Appendix

i. List of participants

	Name	Company / Organization		Name	Company / Organization
1	Ayu Abdullah	Masdar Institute	21	Matthias Schmidt	KfW
2	Berit Müller	Reiner Lemoine Institut	22	Michael Wollny	SMA
3	Bhupendra Shakya	Renewable Energy for Rural Livelihood program	23	Oliver Haas	Global Public Policy Institute
4	Binod Koirala	Fraunhofer ISE	24	Philipp Blechinger	Reiner Lemoine Institut
5	Brian Edlefsen Lasch	Micro Energy International	25	Philipp Neff	oneshore Power Solutions
6	Christian Breyer	Reiner Lemoine Institut	26	Pol Arranz-Piera	Trama TecnoAmbiental
7	Christian Liedtke	GIZ	27	Prof. Daniel Kammen	UC Berkeley
8	Daniel Philipp	Micro Energy International	28	Prof. Kai Strunz	TU Berlin
9	David Lecoufle	Fichtner GmbH	29	Robert Seguin	Reiner Lemoine Institut
10	David Ludwig	Reiner Lemoine Institut	30	Sanjoy Sanyal	Regain Paradise / New Ventures India
11	Debajit Palit	The Energy & Resources Institute	31	Santosh Singh	GIZ
12	Dimitry Gershenson	UC Berkeley	32	Saurabh Mehta	Veddis Solars Pvt. Ltd
13	Elisa Gaudchau	Reiner Lemoine Institut	33	Shariar Chowdhury	UIU Bhaban
14	Fabian Jochem	Juwi Solar GmbH	34	Scott Kennedy	Masdar Institute
15	Hannes Kirchhoff	Micro Energy International	35	Stefan Trittler	Energiebau
16	Johannes Wuellner	Soitec	36	Teo Sanchez	PracticalAction
17	José María Ordeix	Micro Energy International	37	Vegar Lein Ausrod	NTNU
18	Joseph Theune	Micro Energy International	38	Verena Steub	Micro Energy International
19	Konrad Ritter	Wenergyglobal	39	Vivek Sinha	NTNU
20	Martin Baart	ABB			

ii. Presentations

PV-based Mini-Grids for Electrification in Developing Countries

Christian Breyer, A.-K. Gerlach, E. Gaudchau, M. Hlusiak, C. Cader

The Mini-Grid Workshop
Side Event of 2nd International Conference
Micro Perspectives for Decentralized Energy Supply,
Berlin, February 27, 2013

Reiner Lemoine Institute

Research focuses:

- **Integrated energy systems**
  - Optimization of energy systems
  - Energy transition processes
  - Off-grid energy systems
- **Mobility with RE**
  - Integration of renewable energies into mobility
- **Renewable energy technology**
  - Small wind power

Reiner Lemoine
Founder of the Reiner Lemoine Foundation

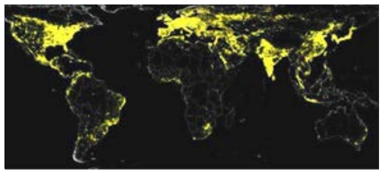
Scientific research for an energy transition towards 100% renewable energies

Agenda

1 **Introduction**
2 Potential Analyses
3 Business Models
4 Summary

Status Quo Electrification

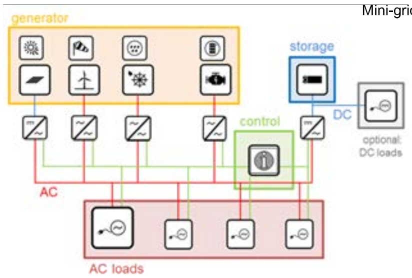
> Worldwide 1.3 billion people live without access to electricity
> Especially rural regions without grid connection are affected by this
> Grid extension is there often improvident.



earth by night Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency.

- Electricity is a fundamental requirement for economic development and basis for improving elementary needs like education, health, security and communication.
- Autarkic island grids are often the only possibility to enable flexible access to electric energy for people in rural areas and to enhance local creation of value.

Island Grids/ Mini-grids



Mini-grids consist of at least

> one energy generator,
> one energy storage,
> one control unit,
> one consumer load and

at a capacity range of kW – MW

- Mini-grids offer ideal conditions for a grid independent electricity supply.

Agenda

1 Introduction
2 **Potential Analyses**
3 Business Models
4 Summary

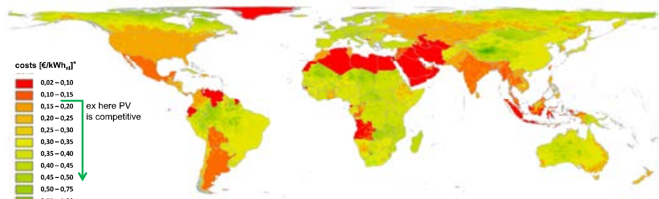
Cost analyses on a global scale

analysis of national diesel price + **analysis of existing road network** + **recording of solar irradiation** = **most convenient local energy source (PV vs. diesel)**

- PV mini-grids compete with grid extension and pure diesel-grids.
- Increasing distance to the national grid and low density of consumers make grid extension improvident.
- High national diesel prices make pure diesel-grids improvedent.
- Increasing distance to large trade routes leads to high transport costs for diesel.

» With high local diesel prices and good solar irradiation in rural areas solar energy becomes the most convenient energy source.

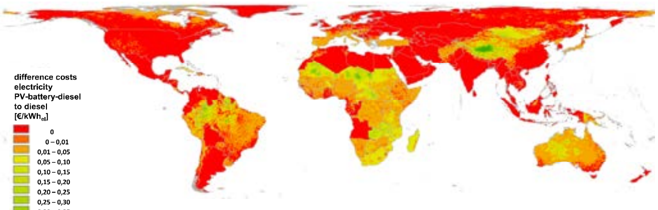
Electricity generation costs of pure diesel grids



- Costs of local energy production depend highly on the diesel price
- Subsidization and taxation of diesel have strong effects on costs

» Diesel price is essential for competitiveness of PV-based mini-grids

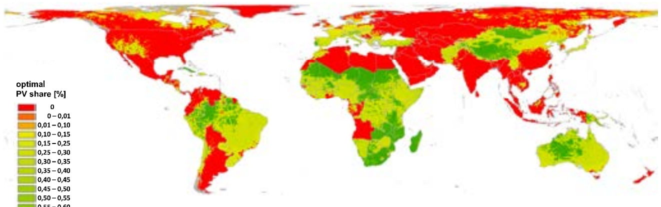
Cost advantage of hybrid PV-battery-diesel systems



- Remote areas profit intensively by decentralised energy supply
- Subsidization of diesel makes PV improvident

» In many areas PV-battery-diesel systems have already a clear cost advantage

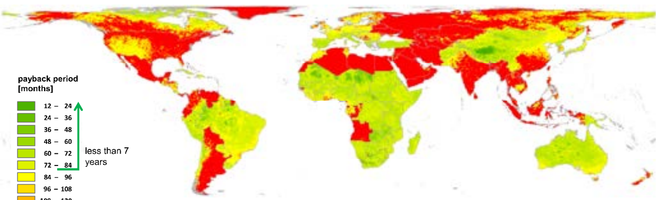
Optimal PV share in hybrid PV-battery-diesel systems



- In areas where use of batteries is profitable, also evening- and night-hours can mostly be covered by PV, i.e. ca. 85 % PV share
- 100 % PV share is possible, but does not lie in the economic optimum because of the required battery capacity

» 25-85 % PV share of energy supply is economically optimal

Amortization of hybrid PV-battery-diesel systems

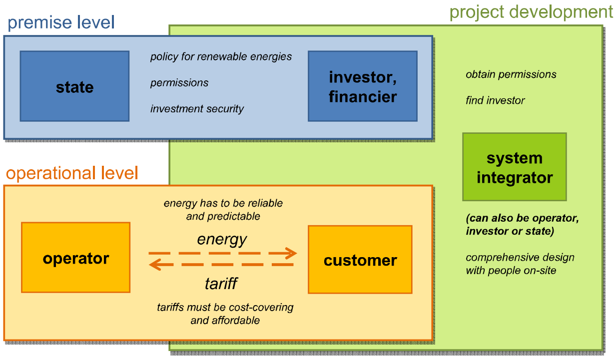


- In many regions in Africa and South America payback periods of only 5 – 7 years can be reached
- In very remote areas very lucrative payback periods of less than 4 years arise for PV mini-grids

» In many regions are already reached very attractive payback periods for PV-based mini-grids

Agenda

Levels and Participants of Electrification Projects



Best Practice: Approaches of Existing Business Models

- **financing**
  - capital costs are subsidised and running costs are covered by tariffs
  - tariffs are subsidised in order to ensure equal electricity prices nationwide
  - social funds or family offices as investor
- **operator**
  - national utility
  - single operator model – operator has much power
  - community model – villagers need access to technical expertise
- **tariffs**
  - no prepaid – more non-payer, risk of high debts
  - prepaid without time limit – less planning security
  - intelligent tariffs – technically useful, but complex; facilitates awareness for the system

pictures: top: Namibia, 200 kWp solar power plant; below: Rwanda, training of technicians [© Juwi Solar GmbH]

►► There are already good approaches for business models but only few successfull implementations

Best Practice: INENSUS Micro Power Economy

- **public private partnership (ppp)**
  - private investor owns production units (power station operator)
  - community owns fixed assets (mini-grid operator)
  - micro finance inst. allows capital expenditures in commercial activities
- **six months contract duration**
  - continous adapting to needs
  - sufficient planning security
  - satisfaction and good service through periodical negotiations
- **electricity blocks**
  - units of fixed energy amount and specific capacity
  - only valid in determined period
  - additional energy is available at higher prices
- **Load Management and Accounting Unit (LAU)**
  - load shedding based on determined priorities
  - prepayment meter and house connection
  - electricity block trading

> - subsidies for grid possible
> - prospective subsidies will not be necessary through proven model and growing trust

INENSUS

pictures: top: technician; below: LAU [INENSUS]

►► Separation of property enables mutual quality check and flexible ending of business relationship at breaking contracts

Agenda

1. Introduction
2. Potential Analysis
3. Business Models
4. **Summary**

Summary

- massive need for rural electrification
- PV-based mini-grids are an (economic) optimal solution
- Considering of local macro-economic conditions essential for success of business models
- financing is an enormous obstacle and has to be addressed early
- several preconditions still often have to be created
  - clarifying the benefits and chances of renewable energies
  - reduction of political and economic barriers
  - training/ support of local banks, project developers and companies
  - linking of all parties
  - implementation and presentation of sustainable projects
- For success on a long-term interests of consumers, operators, financiers and governmental organizations should complement each other positively

[© KAITO Energie AG, München]

►► With successfull pilot projects business models can become reproduceable and the electrification of rural regions can be pushed

picture: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

full presentation and study available at:
www.sma-stiftungsverbund.de → Downloads

Thank you for your attention.

Backup

Parameter	Szabó et al.	RLI
Availability PV/Battery-System	95 % according to text but does not match results	PV/Battery/**Diesel**-Hybrid
Diesel transport cost	0.08 • travel time in h • nat. diesel price	**0.02** • travel time in h • nat. diesel price
PV cost	3,500 €/kW$_p$ (70 % modules, 30 % BOS)	**2,000 €/kW$_p$**
Battery cost	125 €/kVAh$_{nom}$	**120 €/kWh**
Interest rate	5 % p.a.	**8 % p.a.**
Irradiation	Daily GHI, PVGIS (HelioClim) 15'-pixel size	Hourly GHI, DLR (NASA) 27'-pixel size
Load curve	1/3 PV direct (daytime), 2/3 via Battery (nighttime), no seasonal changes	
Performance Ratio	70 % (includes battery cycle efficiency)	
Max DoD	70 %	
Life times	PV 20 a, Battery 5 a	
Genset efficiency	36 % or 0.286 l/kWh$_{el}$	**30 %** or **0.333 l/kWh$_{el}$**
Opex PV/Battery	2.5 % of Invest p.a.	
Opex Diesel	0,01 €/kWh$_{el}$ (includes genset write-off)	**0.02 €/kWh$_{el}$**
National diesel prices	2009 data	

Preliminary Note

> The SMA Stiftungsverbund gemeinnützige GmbH has as one of its main focusses the development and support of concepts and business models for spreading of PV-based mini-grids

> Within the first project phase "Analysis of market potentials" the Reiner Lemoine Institut was commissioned to carry out a study

> Research period: February-August 2012

> During the study lots of experts interviews were conducted (in particular concerning experience data, business models etc.)

> This document is to be understood as presentation for the study "PV-based mini-grids: A survey of market potential and business models"

What is the background of this presentation?

Photovoltaics

Advantages of PV for decentralised sites

> cost-effective
> modular expandable
> wear-free technology
> solar energy everywhere available
> easy installation

Why PV as basis for decentralised energy supply?

picture: Sunlabob Renewable Energy Ltd.

Possible systems:

solar home systems

> are suitable for very small energy needs
> are linked with small capital costs

mini-grids

> are flexible expandable
> higher power enables supply of commercial usage, hospitals, villages etc.

Island Grids/ Mini-grids

Bild: SMA Solar Technology AG

> AC-coupling enables a flexible expansion with further producers and consumer loads

> Three-phase loads for commercial usage can be integrated as well

- Systems are expandable and can be easily adapted to a growing demand
- PV-based mini-grids enable reliable basic services and local creation of value

PV-basierte Inselnetze als Schlüssel zur Elektrifizierung

1. Global **potential analyses** for hybrid PV mini-grids with regard to

> geographic conditions
> political conditions
> economic conditions

2. Focal **experiences** and **business models**

> based on experts interviews and literature evaluation
> key elements for success of sustainable projects
> promising existing business models

Where is PV-based electrification with which business models sustainable viable?

- The study is to demonstrate challenges and chances of PV-based mini-grids for energy supply in so far notelectrified regions

Comparative Country Ranking

Comparative evaluation of target countries based on statistic data with regard to market potential plus political and financial environment

used criteria and and weighting factors:

40 % **A: market potential**

- 30 % • electrification rate [World Bank, IEA, UNDP]
- 50 % • rural population without access to electricity [calculated]
- 20 % • pump price for diesel fuel [World Bank]

60 % **B: political and financial environment**

- 15 % • political stability [World Bank]
- 20 % • corruption perceptions index [Transparency Int]
- 15 % • inflation [World Bank]
- 50 % • ease of doing business index [World Bank]

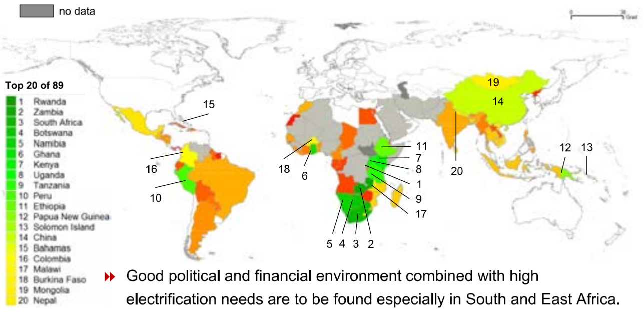
Results of the Country Ranking

exclusion criteria: political instability, travel warning from Ministry of Foreign Affairs, diesel price (≤ 0.25 USD/l)

not considered: electrification rate > 95% and < 200,000 people in rural areas without electricity

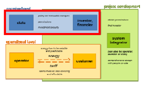
target countries: rank 1 to 89

no data



Good political and financial environment combined with high electrification needs are to be found especially in South and East Africa.

Political and Economic Premises



state

requirements

- has to agree to permit tariffs for mini-grids which are mostly higher than in the remaining country
- has to create legal framework

frequent problems/experiences

- legal framework lacks
- complex licensing procedures
- scepticism about renewable energies
- high import duties
- monopoly on energy supply
- financial sector is underdeveloped

investor, financier

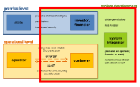
requirements

- investor has to take risks
- financier has to be willing, to provide enough capital (for investor)

frequent problems/experiences

- high investment costs at the beginning
- foreign exchange risk
- lack of credit availability
- high transaction costs
- insufficient trust in project development
- lacking security during project period
- local expectations on investment costs and return times

Project Development



system integrator

requirements

- has to obtain permissions
- has to find investor and financier
- **currently has often firstly to create requirements**

operation

- has to meet cultural needs
- has to plan for long-term operation
- has to integrate and train local participants
- has to create a sustainable tariff structure
- has to ensure that responsibilities are clear defined

frequent problems/experiences

- knowledge lack of local conditions
- projects not adapted to local conditions
- scarce communication with community and integration of local players

Operational Level

cashier
- must be accepted
- has to earn money

payment of tariffs

operator
e.g. community, cooperative, company
- has to ensure maintenance and quality
- has to be addressable and able to react quickly
- has to make provisions and profit

energy

tariff

tariff must be cost covering and affordable

customer
households, workshops
- has to understand the system
- must be willing to pay

technician
- must have technical expertise
- has to earn money

installation, service, maintenance

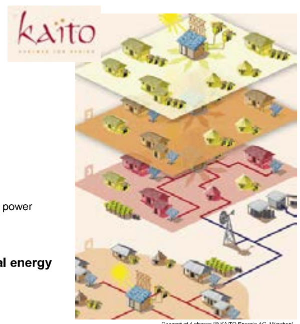
frequent problems/ experiences

- maintenance and responsibility for operation is neglected
- continuous adaption with demand not considered
- poor payment practices of consumers

Best Practice: KAÏTO Concept of Phases

- **phase 1: charging station (franchise)**
  - renting of battery-operated lamps and energy-cases
  - charging cellphones, torches, etc.
  - lamps, spare parts, installation material
- **phase 2: additional PV systems**
  - for public institutions and workshops on lease
  - maintenance by Kaïto staff

  if demand for energy increase:
- **phase 3: interconnection to an AC grid**
  - additional energy production with plant oil, biogas or wind power minimum purchase needed for connection
  - cross-linking of all installed generators
- **phase 4: interconnection of village grids to regional energy clusters**
  - option for the future



Concept of 4 phases [© KAÏTO Energie AG, München]

Single phases build upon each other and will be realized depending on the energy demand and commitment of population

The Swarm Electrification Concept

Side Event
Enabling energy supply for low-income markets through mini-grid solutions
at the MES Conference 2013
by Daniel Philipp

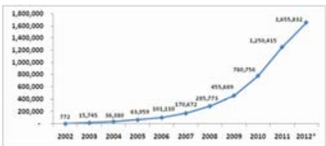
An Impulse for a Discussion
from the Mini-Grid Research Team of MES – TU-Berlin

MES's Perspective

- The focus is micro empowerment from the bottom-up
- Individual households and businesses are the basis for the development
- Technology is based on the identified end-user needs
- Implementation with End-User Financing (Microfinancing)

Microfinanced SHS (Microenergy Supply Units)

- Rapid deployment
- Decentralized generation and storage (Prosumer)
- Located at the customer's side
- Serves basic needs (=small loads)
- Microfinancing is possible

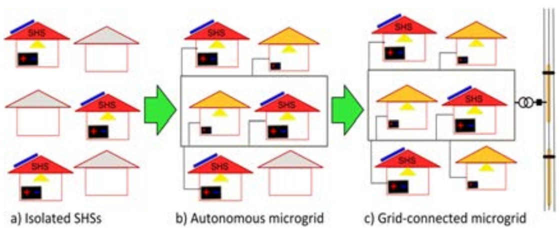


Number of installed systems: IDCOL (Bangladesh)

Challenges Faced

SHSs	Minigrid	Grid Extension

The Process of Grid Connection in 3 Phases

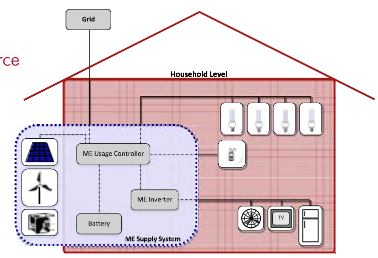


The Seed of Swarm Electrification

ME Supply System (MESUS)
- a decentralized energy supply system

Components of the MESUS :

1. Decentralized energy source
2. Grid electricity (optional)
3. ME Usage Controller
4. Storage unit
5. Inverters (optional)



Hidden resources

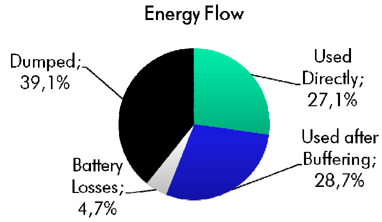
Financial
- High price for basic services already paid when supplied with kerosene, batteries etc.

Generation
- Dumped generation
- Unused capacity
- Seldom used generators (low load factor)

Appliances
- DC appliances in SHSs already in use
- Seldom used appliances for productive uses

Excess generation

MES Simulation for Tamil-Nadu (India) with supply 80% from PV and 20% from grid



Felix Boldt, *MESUS-Concept- An Innovative Solution for the Electrification of Regions with Poor Energy Infrastructure* (Berlin: Promotionskolleg Mikroenergie-Systeme, 2012).

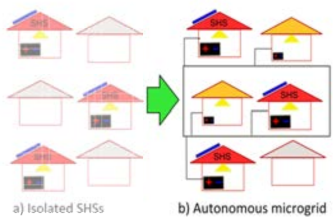
Connecting Microenergy Supply Units

Simulation for interconnecting 8 SHSs at 24 V

➨ less panels needed

Kurtis Unger, "Organically Grown Microgrids: The Development and Simulation of a Solar Home System-based Microgrid" (Master Thesis, Universtity of Waterloo, 2012), http://uwspace.uwaterloo.ca/bitstream/10012/6727/1/Unger_Kurtis.pdf.

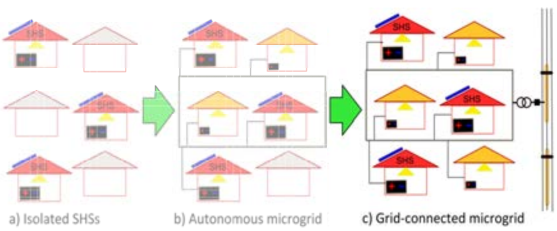
Phase 2: Autonomous Microgrid



- Balancing of systems
- Swarm of generation units
- Further connections
- Bigger loads
- Enhances productive use
- Community based financing

Prosumer units: Producer + Consumer

Phase 3: Grid Connection



Insights from the DC world

- Solar Mini Grid Design on 240 V DC design in Bangladesh

  ➨ avoids inverter investment and losses

M.R. Khan, "A Stand Alone DC Microgrid for Electricity Supply in Rural Bangladesh," in *Developments in Renewable Energy Technology (ICDRET), 2012 2nd International Conference on The*, 2012, 1 –4.

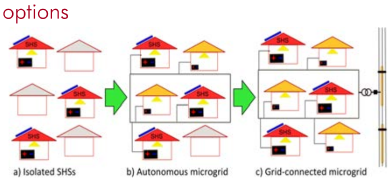
Some of the main Research Needs

- How closely can **productive use** and minigrid **operation** enhance one another
  (alternative methods of storage, baseload concepts, demand response, medium size generation, heterogeneity in income generation…).
- Could a swarm generation microgrid run without a central control with **micro source controllers only and what technology is then needed**?
- Should we have **different voltage levels** within the microgrid and possibly some of them **DC**?

Thank you for your attention!

Summary

- Rapid deployment
- Flexible development
- Enhanced productive use
- Three phase bottom-up process (all optional)
- Multiple financing options
- Research needed



Advantages of different Aspects

- Household based
  - Bottom up
  - Microfinacing
- Minigrids
- Decentralized generation
- Decentralized storage
- Microgrid

RAEL Renewable & Appropriate Energy Laboratory

http://rael.berkeley.edu

Case Study in Clean Energy Mini-grid

Daniel Kammen

Class of 1935 Distinguished Professor of Energy
Energy and Resources Group | Goldman School of Public Policy
Director, Renewable and Appropriate Energy Laboratory
University of California, Berkeley

Micro Perspectives for Decentralized Energy Supply
Feb. 27 to Mar. 1, 2013, Berlin, Germany

RAEL

- **RAEL is focused on *systems science* and design of sustainable, low-carbon energy systems**
- **Large-scale low-carbon energy systems:**
  rael.berkeley.edu/switch
- **Carbon and resource footprinting**
  coolclimate.berkeley.edu
- **Mini-grids and off-grid energy services**
  Malaysia, Nicaragua, Kenya/South Sudan
  rael.berkeley.edu/sustainableislands

Research, Development, and Innovation

Research is inspired by:

		Consideration of use? No	Consideration of use? Yes
Quest for Fundamental Understanding?	Yes	Pure Basic Research (Bohr)	
	No		Pure Applied Research (Edison)

Adapted from *Pasteur's Quadrant: Basic Science and Technological Innovation*, Donald E. Stokes 1997

RAEL

Research, Development, and Innovation

Research is inspired by:

		Consideration of use? No	Consideration of use? Yes
Quest for Fundamental Understanding?	Yes	Pure Basic Research (Bohr)	**Use-inspired Basic Research (Pasteur)**
	No		Pure Applied Research (Edison)

Adapted from *Pasteur's Quadrant: Basic Science and Technological Innovation*, Donald E. Stokes 1997

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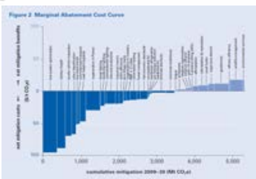
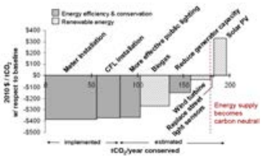
SCALES OF ANALYSIS:

GLOBAL

NATIONAL



LOCAL



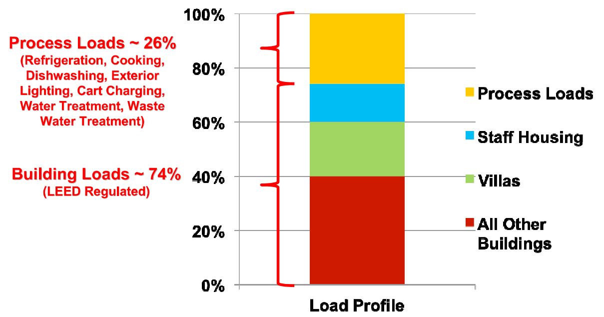
PLANNING AND DECISION MAKING FROM LOCAL TO GLOBAL

PACIFIC BEACHCOMBER

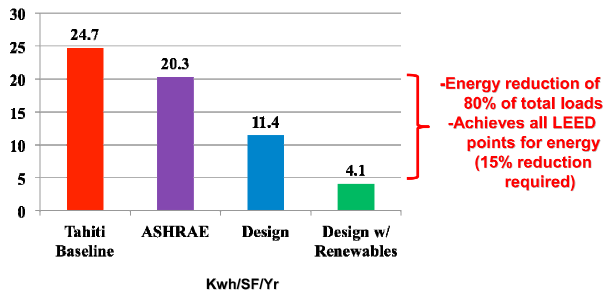
Renewable and Appropriate Energy Laboratory University of California, Berkeley

tetiaroa FRENCH POLYNESIA

The Brando - Energy Load Profile



Net Zero Energy Modeling Results

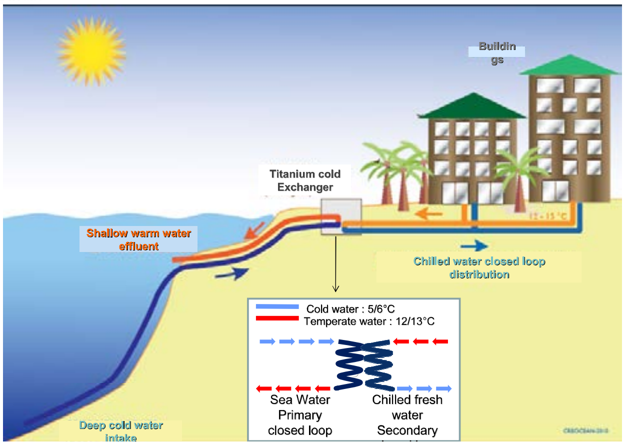


	Energy Requirement		Production Capabilities	
Cold Water	2.4 MWf *1.4 MWf for the hotel*	*1.0 MWf for the residences*	SWAC	Pipe diameter 450 mm
Electricity	3,455,000 KWh per year *2,100,000 KWh per year for the hotel*	*1,355,000 KWh per year for the residences*	Coconut Oil Generators	4 units of 450KW using 100% of coconut oil; 600 T of coconut oil per year
			Solar Panels	500 KWC installed; 2950 panels of 170WC (1.3 m² per panel); 675,000 KWh per year
Energy Storage			ZBB Flow Batteries	2 modules of 500 kW
Water	110 m³ of drinkable water per day		3 water networks: 1.Drinkable water network – lens & desalination (osmosis) 2.Non-drinkable water network – lens + rain water 3.Watering network – Sewage station	
			Underground lens	70 m³ per day on Onetahi; 70 m³ per day on Tiaranau
			Desalination	110 m³ per day

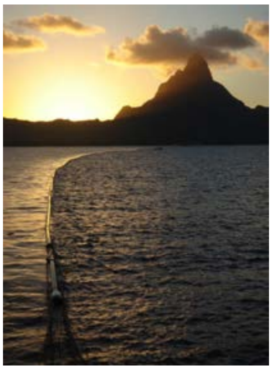
PACIFIC BEACHCOMBER

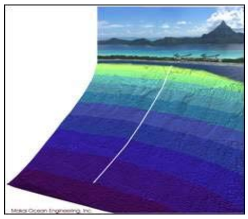
PACIFIC BEACHCOMBER

SWAC: CENTRALISED SEA WATER AIR CONDITIONING



Sea Water Air Conditioning (SWAC)





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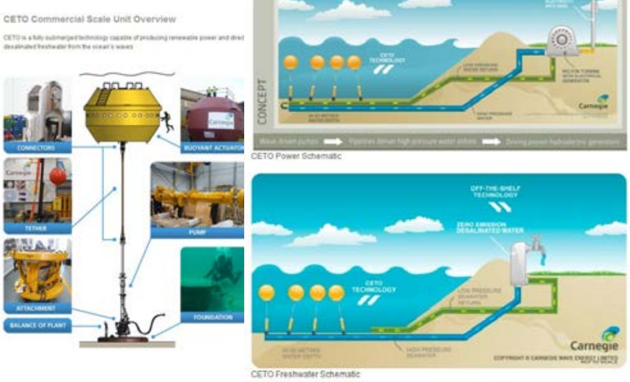
CETO Technology
Wave Energy and Freshwater Production



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Conservation Plan

CONSERVATION TETIAROA
RECHERCHE • EDUCATION • CONSERVATION

- GIS mapping of Tetiaroa's geography, marine and terrestrial biodiversity, habitats and cultural sites
  - Vegetation mapping and native plant repopulation [reintroduction of native plant species including the once extinct (Ofai-Rama) plant].
- Develop conservation, restoration, and management measures to preserve the atoll's ecological health and cultural heritage.
  - Turtle nursery
  - Sustainable fisheries project
  - Bee sanctuary
  - Archeological survey and restoration program
  - Island energy research center / U of California, Berkeley

- Develop educational programs and a "toolkit" to raise awareness locally and internationally. Introduce visitors to activities on Tetiaroa and create a hands-on environmental learning program through which participants will be able to experience the magic of Tetiaroa.

Carbon and Resource Calculator

- Based on the Cool Climate Carbon Footprint Calculator developed at RAEL, UC Berkeley
- Expenditure Data from the 2005 USVI and 2008 US Consumer Expenditure Survey and Consumer Price Index Data
- Emissions Factors

•Utilities: Electricity, Water, Gas, and Waste based on local Utility data

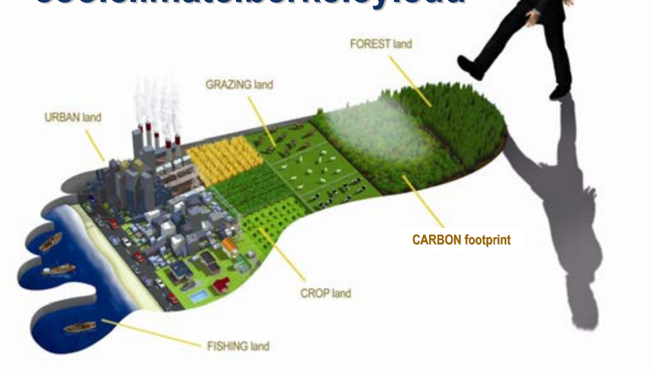
•Food/Goods and Services

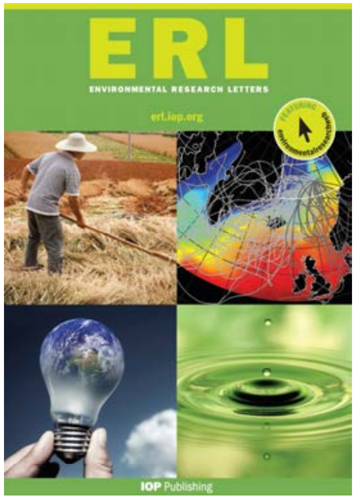
•Transportation: based on EIO-LCA data for vehicle manufacture, local data on taxi, ferry, aircraft and private vehicle use and standard vehicle characteristics

http://coolclimate.berkeley.edu/

D. Kammen, R.Shirley || Renewable and Appropriate Energy Laboratory || University of California Berkeley

The Ecological Footprint:
coolclimate.berkeley.edu





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