Minigrid electricity service based on renewable generation for isolated or rural areas: sizing criteria, management and sustainability models, and case studies in Africa and Europe

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MiniGRIDs are a reality

- 40% of the world's poor live in villages that are typically too remote to be feasibly reached via grid extension in the near term (IEA), particularly in Sub-Saharan Africa and developing Asia.
- In rural or isolated locations, the traditional extension of national electricity networks is technically and financially inefficient because of a combination of factors (e.g. high investment costs, deficient grid supply, long construction times, low consumption patterns, etc.)
- The development of RE mini grids was constrained by several factors: gaps in policies and regulations, a lack of long-term financing, and a lack of capacity or interest among power producers.
- Nowadays, technological and institutional innovations and cost reductions have made mini grids an attractive option to meet the UN SE4ALL goal of universal energy access by 2030, and are high in the agenda of most rural electrification interventions.
- However, a lack of knowledge and exposure to global best practices continues to create policy and commercial barriers that hold back the expansion of sustainable mini grids.

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Universitat Politècnica de Catalunya - BarcelonaTech

Public higher education and research institution

Specialized in the fields of architecture, science and engineering.

Hub of talent, innovation, technology transfer and regional development:

- 2009: Barcelona Knowledge Campus (BKC), a project carried out with the University of Barcelona
- 2011: Campus of Excellence with the UPC Energy Campus project
- 2012: Partner of the KIC Innoenergy project, Leader of the Iberia CC
- €58,800,000 turnover for R&D projects (2017)

21 schools in 10 campuses
42 departments
6 research institutes

205 research groups recognised by the Catalan government

3,066 teaching and research staff members (60% PhD holders)

1,480 administrative and service staff members

19 research centres belonging to the TECNIO network

30,860 undergraduate and postgraduate students

Bachelor's, master's and doctoral degree courses

65 bachelor's degrees, 73 master's degrees, 49 PhD programmes
87 international double-degree agreements with 51 universities
5 UNESCO chairs
2,390 articles published (journals) + 68 patents
2,190 collaborator companies + 8 start ups (Innova programme)

- Research and innovation projects
- Technology-based companies
- Spin-offs and start-ups

TTA profile

- SME - Founded in Barcelona en 1986
- Highly specialized in Renewable Energies and Sustainable Development
  - ➢ Energy management and distributed micro generation
  - ➢ Integration of renewable energies in buildings and bioclimatic design
- Independent consultancy, engineering, research, project management, social aspects, financial,…
- Reference in multiuser micro grids with solar hybrid generation for rural electrification – Off-grid practitioners since 1987
- Headquarters in Barcelona; Units in Brazil, Ecuador, Kenya and Ghana.

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Mini GRID TYPES

	Lower Tier of Service	Higher Tier of Service
Autonomous	**Autonomous Basic (AB mini-grids)** **Generation Sources:** PV, hydro and biomass **Tier of service:** less than 24 hour power **End-users:** Remote community without major commercial or industrial activity Added value: * Enable enhanced energy access * Alternative to grid-extension * Improve quality of life	**Autonomous Full (AF mini-grids)** **Generation Sources:** PV, hydro and wind **Tier of service**: 24/7 power **End-users:** Remote communities, islands, with major commercial or industrial requirements; Industrial sites disconnected from grid Added value: * Alternative to expensive polluting imported fuels * Diversification and flexibility of supply
Interconnected	**Interconnected Community (IC mini-grids)** **Generation Sources:** PV, wind and biomass/biogas **Tier of service:** High critical/ interruptible **End-users:** Medium to large grid- connected community (e.g. university campus) Added value: * Community control * Improve reliability * Response to catastrophic events	**Interconnected Large Industrial (ILI mini-grids)** **Generation Sources:** PV, wind and biomass/biogas **Tier of service:** Very high: Critical/ uninterruptible **End-users:** Data centres, industrial processing or other critical uses Added value: * High reliability for critical loads * Enhance environmental performance * Resiliency

http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Minigrids_2016.pdf

Shaping the Decentralised Energy market

Key components in for an integrated approach:

programme	project	*Goal (as a service)*
Social Development	Social Integration	*Equity*
Technical	Technological	*Reliability*
Institutional	Organisational	*Empowerment*
Financial	Economic	*Viability*

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Social - Demand projections: How realistic?

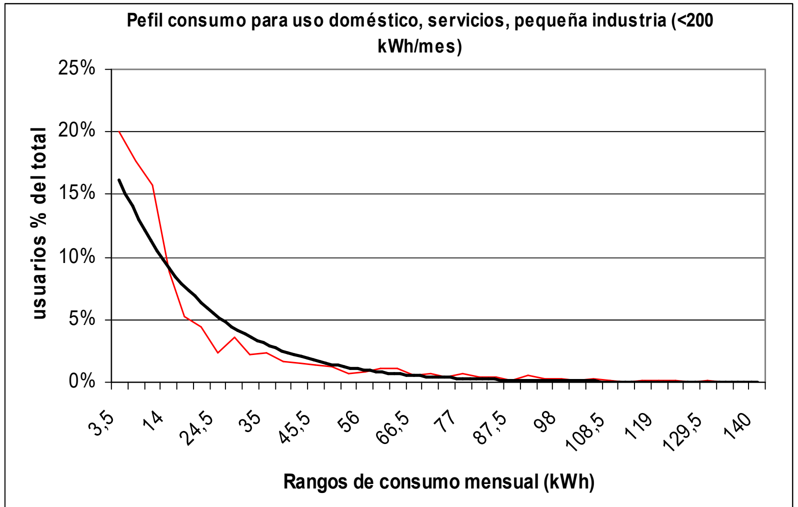
RISK OF OVERSIZING (grid extension approach) or

UNDERSIZING (not considering potential growth, even short term)

1. ASSESS THE ENERGY DEMAND THROUGH SURVEYS and QUESTIONNAIRES
   - The users are not experts
   - Define users' demand requirements
   - Consider socio-economic data

ENERGY EFFICIENCY: MANDATORY IN ALL PROJECTS

2. COMPARATIVE DEMAND CHARACTERISATION
   - Assessment of load categories based on data analysis of similar villages



Social - Demand segmentation

Recent evolutions

<table>
<tr><th>EDA
(Wh/day)</th><th>Maximum Power/connection type
(W)</th><th>NREL MGS Tier
(kWh)</th><th>BGFZ/SWEDEN Tier
(kWh)</th><th>NREL MGS Tier
(W)</th></tr>
<tr><td>275</td><td>500</td><td rowspan="2">Level 2</td><td>Tier H3</td><td rowspan="5">Level 3</td></tr>
<tr><td>550</td><td>500</td><td rowspan="6">Tier P4, I1</td></tr>
<tr><td>1100</td><td>500</td><td rowspan="6">Level 3</td></tr>
<tr><td>1200</td><td>500</td></tr>
<tr><td>1650</td><td>500</td></tr>
<tr><td>2200</td><td>1000</td><td rowspan="10">Level 4</td></tr>
<tr><td>2750</td><td>1000</td></tr>
<tr><td>3300</td><td>1000</td><td rowspan="6">Tier P5, I2</td></tr>
<tr><td>3850</td><td>1500</td><td rowspan="5">Level 4</td></tr>
<tr><td>4400</td><td>1500</td></tr>
<tr><td>5500</td><td>1500</td></tr>
<tr><td>6600</td><td>1500</td></tr>
<tr><td>7600</td><td>2000</td></tr>
<tr><td>13400</td><td>2000</td><td rowspan="4">Level 5</td><td rowspan="4">Tier P6, I3</td></tr>
<tr><td>14850</td><td>2000</td></tr>
<tr><td>30625</td><td>5000</td><td rowspan="2">Level 5</td></tr>
<tr><td>53350</td><td>5000</td></tr>
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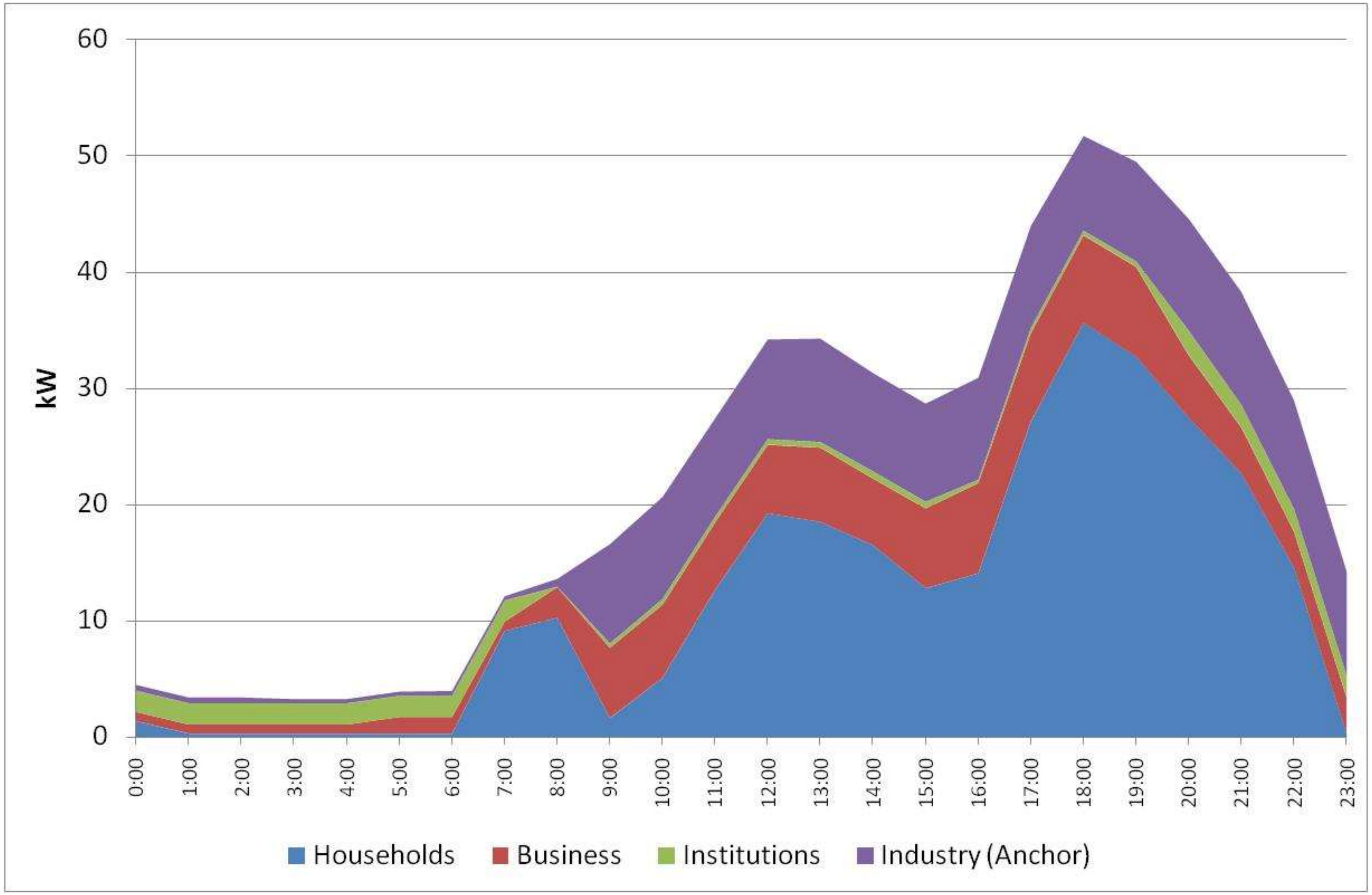
King of the Universe

Sizing - Load Profile

Takawiri Island (Kenya) example – 5 year projection



Technology, quality & functionalities

2013年10月，IEC投票通过由中国主导制定两项IEC微电网国际标准。

OCT. 2013. IEC voted and decided that china lead the development of two IEC international standards about microgrids

2014年1月，IEC/TC8/WG7国内工作组成立，该工作组致力于IEC/TS 62898-1与IEC/TS62898-2两项标准的制定与组组织协调工作。

JAN. 2014. IEC/TC8/WG7 domestic work group, which devote itself to the development and coordinating of IEC/TS 62898-1 and IEC/TS 62898-2, is established.

IEC/TS 62898-1：微电网规划与设计导则
IEC/TS 62898-1:Guidelines for Ge
Microg

IEC/TS 62898-2：微电网
IEC/TS 62898-2:Technical Requi
Control of M

Source: Prof. Zhang Jianhua
North China Electric Power University
(presentation given at the Niagara 2016 Symposium on Microgrids)

Issue	Base Level of Service	Standard Level of Service	High Level of Service
Power Reliability			
Unplanned-SAIFI$_{xx}$ (1,3)	<52 per year	<12 per year	<2 per year
Unplanned-SAIDI $_{xx}$ (1,3)	<876 hours (90% reliability)	<438 hours (95% reliability)	<1.5 hours (99.99% reliability
Planned-SAIFI$_{xx}$ (1,2)	No requirement but should be defined	No requirement but should be defined	<2 per year
Planned-SAIDI$_{xx}$ (1,2)	No requirement but should be defined	No requirement but should be defined	<30 minutes - 100% reliability

(1) System Average Interruption Frequency Index (SAIFI) measures the average number of power outages that an average customer experiences in a year and is defined as Total Number of Customer Interruptions/Total Number of Customers Served.
(2) System Average Interruption Duration Index (SAIDI) measures the average number of minutes that an average customer is without power over the defined time period, typically a year.
(3) SAIFI and SAIDI are typically assumed for power systems that are specified to provide full-time energy service 24 hours/day. A subscript is used in this report for systems that provide partial hours/day service since the number of planned and unplanned interruptions and length of any interruptions should be normalized by the percent of hours of service.

Source:
Quality Assurance Framework for Mini-Grids (National Renewable Energy Laboratory,
U.S. Department of Energy) 2016

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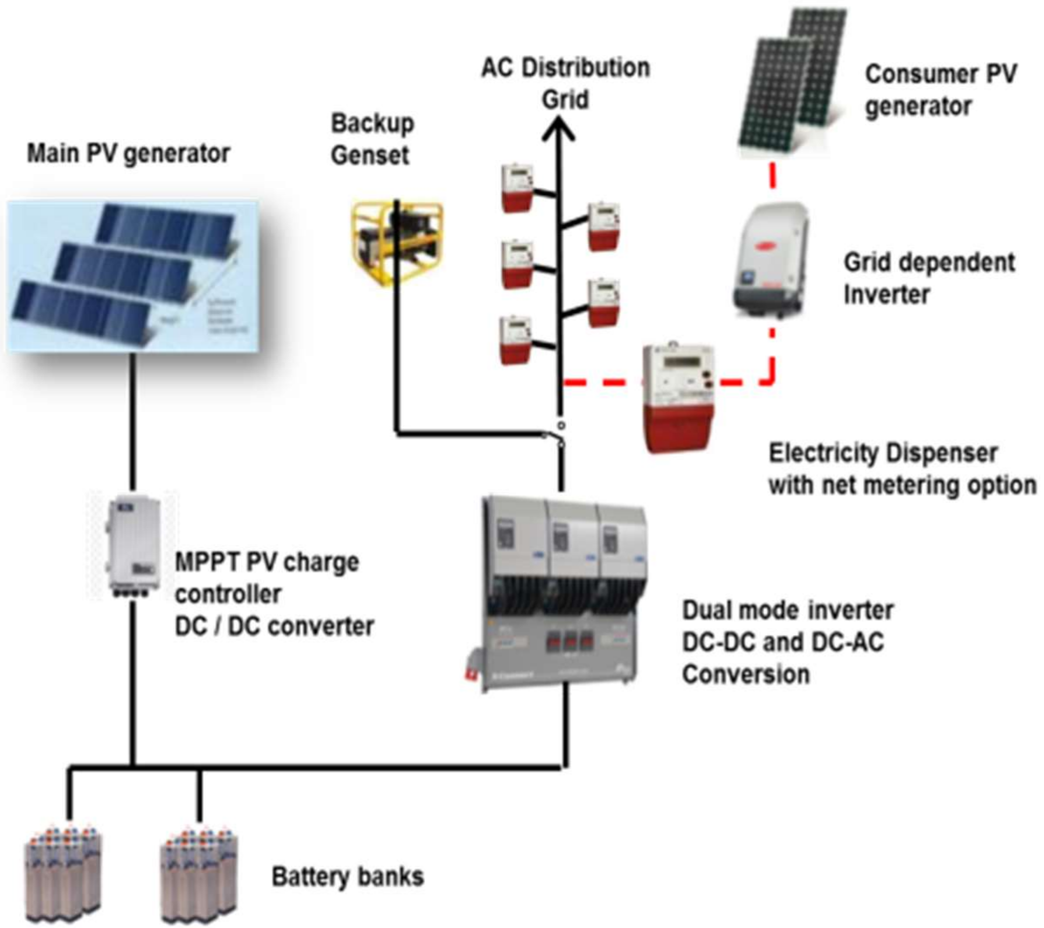
Sizing – Engineering configuration

ENGINEERING

DC coupled micro power plant with storage

High PV penetration with diesel genset back up

3 phase LV standard 230V – 50Hz electricity supply - **Aerial** grid



Institut Universitari de Recerca en Ciència i Tecnologies de la Sostenibilitat IS.UPC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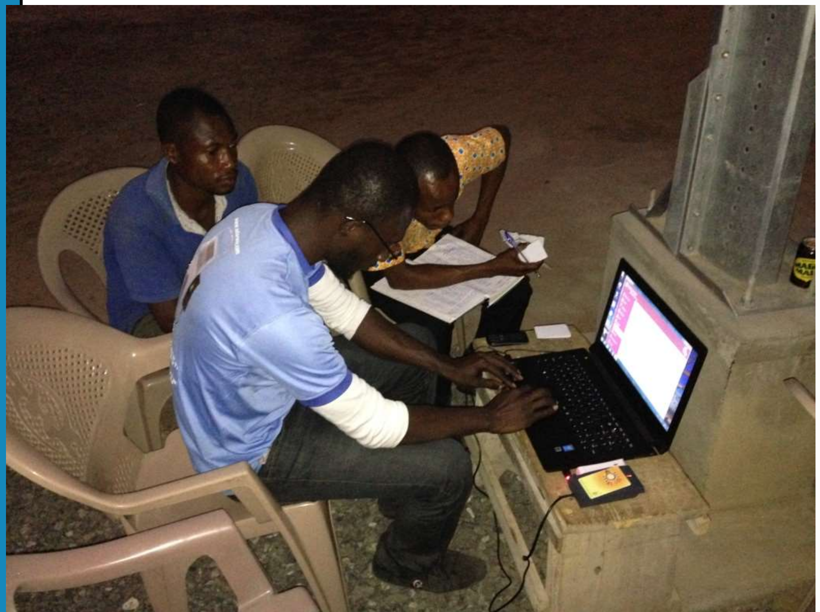
Ghana Microgrids Electricity Services



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Institutional component → key roles!

KEY ROLES		MAIN RESPONSIBILITIES
1. PROGRAMME COORDINATOR	I	Plan, control and management of the programme over its whole life. Ensure communication with and between the key roles
2. INSTITUTIONAL DEVELOPER	I	Defines objectives, strategies and mechanisms for the project execution, according to the conditions set by the regulator.
3. REGULATOR	I	Establishes the conditions for the infrastructure implementation and management of the service (licensing, permitting, tariffs, quality criteria, subsidies...).
4. STANDARDIZING AGENT	R	Establishes the technical conditions for the infrastructure implementation and management of the electricity service (equipment certification and guarantee, quality criteria, safety)
5. FUNDER(S)	I	Provides economic resources (possibly financial options as well)
6. USERS	I	Beneficiaries from the service, must commit to the system conservation, and to the payment of a tariff for the service.
7. SOCIAL DEVELOPER	I	Represent and assist the users' rights, mediate and communicate with other key roles..
8. TECHNICAL DIRECTOR or IMPLEMENTER	I	Controls the adequate execution of the infrastructure execution and the service start-up. Can provide further assistance to the service operator or the users, if required.

Built on IEC TS 62257-6 Recommendations for small renewable energy and hybrid systems for RE.

9. GENERATORS	I	Own the generation systems and produce electricity under the quality conditions set by the Regulator and Standardizing agent.
10. ELECTRICITY SERVICE OPERATOR	I	Controls the sustained and correct operation of the system, the service management, financing (incl. users payments).
11. INSTALLER	I	Adequate installation, start-up and commissioning of the system equipment.
12. MAINTENANCE PROVIDER	I	Technical specialist, conducts maintenance of the system infrastructure (spare parts, collection of used parts, etc.)
13. BIOMASS SUPPLIER(S), TRANSPORTER	I	Production and supply of the biomass resource, under the conditions and quality criteria set by the Regulator and Standardizing agent.
14. PROVIDER(S)	I	Supply materials and equipment (and corresponding guarantees)
15. TRAINER – COMMUNICATOR	I	Conducts specific training and capacity building activities for local technicians, users, and other local entities involved in the management of the system.
16. EVALUATOR or INSPECTOR	R	Periodical supervision of the infrastructure execution and service provision according to the conditions set by the regulator. Verifies the adequacy of the global performance in accordance to the objectives, strategies and mechanisms set by the project developer.
17. DISSEMINATION DIRECTOR	R	Conducts promotional and awareness raising activities related to the infrastructure implemented and the service provided.

Delivery models – No recipe magic

- Public model (public sector provides G&D) - highly reliant on cross-subsidies, no role for private sector; customers have low tariffs
- Private model (public sector provides G&D) - less reliant on subsidies, but high revenue risk (from negotiation of tariffs and non-payment) and high transaction costs, so limited interest to date. Likely to require higher, cost-reflective tariffs
- Public generation, public distribution, private management (Mixed model 1) - possible conflicts over long-term regarding responsibility on re-investments; lack of precedents.
- Private generation (on the basis of a power purchase agreement or PPA), public distribution (Mixed model 2, also known as the "PPA model")—clear division of responsibilities; requires recurrent subsidies (can be through cross-subsidies), but customers have low tariffs.
- Community—community buy-in but serious concerns regarding technical and managerial capacity in and around Lake Volta

Source: ESMAP Knowledge Series 010/16 Conference Edition. Ghana: Mini-grids for Last-Mile Electrification

Are Minigrids costs well understood?

1) Life cycle costing 2) Level of service

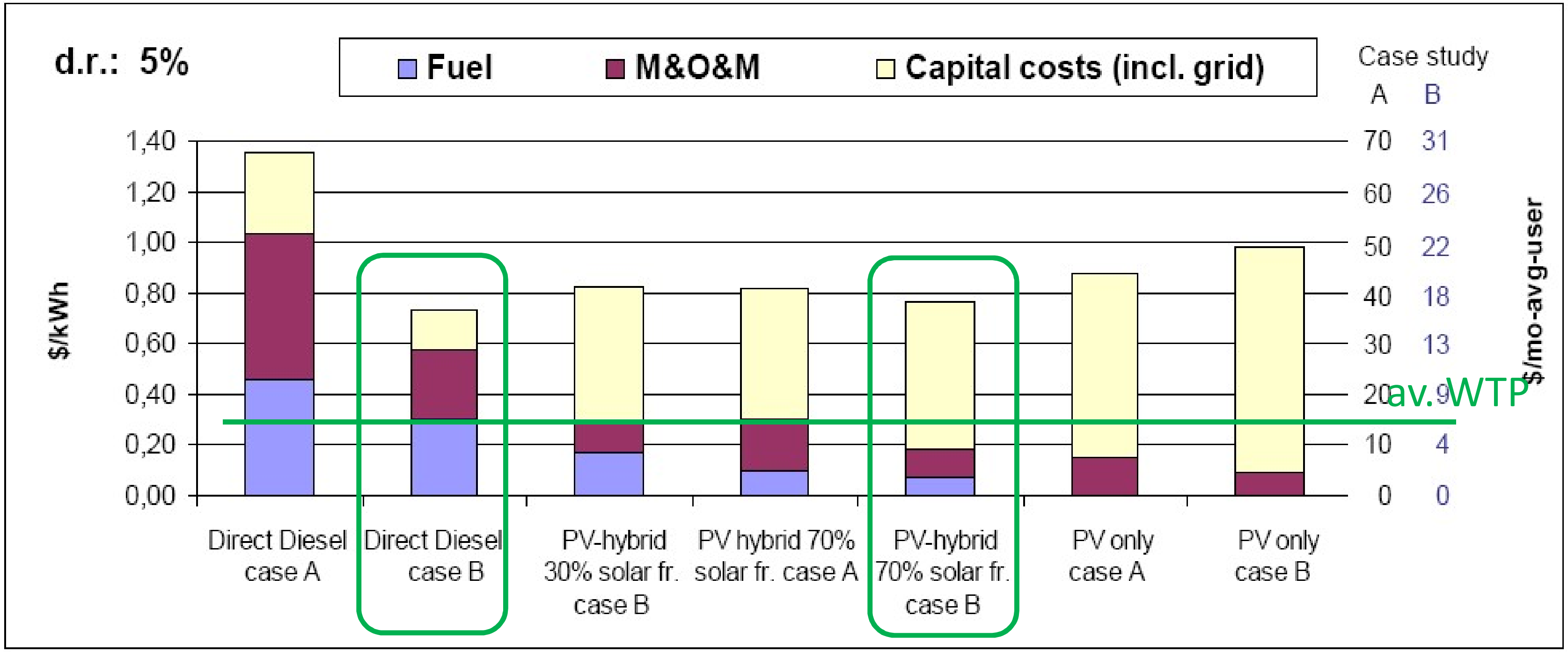
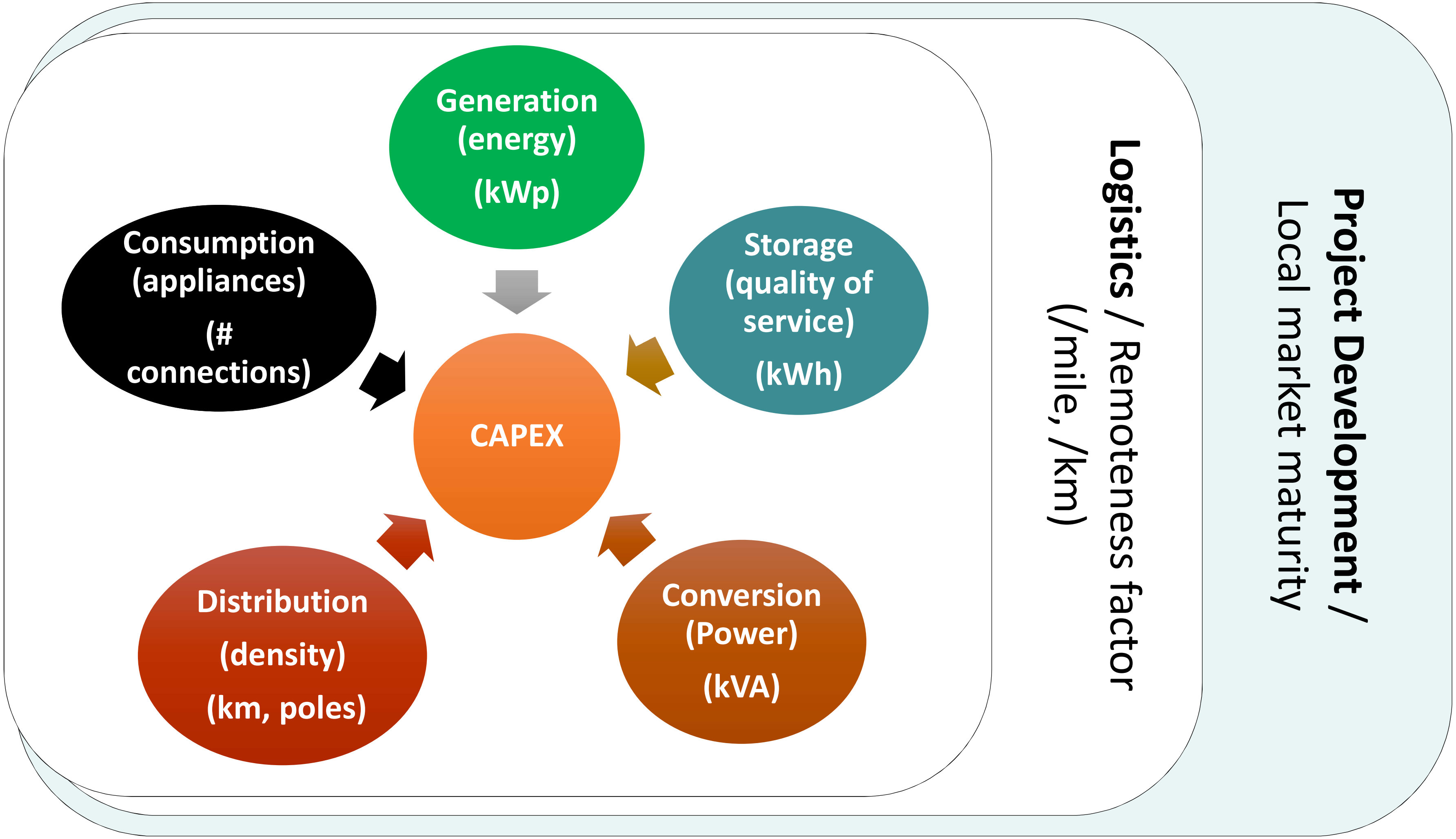


Figure 3.- Breakdown of levelized energy costs in Floreana (case A) and Padre Cocha (case B) at 10% and 5% discount rates. Average kWh cost are acceptable to compare different solutions for one application, but for different systems for different locations and small demands, transaction costs, local management, etc, represent a high fraction of the service costs, and the cost per user must also be assessed.

Source: Arranz-Piera, P. Vallvé, X., González, S. (2006)

Are Minigrid CAPEX well understood?



Logistics…

Ministry of Energy GEDAP

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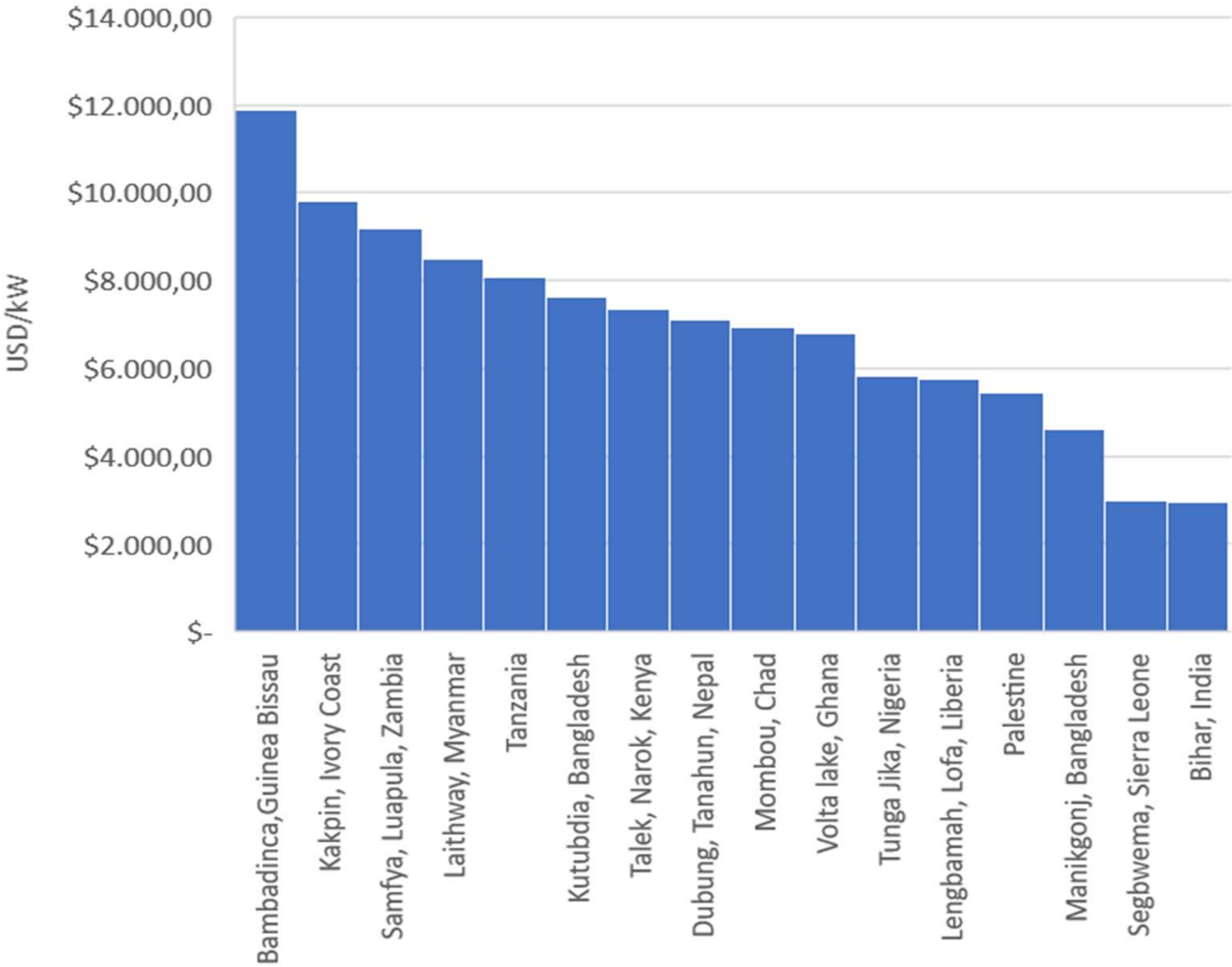
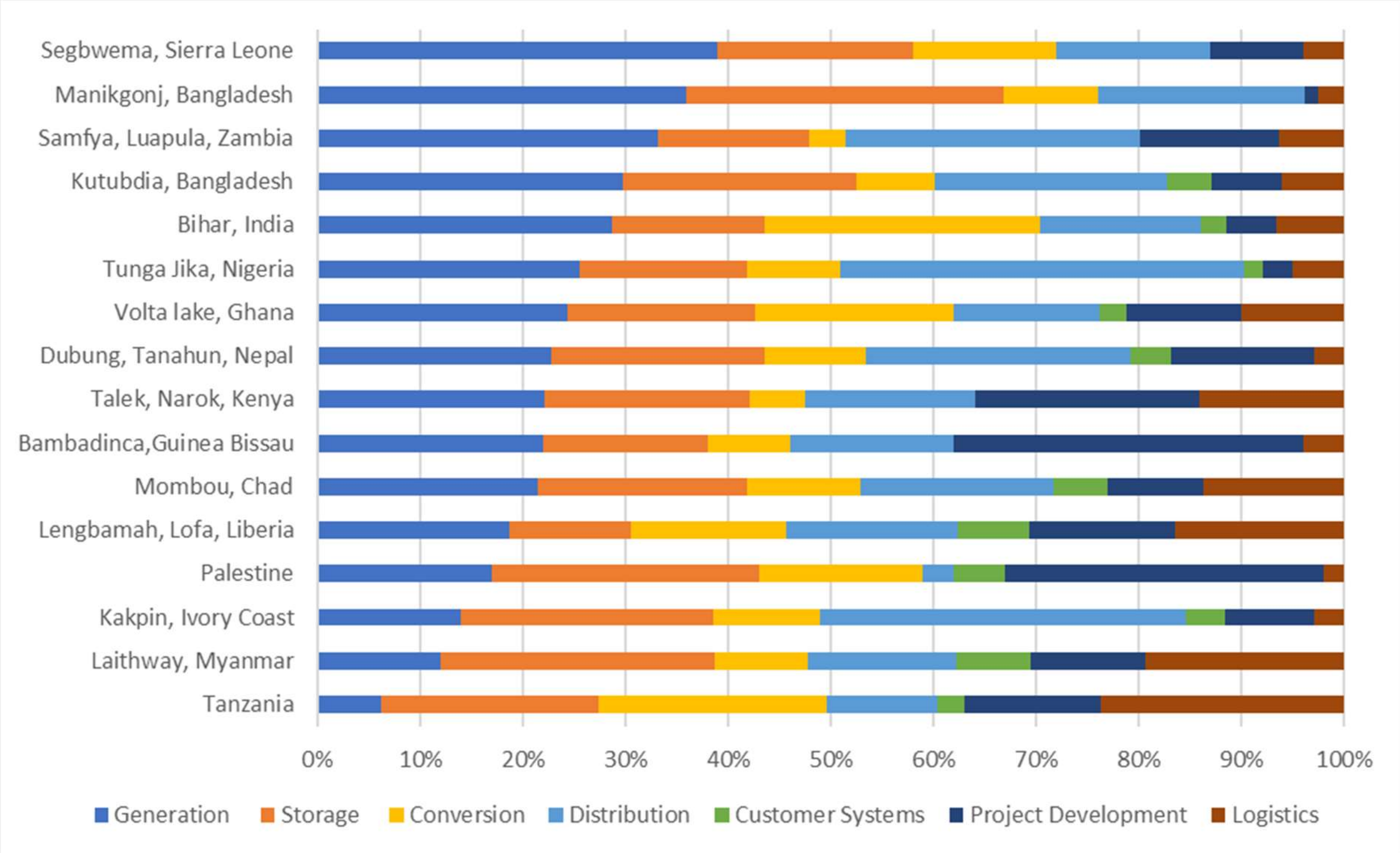
OVERALL CAPEX PER KW (16 PV MINIGRID CASES)



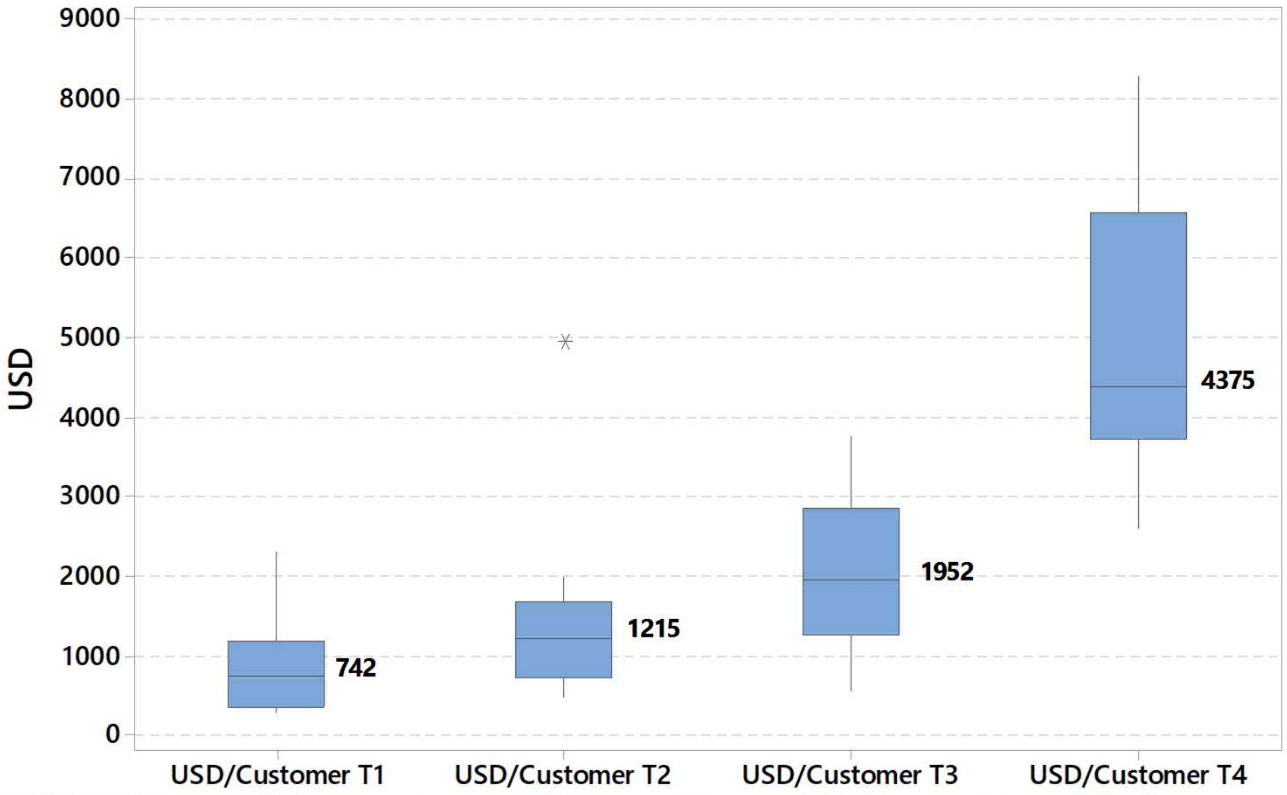
Wide Range of Costs

Studied Variables affecting this Cost

CAPEX BREAKDOWN BY COST CATEGORY



CAPEX PER CUSTOMER



Tier 1 - Residential basic (<8kWh/month)
Tier 2 - Residential med (<20kWh/month)
Tier 3 - Residential high (<50kWh/month)
Tier 4 - Productive (<110kWh/month)
Anchor load(s) (110kWh/month and above)

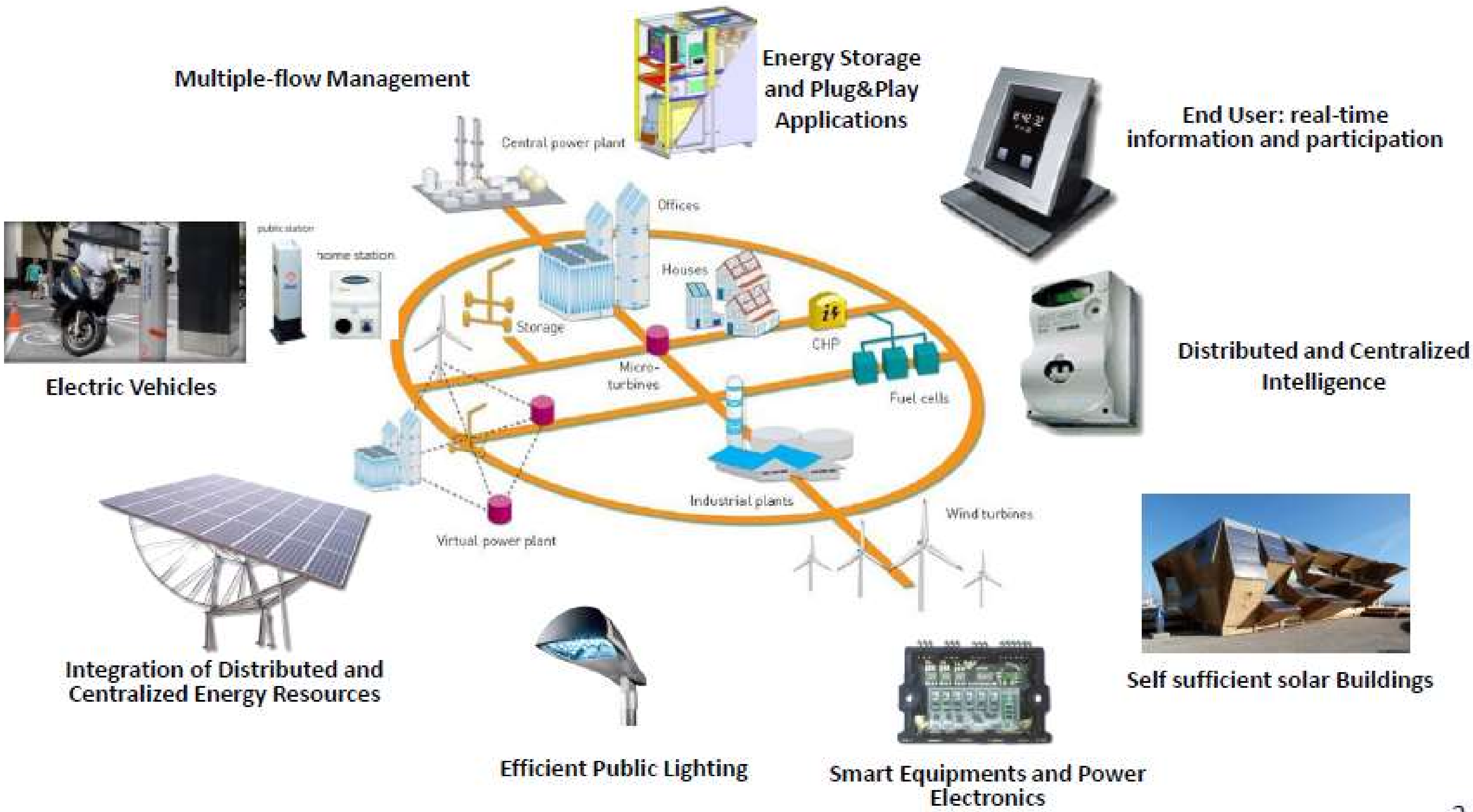
MIN	$288	$484	$559	$2.597	$1.215
MEDIAN	$742	$1.273	$2.516	$5.277	$5.492
MAX	$1.892	$3.080	$4.845	$8.279	$38.427

MINI GRIDS IN EUROPE: TRENDS

endesa

Evolution in Distribution Systems

Every new element must be integrated in a grid with decentralized control

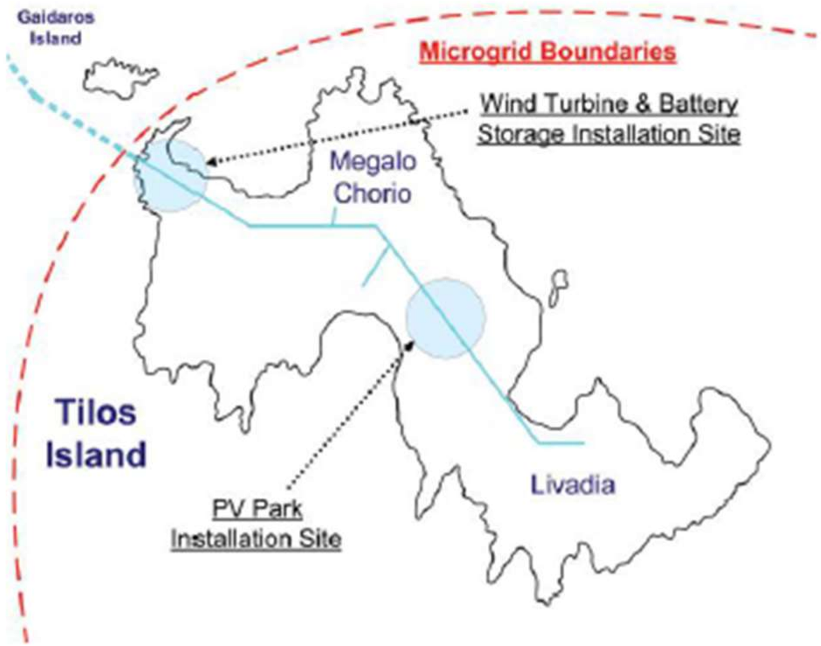


MINI GRIDS IN EUROPE: TRENDS

Minigrids for islands with deficient interconnection

new **prototype hybrid system for electricity production and storage** consisting of:

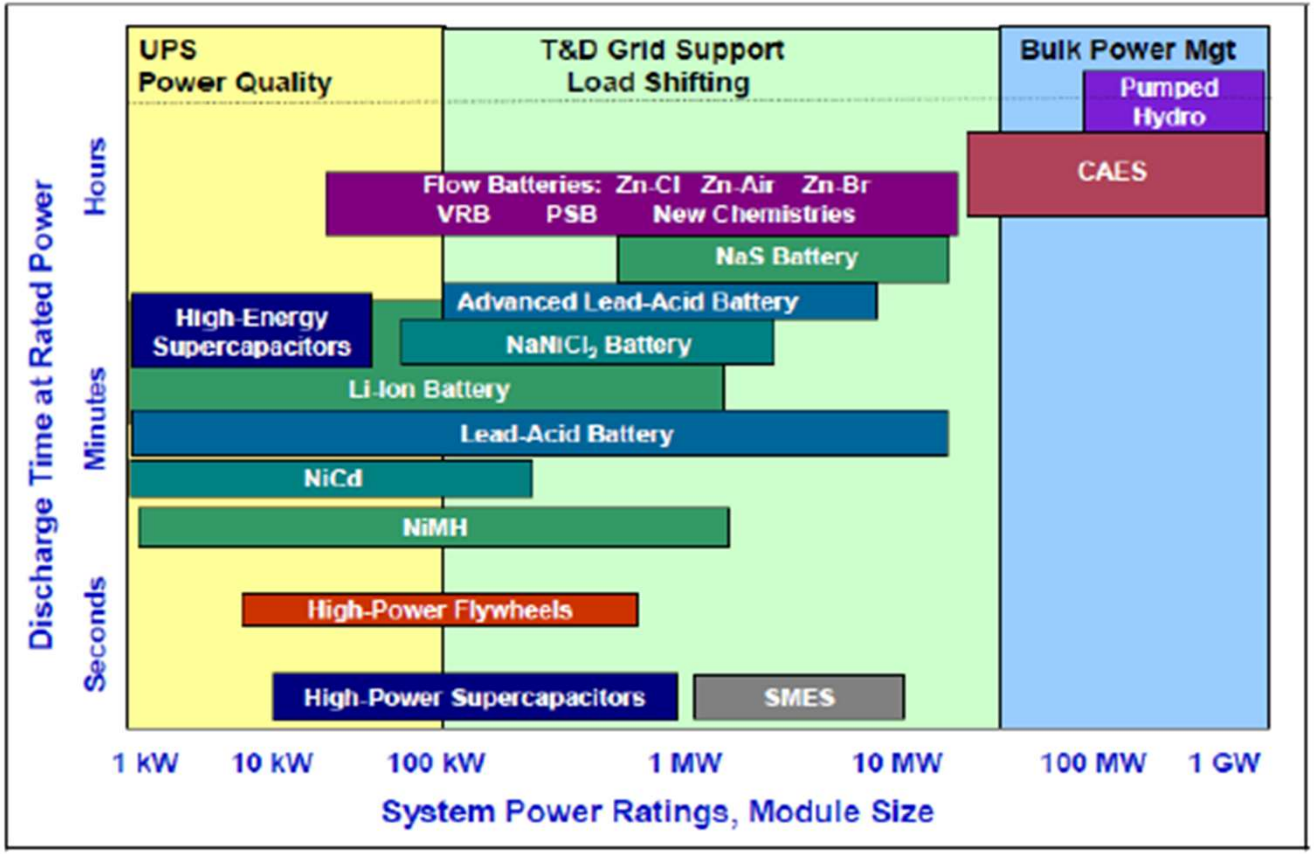
- a medium-scale wind turbine of 800kW;
- a small-scale photovoltaic park of 160kW; and
- a battery storage system of 2.4MWh useful energy capacity



Source: Project Tilos, www.tiloshorizon.eu

MINI GRIDS IN EUROPE: TRENDS

Quest for Storage improvements: autonomy, decentralisation, control



Gràcies Me dase Thank you

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