deployment of RES-E on Galápagos (WEC, 2013). Although renewable generation can be much cheaper in the long term, alternatives such as diesel generators have low capital costs and are therefore widely used on islands (Rawlins and Ashcroft, 2013).

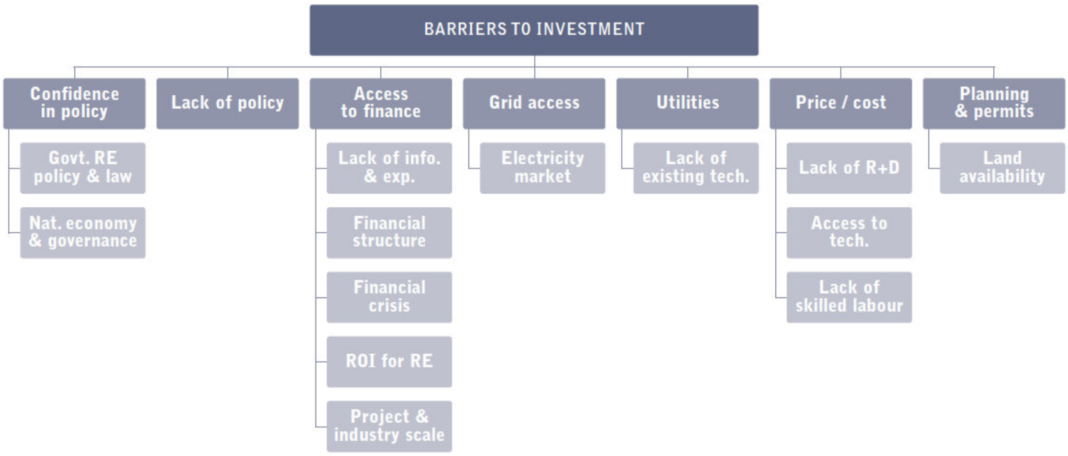

Figure 29: Key barriers to renewable energy investment
Source: (Greenpeace/ EREC/ GWEC, 2012: 52)

Nevertheless, barriers for investment into RETs are manifold (see Figure 29) including limited access to financing (Greenpeace/ EREC/ GWEC, 2012: 52;

[79] There exist several indicators to evaluate the economic feasibility of a RE project. Within this context the cost of energy (cost of generating 1kWh electricity) is the primary indicator. Also, to a lesser extent, net present cost, the return on investment and the payback time are adopted. These are important figures indicating if an investment is interesting and viable for the private sector.

Rawlins and Ashcroft, 2013). Small islands are, according to Weisser (2004: 128), especially affected by a deficient financing framework and missing investment opportunities since they are rarely in a position to develop economies of scale. In addition, they are often unable to raise large amounts of capital or finance on the home market (Encontre, 1999). In fact, the relevance of this barrier for the Galápagos becomes clear when analyzing the financing schemes of the existing projects on the archipelago regarding energy, environmental protection or development aid. Between 2007 and 2012, RETs have nearly exclusively been driven by public money – either bilateral or multilateral funds, NGOs, or the Ecuadorian government. According to SETECI (2013a), the Ecuadorian Secretariat for International Cooperation, from 2007 to 2012, around USD 87 million has reached Galápagos, most of it from Japan (around 20%), and each 10% from Germany, Korea and the UN[80]. The only identifiable private investments have been involved in connection with CDM under the KP, and Toyota in cooperation with the WWF (SETECI, 2013b; SETECI, 2013c; SETECI, 2013d).

Distortions of the real energy costs

The real energy generation costs, and therefore the competitiveness of RETs, are distorted by subsidies and missing internalization of externalities. The latter is a method to account for environmental and social externalities such as pollution and noise[81] (Roehrl, 2013: 147; GEA, 2012: 401ff.). This is a means to "*get the prices right*" in order to achieve certain envisaged environmental goals such as the protection of biodiversity in Galápagos. Since these measures, such as carbon taxes, are still in their development phase they will not be considered in this thesis.

Considerably more tangible are distortions by subsidies. Moreover, they play a vital role for promoting or hindering sustainable RE development (Riahi et al., 2012: 1264). In the case of Ecuador, both fossil fuels and electricity are highly subsidized (SENPLADES, 2010; Jacome, 2007; CONELEC, 2013c). Therefore, the dependence of Galápagos on fossil fuels represents considerable cost for the Ecuadorian government. Due to the additional transport and bio-security efforts,

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[80] See Annex 5 for detailed information.

[81] "Externalities arise when an economic agent enjoys benefits or imposes costs without having to make a payment for doing so. As such, externalities can be positive or negative. For example, the adverse health and environmental damages (hidden costs) caused by fossil-sourced electricity generation that are not compensated by the producer are negative externalities. At the same time, the cheaper electricity (without externalities) enjoyed by consumers and that contribute to overall welfare generation represent positive externalities. Factoring external costs into the market price of energy ("internalization") would raise prices. It would send correct pricing signals to the marketplace and thus change the merit order of investment and operating decisions as well as reduce demand and emissions, with subsequent lower externalities." (GEA, 2012: 401).

fossil fuel and electricity generation costs on Galápagos are substantially higher than on continental Ecuador. In spite of the higher costs, the Ecuadorian government maintains the consumer prices nearly at the same level, leading to substantially higher subsidies than on the mainland (GEF/ UNDP, 2006) (SENPLADES, 2010). Table 15 depicts the average real costs of fossil fuels on the islands as imported products. These include maritime shipping costs from the Ecuadorian continent to the islands, plus shipping between islands and overland transport, from the dock to the fuel storage sites, as well as VAT and marketing expenses. The variations of the real costs between islands are due to different transportation and storage costs (Jacome, 2007; MEER/ GIZ, 2012).

Table 15: Real Costs for Fuel on Galápagos
Source: Data adapted from (MEER/ GIZ, 2012)

	2010: Diesel Fuel[82] (USD/ gal)	2011: Diesel Fuel (USD/ gal)	2012: Diesel Fuel[83] (USD/ gal)	Jatropha (USD/ gal)
Santa Cruz	3.42	4.46	5.55	5.54
San Cristóbal	3.10	4.09	5.43	5.55
Isabela	3.14	4.14	5.47	5.60
Floreana	3.32	4.32	5.65	5.78

The subsidy for fossil fuels is equivalent to the difference between the legally fixed sales price on the islands for the fossil fuels derivatives and the real costs[84]. The internal sales prices for diesel fuel are around USD 0.9–0.92 per gallon for electricity generation and USD 1.010 per gallon for transport (Jacome, 2007; EP Petroecuador, 2014). If compared with the international market price for diesel of around USD 4.5 per gallon (MEER/ GIZ, 2012), this corresponds to a subsidy of approximately USD 3.5 per gallon.

The real costs for diesel are then used to quantify the subsidies for electricity generation as demonstrated in Table 16. First, the real electricity generation costs are calculated per kWh. It is indicated that these are between USD 0.35 and USD 1.45 per kWh. This shows that electricity generation costs are driven by economies of scale as the island with the largest consumption, Santa Cruz, has the lowest

[82] These have been calculated based on average price for diesel fuel imports in 2010 were 2.3 USD per gallon (MEER/ GIZ, 2012).
[83] Considering an adjusted import price of 4.5 USD per gallon instead of 2.3 USD, with reference to the "*Decreto Ejecutivo No. 175*" which lays down more realistic costs for diesel in Galápagos. This 4.5 USD per gallon have been chosen according to international diesel fuel price.
[84] The subsidized fuel is only available to final consumers and certain exceptions. For instance, according to the "*Decreto No. 736*" from 15 April 2011, subsidized fuel for ships are restricted to ships used for fisheries. Touristic ships have a special price that will not be lower than the subsidized one if they fulfil the requirements mentioned in decree 736. For example, it refers to gross revenue of less than USD 1 million or to an application of the lower price only for the first 6,000 gallons. International ships are on principle excluded and have to pay the international market price (Gobierno del Ecuador, 2011).

costs while the smallest island, Floreana with the lowest consumption, has the highest costs.

Table 16: Subsidies for Electricity Generation Costs on Galápagos
Source: Data adapted from (MEER/ GIZ, 2012)

	2010 Real Electricity Generation Costs (USD/kWh)	Electricity Consumed in 2010 (kWh)	Annual Electricity Subsidy in 2010[85] (USD)
Santa Cruz/ Baltra	0.353	18,982,714	5,006,484
San Cristóbal	0.406	8,269,689	2,619,596
Isabela	0.475	2,459,408	948,224
Floreana	1.456	69,156	94,563
Total			8,668,867

These electricity generation costs are then compared to the consumer prices, which are set on a national level by CONELEC. These electricity tariffs are ranked according to voltage level, consumption and consumer type amount as illustrated in Annex 7. They stretch for residential consumers from USD 0.081 per kWh for the lowest consumption to USD 0.6712 per kWh for more than 3,500 kWh of energy consumption (CONELEC, 2013c). In 2012, the invoiced mean price for electricity on the archipelago was USD 0.088 per kWh, for the residential and commercial sector USD 0.0913 per kWh, and for the public sector USD 0.0801 per kWh (CONELEC, 2008a; INER, 2013; OLADE, 2013). The created deficit is covered by governmental subsidy. In fact, cross-subsidies are used through an allocation from the *Rural and Urban Marginal Electrification Fund – FERUM* (GEF/ UNDP, 2006). In 2010, the real subsidies for electricity amounted to approximately USD 8.7 million.

Whereas the sales price is nearly uniform across Ecuador, the electricity generation costs for one kWh are significantly higher on the Galápagos. Therefore, the use of RETs on Galápagos is especially interesting because they allow the government to save subsidies.

Table 17: Real Electricity Generation Costs on Galápagos per Energy Source
Source: Data adapted from (MEER/ GIZ, 2012)

	Diesel (USD/kWh)	Jatropha [86](USD/kWh)	Wind [87](USD/kWh)	Solar PV	Hybrid System (USD/kWh)
Santa Cruz/ Baltra	0.51	0.50	0.146	0.215	0.350
San Cristóbal	0.53	0.509	0.184	n/a	0.366
Isabela	0.55	0.505	n/a	0.247	0.420
Floreana	1.845	n/a	n/a	n/a	n/a

[85] These have been calculated based on the assumption that the sales price in Galápagos for diesel was in average 0.088 USD per kWh.
[86] Levelised Costs of electricity generation with vegetable oil Jatropha Curcas.
[87] Levelised Costs of electricity generation with wind turbines.

Table 17 illustrates that in 2012, the real cost for electricity was between USD 0.51–1.845 per kWh while the average price paid by the consumers was USD 0.088 per kWh. These costs are inside the range of levelized cost of electricity on other pacific islands as demonstrated in Figure 30 (IRENA, 2013: 22).

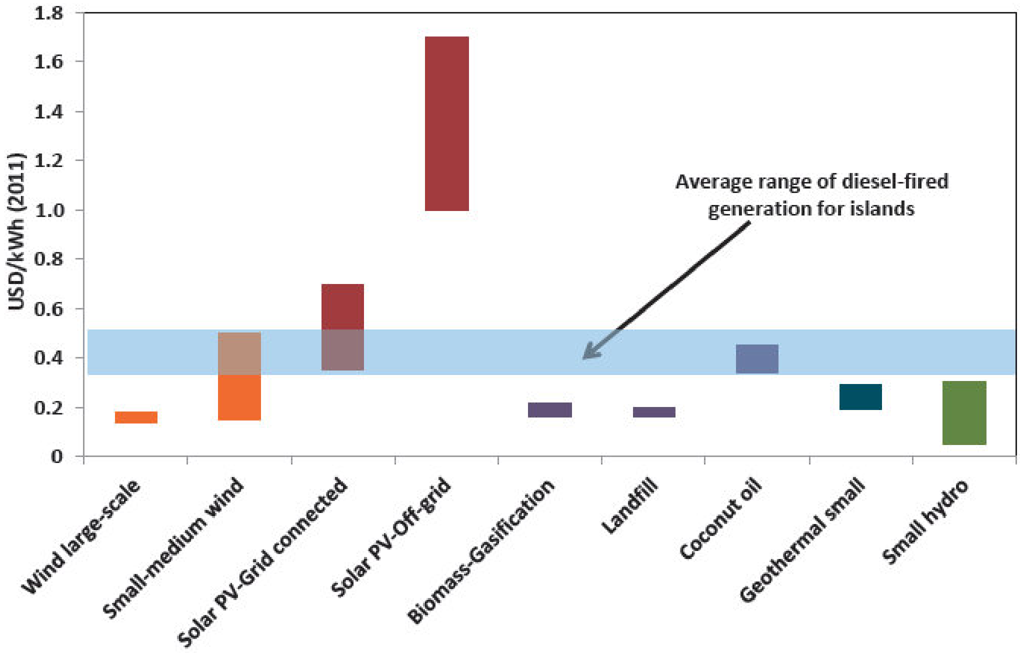

Figure 30: Levelized Cost of Electricity from Renewable Power Generation for Pacific Islands Source: (IRENA, 2013: 22)

Scientists agree that subsidies on fossil fuels create inefficiencies and market distortion (PBL, 2012; IEA-RETD, 2012; IAEA/ UNDESA/ IEA/ EEA, 2005). Nevertheless, they do not agree whether subsidies are generally bad or if they always reduce social welfare. Nonetheless, it is often argued that fossil fuel subsidies, electricity subsidies and government-mandated pricing hinder sustainable business investment (Yépez-García et al., 2011; IRENA, 2012a: 2f.).

A comprehensive analysis of the situation is required to find out whether private investment into RETs faces unfair competition in the case of Galápagos since there this depends on many aspects. For instance, not only fossil fuels are subsidized but also RETs receive a FiT. This incentive scheme is equally characterized as a subsidy with the aim to cover the difference between generation costs and wholesale electricity prices (Greenpeace/ EREC/ GWEC, 2012: 24). In addition, public incentives have been justified with the need to create fair competition with fossil fuels (PwC/ PIK/ IIASA/ ECF, 2010: 28; IRENA, 2012a: 2). Although it remains unclear whether subsidies negatively affect business investment, there is agreement that they pervade the electricity sector, as they make energy cheaper for consumers and encourage higher levels of consumption. Nevertheless, according to a survey conducted by Westerman (2012: 115), on Galápagos both locals and industry experts agree that there is a need for governmental support, as without subsidies, the energy would not be affordable to most of the population. The survey revealed that if the population would be charged the real cost of electricity, 66% would reduce their consumption, 31% would invest in energy-saving technologies or appliances, 14% said that they would pay, 10% would subsequently increase their prices, and 7% said that they would not be able to pay. This shows that residents' electricity consumption is directly linked to the price and that there is some leeway in increasing the sustainability of the electricity system from an economic point of view.

Conclusion

In conclusion, investment costs for RETs are generally high and there are several barriers to financing that complicate the competitiveness of RETs. Hence there seems to be some leeway for improving the sustainability of the electricity system such as removing subsidies and internalizing external costs[88] (PwC/ PIK/ IIASA/ ECF, 2010: 28; IRENA, 2012a: 2).

Nevertheless, in order to design a sustainable and appropriate scheme, it is necessary to carefully consider the whole picture. For instance, Jacobsen and Delucchi (2011) argue that the barriers to RE deployment are primarily social and political, not technological or economic. They claim that this is especially true for islands where RE systems have several advantages. Most importantly, RETs generally do not require any fuel import since the source is indigenous, with the exception of biofuels. This diminishes fuel costs and therefore the risk of price volatility (Rawlins and Ashcroft, 2013). Obviously, the significant upfront costs exist and are necessary to design a sustainable, adequate and reliable energy system. Nevertheless, the costs of integrating RE into an existing energy supply system depend on the share, availability and characteristics of RES, the system characteristics, and how the system evolves and develops in the future (IPCC, 2011). For instance, the inclusion of a desalination system could allow using the RE potential in an economically more efficient manner according to Jaramillo-Nieves and Rio (2010). In addition, high upfront costs are expected to fall since efficiency of

[88] Externalities may be negative (external costs) or positive (external benefits). External costs lead to a too-high demand for harmful activities because the consumer does not bear the full (societal) cost. Two key market failures are typically addressed: 1) the external costs of GHG emissions are not priced at an appropriate level; and 2) deployment of low-carbon technologies such as REs create benefits to society beyond those captured by the innovator, leading to under-investment. Monetizing the external costs of energy supply would improve the relative competitiveness of REs (IPCC, 2011).

RETs advances rapidly and purchase prices of equipment falls (Weisser, 2004: 128). In particular, wind energy costs are decreasing fast (Demirtas, 2013).
The findings of this section show that the Zero Fossil Fuel Program in Galápagos has a difficult financial environment. This could be a barrier for RET deployment. Nevertheless, the challenges have been recognised and more research needs to be done to analyse the best possibilities to resolve them. For instance, Riahi et al. (2012) suggest, when the multiple economic benefits of each technology are properly accounted for, then RETs allow for simultaneous achievement of climate change mitigation, energy security, and air pollution control and thus come at a significantly reduced total energy cost. In addition, RE-deployment is expected to reduce governmental expenditure on fossil fuel and electricity subsidies in Ecuador.

4.3.3. Quality of Life and Social Well-Being

Quality of life (QOL) and social well-being are important dimensions of SD (PBL, 2012). The World Health Organization (WHO, 1997: 1) defines QOL as "… a broad ranging concept affected in a complex way by the person´s physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of their environment". In addition, QOL depends largely on the perception of individuals in their specific context of culture and value system under consideration of their expectations, concerns and standards (WHO, 1997). QOL is also a key aspect of the Ecuadorian constitution and national plan of well-being. Article 66 of the Constitution stipulates that QOL is "the right to a life of dignity, where health, food and nutrition, water supply, housing, environmental sanitation, education, work, employment, rest and leisure, physical culture, clothing, social security and other necessary social services are all guaranteed" (República del Ecuador, 2008). Therefore, improving the quality of life of the population is a multi-dimensional, complex process (SENPLADES, 2013). In what follows, the focus will be on employment and economic opportunities, supply of basic services, independence, health, as well as employee health and safety.

Employment

Over the whole lifecycle, energy systems create direct or indirect job opportunities. When sustainable jobs are created, income and therefore, standard of living of the people improves. Therefore, job creation has been selected by many reports as sustainability indicator, points out Liu (2014). Generally, studies agree that green politics and decarbonisation with low-carbon energy such as RES enable job creation (Jaramillo-Nieves and Río, 2010; UNEP, 2011b; Riahi et al., 2012; IEA-RETD, 2012; Demirtas, 2013). This positive impact on employment is due to the trend that more expensive technologies, such as wind and solar, tend to employ more people throughout their life cycles (UNEP, 2012: 30). However, the local impact on jobs depends on the specific project, the technology chosen and the availability of qualified workers. In this regard the IEA-RETD (2012) points out that the geographic isolation of islands and the comparatively small size of many RE systems in remote areas can create certain challenges. For instance, capacity building and trainings programs may not be cost-effective and there could be a gap between the potential for jobs and the availability to fill them locally.

Economic Opportunities

Green politics, particularly RETs, can create new economic opportunities for residents by stimulating innovation and promoting efficiency (The World Bank, 2012: 11; IEA-RETD, 2012). In order for the Galápagos to maintain and increase their prosperity, it is crucial for them to protect and conserve their delicate biodiversity and ecosystem. In this regard, it is necessary to point out that some studies suggest that there may exist a conflict between tourism and RES. Nevertheless, this does not necessarily need to be the case (Jaramillo-Nieves and Río, 2010). Generally, RETs promote environmental protection and therefore create synergies by reducing environmental risk and increasing prosperity through additional job creation and innovation. For instance, when policies are designed adequately, residents may be able to create their own micro power plants through transforming their own house in a PROSUMER that produces electricity by implementing RETs (Einfalt et al., 2011).

Basic Services

"Sufficient supply of affordable and reliable electricity" is a core precondition for improved QOL according to the World Bank (Yépez-García et al., 2011). The IEA-RETD (2012: 90) confirms that, in particular, RETs in remote areas can create opportunities to improve QOL. For instance, universal energy access and clean cooking, which are promoted through REs, contribute to more equitable economic growth, poverty alleviation and significant health benefits (Riahi et al., 2012). In this regard, it should be pointed out that access to electricity is available to 99% of the population on Galápagos. Nevertheless, other basic services are less well covered. For instance, 96.5% of the population has access to waste collection, 83.2% to public water connection, 68.8% to telephone services, but only 26.8% to a public sewage system (INEC, 2010a). Moreover, most islands of the archipelago have a significant shortage of clean and safe drinking water. RETs combined with solutions for water desalination may represent an economically interesting and valid option to ensure access to clean water and therefore improve QOL in this regard (Jaramillo-Nieves and Río, 2010; IEA-RETD, 2012).

Independence

In regard to the level of independence as mentioned by the WHO (1997: 1) it is certainly meaningful to point out that RE projects reduce the dependency on fossil fuels imports, and therefore can reduce price volatility and the cost of power (IEA-RETD, 2012). Moreover, a decreased dependence on energy imports would make the energy system more resilient and avoid water supply interruptions in case of an electricity shortage due to a potential fossil fuel supply crisis (Jaramillo-Nieves and Río, 2010).

Health

The World Health Organization defines health as “A state of complete physical, mental, and social well-being not merely the absence of disease.” (WHO, 1997). Studies agree that RETs have the potential to protect the environment and generally the physical health of people (Riahi et al., 2012: 1276; WHO, 2012; GEA, 2012; IPCC, 2011; Ban Ki-moon/ UN/ Se4All, 2011). For instance, they improve indoor and outdoor air quality by avoiding pollutants from incomplete combustion of fossil fuels and biomass (GEA, 2012: 260). The hypothetical capability of RETs to improve health conditions is manifold and closely connected to the aspects of environmental sustainability touched upon in the next chapter. In addition, RETs have the potential to enhance health care by making reliable and affordable energy solutions available in remote and resource-poor settings where off-grid systems are required (WHO, 2011). In case of Galápagos, not only the protection of human health is important, but also animal and ecosystem health are of outstanding significance (INGALA/ CDF/ Municipios de Galápagos, 2005). Hence, the possibility to decrease the risk for oil spills and reduce air pollution with RETs is very valuable.

Nevertheless, also potential health concerns for RETs have been identified. Firstly, bioenergy cultivation may require direct and indirect exposure to agrochemicals and derivatives like pesticides. In addition, residue burning and combustion of biomass may negatively impact local air quality and human or animal health (IPCC, 2011: 740; GEA, 2012). Secondly, geothermal energy may cause hydrogen sulphide emission for some operations with local impact (IPCC, 2011: 740). Thirdly, standing water bodies, such as water storages, created for hydropower harnessing may lead to a spread of vector-borne diseases (GEA, 2012: 289). In addition, concentration of population and migrant workers during construction of large dams may cause public health concerns (IPCC, 2011: 740). Fourth, blades form wind energy turbines may trigger nuisance form noise and flickering that can cause negative health impacts (IPCC, 2011: 740). Merely for solar and ocean technologies no direct health impacts have been identified during energy generation (IPCC, 2011: 740). Nevertheless, also the harnessing of ocean and solar energy requires RETs that are manufactured using resources such as steel, silicon and glass fibre as discussed in the next subchapter.

Furthermore, green politics and in particular RETs help to increase the amount of available natural, physical and human capital since a healthier environment positively influences the productivity of workers (The World Bank, 2012: 11). In other words, RETs have the potential to improve not only the physiological, but also the psychological state of a person through creating new economic opportunities or providing a healthy environment (IEA-RETD, 2012).

Employee Health and Safety

Employee health and safety is an indicator that “measures the number of fatalities due to large accidents over the life cycle of electricity generation and is expressed per unit of electricity generated” according to Stamford and Azapagic (2011). Large accidents in energy generation are generally associated with nuclear power, due to the widespread public suspicion and fear propagated by Fukushima, Chernobyl and Three Mile Island. Nevertheless, the deployment of RETs can also be associated with accidents. For instance, the Banqiao dam failure in China in 1975 caused between 30,000 and 230,000 deaths including fatalities due to subsequent diseases and famine (OECD, 2010). In the coal sector around 21,000 immediate fatalities were recorded between 1969 and 2000, and in the oil sector around 20,000 (OECD, 2010). It is important to recognise the fact that large accidents occur at a higher frequency in energy chains connected to mining activities although fewer consequences per incident are evoked. This is illustrated in Figure 31 comparing the maximum number of fatalities and the fatality rate for the nuclear, gas, coal, hydro, PV and wind supply chains, based on historical OECD data.

According to Stamford and Azapagic (2011), the fatality rate for coal is around 25 times higher than that of nuclear power. Nevertheless, the total number of ultimate fatalities from a nuclear accident is with 10,240 by far the highest. In addition, Figure 31 shows that renewables, such as wind and PV, have by far the lowest risk for employee health and safety[89]. Other studies conducted by the Brookhaven National Laboratory (Fthenakis et al., 2008) and the Centre for Sustainable Energy (Centre for Sustainable Energy, 2011: 12) agree that a transformation to a RES-E system would significantly improve health and safety aspects of employees and therefore be more sustainable from a socio-economic point of view.

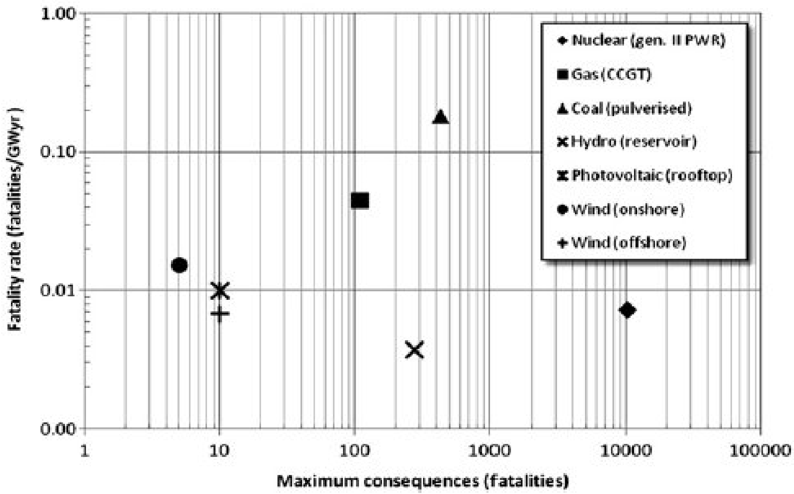

Figure 31: Fatalities associated with different energy chains based on actual data and probabilistic safety assessment for nuclear power
Source: (Stamford and Azapagic, 2011)

Conclusion

Sustainable energy from RETs can contribute to the well-being of people because it creates employment and economic opportunities, improves the supply of basic services, supports independence and increases physiological as well as psychological health of people. In order for RETs to positively contribute to the QOL on Galápagos, they have to be chosen carefully under the consideration of the above-mentioned aspects and the specific site conditions. In addition, their deployment needs to be politically and socially feasible, which means that energy services need to be affordable, adequate and reliable. This is project-specific. For instance, while the use of biomass improves the income of the people cultivating this bioenergy crop, it increases energy access of the people only if the fuel is affordable to them[90] (Sotolongo et al., 2007; Gmuender et al., 2009).

[89] Despite the high-profile incidents the nuclear industry safety record is, with a worldwide fatality rate expressed as 0.048 deaths per gigawatt of electricity per year (0.048 deaths/GWey) due to accidents, relatively good. This statistic compares favourably with coal (6.921; although 90% of this is from China), oil (0.917), gas (0.197) and liquefied petroleum gas (15.058). Wind power, between 1975 and 2010, has 44 recorded fatalities, an average of 0.054 deaths/ GWey. For more information the wind turbine accident compilation (Caithness Windfarm Information Forum, 2014) provides a comprehensive listing of fatalities, accidents and incidents regarding wind power.

[90] In the case of Floreana, pine nut oil is cultivated in Manabí, in the coastal region of continental Ecuador, and then exported to the archipelago leaving an unclear overall picture of QOL.

4.3.4. Public Acceptance of Renewable Energy Technologies

According to the IAEA (2007: 5), public acceptance implies "that a certain policy or a certain concrete measure is clearly or tacitly supported by members of the public who may be affected, positively or negatively, by its implementation". It is necessary to distinguish between various populations according to the policy or measure in question. In particular, a local population or community, such as residents on a specific island of the Galápagos, must often be distinguished from a national population at large, such as Ecuador. Subsequently, in each type of population, different degrees of acceptance may be observed that depend on different factors (IAEA, 2007: 5). The IPCC (2011) confirms that this is true for REs since the general public supports renewables at the generic level, while at the local implementation level they oppose them. This is associated with direct impacts for individuals, such as through new installations of wind turbines. Nevertheless, according to Devine-Wright (2007), studies are not conclusive since those living in close proximity not only show higher resistance but also tend to have more positive attitudes towards RETs. While this is true for wind and solar energy, Hubner and Meijnders (2004) found that those living in proximity to biomass power plants had more negative attitudes towards bioenergy.

Generally, social acceptance is crucial for successful adoption and diffusion of innovations and of RETs in particular (Jaramillo-Nieves and Río, 2010: 794). Therefore, if the Zero Fossil Fuel Program shall be successful, it is vital to have high levels of acceptance. Currently, however, there has been some criticism in this regard (Curbelo, 2010: 58). Whether public acceptance on Galápagos exists or not can be estimated or judged with varying degrees of precision. Means range from formal referenda and opinion polls to "media debates and informed judgments from people familiar with what is discussed among members of the public" according to the IAEA (2007: 5). In the case of Galápagos, two studies have been identified that assessed, based on interviews, the acceptance and awareness regarding RETs on the archipelago conducted by Westerman (2012) and Langer (2013). The small number of available studies is typical since public acceptance has hardly been addressed in RE sustainability assessment studies on islands, according to Jaramillo-Nieves and Rio (2010: 794).

Barriers to public acceptance of RETs from a SD perspective may arise from several factors. Firstly, difficulties can appear regarding inadequate attention to socio-cultural concerns. These include barriers relative to behaviour and natural habitats as well as natural and human heritage sites, including not only impacts on biodiversity, ecosystems and landscape aesthetics but also water or land availability, use and rights (IPCC, 2011). Generally, aspects influencing public acceptance of RETs are related to a certain technology since each of them captures different natural resources in different ways. While wind turbines primarily cause landscape impacts, noise from air resistance of wind turbine blades, shadows and disturbances of birds. Biomass plants are criticized for truck movement and smell (Devine-Wright, 2007; Huber and Horbaty, 2010; Aitken, 2010; IPCC, 2011).

Secondly, knowledge and information can be critical factors of social acceptance (Devine-Wright, 2007; Huber and Horbaty, 2010). Survey results from Langer (2013) confirm the founding of other studies regarding the positive correlation between the knowledge of RETs and social acceptance. The higher the information level of the person – the more likely is it that this person has a positive attitude towards them (Devine-Wright, 2007). Nevertheless, Aitken (2010: 68) points out that opposition can also arise due to informed individuals and “in many cases (…) increased knowledge might in fact lead to lower acceptance”. This inconsistency has to be considered carefully when informing the public on the Galápagos.

Thirdly, barriers to public acceptance may occur due to missing transparency and bad communication (Wolsink, 2010). Nevertheless, these are crucial factors influencing the build up of trust in key actors and shape the perceived fairness of the projects. Good levels of trust and perceived fairness are important in shaping positive attitude towards sustainable energy development.

Fourthly, the performance of the RE system and its ability to provide reliable electricity can be crucial factors for creating or decreasing public acceptance. For instance, according to Curbelo (2010: 58), on the Galápagos archipelago the credibility of RE solutions suffered under the failures of the PV system in Floreana and electricity quality issues in San Cristóbal for which the wind park has been blamed.

If these four main barriers are overcome then trust is created and a positive attitude towards renewables is shaped. This requires paying attention to socio-cultural concerns, providing information and proactive communication to create transparency as well as assuring a reliable energy supply. This promotes the necessary active participation of residents and willingness to pay.

Currently, the public acceptance of RETs on Galápagos seems to be relatively good (Langer, 2013). Nevertheless, there are certain aspects that need to be considered. Firstly, when talking about social acceptance it is worthwhile to mention that social acceptance is dynamic, not static (Aitken, 2010). Therefore, the currently relative good acceptance of RES on Galápagos should not be taken for granted, and continuous efforts are needed in order to shape positive social acceptance. Secondly, up to now, only one larger project and a limited number of micro renewables have been implemented, and a number of others initiated. As studies (Devine-Wright, 2007; Huber and Horbaty, 2010) point out, generally small-scale RETs are more positively accepted, attention has to be paid to the acceptance of future implementation of RETs on a larger scale. Thirdly, the study conducted by Langer (2013) found that there is a common consensus under the stakeholders that the archipelago has to implement a sustainable energy system. Nevertheless, they disagree on how to realize this transformation. In addition, it has been criticized that the public should be better involved in project design and decision making through improving communication and the level of information. Generally, the residents are eager to support the RES projects and are also aware of the importance to protect the unique environment in Galápagos. Nonetheless, they show a rather passive attitude (Langer, 2013).

To reach 0% fossil fuels on the islands, however, more will be needed than passive acceptance since this is not sufficient for the long-term decision making process (IAEA, 2007: 5). Adjustments in the energy prices as well as monetary participation of the residents may be necessary. The successful social acceptance of these measures can reflect the robustness and sustainability of final choices. For instance, in case 100% RES-E can be reached, it is questionable whether the very low electricity prices can be maintained since they are currently strongly cross-subsidized by public income generated through oil extraction. Nevertheless, oil reserves will only last for around 20–30 more years[91]. Therefore, it is relevant to consider public acceptance in the context of “willingness to pay”, since a positive attitude towards renewables positively influences how much people are willing to spend on a certain service [92] (GEA, 2012). According to a survey by Westerman (2012: 118), the majority of the residents in Galápagos do not have knowledge about the fact that subsidies may cause negative effects for the environment or increase consumption, since they do not understand the true consequences of subsidies. Therefore, removing subsidies might be a politically difficult decision to make. For this reason, it is imperative that the residents on Galápagos understand the motivation for the goal to eliminate fossil fuels on their islands. It is important that they are aware of the significance to reduce energy consumption, to boost

[91] See Annex 2: Short Historical Overview of Ecuador´s Oil based Development.
[92] Although the willingness to pay is additionally restrained by the ability to pay.

energy efficiency and to implement REs. Therefore they need to understand the effect of fossil fuel extraction, energy consumption and combustion on human health and the environment. Moreover, they have to receive knowledge about the benefits of REs and their functioning. According to a survey by Westerman (2012: 118), merely 55% of the residents in Galápagos would consider paying more for fuel or electricity if they were generated by RES. In addition, the survey also showed that residents perceive REs as expensive and accuse them for causing electricity outages (Westerman, 2012: 121).

Besides the willingness to pay higher prices for energy, it will be vital for eliminating fossil fuels from the archipelago that residents reduce their energy consumption and accept curtailments or other demand-side management measures (Curbelo, 2010: 58). In addition, to realize 100% RES-E on the Galápagos, it will be important that the private sector and residents undertake investments into micro RETs or participate in larger projects. However, primarily residents are expected to invest in energy efficient household technologies. A barrier to this is shown by the survey results from Westerman (2012: 120) that indicate few residents have a comprehensive understanding of how energy consumption affects the islands. Despite their general understanding that REs are good and fossil fuels can have negative impacts on the islands, their main concern are oil spills, not energy efficiency or RETs. The reason for that might be that accidents related to oil transport have happened frequently and quite recently. In addition, they are easily visible with a direct impact that can be easily perceived. According to Westerman (2012: 123), residents that are not aware of the relationship between environmental impact and energy consumption do not see the need to conserve energy – other than to save money. It has been widely recognized that integration of financial incentives and financial involvement may, however, increase the acceptance of REs (Huber and Horbaty, 2010: 48). In addition, private investment will boost the chance to reach the 100% RES goal. This also requires that REs are more accessible and affordable on the micro-level. In this regard seems to be potential for improvement, since residents claimed they were unaware of companies and organizations that are capable of installing and maintaining solar panels, according to Westerman (2012: 121).

The above-mentioned analysis shows that education and raising awareness are crucial for the success of the Zero Fossil Fuel Program. If the concepts shall be sustainable in the long run, residents have to understand, operate and maintain the technologies. Education is an essential part of SD (Clarkson et al., 1995) and the need for improving education on Galápagos has been pointed out by the World Heritage Committee that identified certain critic issues when it recommended placing Galápagos on the list of World Heritage in Danger [93] (Galápagos Conservancy, 2012).

Education

Currently, there are a limited number of educational institutions on the Galápagos Islands[94] (SENPLADES, 2010). Nevertheless, compared to continental Ecuador, the education on the islands is very good with an illiteracy rate of only 1.3% – the lowest of Ecuador (INEC, 2010a). In addition, in 2010 the average number of years of schooling was 11.9 (compared to 9.6 years on the continent) and only 2.3% of the population had not fulfilled the minimum 10 years school education (CGREG: Consejo de Gobierno de Galápagos, 2010; INEC, 2010a). In 2009, around 50% (49.5%) of the population had secondary degrees and less than 20% (17.9%) higher-level degrees (CGREG: Consejo de Gobierno de Galápagos, 2010: 11). This high level of education is also due to the fact that many young *Galapageños* between 15 and 25 leave the islands for educational purposes.

In addition, there are efforts to adjust the curriculum and other educational activities to the special situation of the archipelago, which also strengthens the rationale for RETs. For instance, only recently has the basic curriculum for primary education been adjusted in the area of natural resources and waste, conservation and human development and focuses on the archipelago for an entire year of middle school (Consejo de Gobierno Galápagos, 2013a). A strong emphasis is put on the indigenous concept of "*Suman Kawsay*" – achieving a harmonious relationship between human beings and their environment – and higher-level education (Galápagos Conservancy, 2012). Moreover, during 2011, technological and didactical equipment was installed in eight public schools to enhance knowledge of sustainable development and natural resources[95] (UNESCO, 2012).

Energy specific education of adults and children is driven both locally and internationally. On the one hand, there are locally driven activities, such as government-organized seminars for the public electrical utility, ElecGalápagos,

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[93] Critical points of the local education system included weak teacher base caused by the archipelago's isolation, complicating teacher training and development; little emphasis on independent thought or active learning and missing integration of environmental aspects (Galápagos Conservancy, 2012).

[94] The Galápagos is home to only few educational institutions: 14 schools on 4 islands, 8 colleges, 4 universities, of these there is one private school San Cristóbal, 3 on Santa Cruz – working mainly through distance classes (SENPLADES, 2010).

[95] This program will be extended in the next few years to other public schools on the islands (UNESCO, 2012).

focusing on energy efficiency and solar energy in cooperation with "*creara*" and "*Solar Quest*"[96] (Solar Quest, 2005; creara, 2012). The locally driven and run organization "*Fundar Galápagos*" was active in capacity building concerning energy from 2002 to 2004 and implemented an educational campaign in schools concerning rational use of energy (Fundar Galápagos, 2005). Moreover, they have been organizing educational campaigns for REs in 2005-2006 together with the WWF for both adults and children (Fundar Galápagos, 2006). In addition, they have been involved in developing communication strategy for the project "ERGAL" with the aim to inform the local community about the benefits of REs and to reduce fossil fuels that pose risks to the fragile ecosystem (Fundacion Galápagos, 2009). Other local foundations being involved are the *Scalesia Foundation* and the *Charles Darwin Foundation*.

On the other hand, international support has been provided since around 2000 in developing and executing campaigns to improve specific educational aspects. The energy relevant programs includes a recently developed flyer on "saving energy and efficient use of energy" by the WWF and the Ecuadorian Ministry of Tourism (Ministerio de Turismo/ WWF, 2013). In the past, the WWF has been awarding scholarships to students from the Galápagos to pursue training in environmental management, tourism and business administration. Other achievements include international environmental certification concerning the fuel-handling facility on Baltra Island, a four-year RE teacher education campaign, the creation of the first *Municipal Department of the Environment* on Santa Cruz Island and an oil-recycling program. They also educate local communities about the need to reduce waste and recycle as well as to create a culture of responsible consumption (WWF, 2014). The WWF also supported the Ministry of Tourism and the PNG in developing the Galápagos Tourism Monitoring System, one of the four key components of the new ecotourism model that also aims at reducing energy consumption.

Bilateral support has been provided by Germany, Japan, Korea, Spain and the US. The most relevant with regard to RETs has been the project *ENERGAL* initiated by the German development agency (GIZ). The education part focused on capacity building of local, regional and national actors from both private and public sector with the aim to enable them to correctly integrate REs and optimize energy efficiency in Galápagos (GIZ/ BMU, 2014). The Japan International Cooperation

[96] One seminar has been held in 2012 by the Spanish consultancy *creara* in San Cristóbal. Another project executed in 2004 and again planned for 2012 by ElecGalápagos was *Solar Quest* "proyecto educativo Ignacio Hernández" (creara, 2012). It has a focus on solar energy distance learning and human capacity building. While the project is said having been successful in 2004, there is no information, if this project has been executed again in 2012 (Solar Quest, 2005).

Agency (JICA) has been supporting education, conservation and local development from 2003 to 2008 (UNEP/ WCMC, 2011). The Korean international cooperation agency (KOICA) is currently installing an interpretation centre to promote RES next to the new PV park. In addition, they offer capacitation of technical employees of ElecGalápagos in Korea (KOICA, 2011). The Spanish International Cooperation Agency (AECID) has been cooperating with the project “Science for sustainability in Galápagos” together with *Universidad Autónoma de Madrid*, with the *Universidad San Francisco de Quito*, the *Universidad Andina Simón Bolívar*, the *Universidad Andrés Bello de Chile,* the Ministry of the Environment of Ecuador, and the Galápagos National Park (Laboratorio de Socio-Ecosistemas, 2011). Nevertheless, the PV park sponsored by the Spanish development agency is also a good example for missing education. Opened only in 2004, the system has already been out of operation in 2009 (INiAP/ MEER/ GIZ/ BMU/ IICA, 2013). It has probably been a problem of missing social acceptance due to inadequate capacitation of the affected population (ERGAL/ DED/ MEER, 2008: 63; CONELEC, 2010: 22).

By and large, this section illustrated that the general social acceptance of REs and the Zero Fossil Fuel Program is positive on Galápagos. However, social acceptance is dynamic and several criteria can shape the attitude towards renewables. Therefore, several education and awareness-raising efforts are undertaken to build up consciousness of the population to protect the environment. Nevertheless, it appears that most of the initiatives are rather short-term oriented and isolated from each other, indicating missing long-term and consistent educational strategy. In addition, no initiative could be found that tries to increase the accessibility of RETs for the local population. There are merely efforts to educate the technicians of ElecGalápagos in installing and operating the wind turbines and solar panels. This shows that there is certain improvement potential. It is especially important to empower the citizens, to raise their awareness but also to increase the accessibility to RETs. This requires the creation of a consistent and long-term oriented education strategy as well as knowledge and information campaigns. For instance, obligatory courses on SD and energy efficiency should be included in the curriculum. On another level, residents should receive information on technical aspects and financial participation into RE projects and support to implement RETs, for instance to increase energy efficiency of their homes or to install solar PV. Boosting public participation, awareness of residents towards energy conservation as well as improving accessibility and affordability of RES would require substantial financial resources. Nevertheless, these efforts are vital to reach the goal of 0% Fossil Fuels.

4.4. Environmental Sustainability

In order for Galápagos to maintain and increase their socio-economic prosperity, it is crucial for them to protect and conserve the delicate biodiversity. Nevertheless, unsustainable growth threatens the Galápagos archipelago and is putting increasing pressure on the islands ecosystem and its natural resources (Walsh et al., 2010). Over the next several decades, the Galápagos are expected to experience changes related to global warming, although varying degrees of uncertainty exist (Sachs and Ladd, 2010). The rate of change is unprecedented and humans are not only altering the atmosphere but effects are also observable in other abiotic factors as well as terrestrial and aquatic biota, such as oceans, lakes, rivers, flora, fauna and animals (Nebel and Wright, 1993: 18ff). Currently, the most critical issues are population growth and the tourism-driven economy, influencing demand for resources such as water and energy, while at the same time producing large amounts of waste and pollution. These and other environmental concerns, arising from the conventional energy systems, have been key-driver for developing RET systems (OECD/ IEA, 2012: 212; IPCC, 2011). Hence, renewables are an important aspect of promoting environmental sustainability, which is, according to the World Energy Council (2013: 5), defined as:

> *"The achievement of supply and demand-side energy efficiencies and the development of energy supply from renewable and other low-carbon sources."*

This reflects the aspiration that RETs influence environmental sustainability positively, while the focus lays primarily on CO_2 emissions. Numerous studies agree that carbon dioxide emissions, GHG or climate change are the most important aspects (IPCC, 2011; Cramer et al., 2007; Evans et al., 2009; AIU/ OLADE, 1981). They mention, however, that environmental sustainability of a RE system needs to be reflected by other environmental indicators as well (Liu, 2014). Regarding Galápagos, it should be noted that Jaramillo-Nieves and Río (2010: 794) admonish that the environmental dimension has not yet been analysed sufficiently for islands. They mention that the reasons for that could be that renewables might not notably improve the environment on islands due to their specific conditions. Firstly, they do not use land significantly more efficiently than imported fossil fuels. Secondly, emissions of local pollution are not considerable since islands are usually surrounded by oceans and favoured by maritime winds.

Environmental sustainability is of special importance for the Galápagos since they are particularly vulnerable to environmental pollution or changes of the Earth's climate and their ability to adapt is uncertain (Di Carlo and d'Ozouville, 2012). Already small changes in the micro-climate could have detrimental effects for the delicate ecosystem. This is because the climate in Galápagos is the result of a complex interaction of ocean currents and winds (UNDP/ SPNG/ INGALA/ SESA-Galápagos/ FCD, 2006; Trueman and D'Ozouville, 2010; Wolff, 2010).

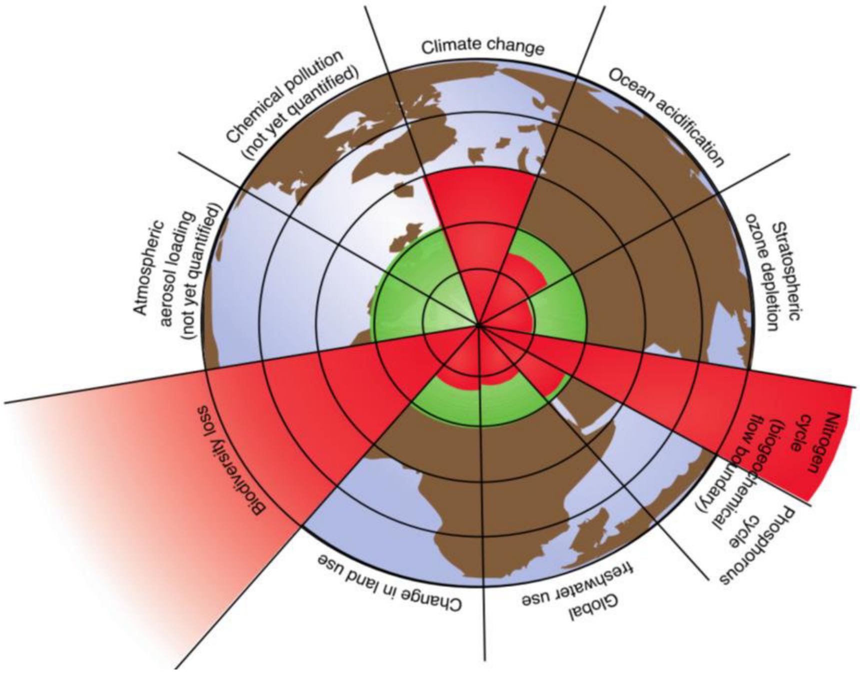

Figure 32: Planetary Boundaries
Source: (Azote Images/Stockholm Resilience Centre, 2009)

One of the most famous concepts of environmental sustainability has been developed by Rockström et al. (2009a; 2009b) from the Stockholm Resilience Centre and is illustrated in Figure 32. It lays down the importance of keeping our planet inside certain planetary boundaries (Jaramillo-Nieves and Río, 2010: 794).

This chapter describes the environmental sustainability of RET deployment on Galápagos. Special importance is paid to land and water resources since these are particularly restricted on islands, such as Galápagos, and therefore have the largest direct impact. Additionally, to begin with, the climate change boundary will be mentioned since this is one of the main drivers to develop RETs.

4.4.1. Climate Change and GHG Emissions

Notwithstanding the existing uncertainty about earth´s climate in general, many scientific institutions (IPCC, 2007; US National Academy of Sciences, 2010; Royal Society - UK National Academy of Science, 2014) have progressively recognized the link between climate change and anthropogenic influence through the consumption of fossil fuels. The Working Group I to the Fifth IPCC report has confirmed that human activity is, with 95 % certainty, the reason for observed global warming (IPCC, 2013: 96). In addition, they confirmed that radiative forcing is positive, leading to an uptake of energy by the climate system. Although all GHG emissions contributed positively to total radiative forcing, and therefore to climate warming, carbon dioxide (CO_2) emissions have been the single most important source (IPCC, 2013: 13). CO_2 is also the central GHG defined by the KP (UN, 1998). The key emitter of CO_2 is the power sector through combustion of fossil fuels. Due to the fact that RETs emit very low or no GHG, they are at the core of any climate change mitigation strategy (IPCC, 2011; OECD/ IEA, 2012: 238).

In this context, however, it is necessary to point out that while RETs do produce little or no CO_2 emissions during electricity generation, lifecycle CO_2 emissions are formed during their manufacturing, transport and installation (Liu, 2014). Lifecycle assessments for electricity generation indicate that GHG emissions from RETs are generally considerably lower than those associated with fossil fuel options as seen in Figure 33 (IPCC, 2011). In addition, it illustrates that hydro, ocean and wind energy have the lowest lifecycle emissions, followed by geothermal and CSP. PV and bioenergy show slightly higher lifecycle emissions but considerable uncertainties, nevertheless all PV and most bioenergy systems reduce GHG emissions compared to fossil-fuelled systems (2011: 711, 733). Variability for bioenergy system stems from capacity factor, combustion efficiency, carbon content of the fuel, and conditions under which the fuel is grown and transported. Additionally, in the case that landfilling of organic material can be avoided, the use of biomass for power generation can be considered as avoiding methane emissions (IPCC, 2011: 733). However, in general, currently available biofuels have only a limited potential for reducing GHG (OECD/ IEA, 2012: 222). Hence, there are efforts and hope that next-generation biofuels may result in greater climate benefits (IPCC, 2011: 711). For PV systems, variability arises from multiple and rapidly evolving solar cell designs as well as primary energy resource potential at the site. Latter also significantly influences power output of wind, CSP, ocean, and geothermal technologies (IPCC, 2011: 733).

To find out the real GHG emission reduction potential of the RE systems in Galápagos, it would be necessary to make a site-specific assessment comparing the alternative systems. This is not part of this thesis due to the scope restrictions, as it would require the implementation of an extensive life-cycle assessment. This includes taking into consideration the transport of the equipment as well as fuel, RES potential, and in the case of bioenergy crops, feedstock production and agricultural practises (IPCC, 2011: 733). For a comprehensive picture, the land-use changes also need to be reflected (GEA, 2012).

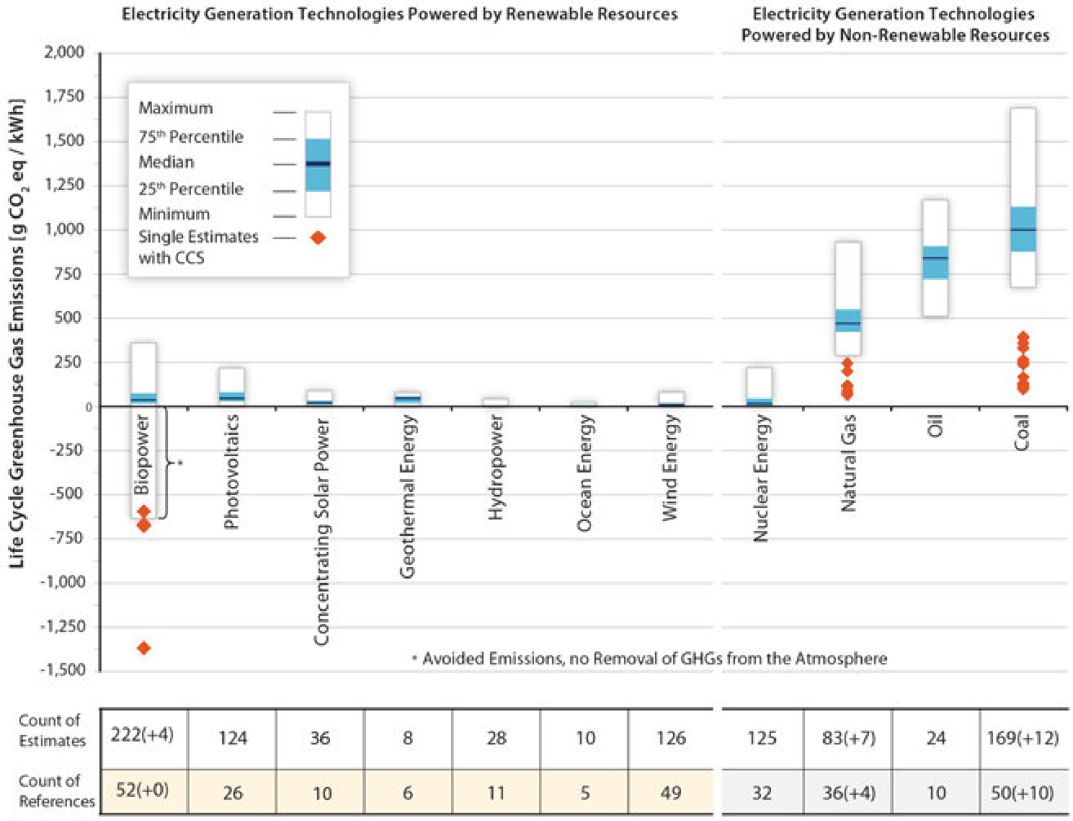

Figure 33: Estimates of lifecycle GHG emissions (g CO²eq/kWh) for broad categories of electricity generation technologies, plus some technologies integrated with CCS[97].
Source: (IPCC, 2011: 732)

Currently, the transformation of the electricity sector on the Galápagos is based on the implementation of hybrid-systems that are backed up with diesel fuel or a mixture of vegetable oil and conventional fuel. As natural consequence, these have CO_2 emissions (Liu, 2014). However, since the GHG emissions of the islands are negligible on a global scale, they are not even able to cause “clime noise” as climate scientists would say. Therefore, due to the small amount of emissions and general

[97] Land-use related net changes in carbon stocks (mainly applicable to biopower and hydropower from reservoirs) and land management impacts are excluded; negative estimates for biopower are based on assumptions about avoided emissions from residues and wastes in landfill disposals and co-products. The number of estimates is greater than the number of references because many studies considered multiple scenarios. Numbers reported in parentheses pertain to additional references and estimates that evaluated technologies with carbon capture & storage (CCS). Distributional information relates to estimates currently available in LCA literature – not necessarily to underlying theoretical or practical extremes, or the true central tendency when considering all deployment conditions.

disagreement and uncertainties concerning the contribution of CO_2 to global warming[98], this planetary boundary will not be considered further in this study.

4.4.2. Freshwater Use

Water is a key aspect of SD and is especially crucial for islands (IRENA, 2013; AOSIS, 2012). According to Rockström et al. (2009b), humans alter the water cycle affecting biodiversity, food and health security as well as ecological functions such as climate regulation and carbon sequestration, undermining the resilience of aquatic and terrestrial ecosystems. As energy plays an important role for water availability the energy, water, and land-use nexus must be assessed carefully for islands where water constraints are more pronounced (Jaramillo-Nieves and Río, 2010; IRENA, 2013: 36). In this regard Jaramillo-Nieves and Rio (Jaramillo-Nieves and Río, 2010: 769) claim that there might also be a conflict between the contribution of RETs to water and electricity supply.

Water-Energy Nexus

There is intensified discussion and growing recognition by various scholars and institutions (Hellegers and Zilberman, 2008; NCSL, 2009; Hussey, 2010; Baziliana et al., 2011; UN-DESA, 2011; Welsch et al., 2014; ADB, 2014) that water, food and energy are inextricably intertwined, deeply connected, and reciprocally linked. This interrelationship is often referred to as energy-water-food nexus or the CLEWS approach, standing for climate-land-use-energy-water-systems. These refer to the several common aspects of water, food and energy that give rise to efforts to address them comprehensively (Baziliana et al., 2011; ADB, 2014): Water, energy and food are limited resources with constraints, moreover, they are characterized by rapidly growing demand due to population growth and modernization as well as different regional availability and variations in supply and demand. Therefore, similar security issues arise since these resources are fundamental to the functioning of society. Although, they are critical to human development, there are still billions of people without adequate access. In addition, they also have strong interdependencies with climate change as well as the environment and are part of heavily regulated markets.

[98] For example, there are many factors that can cause changes in the earth climate not just CO_2. In addition, there are feedback effects that can decrease temperature, such as rising temperatures may cause increased evaporation with subsequent increased cloudiness and in turn greater albedo effect, which could lower the temperatures (Páez, 2011).

The approach to the energy-water-food nexus depends on the perspective (Hellegers and Zilberman, 2008). From an energy perspective water and food can be both inputs and outputs. On the one hand, water and bio-resources, such as in the form of biomass, are generally inputs into energy production (Baziliana et al., 2011). In other words, when seen from a water perspective, food and energy systems are users of the water resources (Hellegers and Zilberman, 2008) because food and energy production require large amounts of water such as for irrigation of crops and cooling for power plants (ADB, 2014). The greatest consumptive use of water remains irrigation (IPCC, 2011: 743). That is why irrigation of feedstock for production of biofuels (such as Palm oil) results in such an enormous water footprint. But even non-irrigated crops use substantial amounts of water in the conversion process (from crop to bio-fuel), like that of sugarcane in Brazil. Moreover, bio-resources act as direct input for energy production, for example in the form of wood or biofuels from palm oil. On the other hand, food and treated water, such as in the form of desalination or wastewater treatment, are outputs that require significant energy input[99] (Baziliana et al., 2011; UN-DESA, 2011). For instance, energy demand for the re-use of water through treatment with reverse osmosis and high-pressure membranes can be very high (Baziliana et al., 2011).

These close interconnections beg for a systemic, coordinated and combined planning approach for all three resources. A better integration between energy and water policy frameworks will be needed. The aim should therefore be to identify and implement synergistic policies and technologies that have a positive implication for water, energy and food. Such as energy and water conservation or the combination of RETs and water treatment plants (Hussey, 2010).

Water Resources Management on Galápagos

> *"... from the well there came out water saltier than that of the sea; on land they were not even able to find even a drop of water for two days…". Tomás de Berlanga, 1535* (Liu and d'Ozouville, 2013: 76)

Water resources are critically important to Galápagos since both quantity and quality of freshwater have always been a challenge on the archipelago (d'Ozouville, 2007). In this regard, the increasing demand puts pressure on the generally limited freshwater resources[100]. As illustrated in the overview of aspects related to water on

[99] The energy demand during the water use cycle is illustrated in Annex 9.
[100] Water demand is also increasing because of the economic growth, the subsequent modernization and evolution of the lifestyle requiring more water. In addition, distribution losses are increasing due to missing maintenance of the distribution network. Moreover, the absence of water meters and the low

Galápagos in Table 18, the only water resource available on all islands is subsurface brackish water (Nguyen, 1985; Guyot-Téphany et al., 2013). Collection of rainwater is used to a lesser extent and keeps loosing importance, particularly in urban areas (Nguyen, 1985; ElecGalápagos/ PSI/ PNG, 2011; Guyot-Téphany et al., 2013). This is due to several reasons. For instance, a study by *Consulambiente* (2012) points out that evapotranspiration is high, leaving little water available to recharge the aquifer. In addition, the retention capacity is low and the water is flowing towards the profound aquifers that are interconnected with the ocean.

Table 18: Water on Galápagos
Source: Own elaboration based on data from (d'Ozouville, 2007: 152; PNG, 2009b)

	Santa Cruz	San Cristóbal	Isabela	Floreana
Drinking water supply in urban region	Public network	Public network	Public network	Public network (since 2013); rainwater collection and spring
Quantity	Brackish water source from "grietas" (mix of rain and salty water) and deep well (not polluted)	Sweet water from aquifer and rivers; problem of leakages in pipeline; Brackish water source	Water from wells; Brackish water source	During drought & without enough precipitation spring can dry; Brackish water source
Contamination	Yes, contaminated source (salt, faecal coliform)	Yes, during transport	Yes, contaminated source – brackish water	n.a.
Domestic use in rural zones	Rain water collection	Rain water collection; aquifer	Rain water collection	Spring & Rain water collection
Risks	Risk of droughts	Some aquifers could be affected by droughts	Risk of droughts	Risk of droughts
Drinking water	Private desalination plants; Rain water collection	Private desalination plants; Rain water collection	Import of freshwater; Rain water collection; Private desalination plants	Import of freshwater; Rain water collection
Water from agricultural use	Rain water collection-tanks; brackish water, contaminated	Rain water collection; aquifer	Rain water collection-tanks; brackish water, contaminated	Rain water collection-risk of drought

The only island that has adequate perennial supply of surface freshwater and groundwater for human consumption is San Cristóbal (UNEP/ WCMC, 2011). Freshwater is captured in the highlands and a pipeline system installed to transport it to the population centres (Guyot-Téphany et al., 2013). Also on Floreana, there is sufficient freshwater available to supply the small population though groundwater and seasonal springs, driven by precipitation, *garúa* and fog. Strict water

prices lead to uncontrollable water use and dissipation (Guyot-Téphany et al., 2013). Another reason for wasteful consumption of water is its bad quality undermining the intrinsic value of water.

management coordinates when and what quantity is available to the residents on this least populated island (ElecGalápagos/ PSI/ PNG, 2011; UNEP/ WCMC, 2011). Although, seasonal springs occur on Santa Cruz as well (UNEP/ WCMC, 2011), the main source of water supply in this island, as well as on Isabela, is brackish water. This is a mix of rainwater and seawater (ElecGalápagos/ PSI/ PNG, 2011) pumped from the basal aquifer to the residents (Guyot-Téphany et al., 2013).

Currently, the Ecuadorian government is providing running water though the municipalities. In San Cristóbal and Floreana 93%, of the housing units have been connected to the public network providing naturally available sweet water from the highlands. The coastal areas in Santa Cruz and Isabela are provided by brackish water pumped up from the groundwater aquifer. On Santa Cruz, 88% of the housing units have been connected to the public network, while on Isabela 81% (Villacís and Carrillo, 2012: 88-89; Guyot-Téphany et al., 2013).

It is important to emphasize that currently the water quality in most parts of Galápagos is detrimental due to various reasons. Large amounts of water are polluted with pathogenic microorganisms that are amplified through stagnation in the pipework (Liu, 2011; Guyot-Téphany et al., 2013) or are threatened by salt-water intrusion (Cuerpo de Ingeníeros de los Estados Unidos de America, 1998). Wastewater management is closely connected to energy consumption and still one of the greatest challenges on Galápagos. Connection to sewage system is currently inadequate. For example, on the most populated islands, Santa Cruz, San Cristóbal and Isabela, only 3.5%, 73.7% and 32.6% (respectively) of the population is connected to the sewage system. On San Cristóbal and on Isabela the share of connected population is larger while the population much lower (Villacís and Carrillo, 2012: 88-89). Leaching of wastewater into the ground is the main cause for water pollution in all islands due to either poorly constructed sewage or septic waste water systems[101] (Walsh et al., 2010; Gobierno Autonomo Descentralizado Santa Cruz, 2012a; Liu and d'Ozouville, 2013). Subsequently, 93.8% of the population currently treats the water before using (INEC, 2011a; INEC, 2011b), and most of the population buys bottled water for drinking and cooking sold by commercial entities that import it or have small desalinization plants (PNG, 2009b).

[101] The latter are uncontrolled onsite wastewater treatment systems that are often inadequately constructed on Galápagos, causing subsequent leaching into the ground (Walsh et al., 2010) (Gobierno Autonomo Descentralizado Santa Cruz, 2012a). Problems with septic tanks have been identified (Liu and d'Ozouville, 2013) remarking that population density as well as bacterial loads are high, there are no drainage collection areas, the tanks are directly above water sources only separated through permeable lava stones and there is no regular pumping.

Over the next several decades, the Galápagos are expected to experience changes related to climate change that could affect precipitation, despite varying degrees of uncertainty (Nebel and Wright, 1993: 18ff.; Sachs and Ladd, 2010; Di Carlo and d'Ozouville, 2012). For instance, water availability is expected to decline due to decreasing *garúa* – dense fog forming during the dry season. Nevertheless, the extent of change is unknown since the formation is a complex function of sea surface temperature, wind, and humidity depending on ocean-atmosphere circulation currents and el Niño events, and is not yet completely understood (Sachs and Ladd, 2010). Considering the current levels of population growth on the islands and the water shortages that have occurred in urban and rural areas in recent years, when paired with the bad quality and expected aggravating situation in the future due to climate change, good management of the water resources is essential not only for human development, but to preserve the balance of the natural ecosystem (Rueda, 2009).

Nevertheless, good management might not be enough to provide secure drinking water. Potential solutions to improve water quality and quantity require substantial amounts of energy. Currently, for all islands, there are plans to develop desalination plants. For example, on Isabela there are plans for revers osmosis water treatment (Consulambiente, 2012), while in Bellavista on Santa Cruz the first water collection and distribution plant is planned that shall later be expanded to include reverse osmosis (Gobierno Autonomo Descentralizado Santa Cruz, 2012a). Desalination plants have not yet been installed since they require large amounts of energy, use advanced technology and are therefore relatively expensive. As an example, Table 19 provides the prices for water on Isabela.

Table 19: Prices for water resource on Isabela
Source: Data adapted from (Consulambiente, 2012)

Type of water	Unit	Price per unit
Rain water without treatment	25 litres	USD 1
Rain water after treatment	25 litres	USD 1.5
Rainwater from continent	5 litres	USD 2
Treated water from reverse osmosis	15 m^3 (consumption of one household per month)	USD 23.9
Drinking water from bottles	0.5 m^3 (drinking water need of one household per month)	USD 60

The price for desalinated water on Isabela (USD 24 per month) is expected to be higher than without treatment. Currently, consumers usually pay on all islands less than USD 10 per month[102], except for the locality Bellavista (Santa Cruz), where USD 1.21 is charged per cubic meter. Bellavista is the only area with water meters (d'Ozouville, 2007: 152; Guyot-Téphany et al., 2013). Nevertheless, the further installation of meters to measure water usage of housing units is planned (Consulambiente, 2012; Gobierno Autonomo Descentralizado Santa Cruz, 2012a). Considering the current drinking water consumption of around 0.5m^3 per month and family (Consulambiente, 2012), and assuming an average of three persons per household (INEC, 2010a), the water consumption equals around 4.5 litres per day and amounts to USD 60 per month. This shows that a desalination plant could provide safe drinking water without necessarily increasing the costs for the residents.

It can be summarized that the current use of water is not sustainable. Due to the geographic opening, increasing population and tourism are causing a steady increase in demand. From an economic and environmental point of view, precious water resources are wasted. From a social point of view, there is a disconnection between valuing available water and the bad water quality that makes water usage for drinking and cooking purposes a threat to health (Guyot-Téphany et al., 2013). To improve the situation, various steps are necessary: a) safe water quality needs to be provided; b) water use needs to be controlled, and if necessary, limited; c) water needs to be re-valued. This, and the available information on Galápagos, suggests that wastewater treatment as well as water supply from desalination may need to be expanded significantly during the next years, resulting in a substantial increase of the future electricity demand. Expanding individual or collective collection of rainwater is of crucial importance to reduce energy demand and to allow for reaching the Zero Fossil Fuels goal (Guyot-Téphany et al., 2013). Moreover, the less water is used, the better. This can be accomplished by removing subsidies, which encourage overuse of water resources, and introducing incentives for energy efficiency or water saving technologies (ADB, 2014). In addition, improving the pipelines by implementing a tariff for the water consumed and using that money for operation and maintenance of the pipeline network could help to reduce water wastage. In this regard, the installation of water meters is vital to measure and control water consumption (Guyot-Téphany et al., 2013). Nevertheless, it is expected that seawater desalination, fog water catching or ecological water treatment, processing and conditioning are required to allow for sustainably supplying safe and clean drinking water in the long-run. These could include a

[102] See Annex 10.

separation of black and grey water, dry toilets, biogas or fertilizer production that also allow the use of the material for agricultural purposes or to gain energy (Schnoor, 2011; Guyot-Téphany et al., 2013).

4.4.3. Land-use

Land system change is one the planetary boundaries and is primarily driven by agricultural expansion and intensification. It contributes to global environmental change, poses the risk to undermine long-term sustainability and human well-being (Rockström et al., 2009b: 9). An Important driver for land-use change (LUC) is energy generation through mining and resource extraction (IPCC, 2011: 735). Nevertheless, also RES require space for their conversion into electrical energy, water storage for hydropower in reservoirs or bioenergy cultivation (IPCC, 2011: 735; NREL, 2012; GEA, 2012: 773). Furthermore, harnessing energy from renewable sources requires specific spacing to circumvent negative impact on humans or animals as well as to avoid reduction of efficiency due to wake losses for wind turbines or losses through shadowing concerning PV. Generally, the land will be needed for over 20 years and preferably it should be near major loads or the power plant (IRENA, 2013).

Indirect influence on LUC exists because all types of RETs require not only space, but also material for the conversion of heat, wind or incident radiation into useful energy (Haefele, 1981). Essential materials include steel, glass, concrete, copper, aluminium, and other metals that need to be extracted and produced. Material is also needed to stand natural routine and extreme environmental conditions. In the case of Galápagos the most relevant are the high salt content in the air due to the proximity to the ocean, the strong irradiation and to a lesser extent humidity as well (ElecGalápagos/ PSI/ PNG, 2011: 82; de la Torre, 2004).

This evidence indicates that, in general, all types of energy technologies require a substantial amount of space when the whole supply chain is included (IRENA, 2013; IPCC, 2011: 125). Life cycle land transformation depends on specific resource potential at a site, for instance space requirement for solar PV in northern Germany would be higher than in southern Spain. In addition, it depends on the calculation method. The life cycle analysis needs to take into account impacts such as growth in land use (since mines insatiably expand), toxic by-products and waste processing land use, buffer zones and water use. However, over time a coalmine that produces waste and uses large amounts of water will have a growing footprint, whereas solar or wind energy have a rather static footprint. This shows that land-use on a life cycle basis is far more complex than a simple energy per km^2 outcome (Morris, 2013). However, in general, the limited available evidence suggests that lifecycle land-use by renewables is comparable to or lower than for fossil energy chains (IPCC, 2011: 743). Nevertheless, RETs have certain advantages that offset some of their space requirements. For instance, while the conversion of solar and wind energy to electricity requires large areas; it allows secondary uses such as fishing, farming and recreational activities (IPCC, 2011: 125). Furthermore, each RET exploits a different natural resource and therefore land requirements and the respective rationales are not uniform. The main risk of solar energy is that plant community could change due to shading effect of the PV panels (IPCC, 2011: 740). A simple solution to mitigate these impacts and reduce land requirements are roof-mounted solar energy systems, building integrated solar cells, or solar sources build to provide shade over public parking slots (IRENA, 2013).

The direct space requirement of wind energy is relatively low and the area can be easily used for agricultural purposes at the same time. Nevertheless, noise and the flickering of wind turbines may be a nuisance, and can have a negative impact on human health (IPCC, 2011: 740; GEA, 2012: 820). Therefore, adequate spacing in relation to residential areas is required to mitigate these impacts. To reduce the required land, an alternative mitigation measure could be switching-off the WTGs to avoid shadow flicker during specific times, when residents may be affected. An additional aspect that requires consideration, and might influence land-use and wind park siting, is the visual impact. If correctly managed there is the potential to reduce visual impact while increasing public acceptance through active cooperation with the local community (GEA, 2012). Finally, wind parks might also be sited according to impacts on animals, especially birds. They are often criticized for disturbing air routes of migratory birds, causing collision fatalities of birds and bats, triggering avoidance or displacement from an area or reducing reproduction (IPCC, 2011: 740). Nevertheless, it is argued that land-based wind energy does not appear to have a significant impact on bird fatalities compared with other sources of fatalities, such as collisions with buildings as well as predation by cats (GEA, 2012: 820). Studies also mention that often birds avoid wind turbines or there might even be a familiarization effect, although this depends on the type of the bird and on the time they spend in the proximity of the wind park (Planungsgruppe für Natur und Landschaft, 2012; Landesamt für Umwelt, Gesundheit und Verbraucherschutz, 2013).

The impact of bioenergy on land-use is different from PV or wind energy since land intensity of bioenergy is significantly higher. In addition, bioenergy shows substantial variations in energy yields depending on climate zones and feedstock (IPCC, 2011: 125). In general, land requirements are largely due to cultivation of the crops. Bioenergy production may lead to extensive land use, either directly or indirectly, and is therefore likely to have a negative impact on food security and biodiversity (GEA, 2012: 1248; UNIDO, 2009). Firstly, biodiversity is endangered due to multiple reasons. There is a risk of loosing high quality natural habitats due to the conversion to managed land. There is also pressure on conservation areas that effects agro-biodiversity as well as wildlife through agricultural intensification. The latter can additionally cause soil degradation, eutrophication and pesticide emissions and can also negatively affect aquatic habitats. In addition, bio-energy crops can also permit the introduction of invasive or genetically modified species (IPCC, 2011: 740). Using biomass residues can mitigate these impacts, although these can, as well, lead to soil degradation or a loss of woody debris habitats in forestry systems. Secondly, biofuel production may threaten food production if high-productivity land is used for energy crops while food production is moved into marginal lands with lower yields and a higher risk of degradation (Rockström et al., 2009b: 17).

This shows that the land needed for energy conversion, spacing, resource extraction or cultivation may create competition with other claims and requirements for the use of land, including food production, the protection of ecosystems and conservation of biodiversity (GEA, 2012: 774). In this regard, IRENA (2013: 36) suggests that the spatial constraints of islands are crucial for successful deployment of REs, requiring a careful assessment of the energy-water-land-use nexus.

Regarding land-use and islands, there are additional constraints. On the one hand, the spatial constraints due to the small size of most islands (SENPLADES, 2010; IRENA, 2013) make soil occupancy a more relevant barrier than on the mainland (Jaramillo-Nieves and Río, 2010). On the other hand, the Galápagos are characterized by complex land-tenure since the major part of the islands surface is protected as natural reserve and special legislation applies (IRENA, 2013). In the case of Galápagos 98% of the surface is protected national park administered by the "*Parque Nacional Galápagos*". According to the local legislation, land-ownership and economic activity on the archipelago are only possible for permanent island residents[103] (ERGAL/ KfW/ Lahmeyer, 2001: 49; Gobierno del Ecuador, 1998). In

[103] According to LOREG economic activity on the Galápagos Islands for foreigners is only possible in cooperation with a permanent resident.

addition, throughout the country, other policy and regulatory frameworks concerning land tenure and energy have been set up for centralized utilities that are vertically integrated and state-owned (IRENA, 2013). For instance, each RE project in Galápagos requires an individual approval procedure (ERGAL/ KfW/ Lahmeyer, 2001: 49), requiring time, effort and money. This converts the project development and execution a cumbersome endeavour. To allow widespread RE deployment, these frameworks will likely require some adjustments (IRENA, 2013).

Besides spatial constraints, other aspects complicate RE siting on Galápagos. For instance, siting is complicated by the uneven surfaces formed by uplifted marine lava flows that characterize the islands and undulated soil, showing sudden disruptions, plateaus and partly strong inclinations (UNDP/ SPNG/ INGALA/ SESA-Galápagos/ FCD, 2006). These spatial constraints, paired with complex land-tenure, can pose challenges to RE deployment since wind and solar energy are site-sensitive. This means, economically reasonable sun or wind electricity generation will only be possible if there is access to sites with good wind or irradiation potential (IRENA, 2013) and if the sites are not too far from the consumers. Therefore, site-specific evaluation and adjustment of the RETs are necessary, as well as a careful assessment of the energy-water-land-use nexus to provide sustainable energy services. This also requires social acceptance of the site and the inclusion of all key stakeholders (IRENA, 2013).

4.4.4. Other Environmental Impacts

Ocean Acidification

Ocean acidification refers to a reduction in pH of the ocean, primarily caused by the uptake of CO_2 from the atmosphere (IPCC, 2013: 295). A gradual acidification can be driven by the uptake of anthropogenic CO_2 but might also have natural reasons such as volcanic activity (IPCC, 2013: 52; 295). Therefore, combustion of fossil fuels exacerbates ocean acidification because increased CO_2 is released into the atmosphere (IPCC, 2013: 26). Ocean acidification poses potentially serious threats to the health of the world’s oceans ecosystems (IPCC, 2013: 136), which is also of particular importance for Galápagos. Since CO_2 emissions are decreased through RETs, they can contribute to decrease ocean acidification as well (OCEANA, 2014; Woods Hole Oceanographic Institution, 2012). The extent to which each technology contributes depends on their lifecycle CO_2 emissions as referred to above.

Stratospheric Ozone Depletion

Stratospheric ozone has declined from pre-1980 values mainly due to ozone-depleting halocarbons (IPCC, 2013: 171; 662). This is precarious because ozone in the stratosphere plays an important role for the absorption of ultraviolet and infrared radiation, which is critical to maintain the earth´s climate in equilibrium (Dincer, 2000). The Montreal Protocol was successful in reducing emissions from chlorofluorocarbons (CFCs) resulting in signs of ozone stabilization and even a possible recovery (IPCC, 2013). Currently, N_2O emissions are likely to dominate other emissions in terms of ozone-depleting potential (IPCC, 2013: 672). The main sources of N_2O are agricultural and soil sources but also fossil fuel activities (IPCC, 2013: 675). Therefore, RETs are likely to mitigate stratospheric ozone depletion, though more research is necessary to assess the specific influences that different low carbon technologies would have. For instance, Khatiwada (2013: 87) points out that sugarcane ethanol causes N_2O emissions from crop residues and mineral fertilizer, however, it is necessary to incorporate the actual agricultural practices to acquire reliable data.

Biogeochemical Cycles

The nine planetary boundaries defined by Rockström et al. (2009b) include the global biogeochemical cycles of nitrogen, phosphorus, carbon and water. According to the IPCC (2013: 79), "Biogeochemical cycles and feedbacks other than the carbon cycle play an important role in the future of the climate system, although the carbon cycle represents the strongest of these". Nevertheless, the PBL (2012: 198) confirms that disturbances of the nitrogen and phosphorous cycle have been identified as critical sustainability concerns since these biogeochemical cycles are responsible for many life-sustaining processes on our planet. In fact, it is assumed that the planetary boundaries for phosphorus (Carpenter and Bennett, 2011) and nitrogen (Rockström et al., 2009a) have already been exceeded. This exceedance causes eutrophication and increases the risk for ocean anoxic events (Rockström et al., 2009b). Eutrophication refers to the promotion of biomass growth in an ecosystem due to an influx of nutrients such as nitrogen and phosphorus. This causes algae blooms that deplete oxygen with negative effects on aquatic organisms. It ultimately results in biodiversity loss (Stamford and Azapagic, 2011: 6047; PBL, 2012). Biodiversity is also endangered through phosphorous inflow into the ocean since it has been identified as key driver behind global-scale ocean anoxic events that may explain mass extinction of marine life (Rockström et al., 2009b).

The effect of RETs on these biogeochemical cycles is rather indirect – except for bioenergy – since the most important sources for nitrogen and phosphorous are fertilization and sewage. Nonetheless, important contributions of NOx also come from combustion of fossil fuels and biomass (IPCC, 2013: 97; Liu, 2014). Generally, RETs are assumed to have less impact on biogeochemical cycles with the exception of bioenergy (Pehnt, 2006; Hung, 2010; McCollum et al., 2012). In this regard, McCollum et al. (2012: 227) point out that increased bioenergy production could potentially increase the demand for fertilizer. When synthetic fertilizers[104] are used, there is not only the risk that an excessive use of fertilizers can cause nitrogen, phosphorous and potassium run off, but additionally, high amounts of energy are needed with subsequent CO_2 emissions. Also, according to the DLR, energy systems with biomass increase eutrophication because NOx emissions are higher in small systems (DLR/ ifeu/ Wuppertal Institut für Klima, Umwelt und Energie, 2004: 14). Pehnt (2006: 60) and Hung (2010: 28) show that wind and hydro energy have the lowest eutrophication potential, followed by solar thermal, geothermal and PV. Of the biomass systems, forest wood combustion has the lowest eutrophication potential and biogas the highest. However, more research is necessary to assess the impact of RETs on the biogeochemical cycles on Galápagos.

Biodiversity

The rate of biodiversity loss is unacceptable for ethical reasons, according to Rockström et al. (2009b), and can have unexpected results for ecosystem functioning, as current knowledge is incomplete. Biodiversity is particularly important for the Galápagos Islands. Thanks to its climate, its location at the confluence of three ocean currents and its isolation from the mainland – to which the islands have never been connected – terrestrial and marine biotas were able to develop a unique ecological diversity (Stumpf et al., 2013: 173). Many endemic species and plants can only be found on the Galápagos Islands or in the surrounding marine ecosystem. This unusual terrestrial and marine life inspired Charles Darwin during his visits in the 1830s to develop the *theory of evolution by natural selection*.

[104] From a sustainability perspective, the use of inorganic fertilizer in general has been criticized by McCollum et al. (2012: 227) as phosphorous is a non-renewable, and therefore ultimately a finite fossil mineral (Rockström et al., 2009b) – although global supply is thought to be large. When animal manure or human waste are recycled in agricultural systems, bioenergy crops could be more sustainable.

Moreover, the uniqueness and importance of the islands and its ecosystem has been recognized by the world society in 1978 with the declaration of the Galápagos archipelago as UNESCO World Heritage (UNESCO/CLT/WHC, 2013).

Biodiversity is closely intertwined with all other planetary boundaries such as climate change, ocean acidification, LUC and chemical pollution. Owing to this complex interweaving on a global scale, it seems unfeasible to assess the impact of RETs on biodiversity in the framework of this thesis. More research should be conducted considering the local impact of RETs on biodiversity in Galápagos, since most species are unique to the archipelago. Due to the microclimate on each island and that each potential RE deployment site has different flora and fauna, a generalized assessment is impossible. In this regard, it is important to develop environmental management plans specifically for the site and RET used, to mitigate all potential impacts on biodiversity.

Atmospheric Aerosols

Aerosol loading is considered as "an anthropogenic global change process with a potential planetary boundary" mainly due to their influence on the climate system and their adverse effect on human health at both the global and regional scale (Rockström et al., 2009b). For instance, particulate matter (PM), tropospheric ozone, as well as oxides of nitrogen and sulphur negatively affect human health and crops. Due to its complexity in terms of sources, impacts, and spatial and temporal dynamics, the effect of RETs on aerosol loading is difficult to define (Rockström et al., 2009b). However, it should be mentioned that RETs (except biomass) are expected to have a positive impact on aerosol loading since combustion for power generation is an important source for PM, NOx and SOx (Jaramillo-Nieves and Río, 2010; Liu, 2014; UNEP, 2011a). For instance, acid gases such as NOx and SO_2, HCl, NH_3 cause acid deposition, increasing mortality of aquatic organisms in lakes and rivers, reducing overall biodiversity and eroding buildings (Stamford and Azapagic, 2011: 6047; Liu, 2014). In this regard, Pehnt (2006: 60) and Hung (2010: 28) show that the lowest PM emissions are from run-of-river and reservoir hydro, followed by wind energy and PV. Of the biomass systems, the highest PM emissions are generated by wood, bioethanol and bio waste. Nevertheless, the distance to coal combustion is significant. Regarding terrestrial acidification potential, according to the DLR, energy systems with biogas increase acidification due to increased ammonia emissions of the agricultural system (DLR/ ifeu/ Wuppertal Institut für Klima, Umwelt und Energie, 2004: 14). The least impact have run-of-river and reservoir hydro, followed by wind energy and PV. In conclusion, the overall impact of wind and solar energy on aerosol reduction is expected to be positive, although due to the complexity of the issue, this aspect will not be considered in more detail.

Chemical Pollution

Chemical pollution includes heavy metals, radioactive compounds and organic compounds adversely affecting human and ecosystem health, such as persistent organic pollutants, plastics, or endocrine disrupters (Rockström et al., 2009b). There are complex interrelations of chemical pollution and other planetary boundaries. The effect of RETs on chemical pollution is expected to be generally positive. Nevertheless, according to Hung (2010: 28), PV has a significant amount of ionising radiation compared to wind, hydro or biomass and is in the same range as coal. Concerning human toxicity, Hung shows that the lowest toxicity potential have run-of-river and reservoir hydro, followed by wind energy and biogas, while more is expected for PV and bio-waste. Furthermore, Pehnt (2006: 60) shows that significant amounts of benzo(a)pyrene can be found in wood. Generally, it can be expected that wind and PV energy have a positive impact on chemical pollution compared to fossil fuels and biomass.

A significant difference between hydro, wind and PV on the one side and fossil fuels on the other side is that fossil fuels induce chemical pollution during resource extraction and power generation, while for RETs, they are primarily relevant during manufacturing and recycling. In this context, IIASA points out that in PV production, many new chemical compounds are used with poorly understood toxic properties (GEA, 2012: 273). Therefore, equipment manufacturer should be more actively involved because the impact as well as mitigation potential lies with them. In this regard, end-of-life recycling of solar and wind energy along with energy storage components should play a significantly more important role. PV panels and WTGs are expected to have lifetimes of 20-25 years (IPCC, 2011). But if no recycling strategy is developed, waste accumulates. This is critical since solar PV panels and batteries contain hazardous substances such as cadmium, lead, selenium, and tellurium (Jacobson and Delucchi, 2011). For instance, cadmium is volatile and highly toxic, and therefore there is the risk that it enters the food chain through accumulation in water and soils. Similarly, lead and sulphuric acid[105] have severe

[105] Sulphuric acid is used in batteries as electrolyte having corrosive impact.

negative impacts on health and environment through potential contamination of soil and water.

Therefore, as long as recycling and disposal strategies are not developed, environmental sustainability and soundness cannot be guaranteed. In addition, recycling would also be economically interesting and sustainable because valuable resources, such as selenium, indium and gallium could be recovered and reused. In conclusion, the overall impact of wind and solar energy on chemical pollution is difficult to evaluate due to the complexity of the subject and the global nature of chemical pollution (Rockström et al., 2009b). Therefore, this aspect is not going to be considered in more detail for Galápagos.

5. Sustainability Assessment of the Renewable Energy Projects on Galápagos

Although numerous RE projects have been initiated on the Galápagos, energy demand and fossil fuel imports continue to grow. Despite the intention of the central government to create a model region for RETs, action has been cumbersome and partially shaped by technical, financial and political setbacks. The current status of all identified projects in operation, execution and in the planning phase are listed in Annex 11. In the subsequent chapter, the RES-E concepts of each island shall be analysed, assessing their sustainability with regard to the criteria identified above: technological feasibility, energy security, socio-economic energy equity and environmental sustainability. Nevertheless, only project-specific aspects that have not yet been covered are added in this section.

5.1. San Cristóbal

San Cristóbal is the administrative capital of the Galápagos province and currently home to approximately 8,300 residents, which makes it the second most populated island (INEC, 2010b). It is the geologically oldest and therefore easternmost island of the archipelago[106].

5.1.1. Technological Feasibility

The electrical system on San Cristóbal is currently composed of a thermoelectric diesel generator system, depicted in Table 20, with a total nominal installed capacity of 4.36 MW (ElecGalápagos, 2013d) or effective 3.4 MW (ElecGalápagos, 2014c).

Table 20: Diesel Generators on Galápagos: San Cristóbal
Source: Data adapted from (ElecGalápagos, 2013a)

No.	Model	Motor Brand	Generator Brand	Year Of Fabrication	Capacity		Status
					Nominal (kW)	Effective (kW)	
1	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
2	Ps1386e	Perkins	Stanford	2009	1,000	800	Out of Service
3	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
4	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
5	3408	Caterpillar	Caterpillar	1981	310	160	Operational
9	3516	Caterpillar	Caterpillar	2011	1,100	880	Operational
			Total San Cristóbal		**4,360**	**3,400**	

[106] Due to the volcanic origin of the Galápagos Islands and their location on the Nazca plate the islands very slowly drift east towards the South American Continent.

Peak demand in 2013 was on 27th March at 14:00 with 2,526 kW (ElecGalápagos, 2014a; ElecGalápagos, 2014c). In addition, since 2007, the diesel system has been interconnected with the first Ecuadorian wind power system that has an installed capacity of 2.4 MW and is complemented by micro solar PV systems (e8/ EOLICSA/ ElecGalápagos, 2008). Further, the total energy demand in 2013 was 11,086 MWh (ElecGalápagos, 2014a).

Wind Energy on San Cristóbal

The wind power park on the island San Cristóbal is located on the hill "Cerro el Tropezón", in the highlands of the island, and is the first large-scale wind energy project in Ecuador. It is made up of three wind turbines of 800 KW each, with a total capacity of 2.4 MW. They are model AE59 with a blade diameter of 59 meters and 51.5 meters hub height, manufactured by MADE, now Gamesa. The WTGs are administered by the wind park corporation San Cristóbal (Eólica San Cristóbal S.A.), also referred to as "EOLICSA". Nevertheless, the wind park is soon to be handed over to the public utility ElecGalápagos as it has been agreed to transfer the assets of the private company EOLICSA to the provincial electrical utility after seven years (ElecGalápagos, 2013d).

The wind turbines started their operation in October 2007 delivering electricity to nearly 4,000 consumers; covering – in times of good wind conditions – up to 90 % of the daily electricity demand (Vintimilla, 2011: 5). The produced electricity of 60 Hz and 13.8 kV is transported first through an underground transmission line for three kilometres and then through an overhead grid of 13.2 kV another nine kilometres to the diesel power plants (ERGAL/ MEER/ UNDP, 2007; e8/ EOLICSA/ ElecGalápagos, 2008; Rosero and Chiliquinga, 2011).

The expected average annual wind speed was 6.8m/s (EOLICSA, 2009). As illustrated in Figure 34, the maximum wind speeds were up to 20 m/s appear from August to October. During the hot season from January to March, the wind speeds are rather low because of the Panama current (Molina, 2012: 49; EOLICSA/ GSEP/ ElecGalápagos, 2013). Furthermore, in their review EOLICSA, GSEP and ElecGalápagos (2013: 11) emphasize that 2008 was a year with extremely low wind speeds and since then the wind conditions have been improving as exptected.

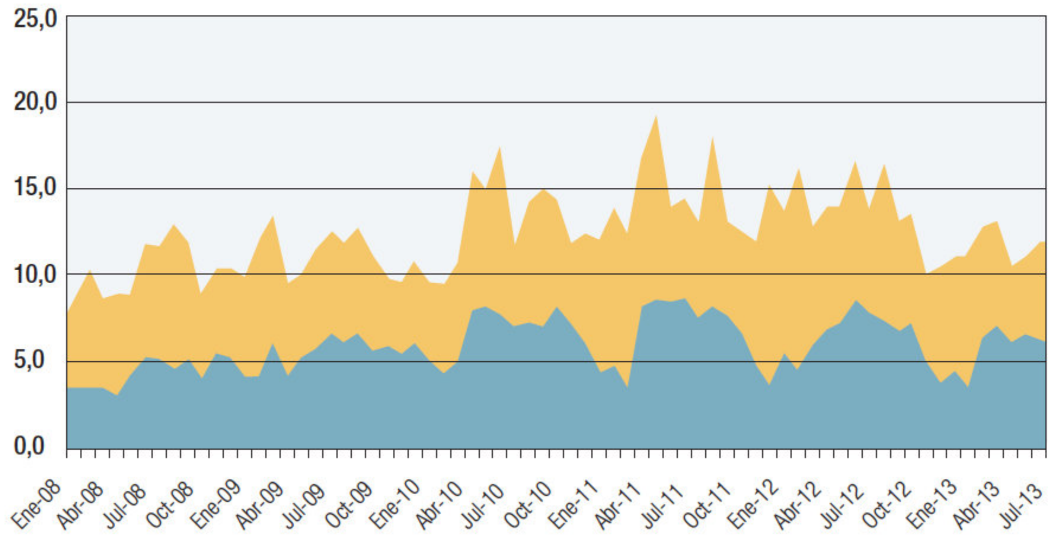

Figure 34: Mean Wind Speeds in m/s of the Wind Power Park in San Cristóbal
Source: (EOLICSA/ GSEP/ ElecGalápagos, 2013: 11);
Comment: yellow – maximum wind speed; blue – mean wind speed

The results of this wind regime, regarding electricity production, are demonstrated in Figure 35 indicating that most of the electricity is generated from May to December. The lowest energy output is from January to April corresponding to seasonal conditons on the islands.

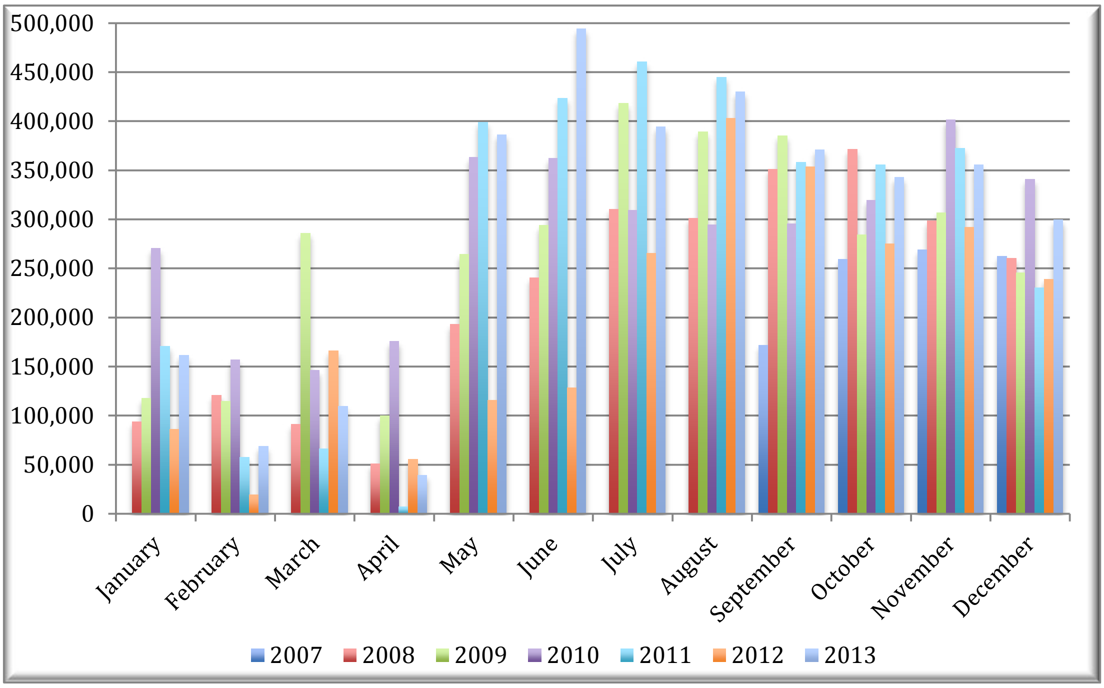

Figure 35: Generation of Electricity from Wind in kWh 2006 to 2013
Source: Own elaboration based on data from (ElecGalápagos, 2014a)

In fact, the Figures 36 and 37 demonstrate that the three installed WTGs were not able to cover the complete electricity demand of the population on San Cristóbal in

2012 and 2013. Nevertheless, average wind penetration was relatively high. Generally, the renewables penetration[107] of a hybrid wind-diesel system is a critical design factor since it determines the complexity of the system (Baring-Gould, 2008). For San Cristóbal, the average monthly penetration of wind energy is shown in Figures 36 and 37.

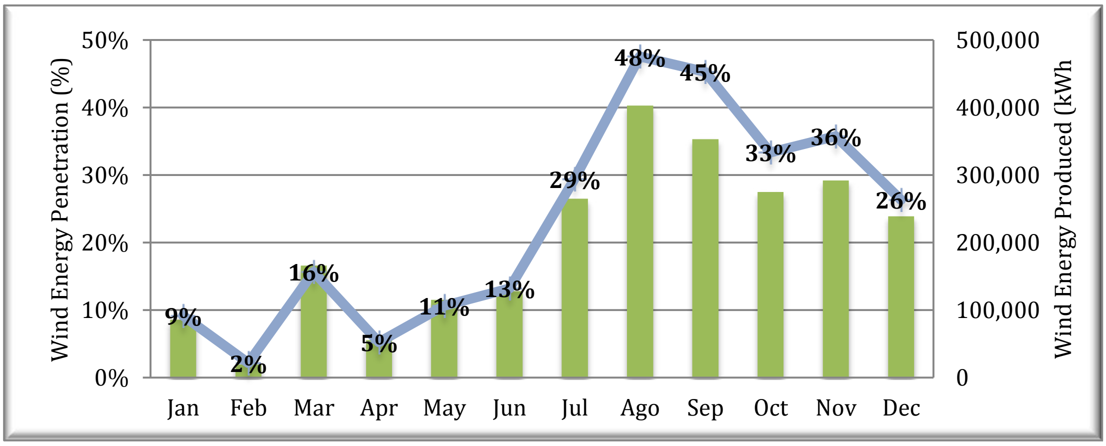

Figure 36: Avg. Wind Energy penetration & Wind Energy produced (kWh) on San Cristóbal 2012 Source: Own elaboration based on data from (ElecGalápagos, 2014a)

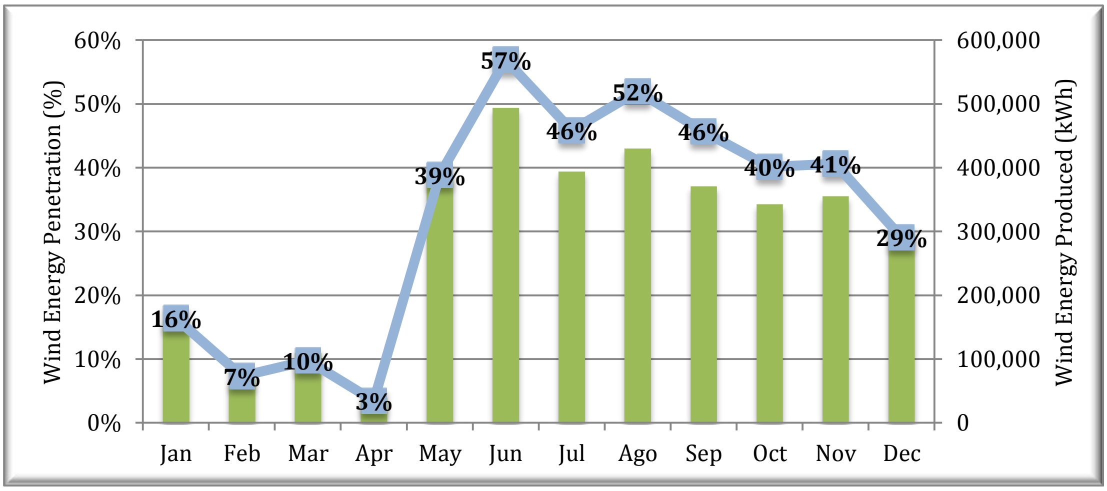

Figure 37: Avg. Wind Energy penetration & Wind Energy produced (kWh) on San Cristóbal 2013 Source: Own elaboration based on data from (ElecGalápagos, 2014a)

In 2012, the turbines produced up to nearly 50% of the electricity demand during the best wind months, while in the low wind months barely 2.2–15.7% were reached. In 2013, the wind share was higher, reaching up to nearly 60% in June. On average, this represents an annual share of 30.2% in 2013. In former years it was: 22%, in

[107] There exist two types of penetration: instantaneous and average penetration. While the instantaneous penetration is used to understand control requirements and reactive power needs, voltage and frequency regulation, the average penetration provides more general information. The instantaneous penetration is the ratio of total wind power output to the total load at any instant of time (Weisser D. and Garcia R.S., 2005). The average penetration is generally calculated on a monthly or annual basis, indicating total energy saving.

2012, 33% in 2011, 37% in 2010, 36% in 2009, and 32% in 2008 (ElecGalápagos, 2014a). The real capacity factor since turbine installation, however, was 12–17% or a generation per unit of capacity of 1,000–1,500 kWh/kW (ElecGalápagos, 2014a). In comparison, the median capacity utilisation in Germany over the past five years was 1,700 full load hours (Lütkehus and Salecker, 2013). ElecGalápagos (2014d) had estimated a capacity factor of 25%, a generation per unit of capacity of 2,190 kWh/kW, or 2,190 full load hours[108]. As a consequence, although the project covers in average 30% of the electricity demand in San Cristóbal, it does not fully meet the expectations of the project developers that had anticipated covering 50% of the electricity demand on the island with wind energy (ERGAL, 2008b).

The limited size of the current wind park and the volatile nature of wind energy require the electricity system to be backed up by other energy sources such as solar, hydro or thermal power generation. In the case of San Cristóbal, the missing electricity is currently delivered by a thermal power plant based on diesel (CONELEC, 2007; Rosero and Chiliquinga, 2011: 55). This makes the electricity model on San Cristóbal one of the largest wind-diesel hybrid systems in the region. Such systems, in which wind becomes a major part of the power system while diesel engines still provide much of the system power control, are so-called *medium-penetration systems*. In such systems, additional components and limited supervisory control are required to assist diesel generators in maintaining power quality (Baring-Gould, 2008). Therefore, the diesel gensets have been equipped with an automated control system to ensure that quality and amount of energy produced meet the demand (Rosero and Chiliquinga, 2011: 62). In addition, the relatively small sizes of the diesel generators on San Cristóbal allow flexibility, permitting instantaneous higher penetrations without the need for energy storage. An advantage of small diesel generators is their ability to shut down single WTGs during high wind availability (Baring-Gould, 2009). Nevertheless, according to Curbelo (2011), frequent power failures have negatively affected the quality of the electricity service on San Cristóbal in the past. This shows that technically the project is feasible, although it appears that improving the technical knowledge of the technicians could reduce power failures. This would also be important in case RES-E penetration increases and the system complexity rises.

[108] This is in the range of recent estimations by experts (IEA, 2012; IEEE, 2012; IPCC, 2011) that indicate capacity factors in Europe of 20-40% onshore and a global average of 21%. Offshore, the capacity factors are likely to be higher with 35-45%.

Solar Energy

In addition to the wind park, the renewable electricity generation on San Cristóbal has been expanded by two micro solar PV systems (ERGAL, 2008b; Rosero and Chiliquinga, 2011: 55). One system of 5.1 kW_{peak} has been installed in the *Pedro Pablo Andrade School* and another system of 5.1 kW_{peak} together with 2.5 kW has been installed on the roof of the control cubicle of the wind park. Nonetheless, the solar electricity penetration is negligible compared to the wind energy share as shown in Table 21.

Table 21: Electricity Generation 2013 on San Cristóbal
Source: Data adapted from (ElecGalápagos, 2014a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Total
Net Energy (MWh)	985	937	1,120	1,134	994	868	859	827	811	853	874	1,029	11,298
Diesel (MWh)	822	867	1,010	1,094	606	372	464	396	439	509	517	728	7,829
% Diesel	83%	93%	90%	96%	61%	43%	54%	48%	54%	60%	59%	71%	69%
Wind (MWh)	161	68	109	39	386	494	394	430	370	342	355	299	3,451
% Wind	16%	7%	10%	3%	39%	57%	46%	52%	46%	40%	41%	29%	31%
PV (MWh)	1.4	1.2	1.3	1.4	1.6	1.4	1.4	1.5	1.4	1.6	1.5	1.4	16.98
% PV	0.14%	0.13%	0.11%	0.13%	0.16%	0.16%	0.16%	0.18%	0.18%	0.18%	0.17%	0.14%	0.15%

Conclusion

In conclusion, the current energy system on San Cristóbal is a so called *medium-to-high-penetration no-storage wind-diesel-hybrid system* that requires a wind-diesel control system to maintain grid stability (Raghavan, 2013: 4). As indicated earlier, the aim of this wind park was to cover 50% of the electricity production on San Cristóbal (ERGAL, 2008b). The statistics above demonstrate that this goal could not be reached since the penetration in 2013 was, on average 30%. In addition, compared to the net electricity production of the whole archipelago, this wind power project produced in the multi-annual average, merely 6–12% between 2007 and 2013 (ElecGalápagos, 2014a). Therefore, to reach the Zero Fossil Fuels goal, it will be necessary to integrate more RETs. Installing more wind power capacity could increase the wind penetration and diesel savings – especially, when considering the fact that demand is increasing continuously and the share of renewables will fall. To increase the share of RES-E, an installation of PV modules would be feasible according to measurements presented in chapter 4. Nevertheless, it is important to consider that with increasing RES-E share in high-penetration systems, it becomes more complex to maintain consistent power quality – requiring advanced automatic control as well as adequately trained technicians (Baring-Gould, 2008). In such systems, diesel gensets are shut off completely during periods of high wind speeds to save fossil fuels. The reason for the complete shut down is the lower efficiency of diesel gensets as the load decreases since the specific fuel consumption increases. Therefore, running a diesel engine at low loads is very inefficient compared to high efficiency close to full load or when turned off completely (Raghavan, 2013). In addition, to reach the Zero Fossil Fuels goal, it will be necessary to consider energy storage, as had already been suggested in the feasibility study of e8 (e8/ EOLICSA/ ElecGalápagos, 2008). The batteries for storage have not yet been implemented due to maintanance considerations (EOLICSA/ GSEP/ ElecGalápagos, 2013). Nevertheless, storage options should be considered in the future as technology improves and they become more affordable (Rosero and Chiliquinga, 2011: 62ff.).

5.1.2. Energy Security

The San Cristóbal Wind Project is part of ERGAL, the *Renewable Energy Program in the Galápagos Islands of the Republic of Ecuador*, supported by the Global Environment Facility (GEF) and UNDP (UNDP, 2006a; ERGAL, 2008b; Rosero and Chiliquinga, 2011: 55). ERGAL involves public, private, local and international donors and hopes to re-electrify the four inhabited islands of Galápagos. Under the framework of ERGAL, the San Cristóbal Wind Park has been realized as a public-private partnership between the Government of Ecuador, the UNDP and the San Cristóbal Wind Project Commercial Trust (*Fideicomiso Mercantil Proyecto Eólico San Cristóbal*). The members of the trust are ElecGalápagos and the e8 member companies[109] that provided both financial and technical assistance. The latter has been made available for example by experts with knowledge and experience in the field of RE development (Rosero and Chiliquinga, 2011: 55). The private corporation *Eólica San Cristóbal S.A.* (EOLICSA), which is to 100% owned by the commercial trust, has been established to own and operate the wind farm. As it holds all necessary environmental licenses, generation permits and land easements for the wind park, all of its assets will be transferred to ElecGalápagos at the conclusion of the commercial trust. Baring-Gould (2009) from NREL compares the structure to an Independent Power Provider (IPP) model and points out that this model "breaks new ground from a contractual perspective, allowing external companies to provide

[109] American Electric Power (AEP) and Duke Energy (USA), Hydro Quebec (Canada), RWE (Germany), Electricité de France (France), ENEL (Italy), RusHydro (Russia), Tokyo Electric Power and Kansai Electric Power (Japan), Eskom (South Africa), Electrobras (Brazil), State Grid Corporation (China).

green energy services to an utility or power sector that would normally not make that investment and are generally hesitant to invest in unproven technologies". Nevertheless, he also mentions the challenge that ElecGalápagos, as the final provider of electricity, is responsible for insuring power quality while the penetration of wind is largely out of their control. According to interviews conducted with engineers from both ElecGalápagos (Moreno, 2013) and EOLICSA (Naranjo and Fernandez, 2013), the cooperation between them is very close and without significant problems in this regard.

It is important to emphasize that the wind park would not have been realized without public financial support provided due to its registration as Clean Development Mechanism (CDM) under the Kyoto Protocol (ERGAL, 2008b; Rosero and Chiliquinga, 2011: 55). The reason for this lies not only in the insecure regulatory framework but also the complex environmental requirements and isolation of the islands that had triggered extremely high project costs. These amounted to around USD 10 million (Vintimilla, 2011: 5) and have been exceptionally expensive with 4.29 million USD/ MW installed capacity, compared to the MW price in Europe or US, of around 1.4–2.7 million USD/ MW[110] (IEA, 2008; EWEA, 2009: 30). The project costs have been covered by a combination of local and international public money, as illustrated in Figure 38. E8 has contributed to the wind farm about USD 5.4 million, United Nations Foundation (UNF) USD 3.2 million, the Government of Ecuador about USD 3.3 million through the FERUM fund, and 0.4 million through tax income donations (ERGAL, 2008b; Rosero and Chiliquinga, 2011: 67).

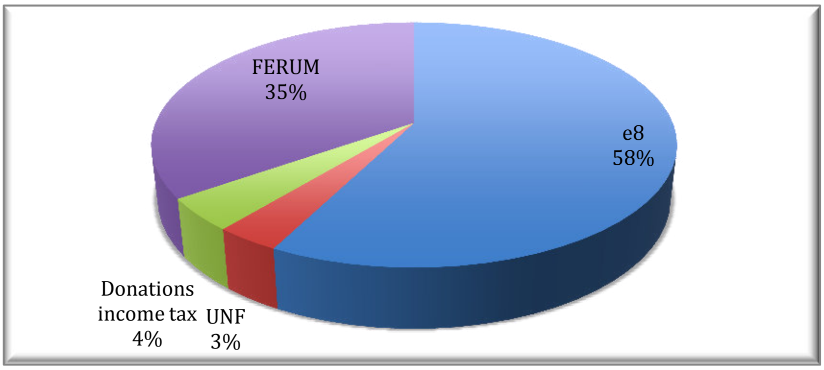

Figure 38: Contributions to the wind park
Source: Own elaboration based on data from (Rosero and Chiliquinga, 2011: 67)

[110] The average turbine installed in Europe has a total investment cost of around €1.23 million EURO/MW. The turbine's share of the total cost is, on average, around 76%, while grid connection accounts for around 9% and foundation for around 7%. The other 8% are land rent, electrical installations, consultancy, financial costs, road construction, and control systems. This accumulates to 1.6 million EURO/ MW (EWEA, 2009). In 2007, onshore turbine costs ranged from USD 1.2 million per MW in the United States to USD 1.8 million in Italy. Total installed costs (incl. turbine) ranged from USD 1.4 million in the UK to USD 2.7 million in Ireland.

In summary, energy security has been increased since a free and indigenous energy source (wind) is used to produce electricity, reducing the dependence on fossil fuels. Nevertheless, additional efforts are needed to reach complete energy independence. Concerning the reliability of the electricity supply, the situation is positive overall. The wind park availability was relatively good at 93%, but there is room for improvement (EOLICSA/ GSEP/ ElecGalápagos, 2013). In the context of investment security, it is important to emphasize that the project would not have been realized without public financial support. Nevertheless, latter is not a project-specific issue, but there is the general need in Ecuador to provide regulatory security and incentives for private investment.

5.1.3. Socio-Economic Energy Equity

From a social perspective, the main beneficiaries of the wind energy project are the residents of the islands, the flora and fauna on San Cristóbal, ElecGalápagos, local companies and the Ecuadorian state. Primarily, the population's access to affordable electricity has improved. This has been possible due to the good wind regime on San Cristóbal and the interest-free money provided by the international community and companies. Generally, the cost of electricity generated through wind power is a function of wind regime at a chosen site. The costs usually range from approximately 0.05 to 0.065 Euro/ kWh at windy coastal sites and approximately from 0.07 to 0.10 Euro/ kWh at sites with low wind speeds (EWEA, 2009). In the case of the wind park in Galápagos, the costs per kWh produced over the complete lifetime are on average USD 0.21 (ERGAL, 2008b; ElecGalápagos, 2014a). This is approximately three times more than the normal average costs.

Table 22: Average electricity costs of wind power on San Cristóbal
Source: Own elaboration based on data from ElecGalápagos (2014a) and ERGAL (2008b)

	Total (kWh)	Project Costs (per year if 20 year lifetime + 20% O&M + reserve costs)	Cost per kWh
2007	962,135	200,000	$0.21
2008	2,682,461	600,000	$0.22
2009	3,204,893	600,000	$0.19
2010	3,434,854	600,000	$0.17
2011	3,344,626	600,000	$0.18
2012	2,398,373	600,000	$0.25
2013 (until 30.6.2013)	1,258,818	300,000	$0.24
		Average cost per kWh produced	**$0.21**

Certainly, the high costs might be explained partially with the specific conditions and isolation of the islands requiring not only extra costs for the complicated and long transport, but also with the special requirements to mitigate negative impacts on the delicate flora and fauna. Compared with the current invoiced mean price for electricity of USD 0.088 kWh (INER, 2013), this is relative high. However, if one considers the subsidies for fossil fuels, their transport to the island and the subsidy for the electricity that are included in this price, then wind energy is relatively cheap. The expected real price of diesel-based electricity is at around USD 0.53 and for the hybrid system at USD 0.35 kWh (MEER/ GIZ, 2012). Therefore, the implemented projects have the potential to increase the accessibility to and affordability of electricity for the population.

Assessing the impact of the RETs on the prosperity of the islands is complex because it is difficult to attribute, for instance, the growth of tourism to the deployment of RES. Nevertheless, specific impacts could be identified based on the creation of three to five new positions for the service team and in the administration of ElecGalápagos (EOLICSA/ GSEP/ ElecGalápagos, 2013; Moreno, 2013). In addition, local companies benefitted from construction work and job creation. Moreover, the Ecuadorian government enjoys lower power generation costs as international partners have realized the largest share of investments, providing the government with money that can be spent on other social or environmental projects. The impact on tourism is rather indirect, since the wind power project reduced the fossil fuel imported, and thereby, the risk of oil spills. In addition, as less fossil fuels are burnt, less CO_2 and other pollutants are emitted into the atmosphere that could affect human health and the health of the ecosystem through inhalation or deposition in soil and water bodies. This maintains the pristine natural paradise that is the reason for thousands of tourists and scientists to visit the “enchanting islands”. Moreover, there are also indirect beneficiaries. These are other islands that plan to implement similar RE systems as this project provides a model for developing and implementing RETs or hybrid systems. In addition, it presents a model of multilateral cooperation of partners form both public and private sectors (Curbelo, 2011).

The above noted reduction of risk of oil spills and air pollution also improves the quality of life. In addition, the level of education has increased because the staff of ElecGalápagos received training to operate and maintain the wind power park and the hybrid system. But also other courses and consultations with the public took place (UNDP, 2006a). Moreover, employee health and safety was an important aspect and is successfully maintained on high standards (EOLICSA/ GSEP/ ElecGalápagos, 2013: 14).

The project is an important step towards realizing the Zero Fossil Fuels goal and showing that RETs on Galápagos are economically feasible and reliable. This shapes a positive attitude of the residents towards renewables, and thereby increases public acceptance. Nevertheless, inhabitants might have partially assumed a negative attitude towards wind energy as frequent power failures caused power breakdowns (Curbelo, 2011), which they associate with the newly installed wind turbines. Overall there seems to be no resistance against RETs, but as mentioned above, passive acceptance might not be enough to reach the Zero Fossil Fuels goal.

5.1.4. Environmental Sustainability

From an environmental point of view, the San Cristóbal wind energy project promotes sustainable development and protection of the delicate environment. The wind power project reduces the fossil fuels imported, and thereby, the risk of oil spills. In addition, as less fossil fuels are burnt, less CO_2 and other pollutants are emitted into the atmosphere that could negatively affect human and ecosystem health through inhalation or through deposition in soil and water bodies. Therefore, it helps fight climate change through reducing CO_2 emissions by about 2,800 tons of CO_2 annually (Consejo de Gobierno Galápagos, 2011: 13).

In addition, numerous mitigation measures have been used to avoid negative impacts of the wind park on flora and fauna. These had been identified in the environmental impact study. A special focus was placed on selecting a site in order to avoid the flight routes and nesting areas of the *Petrel*, an endemic bird. This is illustrated in Figure 39. For instance, the medium voltage cables have been buried underground for the first 3 kilometres (Alvear and Lewis, 2013). In addition, the environmental impact study suggested to include a 15-year Environmental Management Plan, including the protection of the bird population, waste management, citizen participation, worker safety and environmental training (Walsh Environmental Scientists and Engineers, 2007). Additionally, a Program for the protection of endemic bird species in danger of extinction, particularly the Galápagos *Petrel*, has been included (ERGAL, 2008b).

Nevertheless, these measures are not able to completely avoid collision of endangered birds, neither with the wind turbines nor with the overhead line that leads to the thermal power plant (ERGAL, 2008b). Although, these measures are not able to eliminate all risks to flora and fauna, during the project it has been intended to mitigate the risks as much as possible. Therefore, the project can be seen as promoting environmental sustainability.

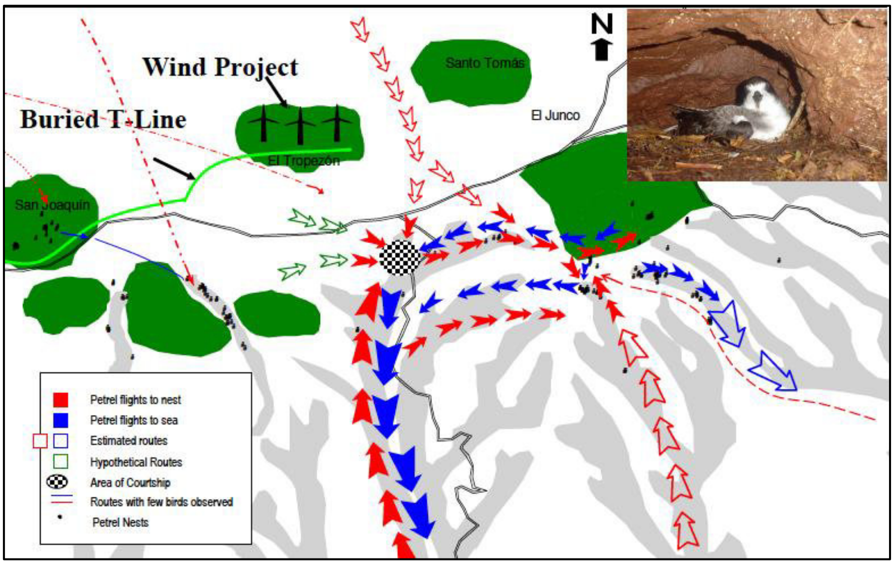

Figure 39: Graphical presentation of the flight path of the Petrel in the highlands of San Cristóbal near the Wind Park site
Source: (EOLICSA, 2009)

5.1.5. Sustainability Assessment

The Sustainability Assessment of the energy system on San Cristóbal can be represented graphically when the above-mentioned arguments are translated into numbers[111]. This allows the comparison between the conventional fossil-fuel-based electricity system with a system based only on wind energy. The hybrid system then represents the sustainability of the current electricity system based on the actual share of diesel and renewables in 2015.

Table 23 and Figure 40 illustrate that a high score concerning technological feasibility of wind and hybrid system has been reached, revealing that this aspect has been a main focus. The technical viability is affirmed, as the potential for RETs is high and international technical know-how supports the implementation of a stable hybrid system.

Table 23: Sustainability Assessment of San Cristóbal
Source: Own elaboration

	Reference Fossil Fuel based System	Wind	Hybrid System (Wind + Diesel)
Energy Security	0.83	2.33	1.28
Environmental Sustainability	0.00	4.50	1.35
Socio-Economic Energy Equity	0.75	4.25	1.8
Technological Feasibility	4.00	4.00	4.00

[111] Since many aspects are rather ambiguous, they are provided with a linguistic representation, and the intent has been made to translate them into numbers from 0 to 5. This has been done using fuzzy logic. See chapter 3.4 for more details.

Furthermore, Figure 40 shows that wind energy has the potential to increase environmental sustainability, socio-economic energy equity and energy security, as compared with a purely fossil fuel based system. Nevertheless, this potential cannot be realized to a full extent, since the share of wind is only 30%. Hence, the still necessary fossil fuels are dampening the results of the sustainability evaluation.

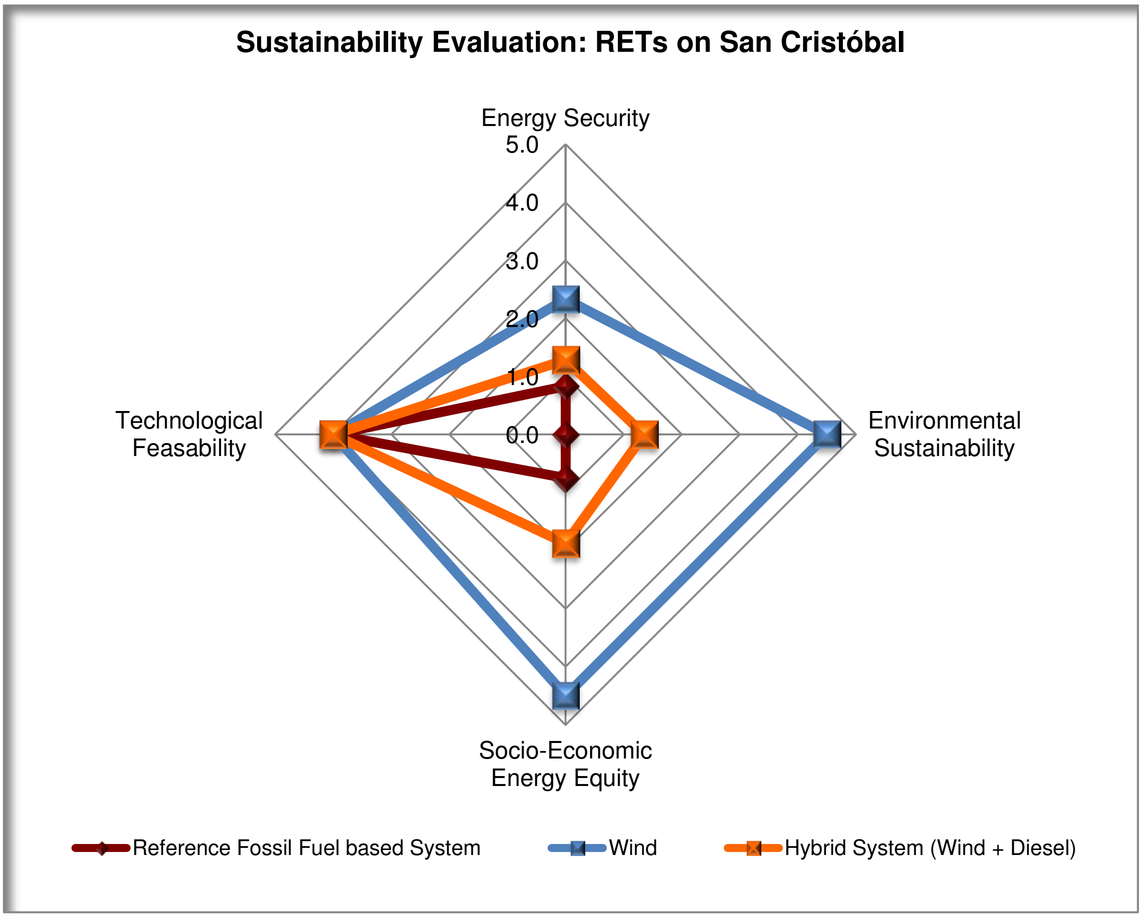

Figure 40: Sustainability Assessment San Cristóbal
Source: Own elaboration

This demonstrates that further efforts are needed to create a fully sustainable electricity system on San Cristóbal. It can be assumed that extending the installed capacity of wind would increase environmental sustainability as well as socio-economic energy equity. In addition, a focus on incorporating other types of renewables, such as sun, but also using the excess energy generated, for example, by incorporating storage, would improve the sustainability of the system also with respect to energy security. Another possibility would be the integration of a desalination plant that uses to excess wind energy during the night, producing safe drinking water. Moreover, it can be assumed that a focus on incorporating small-scale RE solutions, such as rooftop solar PV and micro wind turbines, could boost and promote RET deployment.

5.2. Floreana

Floreana is the smallest populated island and home to merely 133 *Galapageños*. These residents live in around 55 households, mainly on the coast and, to a lesser degree, in the rural highlands. Regarding RETs, there is the intention to implement a twofold hybrid system with a micro-grid on Floreana (ElecGalápagos/ PSI/ PNG, 2011). On the one hand, it combines both solar energy and biofuels, and on the other hand, both the residents of Floreana as well as several communities from the Manabí region on the continent shall benefit from this project.

5.2.1. Technological Feasibility

The electrical system on Floreana is composed of dual thermal generators with a total nominal installed capacity of 138 kW. These generators, operational since 2010, are able to operate with a combination of vegetable oil and diesel (ElecGalápagos, 2013d). In addition, solar PV panels with a total capacity of around 25 kW_{peak} have been installed. Peak demand in 2013 was on the 15th of February and on the 30th of March at the same time (18:00) with 60 kW (ElecGalápagos, 2014a; ElecGalápagos, 2014c). Total demand in 2013 was 348 MWh (ElecGalápagos, 2014c).

Table 24: Diesel Generators on Floreana
Source: Data adapted from (ElecGalápagos, 2013a)

Floreana							
No.	Model	Motor Brand	Generator Brand	Year Of Fabrication	Capacity: Nominal (kW)	Capacity: Effective (kW)	Status
1	Bf4m1013e	Deutz	Leroy Somer	2010	69	56	Operational
2	Bf4m1013e	Deutz	Leroy Somer	2010	69	56	Operational
			Total Floreana		**138**	**112**	

Solar Energy

The initial step to realize Latin America's first solar-hybrid-generation plant was the installation of the first solar PV system, called "Perla Solar" with 18 kW_{peak} in 2004. It has been operational since 2005, and was enlarged in 2006 to 20.6 kW_{peak}. The PV panels were installed above a public community centre of the *Junta Parroquial* and connected to batteries. In addition, a transformer has been installed that transforms the direct current to alternating current, which can be consumed by the residents (Consejo de Gobierno Galápagos, 2011; Curbelo, 2011; ElecGalápagos/ PSI/ PNG, 2011).

The solar PV system has not been operational since approximately 2010 due to several technical and organizational miscalculations (CONELEC, 2010: 22).

According to Edwin Egas (2013) and the IEA-RETD (2012), the main reason for the breakdown has been the increasing demand of the population that probably had not been considered in the design of the system. Electricity demand increased since prior to the PV-diesel hybrid system the diesel gensets operated for only 13 hours a day, supplying the main village with electricity, while outside this village, the households had no connection to the grid (IEA-RETD, 2012). Since supply of electricity increased, residents also bought new equipment, increasing consumption. Therefore, shortly after its start-up, the system was no longer able to cover the electricity demand. Initially, the system had been designed to work with “chips” that each household received and a certain number of kWh allocated to them. These had been defined based on a census of electrical equipment on the island. Nevertheless, after only a few weeks of operation, the households faced the challenge that the chip did not contain enough electricity, and the assigned kWh had been exhausted too early. ElecGalápagos than connected the PVPP directly to the grid without an automated control system. Therefore, disconnecting the batteries and starting the thermal power plants required manual intervention. This resulted inevitably in downtimes of the system triggering problems and electricity outages for the whole population on Floreana.

In addition, one of the battery banks was out of operation in 2009 because one of the elements was damaged and has not been replaced. This made the system non-operational for several months. Moreover, electrical equipment of the residents has been damaged due to the bad quality of electricity. These failures created a negative perception towards the PVPP that also lead to the damage of further batteries due to wrong or missing operation and maintenance (ERGAL/ DED/ MEER, 2008: 63; IEA-RETD, 2012).

Currently, there is the initiative to repower the PVPP and to integrate them in a micro-grid with the two dual biofuel-diesel generators. This plan includes, according to ElecGalápagos (2014b), the following two phases: Phase 1: reactivation of the “*Solar Pearl*” (21 kW_{peak} PV) integrated with the grid commutated inverters; Phase 2: operation without diesel through the implementation of self-commutated inverters, battery bank, electrical panels, control system and SCADA/ HMI.

Besides the *Solar Pearl* in the coastal village on Floreana, independent and decentralized micro PV systems have been installed in the highlands. These systems – with a total capacity of 4.3 kW_{peak} – consist of 2.1 kW_{peak} PV, 1.8 kW_{peak} PV connected to a micro-wind turbine of 500 W, and three PV systems of 0.4 kW_{peak} each. These autonomous micro systems electrify rural houses, which have no access to the public grid (Curbelo, 2011; ElecGalápagos/ PSI/ PNG, 2011). In sum, the total nominal installed PV capacity in Floreana is therefore 24.9 kW_{peak}. In 2008, these delivered approximately 40% of the islands' electricity demand (this roughly corresponds to 26 MWh as depicted in Table 25). However, in case the current energy demand, according to ElecGalápagos (2014a), is taken into consideration, these systems would only cover around 12% of Floreana´s electricity demand.

Table 25: Floreana Solar Electricity Production (kWh)
Source: Own elaboration based on date from ElecGalápagos (2014a)

	2004	2005	2006	2007	2008	2009
Electricity Production (kWh)	2,223	12,846	15,494	18,162	26,687	7,874

Jatropha Curcas: Back up with Vegetable Oil

Due to the volatile nature of solar energy, and in order to cover peak demand, it has been necessary to maintain a back-up through thermal power generation. To reduce the consumption of fossil fuels while guaranteeing reliable back-up energy on Galápagos, another initiative with the aim to completely replace diesel by Jatropha Curcas, oilseeds from which vegetable pine nut oil can be extracted, has emerged (ElecGalápagos/ PSI/ PNG, 2011; CONELEC/ MEER, 2012: 91; IPCC, 2011: 220). This initiative to replace diesel with Jatropha shall act as a pilot project to determine the viability and identify the potential for the use of vegetable oil throughout the entire archipelago.

In 2013, 15,000 gallons of Jatropha oil was consumed. Figure 41 shows that the share of Jatropha has been constantly changing over time while the net energy production on Floreana shows an overall increasing trend. This is due to increased electricity consumption of the population, as well as an increase in tourism. The share of Jatropha vegetable oil varies between 0% and 100%. According to Enrique Heinemann, responsible consultant for the project ERGAL at GIZ, the reasons for the variation are climate, crop and harvest related (Heinemann, 2014). Overall, the project has achieved an annual average biofuels penetration of 50% in 2011 and 2013, but only 25% in 2012. On average, this is approximately 40%. Although, this is a significant reduction of fossil fuel consumption, it demonstrates that the Zero Fossil Fuels goal has not yet been reached.

Losses appear to be very high as the net energy produced and the energy provided to the population during the last three years shows a deviation of up to 50%. This is due to the fact that the currently installed generators are over-dimensioned, since it had been projected to install a desalination plant on Floreana. Therefore, electricity is led into the soil to be able to run the generators at an optimal capacity that will not damage them (ElecGalápagos, 2014a).

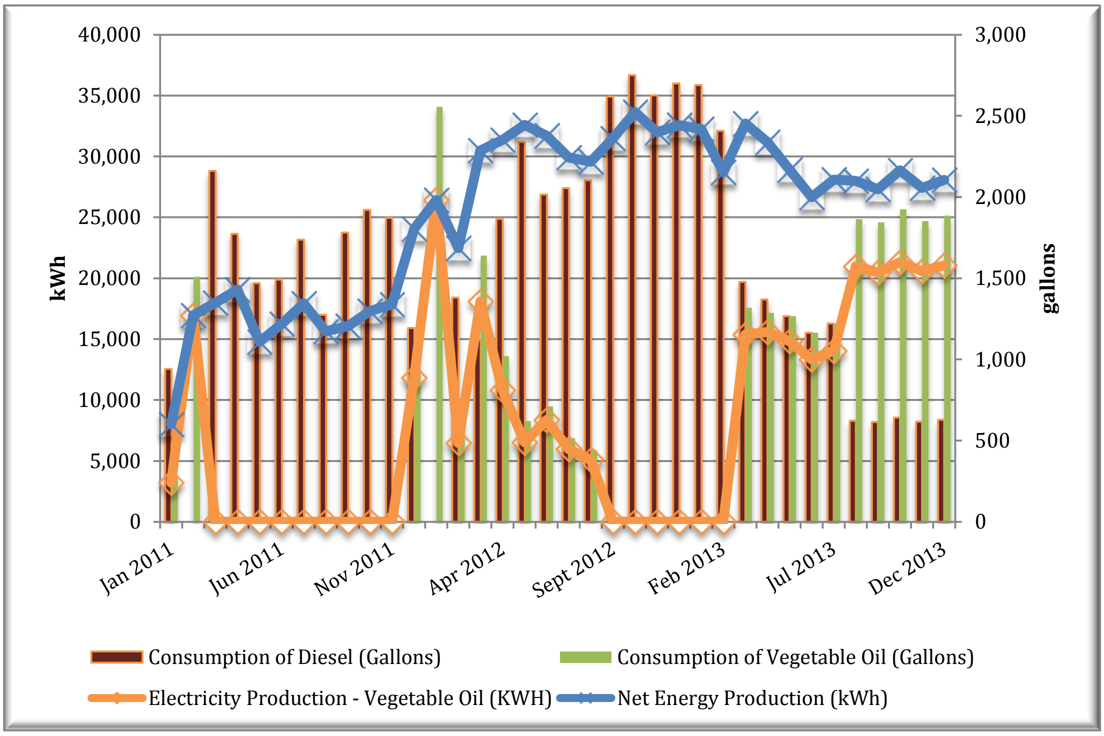

Figure 41: Electricity Production based on Vegetable Oil and Diesel in Floreana
Source: Own elaboration based on data from (ElecGalápagos, 2014a)

Conclusion

In conclusion, the current energy system on Floreana is a so called *medium-to-high-penetration solar-biofuel-diesel-hybrid system with storage*. The statistics above demonstrate that Zero Fossil Fuels goal could not be reached since the biofuel penetration in 2013 was, on average 50%. The solar PV systems would cover additional 12% in case they are repowered successfully. Neverthelss, to eliminate all fossil fuels, it will be necessary to integrate more RETs. Installing more solar and wind power capacity could increase the RES-E share – especially, when considering the fact that demand is increasing continuously the share of renewables will fall. To increase the share of RES-E, an installation of PV modules would be feasible according to measurements presented in chapter 4. Nevertheless, it is important to consider that with increasing RES-E share, in so-called high penetration systems, it becomes more complex to maintain consistent power quality, requiring advanced automatic control and adequately trained technicians (Baring-Gould, 2008). Furthermore, to eliminate fossil fuels on Floreana, it will be necessary to consider additional energy storage.

5.2.2. Energy Security

It is important to emphasize that vegetable oil from the pine nut, Jatropha Curcas, is grown and processed on the Ecuadorian mainland in the province of Manabí and then imported to Galápagos via ship (ERGAL, 2013a). For several reasons, it has been decided not to grow this plant on Floreana. Firstly, although Jatropha does already exist on the Galápagos Islands, it is a non-endemic, introduced species that could negatively affect the fragile equilibrium of the islands ecosystem (IPCC, 2011: 270). Secondly, there is a danger of affecting food security on the islands negatively by competing with other agricultural products (FAO, 2010: 40). Thirdly, a cultivation of biomass on the islands would require space and other resources by boosting production, infrastructure and related services. Technically it would be feasible to grow sufficient Jatropha on Floreana to cover its own electricity demand, which would allow the island to reach self-sufficiency. Nevertheless, nearly 99% of the islands surface is protected leaving only around 290 hectare (ha) in the rural zone for agricultural use (INGALA/ CDF/ Municipios de Galápagos, 2005: 30). To cover the electricity demand of the population and a desalination plant in Floreana with vegetable oil, it has been expected that 8-12% (23-34 ha) of the agricultural area would be needed (ERGAL/ DED/ MEER, 2008). Fourth, a study conducted by ERGAL, DED and MEER (2008: 51) claims that cultivation conditions in Manabí are favourable since the oil content rises in arid conditions. Nevertheless, there is no agreement on this last argument. For instance, there are assertions that Jatropha increases yield and oil content in fertile and irrigated land (FAO, 2010: 40; Camaggio and Amicarelli, 2012: 16). Besides this contradiction, the risks for a local cultivation of Jatropha on Floreana weigh stronger than potential benefits, such as saving of transport time and fuel, the creation of jobs on Galápagos and an approximation towards auto sufficiency (ERGAL/ DED/ MEER, 2008).

As laid down in chapter 4, a large number of different bioenergy crops is available that can be converted into distinctive biofuels. In the case of Floreana, Jatropha Curcas has been chosen due to several reasons relevant for energy security. Firstly, the oil extracted from this plant has similar characteristics to diesel (compare Table 26). Nevertheless, vegetable oil has a generally higher viscosity and density, which might cause problems during their combustion. A costly adjustment of the generators is required while for biodiesel only little adjustment would be necessary leading to lower costs. Slightly higher amounts of Jatropha would be needed compared to diesel since its energy density is 8.9 kWh/ litre, which is good compared to gasoline 8.6 kWh/ litre, but lower if compared with diesel 9.8 kWh/ litre

(ERGAL/ DED/ MEER, 2008). Secondly, in addition, vegetable oil is less polluting and only a simple technological process is needed according to ERGAL, DED and MEER (2008). Nevertheless, in this regard, the FAO (2010: 47) disagrees, and notes that the production of biodiesel from Jatropha oil requires expertise, equipment and handling of dangerous chemicals, and therefore is not suitable for resource-poor communities in developing countries. This could endanger energy security on the Galápagos.

Table 26: Comparison of the Physical and Chemical Characteristics of fuels
Source: Data adapted from (ERGAL/ DED/ MEER, 2008: 67)

	Diesel	Biodiesel (based on palm oil)	Vegetable oil (pine nut)
Density (kg/l; 20°C)	0.85	0.88	0.90-0.92
Viscosity (mm^2/s, 20°C)	4.7	7-8	60-80
Boiling point (°C)	60	135	>220
Phosphor content (mg/kg)		<15	<15
Sulphur content (mg/kg)	>100	>100	>10
Chemical behaviour	Explosive	Rapid	Slow
Energy Density (kWh/l)	9.4	8.9	9.2
Environmental Impact		Has to be transported as normal diesel because of its chemical characteristics	Low (biodegradation in case of oil spill)

In conclusion, energy security has only partially been improved. As a result, Floreana is still depending on imports of the vegetable oil and diesel for the back-up. The PVPP would reduce energy dependence significantly since the fuel is indigenous and free. As noted above, reliability of the energy supply has been experienced with the solar pearl, showing that there is a significant requirement to improve planning, maintenance and operation. This requires increased capacity building of the technicians and consumers, but also enhancement of public acceptance.

Regarding investment security it is important to clarify that the PVPP has been realized with financial support from the AECID, MEER, FERUM, GEF, PNG, and the Council of Floreana (Curbelo, 2011: 76). Currently, funding has been secured for repowering the *Solar Pearl* with contributions from the MEER and GIZ-KfW (ElecGalápagos, 2014b). In addition, the GIZ has also supported the project "Climate protection through the use of renewable energies on the Galápagos Islands, with a special focus on power generation using Jatropha Oil" (GIZ, 2013). Therefore, the same is true for Floreana as for the wind park in San Cristóbal. This project would not have been realized without public financial support and development aid from the international community. This emphasizes that Ecuador needs to provide better regulatory security and incentives for private investment.

5.2.3. Socio-Economic Energy Equity

This Jatropha project shall create synergy effects by stipulating socio-economic benefits both on Floreana and in the Manabí region (ElecGalápagos/ PSI/ PNG, 2011). Initially, electricity access on the island has been improved significantly through the solar PV project by extending supply from 13 to 24 hours per day (IEA-RETD, 2012). Although the solar power could not be delivered sustainably in the long run, the extension of the supply has been maintained based of thermal power generation. Moreover, rural electrification took place through micro wind turbines and PV systems increasing rural energy access[112].

Regarding the affordability of the electricity supply, it is not possible to make a clear statement. The real costs of the energy production based on vegetable oil will depend on the demand, fossil fuel prices and generation quantity of vegetable oil – as well as on the political framework (ERGAL/ DED/ MEER, 2008). According to the study by ERGAL, DED and MEER (2008: 104), the costs for fuel per gallon – including transport to Floreana – would be for Jatropha USD 3.65, diesel USD 2.73, palm oil USD 4.29 and biodiesel USD 5.29. The study also shows that, with regard to operational costs, an investment in new generators, both palm oil and Jatropha would be able to save money compared with diesel, while biodiesel would induce additional costs (ERGAL/ DED/ MEER, 2008: 107). In 2012, a new study by MEER and GIZ (2012) stated that real costs for diesel and Jatropha are both around 5.6–5.7 USD per gallon and electricity generation costs are around USD 1.6–1.845 per kWh. Vegetable oil accounts for the lower cost estimations.

Nevertheless, it is important to emphasize that prices for any of the fuels will depend on demand, and therefore, there is no assurance that Jatropha will save costs. Nonetheless, the use of solar PV would clearly reduce insecurities connected to fuel costs and would be able to reduce costs for the Ecuadorian government. For instance, before the installation of the PV system, the electrical system on Floreana required a subsidy of USD 25,000[113] per year from the national government. In addition, there was a diesel subsidy creating a fixed price of USD 0.91 per gallon. (IEA-RETD, 2012: 151). These saved costs would be available for incentivizing and supporting RES investment. For a future adjustment of the power generation and tariff structures, it is important to consider carefully operation and maintenance costs, such as exchange of battery systems (ERGAL/ DED/ MEER, 2008). In addition, the experiences made with adjusting the tariff structure can be valuable.

[112] Nevertheless, an interview with Mrs. Cruz (2013) on Floreana revealed that at least one wind turbine is currently not in operation.
[113] USD 2002.

According to the IEA-RETD (2012: 151), the initial tariff scheme agreed on with users was a fixed monthly charge. Electricity usage was capped by a daily allowance with demand-side controls, and pricing was independent of final electricity consumption. However, the flat-rate tariffs were eliminated by the electric utility despite initial agreements with users. The Ecuadorian national government had an existing national policy of universal tariffs for the islands, which the ElecGalápagos decided to match. The resulting very cheap tariff, of approximately USD 0.08–0.10 per kWh, was not sufficient to cover the project O&M costs. Therefore, high subsidies continued to play an important role and did not provide any incentive to constrain demand and contributed to an energy demand growth.

Regarding prosperity and quality of life, this project shall create synergy effects by stipulating socio-economic benefits both on Galápagos and in the Manabí region (ElecGalápagos/ PSI/ PNG, 2011). The latter is affected by desertification, droughts and poverty due to changes caused by the economic globalization (ERGAL/ DED/ MEER, 2008; ElecGalápagos/ PSI/ PNG, 2011). Several cooperation agreements have been developed for the implementation of the project, describing the acquisition of generators, training farmers, acquiring the seed and promoting the project in Galápagos (Rosero and Chiliquinga, 2011: 51). These shall support sustainable development of the region comprising of around 37 communities, 241 families and 2,000 directly involved persons that grow and process the Jatropha oil (ERGAL/ DED/ MEER, 2008: 61). Job oppportunities are created since Jatropha cultivation and harvest is very labour intensive, even more than coffe and corn, which are the two mostly cultivated crops in this region (MEER/ GIZ, 2012).

It is assumed that thanks to this initiative the families have an additonal income of in average USD 35 per month. This amount is additional, since Jatropha does already exist and has traditionally been used for soap production, however, currently 71% of the seeds are not harvested. Nevertheless, there is no information on how many hours adults and children spend on collecting the oil seeds. It appears to be a rather long time, as 100 kg are sold for USD 6–12 (García Andrade, 2011; MEER/ GIZ, 2012). Although these communities and families benefit from an additional income, it has not been analyzed whether their energy access or QOL has improved through the initiative as well.

The cultivation in Manabí does not directly influence job creation and prosperity on Floreana. Prosperity is, nevertheless, indirectly influenced since reducing the risk of oil spills and decreasing air pollution improves the conditions for tourism. Visitors are, according to Max Freire (2011) who is the head of the *Junta Parroquial*, the most important economic driver and come because of the pristine nature of the island.

Regarding QOL the situation is complex. Manabí primarily benefitted from additional income, while Galápagos benefits from reduced environmental risks. Nevertheless, a strong dependence on each other, and on the legal framework connecting them, has been established. In addition, market prices, climate and other environmental factors, such as plagues can influence the situation. These aspects leave an unclear overall picture of QOL and public acceptance in Floreana.

Regarding employee health and safety there is no concrete information available. Nevertheless, the FAO (2010: 47) points out that the conversion of Jatropha to biodiesel requires the handling of dangerous chemicals. This and the potential use of fertilizers to support plant yield could affect human health or ecosystems negatively.

In the context of public acceptance it can be assumed that the creation of additional income is highly appreciated and therefore social acceptance in Manabí large. Contrarily, on Floreana, social acceptance seems to be passive, since residents of the small island are merely the consumers of the vegetable oil and what is more, the share of mineral fossil diesel is still relatively high. In addition, in light of the negative experiences made with the PVPP, some significant scepticism can be expected. Nevertheless, Max Freire (2011) has reinforced his interest, and that of the island in becoming independent from fossil fuels.

5.2.4. Environmental Sustainability

Generally, the production and use of vegetable oil from Jatropha Curcas has various benefits but also has its drawbacks. Baziliana et al (2011) criticize that policies to develop bio-energy alternatives to replace fossil fuels has often been done in the absence of a wider understanding of the full costs and benefits from multiple perspectives, including deforestation, biodiversity, water, energy, lifecycle emissions and LUC. Nevertheless, the Ecuadorian government is aware of the complexity and negative impact biomass might have, yet, they declared the production, commercialization and use of biofuels a national interest[114]. At the same time, attention is necessary so that biofuels do not have a negative impact on food security, forest, soil and the environment in general (República del Ecuador, 2008; SENPLADES, 2013). Due to the special status of the Galápagos, particular attention

[114] Article 1 in the “Decreto Ejecutivo No. 2332: R.O. No. 482” of 15th December 2004.

is paid to biofuel use on these islands. The GIZ executed feasibility and environmental impact studies jointly with ElecGalápagos and PNG (ElecGalápagos/ PSI/ PNG, 2011; GIZ, 2013), identifying Jatropha as the best choice. Nonetheless, there are still environmental impacts of vegetable oil during growth of the plants and transport to Galápagos as well as during the combustion of the oil. These negative impacts can affect both Galápagos and Manabí and include influences on air, water, and soil quality, noise level, flora and fauna, QOL of the population, and landscape. These impacts are for example caused by emissions as well as by solid or liquid waste (ElecGalápagos/ PSI/ PNG, 2011).

One of the main arguments to replace fossil fuels with bioenergy crops are their reduced GHG emissions but also their potential to decrease the release of other pollutants into the air – lowering the risk for climate change and improving human health. Studies (FAO, 2010: 45; Camaggio and Amicarelli, 2012: 20) agree, that the pollutants released during combustion of vegetable oil are much lower compared to diesel, when generators have been adjusted correctly. For instance, they discharge little sulphur resulting in a decreased impact on humans and the environment. Regarding GHG emissions, vegetable oils emit less in comparison with combustion of diesel (ERGAL/ DED/ MEER, 2008: 67), but they still emit significant amounts. Biodiesel made of Jatropha Curcas is only slightly better than palm oil and their minimum GHG saving can only be 20%, depending on LUC and agricultural practices, transports (IPCC, 2011: 734). In the context of other air pollutants, Jatropha emits less PM, CxHx, and PAH and an equal amount of CO and NOx, when compared to biodiesel.

One of the main arguments against biofuels is their potential competition with food and water resources. According to Baziliana et al. (2011)**,** this competition has caused recent food price spikes. These had been influenced by increased prices for fertilizer and fuel for transport; increased demand for biofuels driven by energy security and climate change concerns; and changing consumption patterns. Globally, there seems to be enough land and water to grow a substantial amount of biomass for both food and bio-energy production, but not without some price impacts. In the case of Jatropha, an uncultivated non-food wild-species that can grow well on marginal, arid and less fertile soil, there is generally no competition with food (Harcourt, 2009; IPCC, 2011; Harcourt, 2009). However, this in only true if the plant is used in this region, or like in the case of Manabí, as a living fence. Nevertheless, it is imaginable that Jatropha cultivation could compete with food production, since good fertile soils have a potentially positive effect on seed yield and oil content (FAO, 2010; UNIDO, 2009). In addition, the same is true for water. Jatropha could theoretically be grown with little water but irrigation can help to increase yield and oil content if done in the optimal range (ERGAL/ DED/ MEER, 2008; FAO, 2010; Camaggio and Amicarelli, 2012). Therefore, there is a risk of negatively impacting water availability.

Another important aspect of bio-energy crops is LUC and the influence on soil conditions. When forest areas are converted into biomass plantations, it negatively impacts biodiversity and can lead to higher CO_2 emissions as well as soil degradation (IPCC, 2011: 226). Jatropha cultivation does not make LUC mandatory (IPCC, 2011: 265), contrarily, this plant can stabilize the soil and store moisture while it grows (IPCC, 2011: 269). Nonetheless, there are fears of deforestation and land degradation because of energy crop production (García Andrade, 2011), along with the risk that Jatropha can become invasive, displace indigenous species and decrease biodiversity. In addition Jatropha is considered weedy in several countries including India and South America (IPCC, 2011: 270).

Another property of Jatropha oil was crucial for the decision to use this crop in Galápagos, since it reduces the risk of oil spills, and therefore, increases biodiversity protection. This is because of the biodegradability of Jatropha oil, as it biodegrades by 95% in 21 days. Contrarily, biodiesel is considered more harmful to the aquatic ecosystem in case of spilling. Therefore biodiesel transport needs to fulfil safety criteria equal to diesel while the transport of vegetable oil is less stringent (ERGAL/ DED/ MEER, 2008: 26; 76; ElecGalápagos/ PSI/ PNG, 2011: 165). The castor oil plant has been excluded because it can only be used as biodiesel, therefore imposing risk to the environment if spilled and also besides it is toxic, does not mix with petroleum products and is not very stable (ERGAL/ DED/ MEER, 2008: 26f). The *African palm olein* could, as Jatropha, be used either purely as vegetable oil or converted to biodiesel (ERGAL/ DED/ MEER, 2008). Nevertheless, the decision was made against palm oil, despite it being the most used plant for energetic use in Ecuador today (ERGAL/ DED/ MEER, 2008: 26) due to several reasons. African palm oil is criticized for the following reasons: (1) requiring large amounts of pesticides (IPCC, 2011: 234); (2) reducing only 20–60% of GHG emissions, depending on LUC, if compared to fossil fuels (IPCC, 2011: 245); (3) deforestation and biodiversity reduction and habitat fragmentation (IPCC, 2011: 269); and (4) LUC causing a negative GHG balance (IPCC, 2011: 304).

Overall, in the case of Floreana, the arguments in favour of Jatropha have been stronger than for the castor oil plant, African palm oil or other bio-energy crops. If only combustion technologies are considered, then vegetable oil use appears to be one of the most environmentally friendly fuels. Nevertheless, if wind and solar energy are considered, then environmental sustainability of vegetable oil is controversial. The main environmental aspect in favour of Jatropha is biodiversity protection through a substantial decrease in the volume of fossil fuel diesel to be annually transported to the islands. Thereby reducing the environmental threat associated with oil spills, which can cause serious damage to the unique ecosystems' biodiversity of the islands (ElecGalápagos/ PSI/ PNG, 2011; Rosero and Chiliquinga, 2011).

5.2.5. Sustainability Assessment

The Sustainability Assessment of Floreana can be represented graphically when the above-mentioned arguments are translated into numbers[115]. Doing this allows a comparison between the conventional fossil-fuel-based electricity system with a system based only on Jatropha or solar PV and storage. The hybrid system then represents the sustainability of the current electricity system based on the actual share of diesel and renewables in 2015.

Table 27: Sustainability Assessment of Floreana
Source: Own elaboration

	Reference Fossil Fuel based System	Jatropha	PV + Storage	Hybrid System (Jatropha + Diesel + PV + Storage)
Energy Security	0.83	0.50	3.17	0.98
Environmental Sustainability	0.00	0.77	4.29	0.82
Socio-Economic Energy Equity	0.75	2.58	3.42	1.80
Technological Feasibility	4.00	1.00	2.00	3.00

Table 27 and Figure 42 illustrate that a high score has been reached concerning technological feasibility of Jatropha, solar PV and the hybrid system, revealing that a main focus has been on this aspect. The technical viability is affirmed since the potential for RETs is high and international technical knowhow supports the implementation of a stable hybrid system. Nevertheless, certain planning issues and difficulties decreased the technical feasibility of PV since the existing solar park had serious technical failures causing its standstill. If the technical challenges

[115] Since many aspects are rather ambiguous and vague they are provided with a linguistic representation and the intent has been made to translate them into numbers from 0 to 5. This has been done using fuzzy logic. See chapter 3.4 for more details.

concerning solar PV are mastered, solar energy has a strong potential to increase environmental sustainability, socio-economic energy equity and energy security when compared with a purely fossil fuel based system.

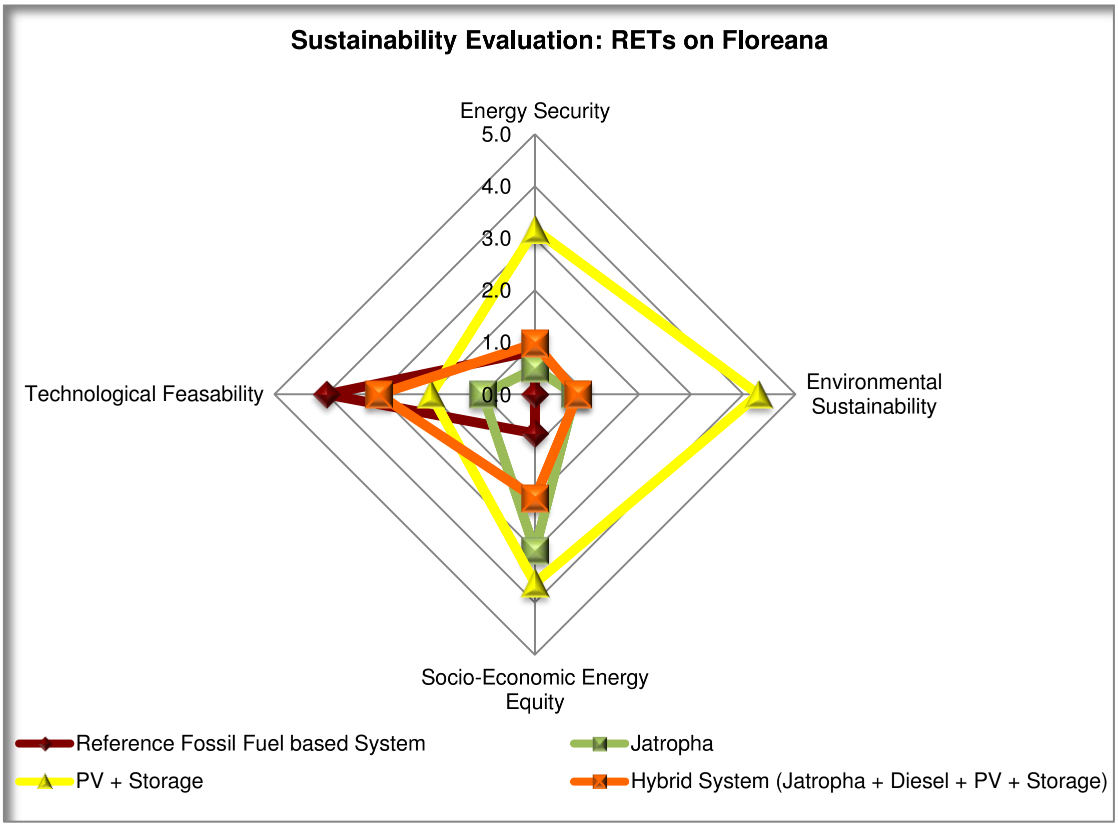

Figure 42: Sustainability Assessment Floreana
Source: Own elaboration

In addition, compared to fossil fuels also Jatropha could have the potential to increase environmental sustainability and socio-economic energy equity further. In particular, the Jatropha project focused on improving socio-economic aspects by increasing prosperity, decreasing poverty and empowering the local communities in the Manabí region, where the vegetable oil is cultivated and produced. Nevertheless, this potential cannot be realized to a full extent, since the share of Jatropha is only 40% and the theoretical share of PV is 12%. Hence, fossil fuels are still required – dampening the results of the sustainability evaluation. Additionally, it is important to stress that biofuels are neither a completely green energy source nor a universal remedy against climate change. It should be taken into consideration that recent studies demonstrate that the harmful environmental and social impact of the biofuel production and its combustion may outweigh the benefits.

This demonstrates that further efforts are needed to create a fully sustainable electricity system on Floreana. It can be assumed that a focus on repowering the

PVPP and extending the installed capacity would increase environmental sustainability as well as socio-economic energy equity. In addition, a focus on incorporating other types of renewables, such as sun, or also using the excess energy generated by incorporating storage, would improve the sustainability of the system with respect to energy security. Another possibility would be the integration of a desalination plant that uses excess wind energy during the night to produce safe drinking water. Moreover, it can be assumed that a focus on incorporating small-scale RE solutions, such as rooftop solar PV and micro wind turbines could boost and promote RET deployment.

5.3. Isabela

Isabela is the largest island of the Galápagos, one of the youngest geologically, and therefore located in the west of the archipelago. With around 2,500 inhabitants, it has a significantly smaller population than Santa Cruz and San Cristóbal (INEC, 2010b). Furthermore, electricity services have only recently been extended from 18 to 24 hours per day in 2000 (ERGAL/ KfW/ Lahmeyer, 2001).

5.3.1. Technological Feasibility

The electrical system on Isabela is currently composed of thermal power generators using diesel with an installed nominal capacity of 2.560 MW or effectively 1.962 MW (ElecGalápagos, 2013d). Peak demand in 2013 was on 13th March at 19:00, with 814 kW (ElecGalápagos, 2014a; ElecGalápagos, 2014c). Total demand in 2013 was 3,683 MWh (ElecGalápagos, 2014c).

Table 28: Diesel Generators on Galápagos: Isabela
Source: Data adapted from (ElecGalápagos, 2013a)

Isabela							
No.	Model	Motor Brand	Generator Brand	Year Of Fabrication	Capacity Nominal (kW)	Capacity Effective (kW)	Status
1	3512	Caterpillar	Caterpillar		650	520	Operational
2	C18	Caterpillar	Caterpillar	2010	545	436	Operational
3	3408	Caterpillar	Caterpillar	1981	310	160	Operational
4	C18	Caterpillar	Caterpillar	2010	545	436	Operational
5		Iveco	Iveco	2001	510	410	Out of Service
			Total Isabela		**2,560**	**1,962**	

Under development is a hybrid system that combines PV, batteries for storage and thermal power generation, which shall be based on vegetable oil from Jatropha – similar to Floreana (Lahmeyer International/ MEER, 2012; Heinemann, 2014). Such a PV-diesel-hybrid system with batteries is according to ERGAL, KfW and Lahmeyer (2001), suitable for Isabela, since electricity demand is relatively low, the grid is small and the solar radiation is very good, while wind conditions are less suitable. The assumption is that with this PVPP, combined with batteries, an average annual penetration of around 45–50% can be obtained on Isabela (ElecGalápagos, 2014d).

PV

The PVPP shall have a capacity of 1.159 MW_{peak}, according to ERGAL (2013), but could probably be slightly smaller with around 1 MW_{peak} (ElecGalápagos, 2014b). Without any storage option, the PV penetration is limited to 20-25% of the total electricity demand in Isabela. In combination with storage, the 1.1 MW_{peak} PVPP was expected to cover around 70% of the electricity in 2001 when total demand was at approximately 1,200 MWh (ERGAL/ KfW/ Lahmeyer, 2001: 62). Due to demand growth, it is expected to cover instead of 70%, only 45% of the electricity demand in 2015 (ElecGalápagos, 2014d). This corresponds to an average annual yield per installed capacity of 1,450 kWh/ kW_{peak} over 25 years (Lahmeyer International/ MEER, 2012: 124). The calculations for this solar energy output are based on the annual average global horizontal solar radiation (GHI), which is around 5.4 kWh/m^2 per day corresponding to 1,989 kWh/m^2 per year. As illustrated in Figure 43, the monthly average solar radiation reaches from approximately 6.4 kWh/m^2 and day in March, to the lowest radiation appearing in July with approximately 4.7 kWh/m^2 per day (Lahmeyer International/ MEER, 2012: 20; 104).

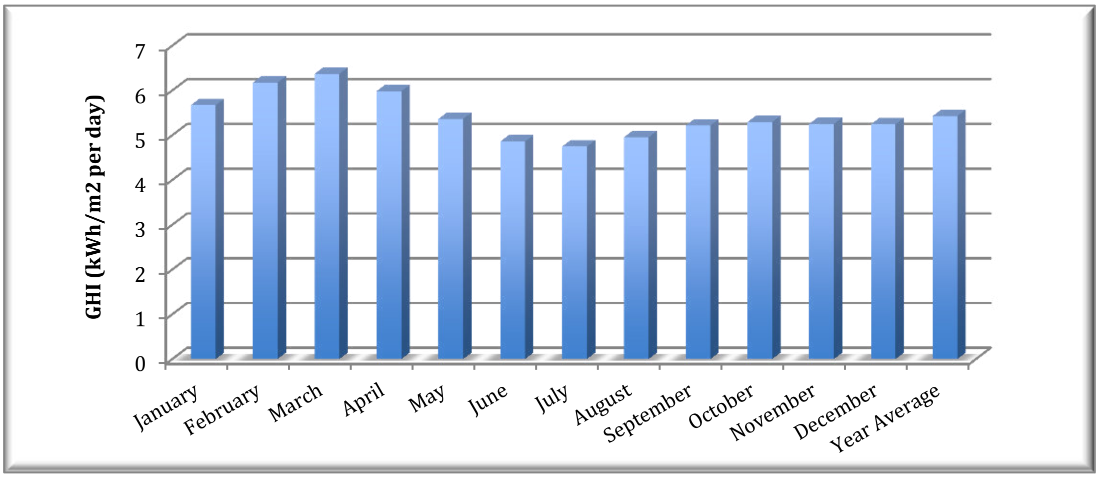

Figure 43: Global Horizontal Radiation in Isabela per month in kWh/ m^2 per day
Source: Data adapted from (Lahmeyer International/ MEER, 2012: 20; 104)

The performance ratio (PR) for the PVPP in Isabela is shown in Figure 44, indicating that temperature has a strong influence on the output. In fact, Lahmeyer and MEER

(2012) assume that temperature accounts for the highest losses amounting to 8.1%. Generally, the PR indicates the quality of the PVPP. It expresses the ratio of the real energy generation versus the theoretical (Lahmeyer International/ MEER, 2012; Sharma, 2013). For the PVPP in Isabela, Lahmeyer and MEER (2012: 124) expect an average PR of 73.5% over a 25-year lifetime, corresponding to 1,680 MWh per year, or 1,450 kWh/kW_{peak} [116]. For the simulation, Lahmeyer chose a poly-crystalline model of the Chinese manufacturer TRINA, TSM-230pc05, with 230WP +3%/ -0% and 14.1% efficiency. It is expected that the PV panels on Isabela are mono- or poly-crystalline having an efficiency of 12-16% (Lahmeyer International/ MEER, 2012: 104). The assumptions for the calculation include that the solar cells loose efficiency each year. In addition, an inclination of 10° has been chosen as it is the minimum to allow for self-cleaning of the module surface (Lahmeyer International/ MEER, 2012: 124).

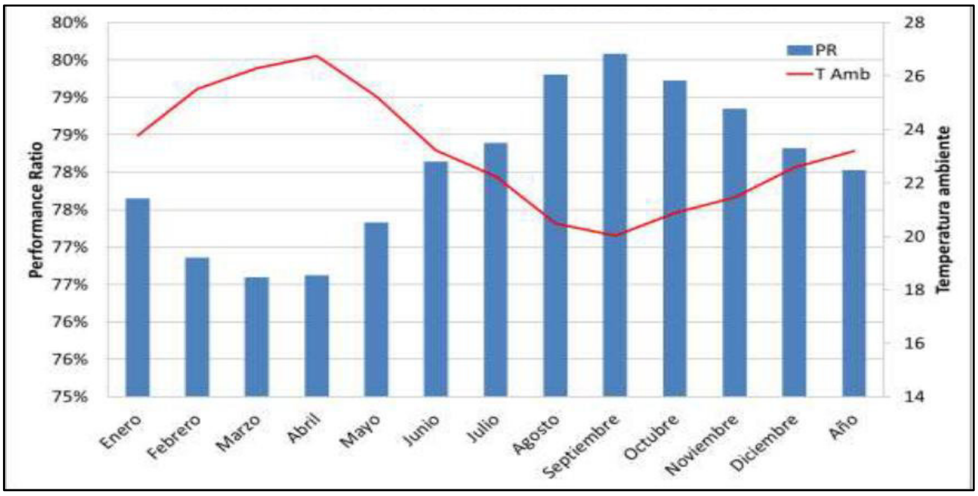

Figure 44: Performance Ratio of the PVPP in Isabela
Source: (Lahmeyer International/ MEER, 2012)

Due to the fact that the aim is to provide a reliable energy supply, it is necessary to complement the variable solar PV with other technologies, such as wind, storage systems, or thermal back-up.

Wind

It appears that in the case of Isabela, wind energy has not been examined comprehensively or in its entirety. Efforts were withdrawn after the first wind measurements. According to the study PNUD ECU/97/G41 conducted in 2001, the wind resources on the island – at the measured site close to the thermal power plant

[116] In the first year the PR is expected to be 78% corresponding to 1,783 MWh/year or 1,539 kWh/kW_{peak}.

– seem unsuitable for wind power development (ERGAL/ KfW/ Lahmeyer, 2001). Measurements made 30-50 m above the ground are shown in Table 29 demonstrating that the wind speeds are too low for an economically feasible energy harvest.

Table 29: Average Monthly Wind Speeds in m/s, long-term corrected
Source: Data adapted from (ERGAL/ KfW/ Lahmeyer, 2001: 45; Lahmeyer International/ UNDP, 2001)

Stat.	Site	Aug 99	Sep 99	Okt 99	Nov 99	Dez 99	Jan 00	Feb 00	Mar 00	Apr 00	May 00	Jun 00	July 00	Avg
Gal-2	Isabela; P. Villamil	3.9	3.4	3.8	3.9	3.8	3.4	3	3.3	3	3.5	4.1	4.1	3.6

Furthermore, another site has been identified, called "*Cerro Las Cazuelas*", in the agricultural area of Isabela on 610 m above sea level. This site raised expectations about suitable wind conditions with average wind speed of 5.2 m/s on rotor height. Nevertheless, the initiative to develop this site has not continued due to three primary reasons. Firstly, some wind data were missing and therefore evidence is not conclusive. Secondly, this site is 22 km from the power station and there is no grid connection to this area and so economic viability is uncertain. Thirdly, land tenure is complicated since the site is privately owned and the landowner is not interested in selling or lending the site (ERGAL/ KfW/ Lahmeyer, 2001: 47).

Back-up

An important building block of the planned hybrid system in Isabela is back-up through thermal generators to assure reliable electricity supply. These are necessary to compensate the natural volatility of solar energy and to cover the difference between the electricity produced by the PVPP and the demand (Lahmeyer International/ MEER, 2012). For 2015, the total demand on Isabela is expected to be approximately 3,700 MWh. Since the PVPP produces around 1,700 MWh, it needs to be complemented by around 2,000 MWh of electricity generated by thermal generators (ElecGalápagos, 2014d). The back-up system is planned to consist of dual thermal generators running with biodiesel, vegetable oil or diesel, and shall have a total installed capacity of 1.2 MW[117] (MEER/ KfW, 2013), but could probably be around 1 MW (ElecGalápagos, 2014b). They will be able to cover the complete electricity demand of the island in case electricity from the PVPP is not available (Lahmeyer International/ MEER, 2012). The intention is to use mainly vegetable pine oil, based on Jatropha, while diesel remains in reserve (Lahmeyer

[117] The thermal generators consist of 2*300kW, 2*240kW and a cold reserve generator of 150kW.

International/ MEER, 2012: 145). Technical feasibility of back-up through Jatropha on Isabela, where demand in significantly higher than on Floreana, is unclear and therefore not considered in more detail. For instance, there are doubts that the communities in Manabí are able to produce sufficient vegetable oil to cover the demand.

Storage

The storage system is an essential building block of the planned hybrid system on Isabela, and is in place to assure reliable electricity supply and increase the share of RES-E. This is due to the fact that only by storing electricity from the sun it is possible to shift it to times when no sun is shining – to make it available in peak times. In the case of Isabela, studies suggest that the storage system is based on batteries and shall increase the average annual RES-E penetration to 45–50% (ElecGalápagos, 2014d). Without batteries, the share of renewables is limited to 20-25% (Lahmeyer International/ MEER, 2012: 70). The proposed storage system shall consist of a battery bank of 3.3 MWh and 900 kVA (MEER/ KfW, 2013; ElecGalápagos, 2014b). To maintain a long battery lifetime, a special automated system controls optimal load and maintains the minimum loading of the batteries at 60%, according to Lahmeyer and MEER (2012: 61). One disadvantage is the reduction of efficiency caused by the transport of solar energy to the batteries through transformers (Lahmeyer International/ MEER, 2012).

Interconnection

An important aspect of the planned hybrid system on Isabela is the interconnection and control of the PVPP, the batteries and the thermal generators. These are used to assure reliable electricity supply and to reach the greatest reduction of fossil fuels possible. Hence, it is planned that the PVPP is controlled by an automated control system (Lahmeyer International/ MEER, 2012: 2). Lahmeyer proposed a frequency droop control scheme that controls the PVPP automatically[118]. This means that when the operation frequency exceeds a threshold, the power is limited and/ or cut and thereby the operator does not have to control the PVPP during normal operation conditions (Lahmeyer International/ MEER, 2012: 49). This allows providing a high reliability of the electricity supply.

Figure 45 demonstrates the complex interconnection of the technologies. The

[118] Such a droop control scheme uses only local power to detect changes in the system and adjusts the operating points of the generators accordingly. This allows the micro grid to dampen the fast effects of changing loads, increasing the stability of the system (Bollman, 2009).

system aims to minimize fossil fuel consumption by maximizing electricity generation through PV. The objective is that during maximal radiation hours the total demand is met by PV and is still able to store some energy in the batteries that will be used during peak demand. During the night the system shall be able to supply demand by releasing stored energy (Lahmeyer International/ MEER, 2012).

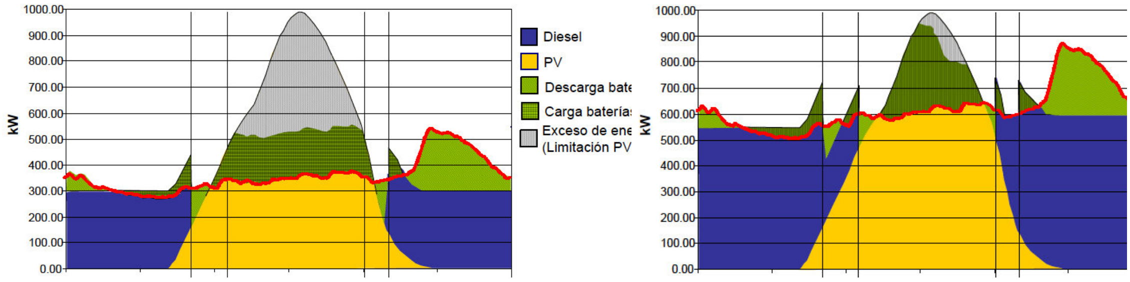

Figure 45: Diagram of exemplary automatic dispatch of the hybrid system in 2012 versus 2017 Source: (Lahmeyer International/ MEER, 2012: 55)

Conclusion

In conclusion, the current energy system on Isabela is a so called *medium-to-high-penetration solar-diesel-hybrid system with storage*. The statistics above demonstrate that the Zero Fossil Fuels goal cannot be reached until 2015 since the RES-E penetration is expected to be in average 45-50% when the solar energy project has been implemented. Therefore, to eliminate all fossil fuels, it will be necessary to integrate more RETs. Especially, when considering the fact that demand is increasing continuously, the share of renewables will fall, requiring additional installation of solar and wind power capacity in order to increase the RES-E share. According to measurements presented in chapter 4, an installation of PV modules and wind turbines would be feasible to increase the share of RES-E. Nevertheless, it is important to consider that with increasing RES-E share, in so-called *high-penetration systems*, maintaining consistent power quality becomes more challenging, requiring advanced automatic control and adequately trained technicians (Baring-Gould, 2008). Furthermore, to reach the Zero Fossil Fuels goal, it will be necessary to consider additional energy storage.

5.3.2. Energy Security

Energy independence is improved through usage of solar energy, an infinite resource that is freely available and indigenous to the islands. Nevertheless, thermal back-up is required to provide a reliable energy supply, and thereby necessitating dependence on fuel imports, either fossil or Jatropha. In addition to diesel generators, reliability of supply shall be improved through lead-acid batteries and an automated control system.

Regarding investment security, it is important to emphasise that, in the case of Isabela, public financial support and development aid from the international community will be responsible for the realization of the project. In fact, financing has been secured with contributions of GIZ-KfW of around 6 million Euros. The remaining costs will be covered by the Ecuadorian government (MEER) and partially by tax incentives (ProEcuador, 2011; ERGAL, 2013b). Lahmeyer and MEER (2012) assume that the total project costs will be approximately USD 9.1 million. Nevertheless, ElecGalápagos (2014b) already expects around USD 11.2 million. Currently, the economic evaluation of the financial offer received during the tender round has been finalized. The offer exceeded the reference budget by almost 80%, and therefore, additional negotiations and another bidding round will be necessary. In addition, a new tender round might require a reshaping of the specifications and will be accompanied by a significant delay (ElecGalápagos, 2014b).

This shows that for Isabela the same is true as for the PVPP in Floreana and the wind park in San Cristóbal. Project costs are especially high on Galápagos due to its isolation and weakness of private investment, indicating that Ecuador needs to provide better regulatory security and incentives for private investment.

5.3.3. Socio-Economic Energy Equity

Energy access on Isabela is already very good, and no significant changes are expected through the RES-E project. Improvements regarding the affordability of the energy supply are anticipated, especially for the supply side, as consumers have very low, fixed electricity prices. According to the project design prepared by Lahmeyer and MEER (2012: 70-71), the expected costs for electricity generation per kWh are USD 0.19 for PV, USD 0.62 for PV when combined with a storage system, USD 0.66-0.9 for Jatropha, and USD 0.52-0.67 for diesel generation. It is important to emphasize that electricity generated through PV is 72% lower than diesel, and 79% lower than production based on Jatropha oil. Even if the battery storage system is taken into account, the costs of PV are still 7% lower than electricity produced through diesel or 31% lower than Jatropha.

The PVPP will be enclosed by a 2.5 m high, metallic fence to deter human intrusion, as well as to protect human health and the solar panels (Lahmeyer International/ MEER, 2012). This installation, however, could reduce the public acceptance of the power plant since residents might feel expelled. Therefore, project-specific management needs to adequately consider this aspect and include the public to find the best possible solution with the aim to maximize public acceptance.

Regarding prosperity, the hybrid system requires well-trained technicians. It will create additional jobs as one plant manager; four mechanical operators; four electrical operators; and three technicians shall operate the hybrid system (Lahmeyer International/ MEER, 2012: 165). No concrete information is available indicating other socio-economic impacts of the Isabela PVPP. However, considering the above mentioned explanations for solar PV in general and the PVPP in Floreana the project is expected to positively influence prosperity, QOL and employee health and safety in case the project is developed and executed sustainably.

5.3.4. Environmental Sustainability

The hybrid system on Isabela shall be developed, executed and operated in line with all environmental protection laws of Ecuador and the Galápagos national park. Therefore, the environmental management plan includes all aspects concerning noise, emissions, waste, sewage, safe fuel management, transport of hazardous materials and products form the continent. To safeguard environmental sustainability, investments include adequate storage facilities for bio-diesel, new substations and underground cables to connect the PV plant with the substation (Lahmeyer International/ MEER, 2012).

Environmental impacts are expected during the civil construction of the hybrid system. For instance, there will be negative effects on soil, atmosphere, water, humans, flora and fauna. However, the intention is to mitigate these as much as possible (Lahmeyer International/ MEER, 2012: 226). For example, with the aim to avoid long transmission lines and interference into pristine nature, the PVPP will be constructed alongside the main road next to the existing power generation site on a lava field with irregular structure.

Figure 46 shows that the PVPP will consist of various rows with panels, three buildings containing inverters and transformers, and will be installed close to the soil in a fixed position. Although, this installation will require a dedicated area of around 1.50 ha or 15,000 m^2, and not allow any use of the area for other purposes, this is not unsustainable as the area is dry, rough lava that is unsuitable for agriculture (Lahmeyer International/ MEER, 2012).

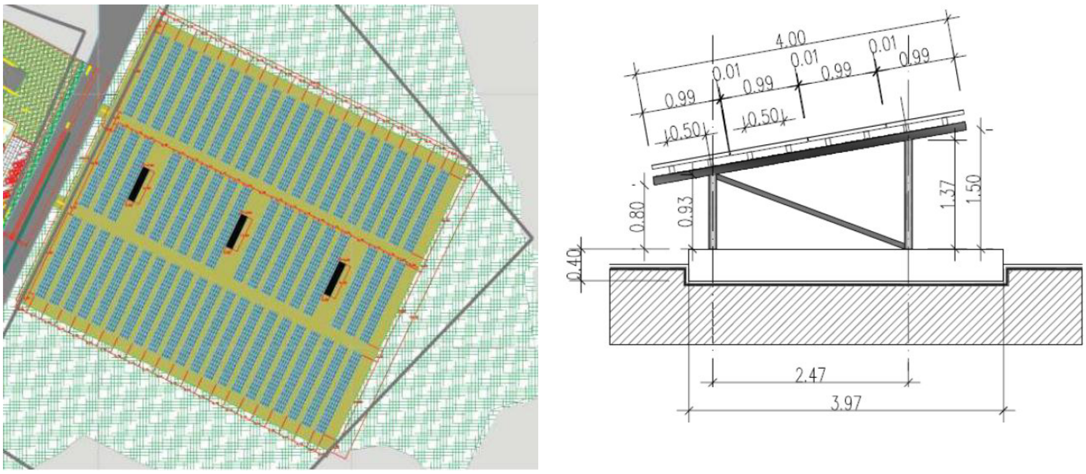

Figure 46: Construction Details of the Solar PV Park on Isabela
Source: (Lahmeyer International/ MEER, 2012)

Environmental impacts during plant operation and maintenance are expected to be low. Nevertheless, liquid and solid waste is generated through the thermal back-ups and other activities that can negatively affect soil, air, water, flora, fauna and humans. In addition, noise generation is possible by the thermal back-up but negligible due to the location next to the road and far from the community. Finally, during the decommissioning or replacement of parts of the hybrid system – batteries, for example – waste is generated. Especially hazardous waste management is critical and requires a special focus.

Due to the proximity to the coast the salinity of the air is high and classified in the C5-M corrosion category, according to EN ISO 12944 (Lahmeyer International/ MEER, 2012). These conditions require special materials to be used for the PVPP. In addition, there is an environmental risk due to Tsunamis and sea level rise because the whole generation system will be constructed close to sea level and a mere 800-1,000 m from the shore. Furthermore, damage of the electrical system can cause long supply interruptions due to the isolation of the islands from the mainland. In addition, environmental pollution is possible when seawater comes into contact with diesel systems or other hazardous substances.

Regarding the impact on water, it is important to mention that the PVPP requires regular cleaning with sweet water because dirt reduces the efficiency of the panels. To reduce water demand, the panels are going to be installed with a 10° inclination allowing for self-cleaning. Nevertheless, the water demand of the system corresponds to 34 m^3 per year (cleaning around each four months), which shall be covered through rainwater collection.

Finally, a comprehensive environmental management plan aims to reduce negative impact on humans, flora and fauna. It includes, among others, the control of dust, noise, atmospheric emissions, waste management plan, emergency plan, capacity building plan, worker safety and security plan, and a community relations plan.

In sum, as mentioned above, solar PV generally has a positive impact on environmental sustainability when compared with fossil fuels. They emit less GHG and other air pollutants, reduce the risk of oil spills and require fewer resources such as fresh water. In addition, they have a positive impact on human health since they have no emissions, no noise and are practically invisible – in case they are fixed on house roofs. On Isabela, the PVPP is next to the power site and along the road, which makes visual impacts negligible. Nevertheless, a recycling strategy is important for PV and batteries to assure long-term environmental sustainability.

5.3.5. Sustainability Assessment

The Sustainability Assessment of Isabela can be represented graphically when the above-mentioned arguments are translated into numbers[119]. Doing this allows one to compare the conventional fossil-fuel-based electricity system with a system based only on solar PV and storage. The hybrid system then represents the sustainability of the current electricity system based on the actual share of diesel and renewables in 2015.

Table 30: Sustainability Assessment of Isabela
Source: Own elaboration

	Reference Fossil Fuel based System	PV	Hybrid System (Diesel + PV + Storage)
Energy Security	0.83	3.17	1.88
Environmental Sustainability	0.00	3.92	1.76
Socio-Economic Energy Equity	0.75	3.33	1.91
Technological Feasibility	4.00	4.00	4.00

Table 30 and Figure 47 illustrate that a high score has been reached concerning technological feasibility of solar PV and hybrid system, revealing that a main focus has been on this aspect. The technical viability is affirmed since the potential for RETs is high and international technical know how supports the implementation of a stable hybrid system.

Furthermore, Figure 47 shows that solar PV energy has the potential to increase

[119] Since many aspects are rather ambiguous and vague they are provided with a linguistic representation and the intent has been made to translate them into numbers from 0 to 5. This has been done using fuzzy logic. See chapter 3.4 for more details.

environmental sustainability, socio-economic energy equity as well as energy security compared to a purely fossil fuel based system. Nevertheless, this potential cannot be realized to a full extent, since the share of solar PV is only 45%. Hence, fossil fuels will still be required, dampening the results of the sustainability evaluation.

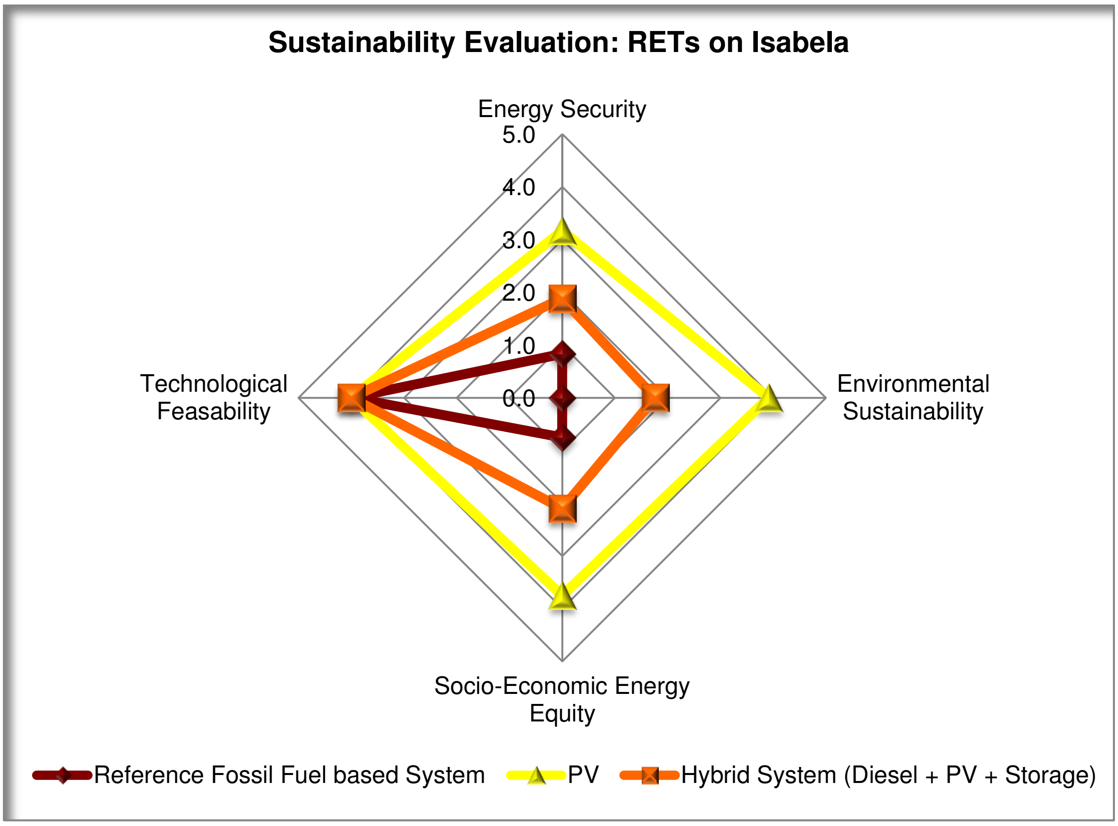

Figure 47: Sustainability Assessment Isabela
Source: Own elaboration

This demonstrates that further efforts are needed to create a fully sustainable electricity system on Isabela. It can be assumed that a focus on extending the installed capacity would increase environmental sustainability as well as socio-economic energy equity. In addition, a focus on incorporating other types of renewables, such as wind – but also using the excess energy generated, for instance, by incorporating storage – would improve the sustainability of the system also with respect to energy security. Another possibility would be the integration of a desalination plant that uses excess wind energy during the night to produce safe drinking water. Moreover, it can be assumed that a focus on incorporating small-scale RE solutions, such as rooftop solar PV and micro wind turbines could boost and promote RET deployment.

5.4. Santa Cruz and Baltra

Santa Cruz is the most populated island and with around 17,000 inhabitants home to 60% of the total population in Galápagos (INEC, 2010b). Similar to all other islands, on Santa Cruz the largest portion (88%) of the island is protected as national park (INGALA/ CDF/ Municipios de Galápagos, 2005: 30). The remaining 12% is divided into rural and urban space for the population. With the aim not to reduce agricultural area and avoid additional intrusion into the delicate ecosystem, the airport is located on Baltra, benefitting from the former military installations. This rather small island is merely 300 metres north of Santa Cruz and commercially very important, since apart from Galápagos' main airport, the PetroEcuador fuel terminal, "*Terminal de Productos Limpios*" and the Ecuadorian Navy can be found on Baltra as well. The fuel terminal acts as petrol station for all touristic cruise ships providing them with diesel and gasoline. In addition, it supplies the gasoline station on Santa Cruz and also the electrical power generators in Puerto Ayora with fossil fuels. The islands Baltra and Santa Cruz are separated by the Itabaca channel and interconnected via ferries. Currently, there is no electrical interconnection between the islands. Figure 48 illustrates the arrangement of the wind park, the airport and the other planned components on Baltra.

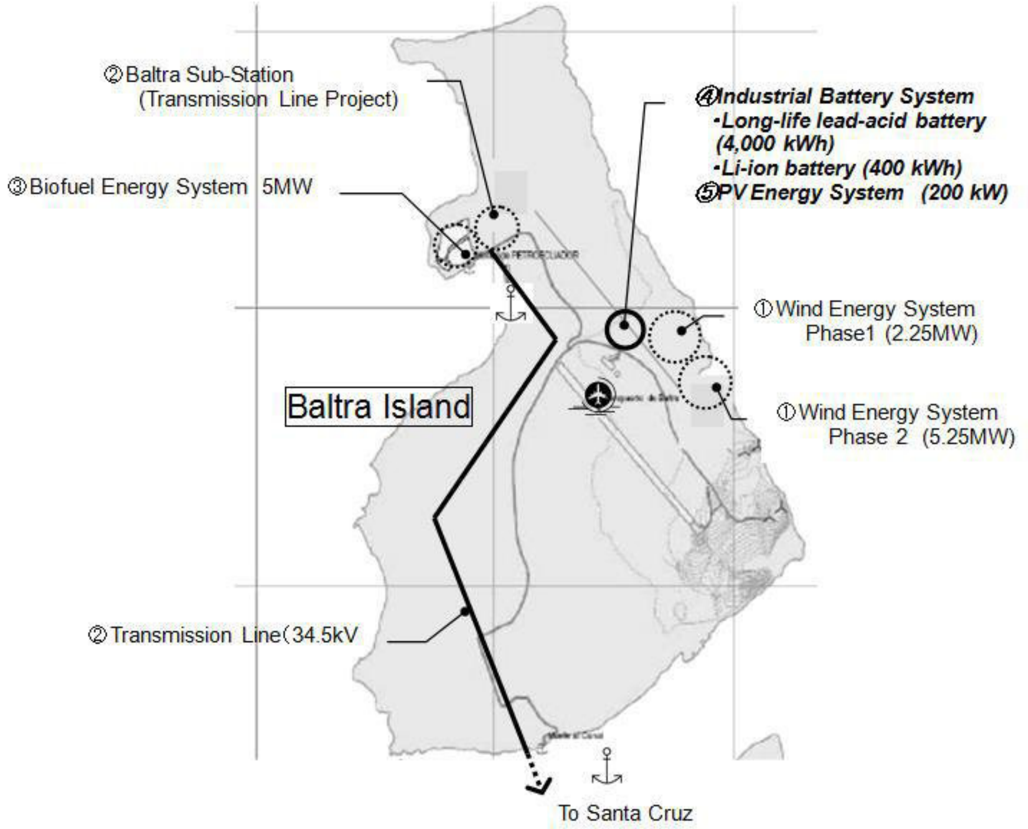

Figure 48: The structure of the planned hybrid system on Baltra
Source: (MEER, 2013a)

5.4.1. Technological Feasibility

Electricity service on Santa Cruz has been extended from 18 to 24 hours per day in 1998 (ERGAL/ KfW/ Lahmeyer, 2001: 5). Currently, the electrical system on Santa Cruz is composed of thermal power generators using diesel with a total installed nominal capacity of 8.01 MW or effectively 6.408 MW (ElecGalápagos, 2013d) (ElecGalápagos, 2014c).

Table 31: Diesel Generators on Galápagos: Santa Cruz
Source: Data adapted from (ElecGalápagos, 2013a)

Santa Cruz							
No.	Model	Motor Brand	Generator Brand	Year Of Fabrication	Capacity Nominal (kW)	Capacity Effective (kW)	Status
1	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
3	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
4	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
5	3516	Caterpillar	Caterpillar	1990	1,100	880	Operational
6	3512 Dita	Caterpillar	Caterpillar	1990	650	520	Operational
7	C32	Caterpillar	Caterpillar	2008	910	728	Operational
8	9h21/32	Hyundai	Hyundai	2011	1,700	1,360	Operational
9	9h21/32	Hyundai	Hyundai	2011	1,700	1,360	Operational
			Total Santa Cruz		**8,010**	**6,408**	

The generators supplying the urban population are situated in the south of Santa Cruz, in the higher part of the main city Puerto Ayora. Demand on Santa Cruz was 25,173 MWh in 2013 (ElecGalápagos, 2014c). Peak demand was 4,734 kW on 19th April 2013 at 11:00 (ElecGalápagos, 2014c). According to CENACE (2013), the system is designed for 5,257 kW, which will most probably be reached at midday during hot season. The electrical system in Baltra consists of around 15 thermal generators with a total installed capacity of 1,055 KVA to supply a demand of around 280 KVA. Nevertheless, the equipment is old and in bad shape (ERGAL/ MEER/ UNDP, 2007: 73).

According to the original RE initiative of 2001, the plan was to reach a RES-E share of 50% on Santa Cruz and 70% on Baltra (ERGAL/ KfW/ Lahmeyer, 2001). Nevertheless, demand already more than doubled from 10,366 MWh in 2003 to 25,173 MWh in 2013. Therefore, the planned initiative will cover less than expected. According to ElecGalápagos (2014d), the wind turbines might, by 2015, cover around 20% and the solar PVPPs – 10% of the islands´ total electricity demand. Table 32 illustrates the currently planned hybrid system characteristics and renewables penetration. It is important to emphasize that with increasing demand the RE share decreases.

The hybrid system was planned for the long term and therefore three phases had originally been defined. The first phase includes the installation of up to 3 MW wind capacity and a parallel operation with the grid. This will result in an annual average wind share of around 25% and an instantaneous penetration of up to 50%. In the second phase the RE capacity shall be extended to around 7.5 MW, allowing for a 50% average annual penetration by wind energy and extending the instantaneous penetration up to 100%. This phase shall also include a “co-generation” with a desalination plan and allow for diesel-off mode. The third phase shall reach 100% REs, by including batteries and thermal generation through biofuels to back-up the system, as well as electrical cars (ERGAL/ MEER/ UNDP, 2007; Consejo de Gobierno Galápagos, 2011; ERGAL, 2014).

Table 32: Overview of the Hybrid System on Santa Cruz
Source: Data adapted from (ElecGalápagos, 2014d)

Total demand Baltra-Santa Cruz kWh/ year		**24,160,000**
Thermal Power Plant	**Installed capacity (MW)**	
	Efficiency of thermal generators	13.75
Wind Park Baltra	**Installed capacity (MW)**	2.25
	Capacity (kW)	2,250
	Capacity factor	0.25
	Wind Electricity (kWh/ year)	4,927,500
	Electricity gap covered by thermal backup (kWh/year)	19,232,500
	Impact Fossil Fuel Reduction (gallon)	358,364
PV Puerto Ayora	**Installed capacity (MW)**	1.50
	Capacity (kW)	1,500
	Capacity factor	0.16
	PV Electricity (kWh/ year)	2,102,400
	Electricity gap covered by thermal backup (kWh/year)	22,057,600
	Impact Fossil Fuel Reduction (gallon)	152,902
PV Baltra	**Installed capacity (MW)**	0.20
	Capacity (kW)	200
	Capacity factor	0.16
	PV Electricity (kWh/year)	280,320
	Electricity gap covered by thermal backup (kWh/year)	23,879,680
	Impact Fossil Fuel Reduction (gallon)	20,387
Overview	**Total RES-E (kWh/year)**	7,310,220
	Electricity gap covered by thermal backup (kWh/year)	16,849,780
	Impact Fossil Fuel Reduction (gallon)	531,652
	Wind Share	20%
	PV Share Puerto Ayora	9%
	PV Share Baltra	1%

Wind Power on Baltra

On the island of Baltra a wind park with a total capacity of 2.25 MW, consisting of three turbines of 750kW each, is under construction in the proximity of the airport (ElecGalápagos, 2014b). Baltra has been identified as the most suitable place for wind power generation based on the results of a feasibility study, conducted by ERGAL, KfW and Lahmeyer (2001). Apart from a good wind regime, there is sufficient space for a potential enlargement of the park in the future. In addition, the logistics are relatively simple compared to other sites on the archipelago, as Baltra is small and has a suitable port for the delivery of WTGs and other bulky items.

The annual average wind speed on the site in Baltra is 6.02 m/s in a height of 50 m (ERGAL/ MEER/ UNDP, 2007: 76). Nevertheless, the wind regime in Galápagos is characterized by both daily and seasonal variations of wind as illustrated in Figures 49 to 51. It is shown that the lowest wind speeds can be found in February and March and the maximum wind speeds are reached in September. This does not correlate with energy demand, however, which is highest in February to April because in warm season demand for air conditioning is high.

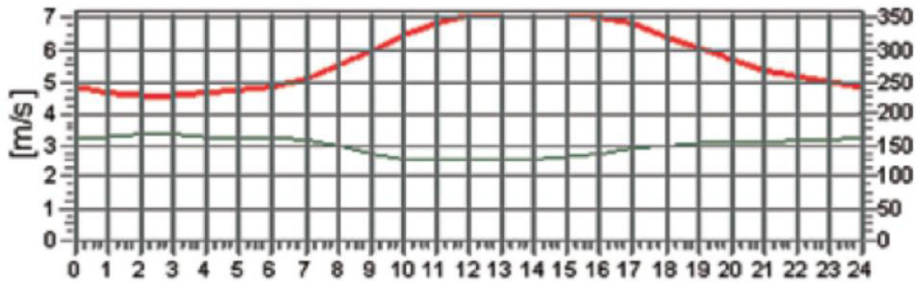

Figure 49: Variation of the average wind speed (m/s; red line) and the prevailing wind direction (degrees related to North/ South; green line) over the day
Source: (ERGAL/ MEER/ UNDP, 2007: 27)

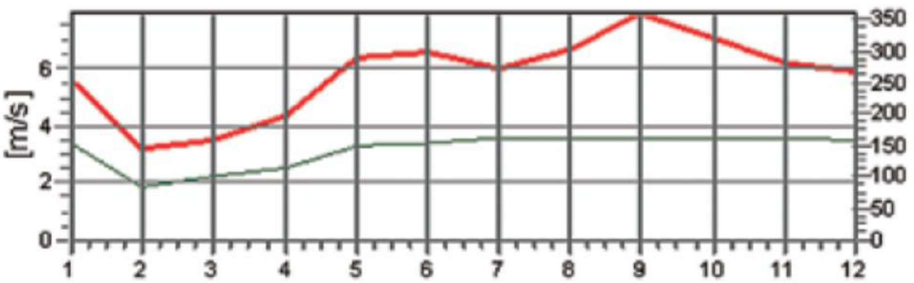

Figure 50: Variation of the average wind speed (m/s; red line) and the prevailing wind direction (degrees related to North/ South; green line) over the year
Source: (ERGAL/ MEER/ UNDP, 2007: 27)

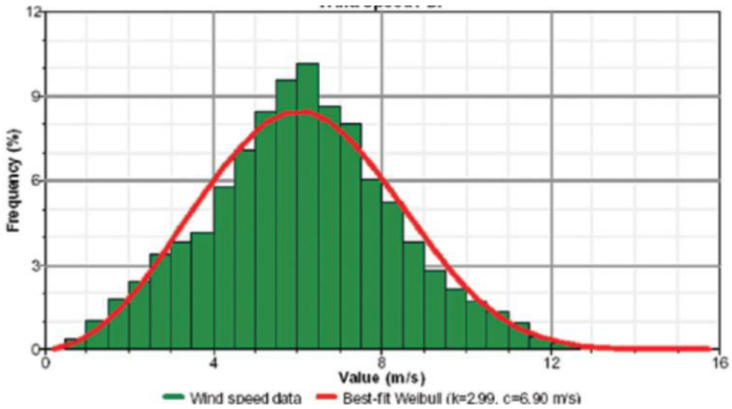

Figure 51: Wind frequency distribution in Santa Rosa at 50m height
Source: (ERGAL/ MEER/ UNDP, 2007: 74)

Photovoltaic Projects on Baltra and Santa Cruz

Due to the fact that solar radiation correlates much better than wind with peak electricity demand, there are also two PV systems under construction. One of them is in close proximity to the wind park on the island of Baltra and shall cover the complete outside roof of the new ecological airport. The project includes the implementation of a 200 kW_{peak} PV system connected to an arrangement of storage batteries, consisting of both rechargeable Li-Ion and long life Lead-Acid batteries (ElecGalápagos, 2014b).

The second PV system is currently under construction in Puerto Ayora, the main city on Santa Cruz of around 12,000 inhabitants (PNG/ CGREG/ CDF/ GC, 2013). The solar farm is going to have a nominal capacity of 1.5 MW_{peak} and a centre for education and capacity building. The photovoltaic system is connected to the thermal power plant through a 13.8 kV grid[120] (ElecGalápagos, 2014b).

Interconnection of the systems in Santa Cruz and Baltra

The two islands, Santa Cruz and Baltra, are separated by the 300–500 m wide Itabaca channel and are not yet electrically interconnected. However, to transport RES-E generated on Baltra to the demand centre in the south of Santa Cruz, it is planned to install Galápagos' first 34.5 kV interconnection line with a total length of around 50 km (CENACE, 2013; ERGAL/ MEER/ UNDP, 2007; ElecGalápagos, 2014b). It consists of an overhead system on Baltra and underground cables through the Itabaca channel to the highlands "Gemelos" (17.31 km). Then the grid connection continues underground to the rural area (3 km) and finally an overhead

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[120] According to ElecGalápagos (2014b), the photovoltaic modules, inverters, and power transformer have been installed. Currently, the installation of the transmission cabling has been initiated and tests as well as commissioning are planned for late April 2014.

line leads to the Puerto Ayora power station, in the south of Santa Cruz (around 30 km)[121]. The planned system of interconnections is illustrated in Figure 52.

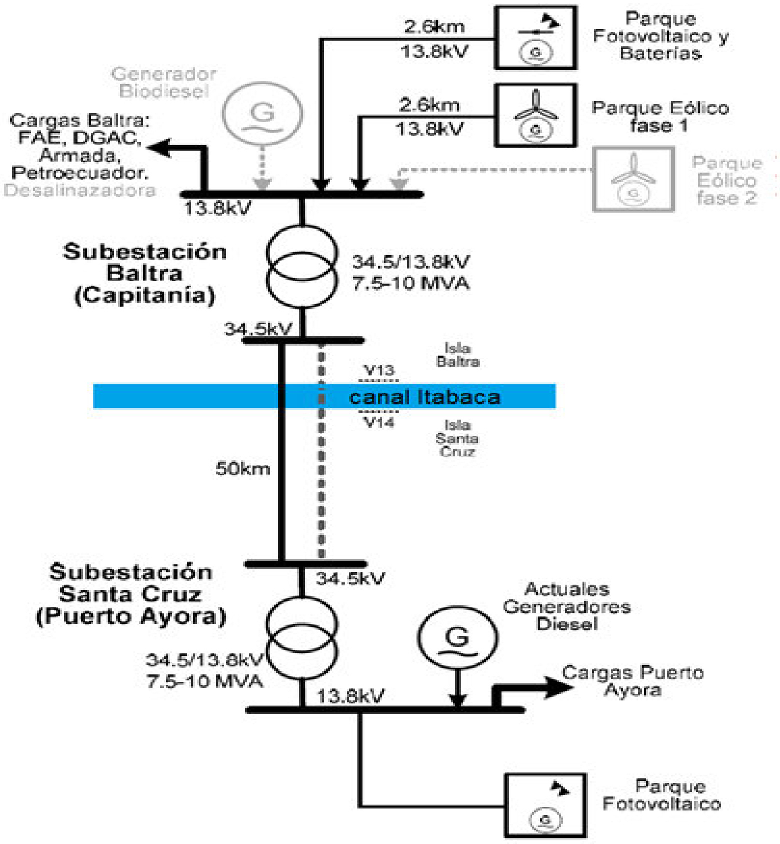

Figure 52: Technical structure of the interconnection Baltra – Santa Cruz
Source: (CENACE, 2013)

Conclusion

In conclusion, the current energy system on Santa Cruz and Baltra is a *medium-to-high-penetration wind-solar-diesel-hybrid system with storage*. The statistics above demonstrate that the Zero Fossil Fuels goal cannot be reached until 2015, since the RES-E penetration is expected to be in average 30% when the wind and solar energy projects have been implemented. Therefore, to eliminate all fossil fuels it will be necessary to integrate more RETs. Especially, when considering the fact that demand is increasing continuously the share of renewables will fall. To maintain or increase the RES-E share, an additional installation of solar and wind power capacity is required. This would be feasible according to measurements presented in chapter 4. Nevertheless, it is important to consider that with increasing RES-E share in high-penetration systems, it becomes more complex to maintain consistent power quality – requiring advanced automatic control as well as adequately trained

[121] Currently, the overhead grid in Baltra is finished, while the connections between Itabaca and Puerto Ayora are under construction (ElecGalápagos, 2014b).

technicians (Baring-Gould, 2008). Furthermore, to reach the Zero Fossil Fuels goal it will be necessary to consider additional energy storage.

5.4.2. Energy Security

The hybrid system significantly increases energy independence since wind and solar energy reduce the required fossil fuel imports. Nevertheless, due to the volatile nature of sun and wind, the system requires regulation of the fluctuations to supply reliable electricity according to the demand. Therefore, the 200 kW_{peak} PV on Baltra and the wind park shall be connected to a system of storage batteries, consisting of rechargeable Li-Ion and long life Lead-Acid batteries. This combination shall allow regulating the fluctuations of the RES-E and store excess energy (ElecGalápagos, 2014b).

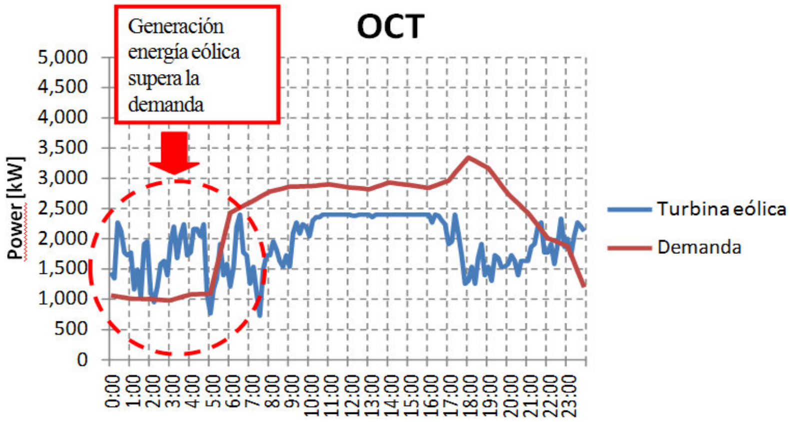

Figure 53: Expected wind energy generation during one day in October
Source: (MEER, 2013a)

As illustrated in Figure 53, it is expected that during the night, electricity generated through wind power will be larger than the demand. In this case, the wind turbines would have to be shut down to avoid an increase of the frequency and a deterioration of the electricity quality. Contrarily, when the electricity generated is too low to cover the demand, then the frequency of the system would decrease if the missing demand were not compensated by other sources of electricity generation (MEER, 2013a). In addition, the fluctuation of the RES-E might cause undesired problems in frequency and voltage. By storing electrical energy when the renewable electricity production is higher than the demand, the curtailment of RES-E can be reduced, allowing the base-load units to operate more efficiently (IPCC, 2011). Therefore, to mitigate the undesired results of the fluctuations, two types of batteries shall stabilize the electricity, increase the share of RES-E and improve the reliability of supply.

As illustrated in Figure 54, on the one hand, long life Lead-Acid batteries charge or discharge depending on the real demand, with the aim to shift loads and support the grid. This means they will be charged mainly by excess wind electricity during the night and discharge during the day to reduce the demand for fossil fuels (MEER, 2013a; IRENA, 2012b: 9).

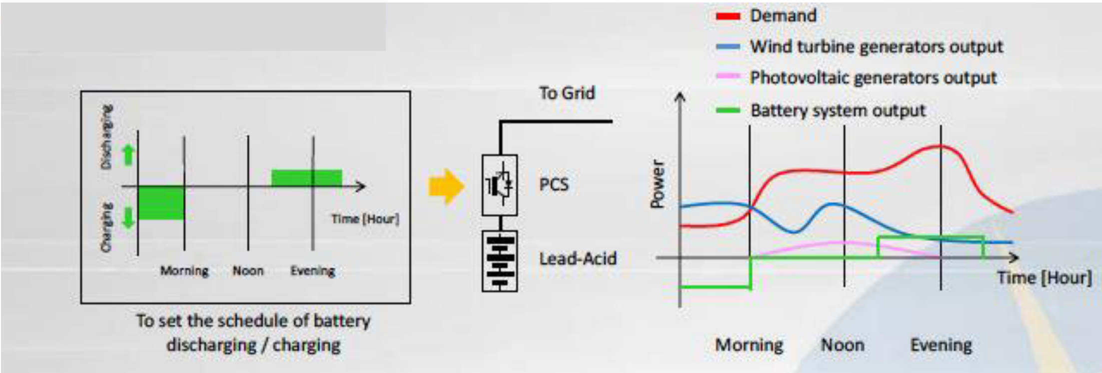

Figure 54: Long life Lead-Acid batteries
Source: (MEER, 2013a)

On the other hand, rechargeable Li-Ion batteries are used to mitigate the high fluctuations of the wind energy, to improve power quality and provide uninterrupted power supply as shown in Figure 55 (MEER, 2013a; IRENA, 2012b: 9). According to the IPCC (2011), they can be used to provide power in the intra-hour timeframe to regulate the balance between supply and demand.

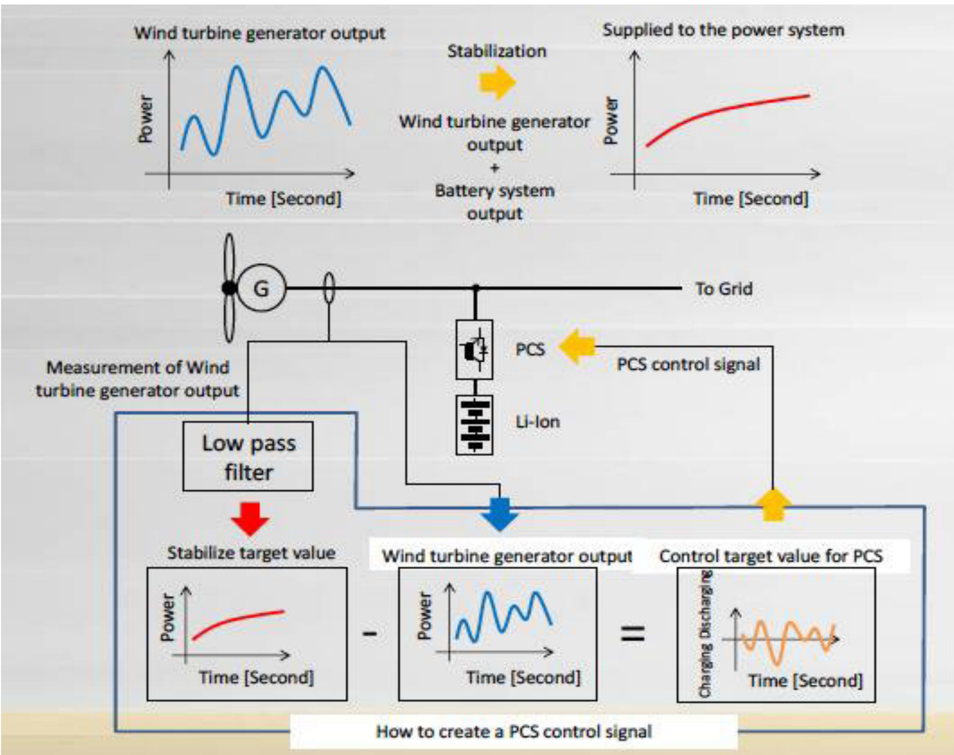

Figure 55: Li - Ion Batteries
Source: (MEER, 2013a)

In the context of reliability of supply, it is also important to mention that it is planned to relocate the thermal power generators from Puerto Ayora to Baltra. It is expected that having the thermal power generation, PV, batteries as well as wind power close to each other will facilitate better management of the hybrid system and reduce costs (ERGAL/ MEER/ UNDP, 2007). Nevertheless, it is unknown if this could increase losses through transmission of electricity over larger distances.

In addition, it has been planned to include a desalination plant in the second phase of the system to absorb excess wind power electricity generated during low demand periods (ERGAL/ MEER/ UNDP, 2007). It is expected that this water treatment plant will have a constant load of 262 kW and improve the efficiency of the electrical system, thereby reducing operation costs (ERGAL/ MEER/ UNDP, 2007: 71).

Regarding investment security, it is important to emphasize again the missing private investments. Financing for the wind park has been secured with contributions of MEER and UNDP-GEF (ElecGalápagos, 2014b) and the PV and storage in Baltra will be financed with contributions of MEER and JICA (Japan International Cooperation). Currently, a redesigning of the specifications for a second international tender round is underway for the storage system (ElecGalápagos, 2014b). The PVPP in Puerto Ayora is currently built through contributions of MEER and KOICA (Korean Cooperation Agency).

5.4.3. Socio-Economic Energy Equity

The access to electricity on Santa Cruz was already good before the RES-E projects since in Puerto Ayora 99.5%, in Bellavista 97.3%, and in Santa Rosa 97% of the population were connected to the public grid in 2010 (Gobierno Autónomo Descentralizado Santa Cruz, 2012b: 286f.). There is no information as to whether or not the deployment of RETs in this case will further improve access, but it can be assumed that the construction of the transmission line will have a positive influence on electricity access.

Regarding affordability of the electricity supply, in the short term no adjustments for the residents are expected since they benefit from very low and legally fixed electricity prices. Nevertheless, for the supply side, implementing RETs will have a positive impact on their profitability and will allow them to maintain the low prices for the population. This can be seen by comparing the real costs of thermal electricity generated in Puerto Ayora of USD 0.23 kWh (ERGAL/ MEER/ UNDP, 2007: 115) and the expected costs for the RE system according to the project design (ERGAL/ MEER/ UNDP, 2007). It has been calculated that the specific energy generation costs for the electricity generated through the wind park will be between USD 0.1293 and USD 0.1752 per kWh, depending on turbine type and financial model. This is more than the currently subsidized thermal electricity generation price of around USD 0.09 per kWh. However, when considering the real costs of thermal electricity – including the diesel subsidy transport and electricity subsidy – around 5-10 cents per kWh could be saved (ERGAL/ MEER/ UNDP, 2007: 113).

RES-E generation costs are expected to be higher if costs for the PV and storage system would be included and if the same assumptions would be true for Santa Cruz than for Isabela[122]. Nevertheless, a study by IRENA (2012b: 25) demonstrates that this is not necessarily the case. They assume levelised costs for thermal electricity at USD 0.53, hybrid PV-thermal system at USD 0.55, and a reduction of costs in case the hybrid system is supplemented by a storage system allowing for USD 0.42 per kWh. Nonetheless, the costs will increase to USD 0.68 if the thermal back-up is removed and the system is based on 100% renewables with a very large storage. Therefore, a project specific calculation would be needed to evaluate the affordability of the RE system.

In the context of the affordability it is, however, important to mention that extra costs have originated due to mitigating negative environmental impacts of the grid connection. For instance, the overhead line could not follow the shortest way to avoid the protected Galápagos National Park area (ERGAL/ MEER/ UNDP, 2007). In addition, the choice to pass the Itabaca channel and continue on Santa Cruz with an underground cable produced much higher costs and challenges for maintenance.

Two aspects are significantly increasing the QOL of the residents in Santa Cruz: First, the relocation of the thermal power plant to Baltra, as well as the installation of the wind turbines on the rather “industrial” and nearly unpopulated island (ERGAL/ MEER/ UNDP, 2007). This reduces negative impacts on humans such as noise, air pollution, transport of fuel, and potential shadow flickering. Second, the construction of a desalination plant on Baltra with a capacity of at least $100m^3$ per day would significantly increase water quality and availability improving health and QOL of the population (ERGAL/ MEER/ UNDP, 2007).

No precise information is available to indicate the other socio-economic impacts of the hybrid system on Santa Cruz and Baltra. However, considering assumptions that have already been discussed before, for wind energy, solar PV in general and the PVPP in Floreana, the project is expected to have positive influence on

[122] The expected costs for electricity generation per kWh are USD 0.19 for PV, USD 0.62 for PV and Storage system, USD 0.66-0.9 for Jatropha and USD 0.52-0.67 for diesel generation (Lahmeyer International/ MEER, 2012: 70).

prosperity and employee health and safety. Nevertheless, to assure positive impact it is necessary that the specific project is developed and executed sustainably under involvement of the public and thereby also increasing social acceptance.

5.4.4. Environmental Sustainability

From an environmental point of view, the project is very complex and has various aspects, due to the fact that the hybrid system combines different RETs on two different islands. In the case of Baltra, it is imperative to consider that the island is not pristine but rather “industrial” for assessing environmental impacts. During the Second World War, the construction of a military base with airport by the US presented an intrusion and alteration of the environment on Baltra. Currently, there are no residents living on the island, besides some persons in charge of the airport, a fuel terminal, and navy personnel. Therefore, impacts on humans are negligible.

In addition, the site for the wind turbines on Baltra has been chosen based on a declaration of the Charles Darwin Foundation that there are no petrel birds on the island, nor is there any significant activity of bats or other endemic species (ERGAL/ MEER/ UNDP, 2007). Nevertheless, impacts on flora and fauna, such as tortoise, do exist, both during construction *and* operation due to noise generation and alteration of the site. The impact on the flora is relatively small on Baltra compared to other sites as vegetation is generally scarce and not much soil movement is required. Additionally, infrastructure is available and therefore only few interventions into nature are needed.

The transmission line with a total length of around 50 km has been designed with the aim to minimize visual and environmental impact on both islands. In addition, the electrical line will remain outside of the national park area or will be covered underground. This is necessary to protect birds, as the line crosses the whole island and therefore their flight route and avoids any visual impact, which could eventually negatively affect tourism (ERGAL/ MEER/ UNDP, 2007). The PVPP in Puerto Ayora is next to the city in a commercial area in the proximity of the thermal power stations. Therefore visual influences are low. Regarding other environmental impacts, such as of PV on water resources, RETs in general on GHG emissions and LUC, the same is true as discussed before.

5.4.5. Sustainability Assessment

The Sustainability Assessment of the hybrid system on Santa Cruz and Baltra can be represented graphically when the above-mentioned arguments are translated into numbers[123]. Doing this allows a comparison of the conventional fossil-fuel-based electricity system with a system based either only on wind or solar PV and storage. The hybrid system then represents the sustainability of the current electricity system based on the actual share of diesel and renewables in 2015.

Table 33: Sustainability Assessment of Santa Cruz and Baltra
Source: Own elaboration

	Reference Fossil Fuel based System	Wind	PV + Storage	Hybrid System (Diesel + Wind + PV + Storage)
Energy Security	0.83	2.33	3.17	1.37
Environmental Sustainability	0.00	4.50	3.92	1.29
Socio-Economic Energy Equity	0.75	4.25	3.33	1.71
Technological Feasibility	4.00	4.00	4.00	4.00

Table 33 and Figure 56 illustrates that a high score has been reached concerning technological feasibility of wind, solar PV and the hybrid system, revealing that a main focus has been on this aspect. The technical viability is affirmed since the potential for RETs is high and international technical knowhow supports the implementation of a stable hybrid system.

Furthermore, Figure 56 shows that both wind and solar PV have the potential to increase environmental sustainability, socio-economic energy equity as well as energy security compared with a purely fossil fuel based system. Nevertheless, this potential cannot be realized to a full extent, since the share of wind will be 20% and PV 10%. Hence, fossil fuels will still be required dampening the results of the sustainability evaluation.

This demonstrates that further efforts are needed to create a fully sustainable electricity system on Santa Cruz and Baltra. It can be assumed that a focus on extending the overall capacity would increase environmental sustainability as well as socio-economic energy equity. In addition, a focus on incorporating other types of renewables, such as wind and using the excess energy generated, for instance by incorporating storage, would improve the sustainability of the system also with respect to energy security. Another possibility would be the integration of a

[123] Since many aspects are rather vague, they are provided with a linguistic representation and the intent has been made to translate them into numbers from 0 to 5. This has been done using fuzzy logic. See chapter 3.4 for more details.

desalination plant that uses to excess wind energy during the night to produce safe drinking water. Moreover, it can be assumed that a focus on incorporating small-scale RE solutions, such as rooftop solar PV and micro wind turbines could boost and promote RET deployment.

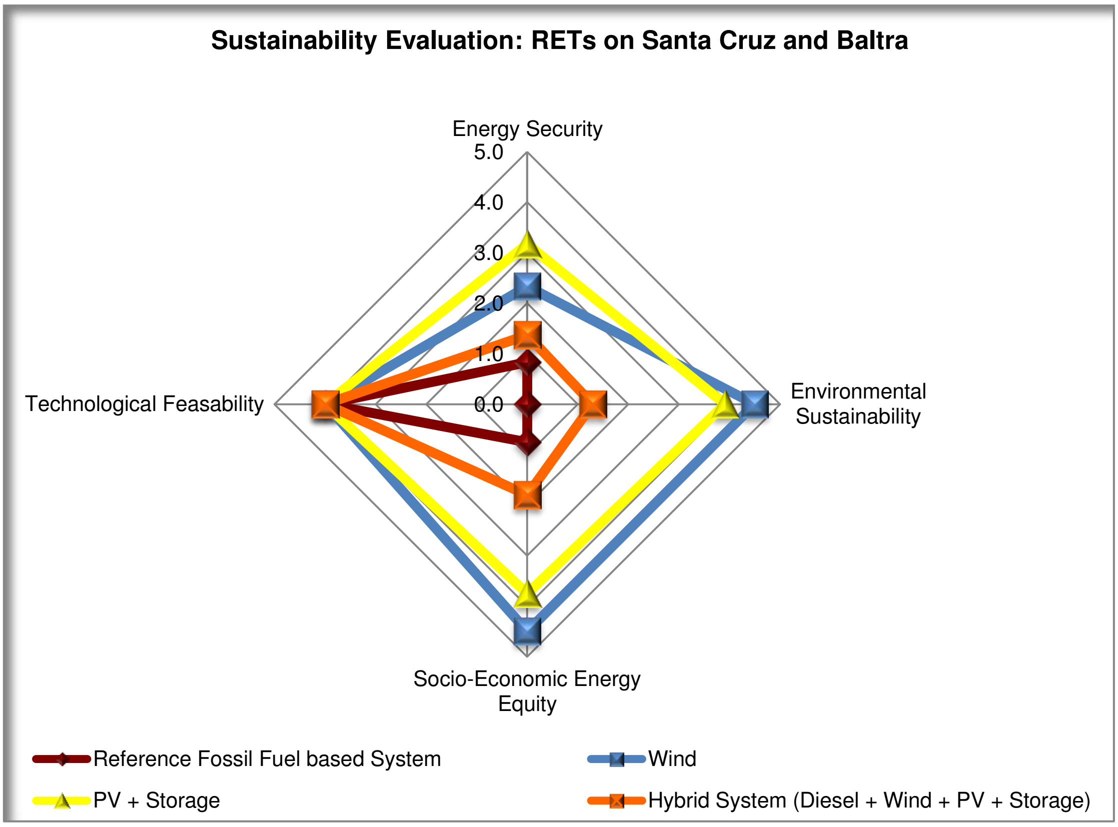

Figure 56: Sustainability Assessment Santa Cruz and Baltra
Source: Own elaboration

6. Conclusion

This chapter summarizes the results of the sustainability assessment of the Zero Fossil Fuels initiative by returning to the two main research questions that were asked at the beginning. The renewable energy systems of each island are put into perspective, drawing an outlook for future development and providing recommendations for improving sustainability.

6.1. Junction of the Sustainability Assessments

The thesis has attempted to assess the sustainability of the Zero Fossil Fuel Program on the Galápagos archipelago. At present, population growth, flourishing tourism and the increasing welfare are putting pressure on the delicate ecosystem and the existing infrastructure since demand for energy, water and other resources is increasing. Against this background the Galápagos Islands need to adjust their energy system by developing alternative scenarios protecting the environment and promoting socio-economic development. RETs are a possible solution to these challenges and have been identified as a priority by the Ecuadorian government, UNDP and the international community. Nevertheless, several aspects, such as financial constraints, uncertain legal framework and missing comprehensive strategic coordination have hampered the effectiveness and scale of the projects. After the first seven years, the review of the Zero Fossil Fuel Program constitutes that the ambitious goal to eliminate fossil fuels from the archipelago by 2015 will most likely not be reached (see Table 34). In addition, this study reflected not only on the success or failure of the initiative but also on the sustainability of the energy system. The fusion of the sustainability assessments of each island system shows that there is still a significant gap to bridge before a sustainable electricity system based on 100% renewables can be obtained. This review offers an opportunity to identify and fill the existing gaps and to develop more sustainable RE systems.

Table 34: Overview of the Status of the Renewable Energy Systems on Galápagos
Source: Own elaboration

	San Cristóbal	Floreana	Isabela	Santa Cruz
RES	Wind	Sun + Micro-Wind + Jatropha + Storage	Sun + Storage (+ Jatropha)	Wind + Sun + Storage
Share of RES expected for 2015	30%	62%	45%[124]	30%

[124] Share is without Jatropha since no detailed concept is available for the replacement of diesel by Jatropha on Isabela.

After having analysed the current status of the Zero Fossil Fuel Program on all four populated islands, a conclusion can be drawn based on the sustainability assessments of the single autonomous and decentralized hybrid systems. The results are aggregated and represented graphically and numerically[125] in Table 35 and Figure 57. In this way it is possible to compare the conventional fossil fuel based electricity system with the hybrid systems. Latter represent the sustainability of the current electricity systems of each island based on the actual shares of diesel and renewables in 2015.

Table 35: Aggregated Sustainability Assessment of Galápagos
Source: Own elaboration

	Reference Fossil Fuel based System	Hybrid System San Cristóbal	Hybrid System Floreana	Hybrid System Isabela	Hybrid System Santa Cruz/ Baltra
Energy Security	0.83	1.28	0.98	1.88	1.37
Environmental Sustainability	0.00	1.35	0.82	1.76	1.29
Socio-Economic Energy Equity	0.75	1.80	1.80	1.91	1.71
Technological Feasibility	4.00	4.00	3.00	4.00	4.00

Figure 57 illustrates that for all hybrid systems, a main focus has apparently been on the technological feasibility of the RETs and therefore a high score has been reached in this indicator. Isabela shows the best sustainability performance since the expected share of *new renewables*, such as wind and solar, is with 45% the highest on the archipelago. The hybrid system on Isabela is followed by the wind-diesel system in San Cristóbal and the PV-wind-diesel hybrid system on Santa Cruz and Baltra. While both systems have a RES-E share of around 30%, on San Cristóbal only wind energy is used, while on Santa Cruz and Baltra, different types of renewables are combined and integrated with a storage system. Due to the experiences made in Floreana, the usage of PV in combination with storage led to challenges and failures, and therefore, the sustainability assessment includes some reservations regarding technical feasibility. Nevertheless, these can be adjusted in case the system proves fully functional. The system on San Cristóbal is less complex and already fully operational. The hybrid system on Floreana is the least sustainable, although the share of renewables is with 52% the highest. The reason for this is the use of the bio-energy crop Jatropha Curcas. This vegetable oil needs to be imported, and therefore, it negatively affects energy security. In addition, the

[125] Since many aspects are rather ambiguous and vague they are provided with a linguistic representation and the intent has been made to translate them into numbers from 0 to 5. This has been done using fuzzy logic. See chapter 3.4 for more details.

combustion of the vegetable oil as well as the cultivation of the crop does affect environmental sustainability significantly stronger than solar PV or wind.

Nevertheless, it has been shown that the integration of more renewable capacity and the combination of different RETs will improve socio-economic energy equity, environmental sustainability and energy security. The potential for REs on Galápagos is high and international technical knowhow supports the implementation of the different RETs and hybrid systems. Nonetheless, these potentials cannot yet be realized to a full extent. Therefore, further efforts are needed to create fully sustainable electricity systems on all islands. In particular, an increase in overall installed capacity is required, as well as a combination of different RETs and an integration of energy storage.

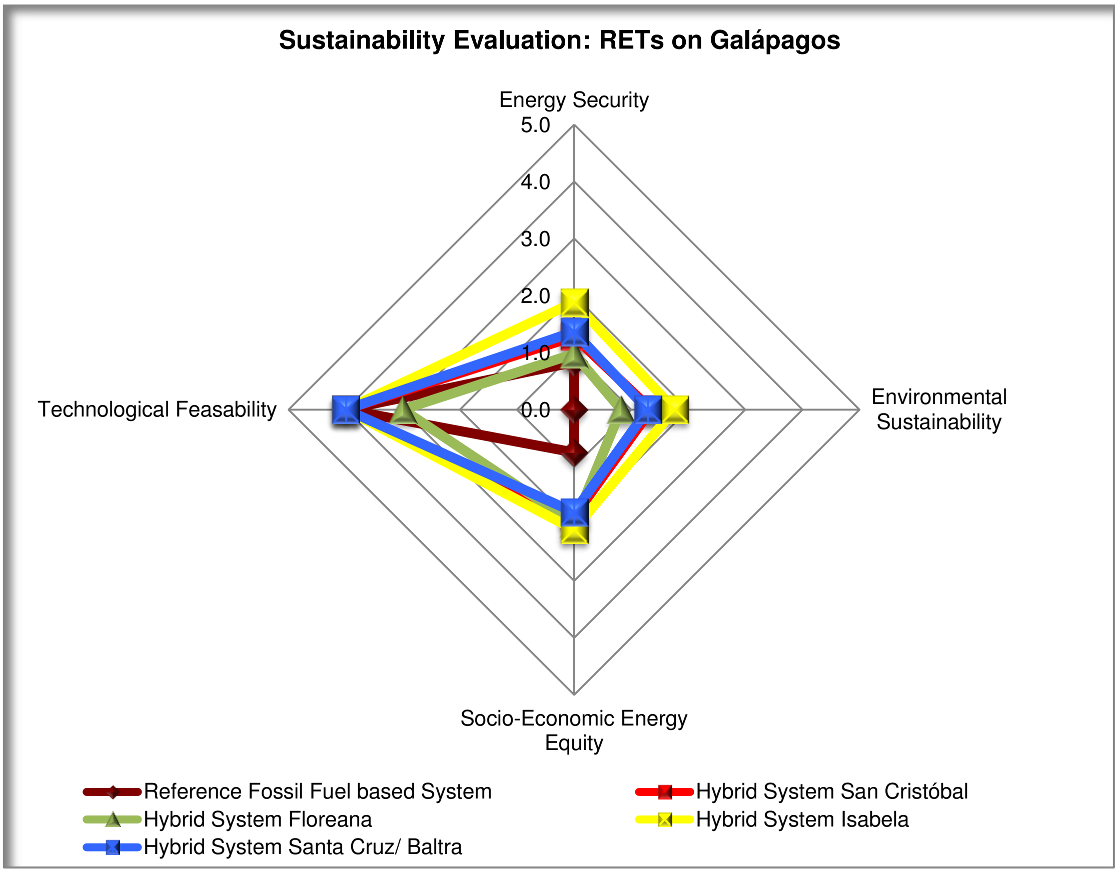

Figure 57: Aggregated Sustainability Assessment Galápagos
Source: Own elaboration

In conclusion, the results of the sustainability assessment emphasize the crucial importance of considering all dimensions of sustainability to get a fuller picture of the impact a RET can have in a certain environment. This can help to identify the most sustainable solution for a specific circumstance. Overall, the study has shown that eliminating fossil fuels from the Galápagos is all but an easy task.

6.2. Outlook

The analysis of the current status of the Zero Fossil Fuel Program reveals that although the Galápagos seem to be on the right track, there is still effort needed to achieve the proposed goal while it is critical to pay attention to several yet insufficiently considered aspects. Primarily, understanding the drivers of local energy demand is critical to effectively reduce fossil fuel consumption in the future when planning sustainably. The missing comprehensive planning of development on Galápagos has already been criticised in 2010 (Curbelo, 2010: 56).

One of the most important key drivers of energy demand is the number of consumers. Therefore, population growth will influence the sustainability of a certain energy system. In the case of Galápagos there has been a very fast population growth from 4,000 inhabitants in the 1970s to around 26,000 in 2010. Nevertheless, stricter immigration regulations are expected to slow down the population increase (INEC, 2010b).

Another important driver that influences the energy demand both directly and indirectly is economic growth. On the one hand, economic prosperity in Galápagos is based on tourism. An increased number of tourists directly provokes higher energy demand due to their activities and higher standard of living. On the other hand, the increasing prosperity creates a new middle class that is legitimately aspiring to increased comfort of homes. Nevertheless, this and the consumption of additional electrical domestic appliances induce higher electricity demand (Curbelo, 2010: 56).

Thirdly, the demand for freshwater can influence energy demand, as water and energy are closely interrelated (see chapter 4.4.2). The installation of a desalination plant would most probably have the single most significant impact on electricity demand[126]. As population expands, tourism increases and so, too does the desire for a higher standard of living. Also, water reservoirs are depleting and underground water quality is deteriorating. This allows the projection that the need for desalination on Galápagos will rise rapidly (Baziliana et al., 2011). Therefore, implementing RETs for desalination, such as thermal desalination[127] technologies based on solar energy, should be considered. Integrating a desalination plant could

[126] The desalination plant in Floreana was expected to consume around 75 MWh per year and produce around 40m^3 of water per day in 2009. For 2017 an electricity demand of 90 MWh per year and a production of 50m^3 per day were planned.

[127] Thermal desalination technologies, which under the appropriate conditions can be based on solar energy, rely on the distillation processes to remove fresh water from salty water. Saline feed water is heated to vaporise, causing fresh water to evaporate as steam, leaving behind a highly saline solution namely, the brine. A feature of this technology is that it can utilise excess thermal energy. Thus, it is possible to combine the production of large amounts of power and water in one station.

also be a way of using excess energy, for instance form wind energy during the night, when electricity demand is low to shift the loads. Nevertheless, Molina (2012: 52) points out that the complex desalination technology needs to be operated, maintained and purchased, which could pose serious barriers to its deployment. Pumping and wastewater treatment is a further driver of energy demand related to water. These could become relevant as currently an adequate sewage system is non-existent (Rueda, 2009; Molina, 2012: 54; Stumpf et al., 2013: 181).

A fourth essential aspect influencing energy demand is the transformation of the energy matrix (CONELEC/ MEER, 2013). In this regard, Ecuador intends to exchange kitchens using LPG [128] with electrical stoves based on inductive technology because they are more energy-efficient and faster than traditional electric cooking surfaces (MICSE, 2012: 35; CONELEC/ MEER, 2012: 83). To meet this goal, the MEER developed the National Plan of Efficient Cooking – *Plan Nacional de Cocción Eficiente* (Vizhñay and Patricio, 2013). In case of successful implementation on Galápagos, a reduction of gas by nearly 95%[129] is feasible while electricity demand will increase significantly. To assess the sustainability of this plan, however, it would be necessary to consider additional aspects such as the cooking efficiency of stoves as well as ambient heat generation[130].

An enormous impact on the energy matrix would also be conceivable if transport would be transformed so that vehicles and vessels would be able to use electricity instead of fossil fuels. Although this would increase electricity demand, it would decrease risk for oil spills immensely, and could also be an opportunity to integrate electricity storage options – allowing for advanced demand-side management. Maritime transport is the most relevant sector for fossil fuel consumption [131]. Therefore, to reach the Zero Fossil Fuels goal a focus has to be put on the maritime transport sector. Although, there are possibilities available to reduce the fuel consumption, including the use of sailing boats and solar boats, there are only few

[128] According to reports from governmental agencies 96% of the LPG demand comes from the residential sector, the missing 4% is from industry and commercial sector. Nevertheless, realistically a significant amount of around 20%-35% of the LPG is expected to be sold across borders or used in the commercial sector but declared as private use. The reasons for that are the high subsidies for LPG keeping the prices low. A 15kg cylinder has a domestic price of USD 1.60 while the real costs are around USD 12. In Colombia, the same amount of gas costs USD 7.65 and in Peru USD 15.30 (Vizhñay and Patricio, 2013).

[129] In Galápagos 93.3% use gas for cooking, 0.8% electricity, and the rest uses either biomass such as wood, charcoal or agricultural residues (INEC, 2010a).

[130] Ambient heat generation through gas cookers and respective efficiencies might change as excess heat requires ventilation or air conditioning in hot climates or replacement through additional heating in cold climates.

[131] On Galápagos the transport sector accounted in 2012 for 75% and 6.6 million gallons of diesel fuel and 3.1 million gallons of gasoline (Curbelo, 2011; Ramos Malo, 2012; PetroEcuador, 2013). Maritime touristic vessels are the greatest consumers with 5.1 million of gallons diesel, accounting for around 50% of the total fossil fuel consumption.

concrete initiatives under way[132] (Zaun, 2010). For instance, Watkins and Cruz (2007) doubt that a reduction of fossil fuels can easily be achieved since only few RETs are readily available and a cutback in the number of cruise ships is unlikely from an economic perspective[133].

Regarding terrestrial transport, a recent publication of the Galápagos Report states that the population on Galápagos is increasingly accustomed to motorized vehicles despite their negative environmental impact[134] (Cléder and Grenier, 2010). In addition, a survey by Westerman (2012: 117) suggests that removing subsidies from fuel for terrestrial transport would motivate residents to reduce their use of cars and instead, walk or use a bicycle. Nevertheless, to reach social acceptance, it is necessary to implement additional measures and incentives. For instance, these could include an expansion of bicycle lines and offering courses how to use the bicycles safely. In addition, expanding public transport for elderly and disabled, should be considered as well as certain occasions where bulky items have to be transported. Furthermore, electrical vehicles need to be taken into account (Arthur Morgan Institute for Community Solutions, 2013). Additionally, a transformation of public transport to be based on electricity would allow to reduce fossil fuel consumption, risk of oil spills, allow for flexible load shifting, and also reduce air pollution such as CO, Sulphur, Nitrogen, particulate matter, poly-aromatic hydrocarbon and heavy metals. However, significantly more research is required to develop sustainable mobility concepts[135].

All the above-mentioned aspects can foster a growth in electricity demand and

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[132] For example, Toyota has worked with the Ecoventura tour group to outfit four ships with hybrid power systems utilizing wind and solar. In addition, there are rumours that Toyota might be offering incentives for permanent residents to exchange their current vehicle for a hybrid car. In addition, many of the tour ships have a desalinization system on board and are using biodegradable soaps and shampoos (Leffel, 2010). Furthermore, INER is working currently on a passenger solar boat for the Itabaca Channel.

[133] A stricter control of new licenses and the introduction of a regulating agency would probably help to avoid a future increase in tourist vessels. According to Art. 43 of the State Administrative Galápagos National Park, it is the right of the tourism operations who are qualified by the Ministry of Environment through the Galápagos National Park Service and approved by the Governing Council natural or legal persons to exercise the right to develop a particular tourist operation activity. A list of ships with the respective company names, number of passengers allowed, and additional information are in the tourist information system at the following link: http://www.Galápagospark.org/documentos/turismo/pdf/Listado_de_embarcaciones_2011-2012.pdf

[134] There is overpopulation of taxis on Santa Cruz due to a lack of regulation on the entrance of vehicles and the lucrative nature of the industry (Cléder and Grenier, 2010).

[135] The Galápagos Geographic Index Project has collected and analysed a large amount of data about perceptions, attitudes and life styles from the local population and tourists. The project also includes information about the most important service sectors including water supply, transportation, waste management, and tourism. They are currently researching the mobility and movement patterns of residents and tourists. All this information is geo-referenced and digitized and fed into a geographical information system, which will provide a tool for further investigations about the impacts and relationships between populated areas and protected areas and their users. More information can be found on the following link http://www.darwinfoundation.org/en/news/2013/01/04/studying-human-mobility/.

therefore need to be considered when planning the RES-E system sustainably. Nevertheless, even if the drivers are known efforts have to be concentrated on restraining or reducing demand. In the case this is not done, the electricity system will become increasingly expensive because more and more generation capacity needs to be installed. At some point it would not be any more economically and environmentally feasible to increase RE capacity. In addition, RES potential is restricted and cannot be extended indefinitely. This “point of no return” is illustrated in Figure 58 indicating that it is not possible to simply move from fossil fuels consumption to using RES while maintaining high levels of, or even increasing, energy consumption. REs might not be sufficient to cope with elevated energy demand and to sustain the consumer society of today (Trainer, 2010). Therefore it is essential to also consider demand side management (DSM) such as energy efficiency measures to reduce energy demand.

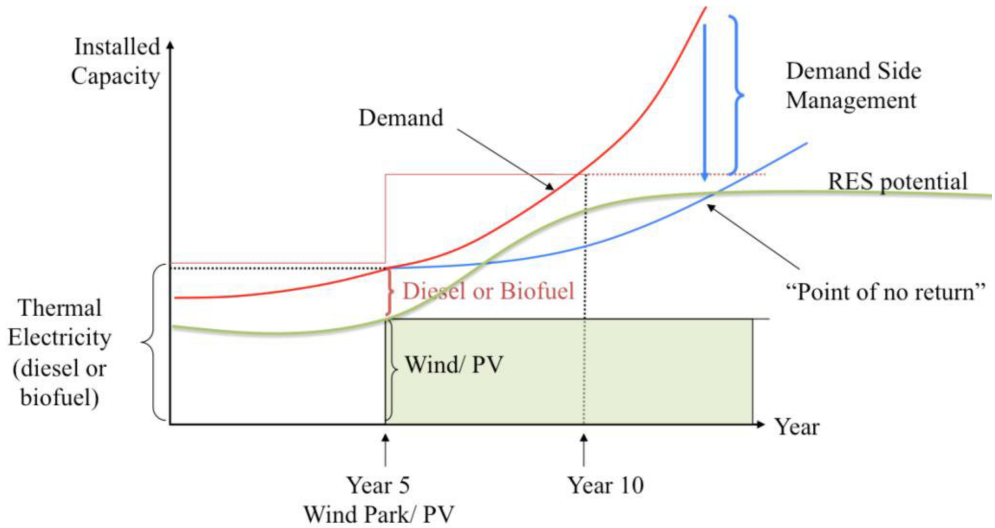

Figure 58: Demand and Supply and the “point of no return” to Renewables
Source: Adapted from (ElecGalápagos, 2011)

Possibilities to offset demand growth are based on DSM including financial incentives and energy efficiency measures as well as demand response. DSM refers to the modification of consumer demand either by shifting it in time, or reducing the overall consumption (Brauner et al., 2006). These measures include financial incentives, education and energy storage.

In the context of energy efficiency, there are critics that measures on Galápagos have been insufficient (Curbelo, 2010). Experts assume that the residential sector is the most relevant on the archipelago for fast energy efficiency results. For instance, Lahmeyer and MEER (2012) expect that around 70% of the total electricity demand goes back to electrical household appliances, with refrigerators using 50-60%, lighting 20%, and air conditioning 15% (CONELEC/ MEER, 2012: 82). In addition, they assume that the demand of the residential sector could be reduced by around 4.5% thanks to energy saving (Lahmeyer International/ MEER, 2012). Possibilities in this area have been identified for air conditioning, refrigeration and lightning. In this regard the Ecuadorian government has launched the nation wide program *Programa RENOVA* (Renewal Program). This initiative aims at replacing refrigerators that are older than 10 years with new energy efficient appliances. On Galápagos 3,000 fridges[136] will be available at a low cost to residents consuming less than 200 kWh per month (MICSE, 2012: 35; CONELEC/ MEER, 2012: 83). A study conducted by *GalagoSolar*, finds that an average refrigerator on Galápagos consumes around 1,105 kWh annually (Westerman, 2012). The new appliances chosen are expected to consume approximately 780 kWh annually (MICSE, 2012: 35; CONELEC/ MEER, 2012: 83). For comparison, the most energy efficient refrigerator/freezer combination in the EU in 2014 consumed 130 kWh annually (Zygmund, 2014). Although the program is generally positive, the comparison shows that energy saving could be higher when more energy efficient fridges would be selected. Despite their likely higher initial price, the lower consumption would reduce subsidies on a national level, electricity costs in the households and environmental risks due to saved fuel imports, transports and burning. Aside from refrigerators, the government plans to increase energy efficiency of lightning by replacing 32,400 lamps in Galápagos (MICSE, 2012: 35; CONELEC/ MEER, 2012: 83; CONELEC/ MEER, 2013). In this regard Lahmeyer and MEER (2012) expect that a change of lightning from filament lamps to fluorescent lamps in households and hotels could save around 1.5% of the total annual electricity demand[137].

Another important aspect that could reduce energy demand is bioclimatic housing. Currently, most residential constructions have not taken into consideration ecological criteria. Therefore, it is expected that the potential to adjust housing, adequately to the climatic conditions is high. Possibilities are illustrated in Figure 59 and include the integration of shading, isolation, or controlled ventilation, as well as solar systems for heating and cooling[138]. This would allow reducing energy

[136] In total there are 330,000 refrigerators available all over Ecuador.

[137] In addition, with the aim to remove the fossil fuels on the archipelago the government aims at changing public lightning. In 2010 the public lightning consumed 1.243 MWh, which is 4.2% of the electricity consumption of the islands and 1,377 MWh in 2012 (MEER/ CONELEC, 2012: 91).

[138] One interesting comparison here would be the Canary Islands with a similar climate. On Tenerife, the “Instituto Tecnológico de Energías Renovables” conducted a competition concerning bioclimatic houses, which had as a result a diverse choice of designs and materials (ITER, 2011). Furthermore, there are even more innovative ideas emerging such as the possibility to integrate algae to provide energy and shade for buildings (Milton, 2012).

consumption by also considering other environmental and health aspects, such as adaptation to climate change and the eradication of asbestos[139] (IARC, 2012). In this regard, MIDUVI launched a pilot project[140] to construct 25 ecological houses on Galápagos that shall be equipped with natural ventilation, proper disposal of sewage, energy and water self-sufficiency (such as rain, solar energy systems for water heating and electricity generation), native gardens and thermal isolation. They are expected to have a price of less than 14,000 USD plus 7,000 USD for the solar system (Mena, 2011; InsularGalápagos, 2011; InsularGalápagos, 2012).

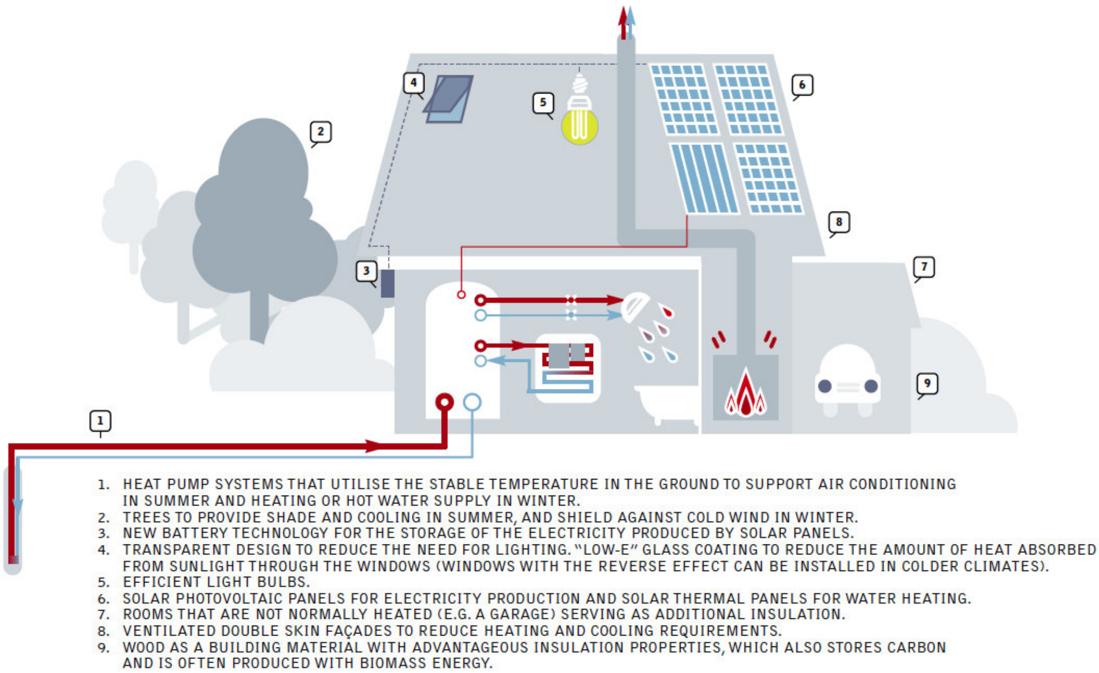

Figure 59: Elements of new building design that can substantially reduce energy use
Source: (Greenpeace/ EREC/ GWEC, 2012: 268)

Most importantly, however, it is to change the behaviour of the consumer since this is the fastest, simplest and cheapest way to save energy. It is important to emphasize that energy consumption is directly linked to the prices for energy. Therefore, the relatively low consumer prices for fossil fuels and electricity on the islands do not encourage energy saving behaviour (Westerman, 2012: 115). Hence, increasing prices charging the real costs of energy generation would enhance the attractiveness of energy saving and investments into alternative energies. To be effective this has to be coupled to an education campaign and awareness rising to

[139]Ecuador is one of the countries with the largest per capita utilization of asbestos, which is dangerous for human health due to its cancerogenic effects (IARC, 2012).
[140] The national government, MIDUVI in cooperation the governing council of Galápagos developed a pilot plan „Plan Piloto de Viviendas Ecológicas para Galápagos" (Mena 2011). Finally, 19 houses were built in Isabela, two in Santa Cruz and four in San Cristóbal. Although the total project price increased from 330 to 380 thousand USD the houses have not been equipped as expected, for example solar panels seem to be missing (InsularGalápagos, 2012).

promote accessibility and knowledge about RETs.
Finally, it is important to emphasize that for a successful reduction of demand in an autonomous decentralized RE-based micro-grid, aside from DSM, storage options and an intelligent management of the system are crucial (Einfalt et al., 2011). Both centralized and decentralized storage options, such as batteries and pro-active houses or battery electric vehicles respectively, are vital to reduce the need for oversizing and to smooth out fluctuations of renewables (Einfalt et al., 2011; EnerNOC, 2013). In addition, demand response, which is the temporary reduction in load, makes the system more reliable, enables higher RES harvesting and reduction of operating costs (EnerNOC, 2013; de La Selle and Pichori, 2008; Critz et al., 2013; Einfalt et al., 2011). Examples include the direct load control of end-use devices such as air conditioners and water heaters, but also price based initiatives such as critical peak pricing, time-of-use pricing and real time pricing (EnerNOC, 2013). Curtailments can be done either manually or through automation.
The complexity of combining various RES at different sites with varying volatilities requires – if a reliable system shall be provided – that the "demand will be adapted to the stochastic supply at any time by an intelligent balance- and control algorithm" (Einfalt et al., 2011: 1). Such an automated energy management control system would integrate the demand into a virtual power plant (Greenpeace/ EREC/ GWEC, 2012: 34; EnerNOC, 2013). For instance, intelligent appliances will have the autonomous and individual ability to change their demand and react to power deficiencies or surplus without falling below their emergency supply (Einfalt et al., 2011). Attention should be paid to specific consumers such as hospitals and airports providing them with the possibility to opt-out if their circumstances prevent them from participating (EnerNOC, 2013).
In conclusion, reaching the Zero Fossil Fuels goal will only be sustainable and feasible if RES are combined, the grid intelligently managed through integrating storage possibilities, demand response and the highest efficiency (Einfalt et al., 2011; Elliston et al., 2012; Critz et al., 2013).

6.3. Recommendations

"Innovation rarely happens in a vacuum. It will be driven by: a real or perceived need; or a financial incentive" (Hussey, 2010: 8)

A glance back in history shows the importance of Galápagos for understanding human evolution. The time has come to progress and to reduce the risks the archipelago faces due to unsustainable use of resources and the use of finite fossil fuels that put pressure on the delicate ecosystem. With the aim to live in better harmony with the nature and to reduce risks of pollution, the goal is to eliminate fossil fuels on the islands by implementing a sustainable 100% RE-system. The need for changing the conventional energy system on Galápagos is especially pronounced since it suffers from elevated energy generation costs, tremendous dependence on imports and risks on ecosystems. In contrast, plenty of freely and indigenous RESs are available, and the international community provides remarkable financial and technical support. During this study it was possible, by analysing the current status of the projects and through alignment with other RE systems, to identify certain barriers that currently seem to impede the success of the Zero Fossil Fuel Program. As a consequence the following recommendations have been defined that could help to overcome the barriers. Reflecting on them could support during the redefinition of the strategy on how to eliminate fossil fuels sustainably.

Recommendation 1: Include Energy Demand Management

Currently, the energy system on Galápagos is characterized by strongly growing demand, wasteful use of electricity and a focus nearly exclusively on the supply side. Therefore, the integration of energy demand side management (DSM) is crucial to reduce and shift demands so that it can be delivered by renewables. An essential element is proper knowledge about energy demand in the future. This would, for instance, include the installation of water meters to be able to plan energy demand for water desalination. Possibilities to incorporate demand response management include air conditioning, washing machines, television, refrigerators, and in the future, also managing the charging cycles of electric vehicles. In case RES-E supply shortage is predictable, such as wind shortage during the hot season, it is conceivable to provide the consumers with a fixed timetable for their assigned curtailment. This could be done, for example, per street or district. Nevertheless, it is important to be conscious that a barrier to consumer participation in demand response programs is lack of education about the environmental and financial impacts (Critz et al., 2013: 618). Therefore, an introduction of demand response would need to be accompanied by an educational campaign to be effective and sustainable. Nevertheless, more investigation by experts who have high level of intimacy with all concerned processes on the islands is needed, to design an adequate and sustainable DSM system. For instance, if refrigerators should be switched off certain hours than they need to be well-insolated. These ideas and concepts should be considered for Galápagos through conducting a feasibility study concerning costs, technical feasibility, ecological and social issues. Subsequently they could be implemented through a pilot project and then rolled out.

To complement DSM it is necessary to integrate energy efficiency and create an atmosphere of energy sufficiency by raising awareness, encouraging energy saving and utilizing efficient electrical appliances. For example, extending the "*Programa RENOVA*" to include other appliances such as air conditioning should be considered. Moreover, it is important that the most energy efficient solutions are selected and implemented to reach the best possible effect. However, policy makers should consider that offering trainings to raise awareness about energy saving is the cheapest option to reduce the demand and is vital to realize 100% coverage through RETs. Raising awareness combined with offering possibilities to save energy would reach more residents and encourage the use of energy efficient appliances. Thereby fossil fuels consumption as well as public and private expenditures at all levels would be reduced. In addition, the risk of oil spills and pollution caused by combustion would be diminished. Both efficiency and sufficiency strategies have an important role to play in the future of a sustainable RES-E system.

Recommendation 2: Strengthen Good Governance by Creating Synergies supported by implementing a Coordination Body

Currently, neither ERGAL nor the governing council of Galápagos have adequate capacity to implement a sustainable 100% RES system on all four populated islands of the archipelago (Curbelo, 2010: 59). As a result, the RE projects implemented at present are characterized by missing synergies. Nevertheless, these are vital to develop sustainable solutions since they allow reducing costs, drawing lessons learnt, and creating a knowledge base. To foster the creation of synergies it would be beneficial to implement a RE institute on Galápagos, to coordinate, as well as support execution and operation of the projects. This association should also conduct capacity building and promote research. Furthermore, joining international networks and connecting with other 100% renewables initiatives[141] would promote exchange of knowledge and advance the elimination of fossil fuels from the islands more sustainably. In addition, the creation of an energy ministry on the national level is crucial to coordinate all types of energy: electricity, transport, and fossil fuels. If these institutions are complemented by enhanced cooperation, public participation, and dialogue among stakeholders a sustainable initiative would be promoted.

Recommendation 3: Include Transport into the Zero Fossil Fuel Strategy

A sustainable transport strategy is required to complement the Zero Fossil Fuels plan for the electricity sector because transport is the largest consumer of fossil fuels. On the one hand, terrestrial transportation options need to be adjusted. This sector shows a clear potential for energetic improvement through simple measures, such as increasing the number of bikes, decreasing the number of cars and expanding public transport options. For instance, an expansion of public transport through minibuses circulating regularly between the ports and the highlands could be another possibility to reduce energy consumption. The use of bicycles would be encouraged through expanding bicycle lanes and narrowing roads. Combined with courses for biking and creation of knowledge on the benefits for both individual health and the environment would encourage residents to use the bicycle increasingly. In addition, the introduction of electrical vehicles should be promoted while RES-E is expanded. Nevertheless, for the efficient and sustainable use of electrical vehicles capacity building is necessary as well. Both the drivers and the mechanics need to be aware how to best maintain the functioning of the cars and batteries. If correctly implemented, electrical cars could store excess electricity produced during night by the wind turbines and use it during the day. On the other hand, maritime transport possibilities need to be adjusted because maritime vessels for touristic purposes are the largest consumers of fossil fuels. However, it is also the most challenging to reduce, as technologies are not yet readily available for all maritime requirements. Nevertheless, available technologies such as on board RETs could provide electricity in cruise cabins and thereby reduce the fossil fuel being used by generators on board. A noteworthy initiative has been started by INER to develop a passenger Catamaran driven by solar energy. This boat shall transport up to 42 passengers between Baltra and Santa Cruz crossing the Itabaca channel as from October 2014 (INER, 2014). Nevertheless, additional research is necessary to develop a sustainable – all-encompassing – mobility concept[142].

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[141] For instance: Global 100%RE (See the following link for more information: http://go100re.net/).
[142] Currently a Galápagos mobility plan is under development (MTOP/ INECO, 2012; MTOP, 2014).

Recommendation 4: Integrate Small-Scale Solutions

Currently, RE projects on Galápagos are characterized by their rather large scale and centralized nature. Nevertheless, according to several studies (Westerman, 2012; IEA-RETD, 2012; IRENA, 2013), policymakers agree that utility scale RE projects will not be able to cover 100% of the Galápagos energy needs. Therefore, decentralized small-scale solutions that could be realized faster, and thereby show sooner results, need to be integrated. They would also allow for a better adaptation to the landscape of the islands.

Tangible small-scale RET solutions include the adaptation of residential homes, hotels and offices to become both energy consumers and energy producers, which are also known as PROSUMER solutions (Einfalt et al., 2011). Examples embrace roof top PV, micro wind turbines, as well as RE cooling and heating. In order to implement these technologies and integrate them, a so-called decentralized mini-grid is required[143]. Hence, integrating local RES under single control allows balancing of the inefficiencies and volatility of wind and PV. On the one hand, consumers need to adjust their demand patterns to the grid capacity, while on the other hand, energy storage opens space for variations on the supply side. Additional capacity might be necessary, for example if a cloudy day limits the energy output of the PV system (Brauner et al., 2006; GEA, 2012; Brauner et al., 2012).

In order to promote small-scale solutions, a close coordination with the local residents is needed while identifying certain pilot areas for decentralized RET application. To facilitate these solutions a local RE development plan that defines the legal framework for installation, connection, and recycling of the materials and also to protect human and ecosystem health is indispensible. In this regard, experts and technicians should constantly be available for the implementation and operation of the RETs. Consequently, substantial human and financial resources should be allocated to sustain this initiative.

Recommendation 5: Incentivize Private Investment by increasing accessibility to RETs and removing subsidies

Thus far, financial limitations have hampered the elimination of fossil fuels on the Galápagos Islands. It has been widely recognized that private investments play an important role to facilitate the transition to a low carbon future by reaching a significant share of RETs, overcome high upfront investment and create economies

[143] For a sustainable micro-grid design sizing is critical. For instance, the load must be served with an adequate amount and quality of electricity while it must be accounted for load dispersion and variations. As a result, adequately planned electricity storage is required (Berezzi 2011). The overall objective is a balanced demand with the supply needs.

of scale (IPCC, 2011: 932; WEC, 2012; GEA, 2012: 1748). To promote private investment a stable regulatory framework for RETs is crucial as well as incentives brought forward through coherent and predictable governmental energy policies (Komendantova et al., 2009; Rosero and Chiliquinga, 2011: 52).

Moreover, to encourage local investment of residents into renewables, it is crucial to increase the accessibility to RETs. This requires capacity building of residents through regular classes or workshops to train locals on how to select install and maintain their technologies. In fact, this would not only increase the share of renewables, reduce the consumption of fossil fuels and mitigate the connected risks, reduce costs and increase energy independence, but also boost awareness for energy issues in general. Due to the current lack of small projects, the development of pilot projects on each island would be required after conducting the relevant surveys on how to integrate small-scale solutions into buildings and the grid. These pilots would allow the local technicians and community to acquire the necessary knowledge and inspire them. Consequently, substantial human and financial resources would be required to sustain this initiative and provide technical support.

A key factor to increase private sector involvement as well as to reduce energy consumption would be the redesign of subsidies since they are one of the largest barriers to increase the share of renewables on Galápagos. The excessive misuse of energy and subsequent exorbitantly increases in energy demand is due to low fossil fuel and electricity costs, as both are subsidized. In addition, subsidies make investments in energy saving technologies and appliances less appealing, as it prolongs their payback periods[144] (Westerman, 2012: 115). Therefore, policy makers need to consider redesigning subsidies in order to encourage energy saving, implementation of REs and energy efficient appliances. While energy costs for the commercial sector should slowly reach true costs, the socially deprived and poorer population will still require support to have a decent standard of living.

Recommendation 6: Enable Innovation and Allocate Resources for Research

Currently, RE development and deployment on the Galápagos are driven by foreign donors and experts – not only from a financial, but also from a technical point of view. However, the efforts of external donors might not be sufficient or they might be discontinued in future. Nevertheless, innovation and knowledge are crucial to eliminate fossil fuels sustainably from the archipelago. Therefore, it is necessary to encourage public and private initiatives that enable innovation and foster research,

[144] Payback period refers to the time it would take for the money saved from using energy-saving technologies to be equal to the cost of the initial investment in the energy-saving technology.

development and demonstration in all areas of energy technologies (WEC, 2012). It is of importance that substantial financial as well as human resources are allocated to the Zero Fossil Fuel Program. This could be done through establishing a fund administered by INER, MEER, ElecGalápagos or a local institute on the Galápagos such as CDREG or PNG. Interested residents should be able to request technical and financial support with this fund in an unbureaucratic and transparent manner.

Moreover, an allocation of additional and substantial resources for research and development would enable innovation and allow inclusion of new technologies. Such technologies for energy generation, demand reduction or energy system management could include fog harvesting[145]; portable PV systems for electricity generation; liquid biofuels from algae (IPCC, 2011); marine energy; bioclimatic housing with renewable heating and cooling systems; and energy storage. In addition, desalination with renewables will be one of the most important technologies to assure human health and ecosystem protection. Possibilities include desalination with wind and solar energy, for instance with ENERCON EDS S 1200[146] or solar-based desalination units[147] (IPCC, 2011: 351; ENERCON, 2012; ProDes project/ Intelligent Energy for Europe, 2010).

Recommendation 7: Consider Energy Recovery from Waste

Recovering energy from waste through incineration is difficult to implement on the Galápagos. According to the WWF (2010: 15), the amounts of waste are currently not large enough to implement a cost-efficient plant based on available technology[148]. Nevertheless, population growth and general economic development cause a steady increase in the amount of waste, which might be a reason to rethink the strategy in the future (Molina, 2012: 78). Today energy is recovered from waste only on a small scale. Oil from tourism boats and workshops on San Cristóbal and Santa Cruz is collected, exported and the energy created through its incineration is used in the cement production on the Ecuadorian mainland (WWF, 2010: 15). Other initiatives include the collection of organic waste on the islands for composting operations, and glass is recycled locally and made a part of paving stones (Leffel, 2010). Generally, it should be considered to reduce waste or to re-use it either through recycling, composting or energy generation. This would save fossil fuels in

[145] More information can be found on: www.Fogquest.org.
[146] More information can be found on: www.adu-res.org/pdf/Enercon.pdf.
[147] “Multiple-effect humidification desalination units indirectly use heat from highly efficient solar thermal collectors to induce evaporation and condensation inside a thermally isolated, steam-tight container.” (IPCC, 2011). For more information also see the report on water desalination by CSP from DLR and the discussion of SolarPACES Task VI.
[148] The WWF (2010) provides an overview of the type and amount of waste produced on Galápagos.

various aspects. For instance, less waste would be needed to be transported on the islands and to the mainland. Finally, recovering energy from waste could save fossil fuels used for electricity generation and be an alternative for flexible base-load energy for backing up intermittent RES. Nevertheless, it is necessary to analyse in detail the amounts and types of waste to create an economically viable solution that

Recommendation 8: Act Now

In particular, it is vital not to postpone the elimination of fossil fuels and the RET deployment. Currently, the fragile ecosystem of the Galápagos is still intact but oil spills could cause serious damages, hurting the economic prosperity of the islands. In addition, pressure on water resources will require alternatives to be found rather quickly since water scarcity could negatively affect biodiversity, ecosystems and human health. It is crucial to start acting at a time when monetary and technical supports are there. Currently, Ecuador's oil resources still provide large amounts of income that should be reallocated to support long-term sustainable development. In addition, RET is readily available as well as technical and financial support from the international community.

Recommendation 9: Adapt

Charles Darwin claimed that neither the strongest nor the most intelligent would survive but probably the one that adapts best to change or is the "luckiest" (Darwin, 1859). For the Galápagos Zero Fossil Fuel Program, it can be concluded that the energy systems should be adapted to the available renewable source. In addition, also residents need to adapt to the available resources and climate by choosing adequate housing, saving energy and selecting energy-efficient appliances. They have to commit to adapt to the special situation of the island by consuming less energy and accepting curtailments of their energy supply if necessary.

It is important to emphasize that these recommendations are in no way claiming to be complete. However, they might represent inspirations to reconsider and reformulate the Zero Fossil Fuel Program for the Galápagos archipelago. The initiative and the already realized projects indicate the intention of the Ecuadorian government and the international community to save one of the last paradises on Earth. At the same time, the islands show, in a microcosm, precisely what occurs all over the world:

"(E)nergy is the golden thread that weaves together economic growth, social equity, and environmental sustainability" Ban Ki-moon in WEC (2013: 10).

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Appendices

Annex 1: Zero Fossil Fuels Official Announcement[149]

Ministerio de Energía y Minas
República del Ecuador

Cero Combustibles Fósiles en Galápagos

Un país con el potencial de energías renovables como el Ecuador tiene que empezar a cambiar en forma drástica su visión energética. La tarea pasa por definir planes adecuados de aprovechamiento, así como el establecimiento de incentivos para que el uso de la energía solar, eólica, geotérmica, de la biomasa e incluso mareomotriz pueda ser una realidad. En las Islas Galápagos, para citar como ejemplo un caso, el Ecuador debe desarrollar todo un proceso de experimentación que permita en pocos años erradicar las energías depredadoras en el archipiélago manteniendo su frágil y única biodiversidad en estrecha armonía con las demandas de su población. De esta experiencia extraeremos los conocimientos más adecuados para aplicarlos en el continente.

El Gobierno Nacional ha expresado su preocupación por la viabilidad ecológica, económica y social de las actividades en las islas y ha manifestado la necesidad de adoptar medidas y ejecutar acciones tendientes a impedir la degradación del hábitat y el impacto ecológico en el delicado equilibrio de las especies que coexisten en el Parque Nacional Galápagos y en la Reserva Marina de Galápagos. Es esta preocupación la que ha llevado al Señor Presidente de la República a declarar en riesgo y de prioridad nacional la conservación y el manejo ambiental del ecosistema del Archipiélago de Galápagos. De esta manera, el Gobierno Nacional asume un compromiso real y efectivo con el desarrollo sostenible y la conservación de Galápagos.

Como parte de este compromiso, el Ministerio de Energía y Minas, en el marco del proyecto Energías Renovables para Galápagos – ERGAL que el Ministerio ejecuta con el apoyo del Programa de Naciones Unidas para el Desarrollo, ha resuelto iniciar el programa ***Cero Combustibles Fósiles en Galápagos***, bajo el objetivo de erradicar del Archipiélago el uso de combustibles derivados del petróleo. Esta iniciativa esta articulada alrededor de tres líneas estratégicas:

- La eliminación del diesel en la generación de energía eléctrica y su substitución por electricidad eólica y solar. La generación de electricidad necesaria para compensar el carácter fluctuante de la radiación solar y el viento será generada a partir del uso de biocombustibles.

- La reconversión gradual de los motores de vehículos a diesel en motores a biocombustibles y el establecimiento de normas que permitan la introducción a las Islas únicamente de vehículos eléctricos y/o vehículos híbridos.

- La reconversión gradual de las embarcaciones de pesca y turismo que utilizan diesel para la utilización de biocombustibles incluido el biodiesel.

El programa ***Cero Combustibles Fósiles en Galápagos*** es una **iniciativa tecnológicamente factible, económicamente viable y ambientalmente imprescindible, pero sobre todo humanamente responsable**. Esta iniciativa reafirma el compromiso del Gobierno Nacional adquirido con la humanidad, con la protección y el desarrollo sostenible de Galápagos.

Alberto Acosta
Ministro de Energía y Minas

[149] Document received from Mr. Heinemann, GIZ, 2013 in Quito

Annex 2: Short Historical Overview Of Ecuador's Oil Based Development

The history of commercial oil use in Ecuador began in the 19th century, although, oil has already been used by the aborigine population, for example to impregnate their canoes and for the preparation of medicine (Banco Central del Ecuador, 1990: 3) It is possible to divide the commercial use of oil in Ecuador in two phases. The first is the time between 1911 and 1960, in which the oil has been produced in the pacific area of Ecuador on the peninsula of Santa Elena by the British oil company Anglo Ecuadorian Limited (subsidy of British Petroleum). This period is characterized by the non-consideration of the environment; the use of technology of the first generation; and missing socio-economic development for the country as 99% of the profits went to the foreign oil companies (Banco Central del Ecuador, 1990: 4; Guerra V., 2003: 11). The second period started around 1967 when the American oil company Texaco and Gulf discovered the first oil well in the north Amazon region at "Lago Agrio" (el tiempo, 1967; Banco Central del Ecuador, 1990: 4). In 1972 `Corporacion Estatal Petrolera Ecuatoriana` (CEPE), the public oil company has been founded and successively managed to take over control, reaching 100% in 1977 (Petroecuador, 2010: 19ff.). In 1978 civilian rule was reached through a new constitution ending the last military regime (Freedom House, 2013). A multiparty democracy was implemented (EC, 2012: 6) and the market has been opened for privatization (Guerra V., 2003: 12). The export of crude oil started to be part of the national economy in 1972 having a share of 38–70%[150] of total exports during the 70s and 80s (Banco Central del Ecuador, 1990: 6). Its share of GDP was between 10% to 15% (ILO, 2001: 32). One year later in 1973 Ecuador became member of the OPEC (Banco Central del Ecuador, 1990: 6). During the second period only 12.5% of the profits went to the Ecuadorian state, while the multinationals received 87.5% and did not pay taxes while leaving serious damages to the sensitive Amazonian region (Guerra V., 2003: 12). The widespread movements in LA from authoritarian to democratic regimes in the 1970s, 1980s and 1990s have been triggered mainly "from within" by popular reaction against military dictatorships and other forms of authoritarian regimes (Emmerich, 2009: 5). This period of democratic waves[151] has been accompanied by high levels of debt, deep recessions, and hyperinflation (Huntington, 1991: 15-16) that caused the region to lose a decade of growth and development. Also for Ecuador the 1980s were a `lost decade` (Hellinger, 2011: 210). Its oil could not impede the crisis domestically, as demand for oil decreased and the production of oil outside OPEC increased, resulting in an oil price drop (Hellinger, 2011: 213f.). The 1990s were not much better. Corruption, ineffectiveness and a lack of accountability pervaded many governments[152]. Consequently, countries experienced

[150] The lowest share of 38% was caused by low oil market prices and the earthquake damages to the pipelines in 1987.
[151] During the 1980s and 1990s Latin America experienced a democratic wave, in which Huntington counts Venezuela, Ecuador and Bolivia to the second (1943-62) and third (1974 - now) wave of democratization.
[152] Strikes organized by trade unions and street movements against unpopular economic policies were common.

breakdowns of their political systems; the disempowerment of the president; and the emergence of new movements; although they were predominantly able to retain their democratic institutions (Haggard and Kaufman, 1995: 25-26, 37; Shifter, 2004; Mainwaring, 2006; Pachano, 2008: 9; Emmerich, 2009: 5). In response, many countries embarked on a profound shift in their economic policies. They opened markets, allowed increased foreign investment, signed trade agreements, and ended a long period of relative isolation from the world economy. These policy changes became known as the Washington Consensus and helped to bring an end to the Lost Decade. However, economic growth remained relatively low, financial crises continued to undermine economic gains, and traditional issues of economic fairness were largely ignored.

In Ecuador during the 1970s until the 1990s between 70 and 140 million barrels of oil have been produced by the public and private oil companies each year. The private companies have been granted licenses for exploration and perforation in so called “rondas”. There have been 8 rounds between 1985 and 1997, granting licenses for specific sectors called “Bloques” to multinationals (Petroecuador, 2010: 29, 65). With the aim to reduce bureaucracy and make the national oil company more competitive in the free market the public oil company Petroecuador has been founded to replace CEPE in 1989 (Petroecuador, 2010: 22). These findings support Torre´s (Torre, 1997: 12) argument, that historically, Ecuador had a turbulent transition from colonialism, through authoritarian rule to democracy[153] and was not able to use its oil resources to impede economic crisis. Ecuador is one of the resource abundant countries. It was historically integrated into the world economy as a supplier of raw materials and agricultural products (Hellinger, 2011: 483). To benefit from its oil wealth Ecuador started to increase its oil exports in the 1970s, which soon took over the lead from agricultural products as the most important export good. While this opening to the global economy brought a slight GDP increase since the 1980s[154], the government faced limitations vis-à-vis the interests of its own population as the international commercial interests had priority (Jawara and Kwai, 2002). Ecuador saw in this time poor labour and environmental standards, low salaries, and harsh living conditions, also known as the “race to the bottom” in economics. Globalists counter these critics with the argument that also industrialized nations had to go through this phase. However, the difference seems to

[153] Historically it was in Quito, Ecuador’s capital, that the first call for independence from Spanish colonial empire in South America started in 1809. Ecuador joined Simon Bolivars Republic of Gran Colombia and became an independent republic in1830. The 19th century was marked by instability, with rapid succession of – main authoritarian – rulers and significant influence of the Catholic Church. Liberal Revolutions of 1895 under Eloy Alfaro maintained in power until the military “Julian Revolution” 1925, followed by populist politicians – such as Jose Maria Velasco Ibarra who gained the Presidency in five different occasions. He inaugurated the most important political phenomenon in contemporary Ecuadoran history: populism. (Torre 1997, 12) In 1972 a revolutionary and nationalist military junta overthrew the government. In 1978 civilian rule was reached through a new constitution, which was approved by referendum ending the last military regime. (Freedom House (b) 2013) A multiparty democracy was implemented (ECb 2012, 6) and in 1979 the first constitutionally elected president Jaime Roldos Aguilera came to power. He had a reformist Agenda and governed until 1981 when he died in an airplane accident, which was believed to be assassination.

[154] However, the increase was relative small with an average of only 2.3% from 1980 to 2000, but an average of 4.5% from 2001 to 2011 (IMF 2013)

be that in the age of Fordism and import substitution industrialization (ISI) most of the profit and expenditures of investment remained in the host country while in the case of Ecuador, most of the oil revenues left the country. Therefore, Ecuador's historical development reflects the oil curse with most of its negative aspects. First, the country remains relatively poor and is still dependent on oil incomes. While in the 1980s, 1990s and 2000s the government budget consisted of 30-70% of oil incomes (Bustamante, 2003), in 2010 they equalled 45% of fiscal government incomes. In addition, Ecuador's exports are still based on oil and agricultural products. Oil exports were in the 1990s 33.2% and in 2010 59% of total exports and the rest are agricultural products, mainly Banana (ILO, 2001: 95; Petroecuador, 2010: 5). Moreover, the share of oil in the GDP remains more or less equal to the 1990 with around 13% (ILO, 2001: 31; Petroecuador, 2010: 5). The negative effect of this dependence can be seen in the disastrous crisis of Ecuador in 1999 which as been influenced by the falling oil prices[155] (ILO, 2001: 11).

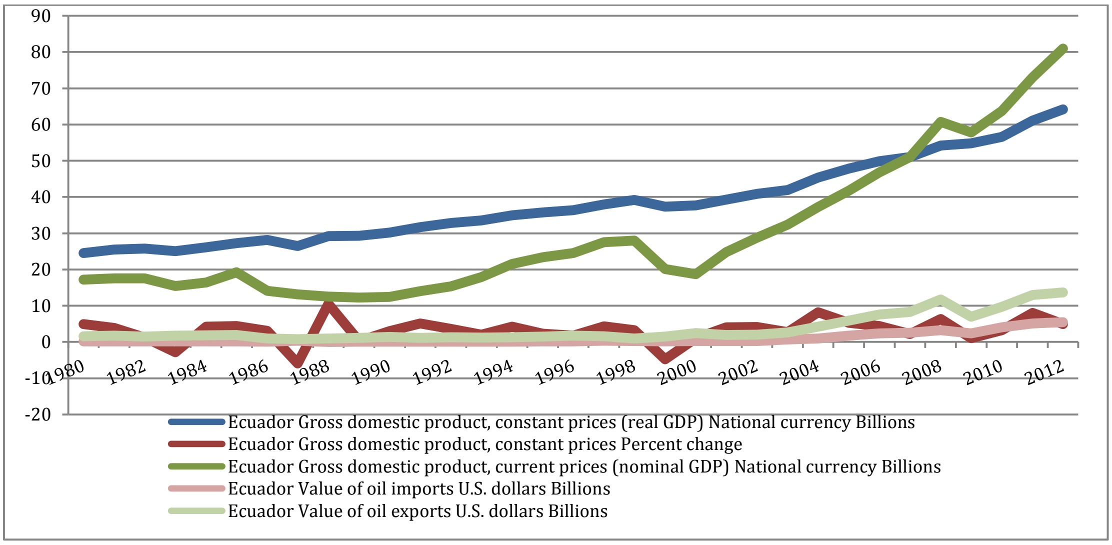

Figure 60: GDP Development in Ecuador and value of oil exports/imports (bn USD), 1980–2012
Source: (IMF, 2013)

In addition, oil production has been concentrated until recently in the hand of a few elites. Those with money got positions and acquired lucrative contracts, and the revenues of these were again used for further manipulating and bribing those in power. This created a circle of patronage, corruption and clientelism, secured by the poor democratic standards of a developing country, without press freedom, lacking transparency and accountability (Schubert, 2006; Hellinger, 2011: 456ff.; Transparency International, 2012). Moreover, the sector created few jobs, little investment in infrastructure, education or health system and affected the environment negatively. A comparison of the agricultural and oil sector shows that while around 26-28% of the workforce have been working in agriculture creating around 6-7% of GDP the oil sector only employed 0,5% creating twice that GDP (ILO, 2001: 33; Pascual, 2005: 77; UNICEF, 2010).

[155] There have been three main factors fort he crisis in Ecuador: the falling oil prices; the El Nino Phenomenon which damaged large parts oft he agricultural product and infrastructure; and the international financial crisis which led to an interruption of inflowing foreign capital into the country.

Annex 3: List Of Interviews in Galápagos August and September 2013 (Chronological)

San Cristóbal		
San Cristóbal	ElecGalápagos	Adrian Moreno
San Cristóbal	ElecGalápagos	Ing. Marco Salao
San Cristóbal	ElecGalápagos	Marco Toscano
San Cristóbal	ElecGalápagos	Milton Avas
San Cristóbal	Consejo de Gobierno (Transport)	Juan Carlos de Serra
San Cristóbal	Consejo de Gobierno (Transpot, Efficiency, Renewable Energies)	Andrea
San Cristóbal	Consejo de Gobierno (Capacity Building & Education)	Marcelo Martinetti
San Cristóbal	Consejo de Gobierno (Production)	Ing. Jimmy Volanios
San Cristóbal	Municipio - Gestion del Medio Ambiente	Biologo Juan Tigua
San Cristóbal	Municipio (Cataster)	Licenciada Fabiola Diez; Senor Cabeza
San Cristóbal	Municipio - Turismo (Campana de Turismo)	Veronica Agama
San Cristóbal	Municipio - Obras y Servicios Publicos	Ing. Carlos Chimbo
San Cristóbal	Municipio	Pedro Zapata
San Cristóbal	Ministerio de Turismo/ Dirección Técnica Provincial de Turismo de Galápagos	Gabriela Echeverria
San Cristóbal	Aeropuerto de San Cristóbal (DAC - Direccion de Aviacion Civil)	Geovanni Espinosa
San Cristóbal	Aeropuerto San Cristóbal (Responsible)	Raul Jacome
San Cristóbal	EMETEBE	Alessandro Pitassi
San Cristóbal	Agencia National de Transito	Trudi Velez
San Cristóbal	Capitania de Puertos	Commandante Pablo Gordillo
San Cristóbal	Eolicsa	Fernando Naranjo
San Cristóbal	Eolicsa	Cristian Fernandez
San Cristóbal	ElecGalápagos	Pablo Carrera
San Cristóbal	ElecGalápagos	Adrian Moreno
San Cristóbal	Universidad San Franciso/ Galápagos Science Center	Diana
San Cristóbal	Universidad San Franciso/ GAIES (administrator estudiantil GAIES)	Cecibelle Narvais
San Cristóbal	Parque National Galápagos	Marjury Yeppez
Santa Cruz	ElecGalápagos	Pablo Echeverria
Santa Cruz	Municipio - Gestion del Medio Ambiente	Mario Piu
Santa Cruz	Consejo de Gobierno	Licenciado Diogenes Aguirre
Santa Cruz	ERGAL	Leonardo Zaragozin
Santa Cruz	MIDUVI	Ing. Rosanna Culqui
Santa Cruz	MIDUVI	Pablo Jaime Perez
Santa Cruz	Ministerio de Turismo (programma de Buenas Practicas)	Sra. Veronica Alban y
Santa Cruz	Ministerio de Turismo (Regulation and Control)	MaJose Castro
Santa Cruz	WWF	Ulf Thorsten Harder
Baltra	ADAG	Edgar Navas
Baltra	Aeropuerto Ecologico	Jorge Rosillo
Santa Cruz	ERGAL	Leonardo Zaragozin
Baltra	Petroecuador	Sr. Lopez
Santa Cruz	Parque National Galápagos	Washington Tapia
Santa Cruz	MAGAP	Juan Carlos Guzman
Santa Cruz	Petroecuador	Nelly Garces
Santa Cruz	Fundacion Charles Darwin	Stuart Banks
Santa Cruz	Capitania de Puerto	Xavier Rubio
Santa Cruz	Petrocommercial	Nelly Garces

Floreana	ElecGalápagos	William Ramirez
Floreana	Junta Parroquial Floreana	Max Freire
Santa Cruz	ElecGalápagos	Roberto Robles
Santa Cruz	Biblioteca de la Fundacion Charles Darwin	Lorraine Crouche
Santa Cruz	Biblioteca de la Fundacion Charles Darwin	Erika Loor
Santa Cruz	BJ Power	Jose Vida
Isabela	ElecGalápagos	Galo Rosero
Isabela	Municipio	Ing. Ivan Yeppez
Isabela	Municipio	Patricio Almeida
Isabela	Municipio	Romero
Isabela	Consejo de Gobierno	Roberto Revelo
Isabela	Capitania de Puertos	Patricio Almachi
Isabela	Consejo de Gobierno	Johnny Farfan
Isabela	Gasolinera del Consejo de Gobierno	n.a.
Isabela	Consejo de Gobierno	Ana Tupizo
Isabela	Municipio - Gestion del Medio Ambiente	Christian Cabzeda
Isabela	Municipio - Planificacion	Peter Dejada
Isabela	Municipio; Ministerio de Turismo; WWF	Ruben Carrion
Isabela	Municipio - Minsterio de Turismo	Carla Flores
Isabela	MAGAP	Dr. Manuel Lucas Flores
Santa Cruz	Petroecuador	Nelly Garces
Santa Cruz	Petroecuador	Erika Ramos
Santa Cruz	MAGAP	Juan Carlos Guzman
Santa Cruz	Capitania de Puertos	Capitan Rubio
Santa Cruz	Municipio	Mario Piu
Santa Cruz	Camara de Turismo	Oscar Aguirre
Santa Cruz	Biblioteca de la Fundacion Charles Darwin	n.a.
Santa Cruz	Ministerio de Cultura	Maria Eugenia Proano
Santa Cruz	Ministerio de Cultura	Nubia Recaute
Santa Cruz	Ministerio de Educacion	Magdalena Aide Torres Munoz
Santa Cruz	Ministerio de Educacion	Maria Salcedo Aldaz
Santa Cruz	Taller de Guis Naturalistas; Centro de Interpretacion	n.a.
Santa Cruz	Ministerio de Industria y Productividad	Edwin Egas
Santa Cruz	FundarGalápagos	Freddy Villao
Santa Cruz	FundarGalápagos	Mario Piu
Santa Cruz	FundarGalápagos	Enio Martillo
Santa Cruz	Fundacion Charles Darwin	Felipe Cruz
Santa Cruz	Fundacion Principe Carlos	Christina Simon y Ana Christina Rousseaud
San Cristóbal	ElecGalápagos	Ing. Andrea Eras Almeida
San Cristóbal	ElecGalápagos	Nelson Tomalo
San Cristóbal	ElecGalápagos	Ing. Salao

Annex 4: Map Of Galápagos Triple Junction

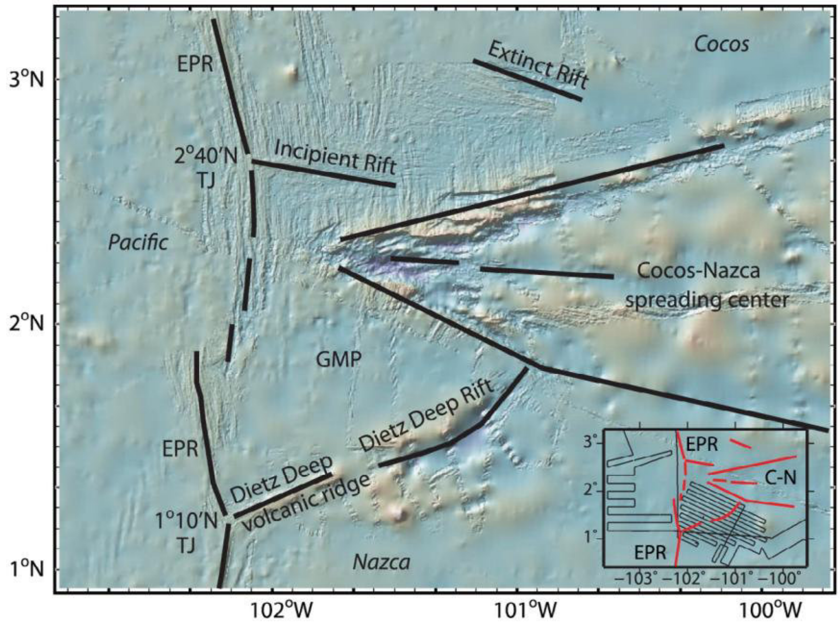

Figure 61: Map of the Galápagos triple junction

Map of the Galápagos triple junction in the eastern Equatorial Pacific showing satellite altimetry data and archived multibeam bathymetry data available from the Global Multi Resolution Topography Data Portal at Lamont Doherty Earth Observatory. The map was generated using GeoMapApp, an exploration and visualization application developed and maintained by the Marine Geosciences Data System. Black lines: plate boundaries. Inset: track lines of R/V Atlantis Voyages 15–41 and 15–45 in 2008/2009. EPR: East Pacific Rise, GMP: Galápagos microplate, C-N: Cocos-Nazca spreading centre.

Source: Ryan et al., 2009 from (Smith et al., 2011: 3)

Annex 5: Funds To Galápagos From 2007 – 2012

An important source of "income" on the Galápagos are bilateral and multilateral funds as well as from NGOs. According to SETECI (SETECI, 2013a), the Ecuadorian Secretariat for International Cooperation, from 2007 to 2012 around USD 87 million have reached Galápagos, nearly all of it from the public sphere.

Table 36: Funds to Galápagos from 2007 to 2012 per country or group
Adapted from: (SETECI, 2013b)

#	Country / Cooperating Organism	# Projects	% Project Participation	Multiannual Amount (USD)	% Participation referred to USD
1	Japan	4	4.12%	$ 19,133,181.64	21.9%
2	US	67	69.07%	$ 18,500,585.29	21.1%
3	Germany	2	2.06%	$ 11,537,558.82	13.2%
4	Korea	1	1.03%	$ 10,000,000.00	11.4%
5	Spain	3	3.09%	$ 6,889,378.54	7.9%
6	Italy	3	3.09%	$ 5,859,784.40	6.7%
7	UNDP	7	7.22%	$ 5,063,869.95	5.8%
8	European Commission	1	1.03%	$ 4,147,188.34	4.7%
9	UNDP, GEF	1	1.03%	$ 2,200,000.00	2.5%
10	BID	2	2.06%	$ 1,998,616.00	2.3%
11	UK	1	1.03%	$ 893,188.00	1.0%
12	World Bank	1	1.03%	$ 820,000.00	0.9%
13	ONUDD	1	1.03%	$ 360,000.00	0.4%
14	Denmark	1	1.03%	$ 86,982.00	0.1%
15	Panama	2	2.06%	$ 50,000.00	0.1%

Table 37: Funds made available through the following institutions.
Adapted from: (SETECI, 2013c)

#	Canalization Entity	# Projects	Multiannual Amount (USD)	% Participation
1	Japan International Cooperation Agency - JICA	4	$ 19,133,181.64	21.9%
2	UNDP	9	$ 10,661,007.35	12.2%
3	Kreditanstalt Für Wiederaufbau - KfW	1	$ 10,166,525.37	11.6%
4	Korean International Cooperation Agency - KOICA	1	$ 10,000,000.00	11.4%
5	World Wildlife Fund - WWF	1	$ 8,618,431.00	9.8%
6	Care Internacional En Ecuador	1	$ 4,147,188.34	4.7%
7	Save The Children España - SCE	1	$ 4,124,250.10	4.7%
8	United States Agency For International Development - USAID	1	$ 3,000,000.00	3.4%
9	Wildaid	2	$ 2,362,000.00	2.7%
10	UNDP/ GEF	1	$ 2,200,000.00	2.5%
11	Conservación Internacional	37	$ 2,179,387.82	2.5%
12	Banco Interamericano De Desarrollo - BID	2	$ 1,998,616.00	2.3%
13	Agencia Española De Cooperación Para El Desarrollo - AECID	1	$ 1,922,932.00	2.2%
14	Sea Shepherd Conservation Society	10	$ 1,684,292.14	1.9%
15	Deutsche Gesellschaft Für Internationale Zusammenarbeit - GIZ	1	$ 1,371,033.45	1.6%
16	Plan Internacional Inc	1	$ 893,188.00	1.0%
17	Fundación Instituto De Promoción Y Apoyo Al Desarrollo - IPADE	1	$ 842,196.44	1.0%
18	Banco Internacional De Reconstrucción Y Fomento - BIRF	1	$ 820,000.00	0.9%
19	Isabela Oceanographic Institute	6	$ 581,321.00	0.7%

20	ONUDD	1	$ 360,000.00	0.4%
21	Fondo Ítalo Ecuatoriano - FIE	1	$ 262,647.00	0.3%
22	IBIS	1	$ 86,982.00	0.1%
23	Galápagos Ice Organization	10	$ 75,153.33	0.1%
24	Fundación Avina	2	$ 50,000.00	0.1%
	Total General	97	$ 87,540,332.98	100.0%

Table 38: Executing Entities of Projects on Galápagos
Adapted from: (SETECI, 2013d)

	# Projects	Amount In USD
Ministerio De Electricidad Y Energía Renovable - MEER	6	$26,128,366
ERGAL	1	$10,166,525
World Wildlife Fund Inc	1	$8,618,431
Parque Nacional Galápagos - PNG Total		$7,740,129
Instituto Nacional Galápagos - INGALA	4	$5,624,937
Care Internacional En Ecuador	1	$4,147,188
Save The Children España - SCE	1	$4,124,250
Instituto Geofísico De La Escuela Politécnica Nacional	1	$3,612,142
Wildaid	10	$3,464,773
Academy For Educational Development - AED	1	$3,000,000
Fondo Para El Control De Especies Invasoras De Galápagos (FEIG)	1	$2,200,000
Cámara Provincial De Turismo De Galápagos	1	$1,848,616
Sea Shepherd Galápagos	6	$1,323,859
Plan Internacional Inc, Programa De Finanzas Populares, Emprendimientos Y Economía Solidaria, Cooperativa De Ahorro Y Crédito San José, Santa Ana, Red Financiera Rural - RFR, Comunidades Plan	1	$893,188
Fundación Instituto De Promoción Y Apoyo Al Desarrollo - IPADE	1	$842,196
Ministerio De Turismo	1	$820,000
ONUDD	1	$360,000
Isabela Oceanographic Institute	1	$281,478
Dirección General De Marina Mercante - DIGMER	1	$280,000
Fundación Charles Darwin (Total)		$266,684
Municipio De Santa Cruz	1	$262,647
Ministerio Del Ambiente - MAE	2	$236,834
Escuela Fisco Misional Cornelio Izquierdo	1	$182,450
Fundación Para El Desarrollo Marítimo, Fluvial Y Lacustre - FUNDEMAR	2	$134,695
Fundar Galápagos Total		$122,855
ECWF	1	$118,551
Corporación De Gestión Y Derecho Ambiental - ECOLEX	5	$109,185
Unidad De Policía Del Medio Ambiente - UPMA	1	$104,984
Parroquia Cristo Salvados	1	$88,000
Movimiento De Los Pueblos Kichwas De La Costa Ecuatoriana	1	$86,982
Galápagos Ice Organization	10	$75,153
JICA	1	$63,408
International Galápagos Tour Operator Association - IGTOA	2	$47,000
Instituto De Ecología Aplicada Ecolap - USFQ	1	$44,000
Policía Nacional/Sea Shepherd	1	$36,198
Ecobiotec Del Ecuador	1	$25,000
Fundación Avina	1	$25,000
Gobierno Municipal De Isabela	2	$19,393
Universidad San Francisco De Quito - USFQ	1	$15,000
Ministerio De Salud Publica - MSP	1	$228
Sum	**97**	**$87,540,332**

Annex 6: ElecGalápagos Invoiced Electricity And Clients

Table 39: ElecGalápagos Invoiced Electricity and Clients
Adapted from: (ElecGalápagos, 2013c)

Year	Month	Type of Consumption	Sum of Clients	Sum of invoiced electric service (USD)	Sum – Average Price (USD ¢/kWh)	Sum – Invoiced Energy (MWh)
2012	Jan	Non-public	8,476	211,391.96	9.03	2,340.48
		Public	322	59,513.64	7.37	807.58
	Jan Sum		8,798	270,905.60	8.61	3,148.06
	Feb	Non-public	8,484	199,281.35	9.12	2,185.93
		Public	321	53,082.45	7.52	705.47
	Feb Sum		8,805	252,363.80	8.73	2,891.40
	Mar	Non-public	8,528	227,470.40	9.19	2,474.46
		Public	321	59,299.97	7.54	786.68
	Mar Sum		8,849	286,770.37	8.79	3,261.15
	Apr	Non-public	8,568	234,379.41	9.16	2,558.15
		Public	318	59,818.95	7.58	788.76
	Apr Sum		8,886	294,198.36	8.79	3,346.92
	May	Non-public	8,602	250,097.62	9.15	2,733.13
		Public	322	62,087.60	7.44	834.65
	May Sum		8,924	312,185.22	8.75	3,567.78
	Jun	Non-public	8,644	225,459.69	9.19	2,452.97
		Public	327	58,985.49	7.30	807.63
	Jun Sum		8,971	284,445.18	8.72	3,260.60
	Jul	Non-public	8,691	201,066.98	9.24	2,175.05
		Public	331	50,232.66	7.34	684.32
	Jul Sum		9,022	251,299.64	8.79	2,859.37
	Ago	Non-public	8,719	199,166.97	9.23	2,156.89
		Public	332	48,244.32	7.30	660.56
	Ago Sum		9,051	247,411.29	8.78	2,817.45
	Sep	Non-public	8,767	193,154.28	9.28	2,080.79
		Public	332	68,864.83	10.38	663.13
	Sep Sum		9,099	262,019.11	9.55	2,743.92
	Oct	Non-public	8,783	171,537.94	8.39	2,043.71
		Public	331	62,297.50	8.84	705.06
	Oct Sum		9,114	233,835.44	8.51	2,748.76
	Nov	Non-public	8,837	185,781.78	9.31	1,995.64
		Public	332	67,784.68	9.60	705,81
	Nov Sum		9,169	253,566.46	9.39	2,701.45
	Dec	Non-public	8,897	190,938.57	9.25	2,065.30
		Public	333	72,947.16	9.24	789.65
	Dec Sum		9,230	263,885.73	9.24	2,854.95
2012 Sum			**107,918**	**3,212,886.20**	**8.87**	**36,201.80**
E.E. Galápagos Sum			**107,918**	**3,212,886.20**	**8.87**	**36,201.80**

Annex 7: Extract Of The Electricity Tariffs For Galápagos

CNEL ESMERALDAS-CNEL MANABI-CNEL LOS RIOS-CNEL GUAYAS LOS RIOS-CNEL SANTO DOMINGO-CNEL EL ORO-CNEL SANTA ELENA-CNEL MILAGRO-CNEL SUCUMBIOS-GALÁPAGOS			
Unitary Tariffs			
Consumption Range	Energy (December - May	Energy (June – November)	Commercialization
	(USD/kW)	(USD/kWh)	(USD/consumer)
	Category: Residential		
	Voltage Level: Low and Middle Voltage		
0-50		0.081	1.414
51-100		0.083	
101-150		0.085	
151-200		0.087	
201-250		0.089	
251-300		0.091	
301-350		0.093	
351-500		0.095	
501-700	0.095	0.1185	
701-1000	0.1350	0.1350	
1001-1500	0.1609	0.1609	
1501-2500	0.2652	0.2652	
2501-3500	0.4260	0.4260	
Superior	0.6712	0.6712	

Figure 62: Extract of the Electricity Tariffs in Ecuador for Galápagos
Source: (CONELEC, 2013c)

Annex 8: Quality Of Electricity Supply

Table 40: Electricity Generation
Adapted from (ElecGalápagos, 2014a)

	2006	2007	2008	2009	2010	2011	2012	2013 (until 30,6,2013)
Max installed potential (kW)	5,3349	5,5029	6,1133	6,4634	6,5787	7,1778	5,5307	4,3805
Thermal (kWh)	25,598,632	25,215,843	26,814,975	28,471,120	29,271,035	31,831,799	36,638,946	20,559,430
Biofuel						32,006	87,721	59,118
Wind (kWh)	0	962,135	2,682,461	3,204,893	3,434,854	3,344,626	2,398,373	1,258,818
PV (kWh)	15,494	18,162	26,687	7,874	16,376	17,851	16,744	8,240
Sum Net Energy (kWh)	25,614,126	26,196,140	29,524,123	31,683,886	32,722,265	35,226,282	39,141,784	21,885,606
% Losses	9.08%	8.92%	6.96%	7.81%	8.94%	7.41%	7.44%	8.69%
Losses (kWh)	2,353,322	2,316,804	2,087,226	2,486,532	2,863,559	2,710,602	2,929,983	2,260,508
Consumption by generation (kWh)	80,403	79,818	80,423	94,339	77,739	168,486	336,014	149,197
Available Energy (kWh)	25,412,874	26,116,322	29,443,700	31,589,547	32,644,526	35,057,796	38,805,770	21,736,409
Total Energy billed (kWh), incl. public lightning	23,059,552	23,799,518	27,356,474	29,103,015	29,780,967	32,515,680	36,211,801	19,475,901
Energy Recovered (kWh)	27,051	68,103	450,367	98,612	52,876	46,878	43,782	0
Energy billed (kWh)	23,032,501	23,731,415	26,906,107	29,003,665	29,728,091	32,468,802	35,059,787	20,066,407
Energy Efficiency (kWh/Gal)	12.41	12.16	12.15	11.93	12.26	12.57	17.65	13.59
Consumption Diesel (Gallons)	2,062,239	2,070,009	2,206,500	2,390,787	2,385,021	2,531,608	2,074,072	1,517,254

Annex 9: Water Energy Nexus – Water Use Cycle Energy Intensities

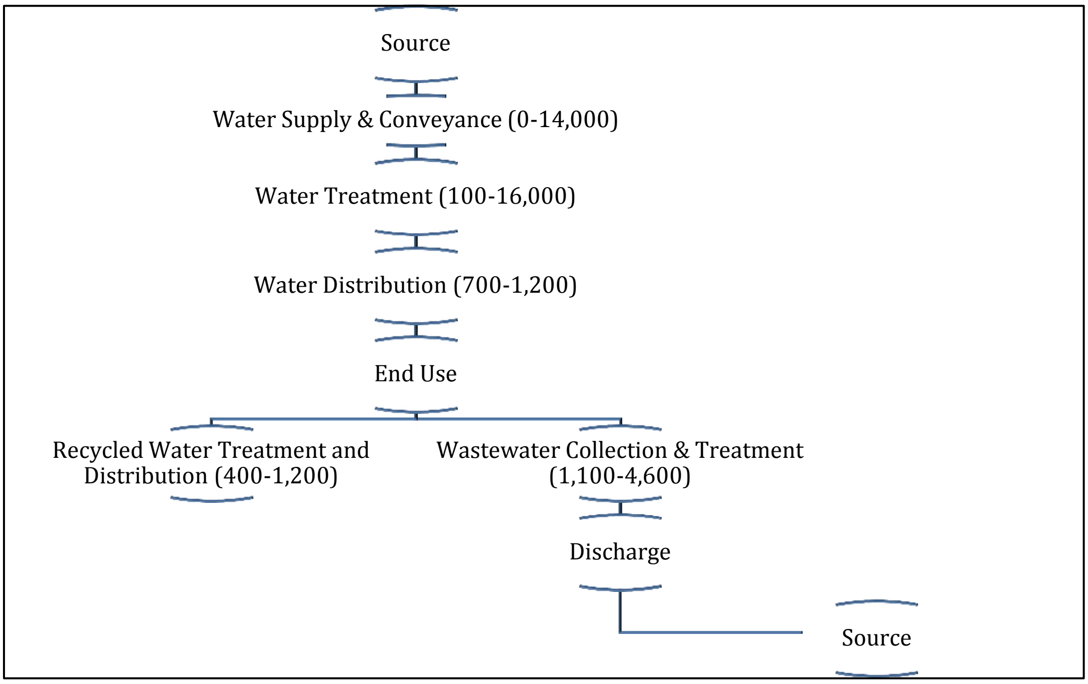

Figure 63: Water use cycle energy intensities in kWh per million gallons (kWh/MG)
Source: (Hussey, 2010: 4)

Annex 10: Water Costs On Santa Cruz In 2006

Table 41: Prices for water resource on Santa Cruz 2006
Source: (d'Ozouville, 2007: 152) (Gobierno Autonomo Descentralizado Santa Cruz, 2012a)

Type of water	Unit	Price per unit
Polluted water of the public network, domestic use	Month	USD 3
Polluted water of the public network, commercial use	Month	USD 8
Water from the deep well, delivered in Bellavista with meters	m^3	USD 1.21
Polluted water delivered in tanks in the rural area	10-20 m^3	USD 10 – 30
Desalinated water	m^3	USD 100 (bottle) USD 25 (house line)
Drinking Water (in bottles or tanks) (Gobierno Autonomo Descentralizado Santa Cruz, 2012a)	Month per household	USD 25.70

Annex 11: RES-E Projects On Galápagos

Table 42: RES-E Projects on Galápagos
Sources: Data adapted from (Consejo de Gobierno Galápagos, 2011; CONELEC/ MEER, 2013; MEER, 2014a; CENACE, 2013; ElecGalápagos, 2014b; Kassels, 2003; Green Empowerment, 2013)

	Name of the Project	Amount (Initial)	Finance	Project Development & Other Stakeholder	Island	Energy Source	Potential (MW)	Storage
In Operation	PV Floreana: "Perla Solar"	$ 780,000	MEM + FERUM + GNP + AECID + GNP, Parish Council, GEF, WWF, SEBA	Execution by SEBA (Spanish NGO); Trama Tecnoambiental	Floreana	Sun	(18 kWp in 2004 + 3kWp in 2006) 21 KWp; 24 kWp?	Batteries
	Wind Park San Cristóbal - EOLICSA	$ 10,000,000	e8, UNF, FERUM, MEM + GEF (UNDP, 2006) => qualified as CDM Project under the KP	San Cristóbal Commercial Trust	San Cristóbal	Wind	2.4 MW	n/a
	PV for electrification of 15 rural houses	$ 12,000	FERUM (CONELEC/ MEER, 2009)	n/a	all islands	Sun	n/a	n/a
	Floreana Highlands PV + Wind microgrid	n/a	n/a	ElecGalápagos	Floreana	Sun	5.1 kWp (2,1kWp + 1,8 + 3* 400Wp)	n/a
						Wind	0,5 kW	n/a
	Biofuel Floreana (Jathropha) - ENERGAL	$ 612,500 (2014 additionally: 882,120)	GIZ + National Government	ERGAL; MEER, ElecGalápagos	Floreana	Vegetable Oil (Jatropha)	138 KW	n/a
Execution	Wind Park Baltra - ERGAL Phase 1	$ 15,000,000	MEER + UNDP/GEF + UNF	n/a	Santa Cruz	Wind	3 MW; (3*750kW =) 2.25MW	n/a
	Hybrid Project Isabela: PV + Biofuel	$ 11,200,000	GIZ / KfW + Ecuadorian Government	Lahmeyer; ElecGalápagos, PNG, CGG	Isabela	Sun	1 - 1.1 MWp; 0.7 MW	Battery bank: 3.3 MWh; 900kVA
						Vegetable Oil (Jatropha)	1.32MW	n/a
	Hybrid Project Isabela: Energy efficiency	$ 8,280,000	n/a	n/a	Isabela	Energy Efficiency	n/a	n/a
	PV Baltra Airport Covering	$10,180,000 - $ 10,400,000	JICA + MEER => CDM under the KP	n/a	Santa Cruz	Sun	0.2 MWp	0.9-1 MW Batteries: a) LI-Ion => 500kW / 400kWh; b) Lead-Acid Batteries => 600 kW/ 4000kWh

	PV Puerto Ayora	$ 10,000,000	KOICA + MEER	n/a	Santa Cruz	Sun	1.5 MWp	n/a
	Feasibility Study for Palm oil on Galápagos	n/a	n/a	n/a	all islands	n/a	n/a	n/a
Initiatives	Mini Hydroelectric power plant San Cristóbal	$ 120,000	Without finance	n/a	San Cristóbal	Water	n/a	n/a
	Biofuel San Cristóbal	n/a	n/a	n/a	San Cristóbal	Vegetable Oil (Jatropha)	3 MW	n/a
	PV San Cristóbal	$ 6,000,000	Private, Global Sun Partner (SIEMENS); "Captain Sunshine" - Abramowitz	n/a	San Cristóbal	Sun	1MW	n/a
	Illumination of the wharf Santa Cruz	$ 48,000	n/a	n/a	Santa Cruz	Sun	n/a	n/a
	Biofuel Baltra - ERGAL Phase 2	$ 12,000,000	National Government + GEF + UNF	n/a	Santa Cruz	Vegetable Oil (Jatropha)	7MW	n/a
	Wind Park Baltra - ERGAL Phase 3	n/a	National Government + GEF + UNF	n/a	Santa Cruz	Wind	12 MW	n/a
	PV for small boats in Santa Cruz	$ 10,000	n/a	n/a	Santa Cruz	Sun	n/a	n/a
	Enlargement PV Floreana "Perla Solar"	$ 200,000	WWF	n/a	Floreana	Sun	21KW	n/a
	PV Baltra	$ 5,103,750	n/a	n/a	Santa Cruz	Sun	0,2 MWp (+ 1MW storage)	n/a
	„Plan Galápagos" Capacity Building to reach Zero Fossil Fuels	$ 42,000	MEER + GIZ/KfW	n/a	all islands	Energy Efficiency	n/a	n/a
	Reactivation PV Floreana "Perla Solar"	n/a	GIZ (KfW) + MEER	n/a	Floreana	Sun	21KW	n/a