

Milligrids and its role towards Smart Cities

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Instituto Superior Técnico, Berkeley Lab - UC Berkeley

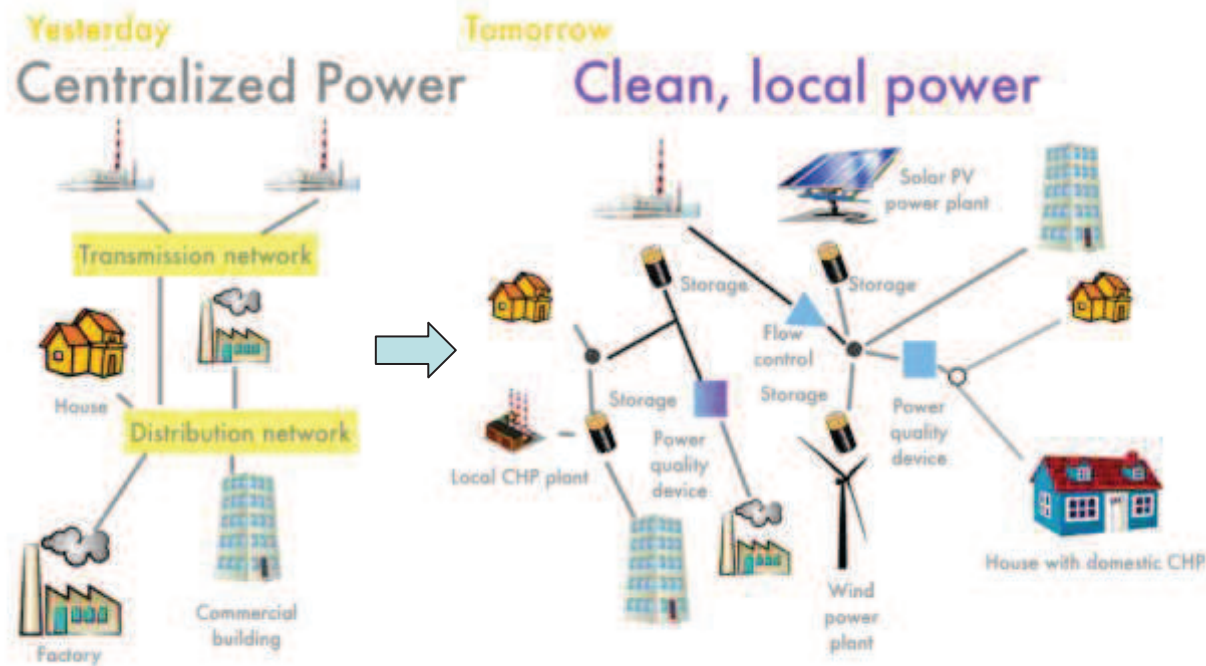
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MIT Portugal Program - Sustainable Energy Systems

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A new Energy paradigm

Current economic, environmental and technological trends lead to a whole **reform** of the energy system, towards multiple **small-scale cleaner** and **local** energy generation sources

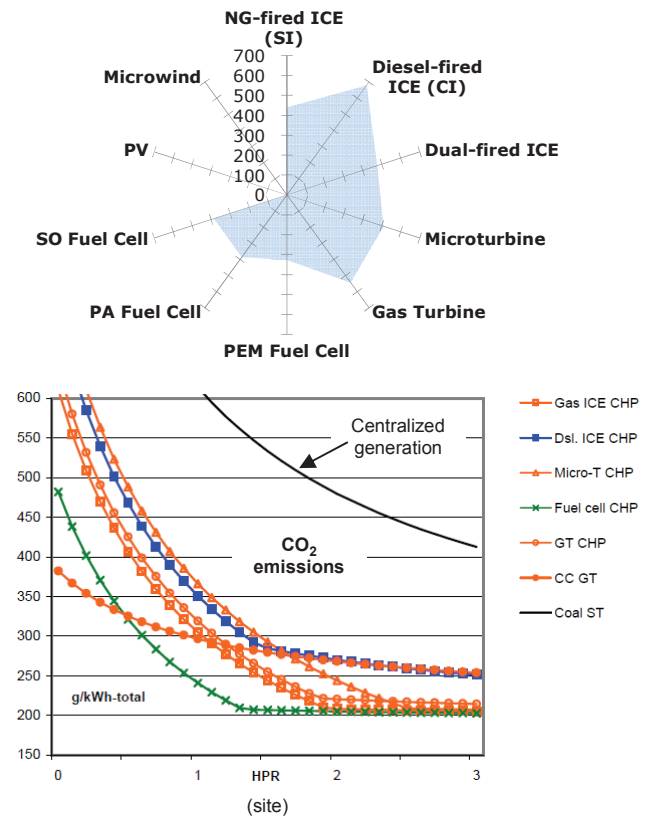
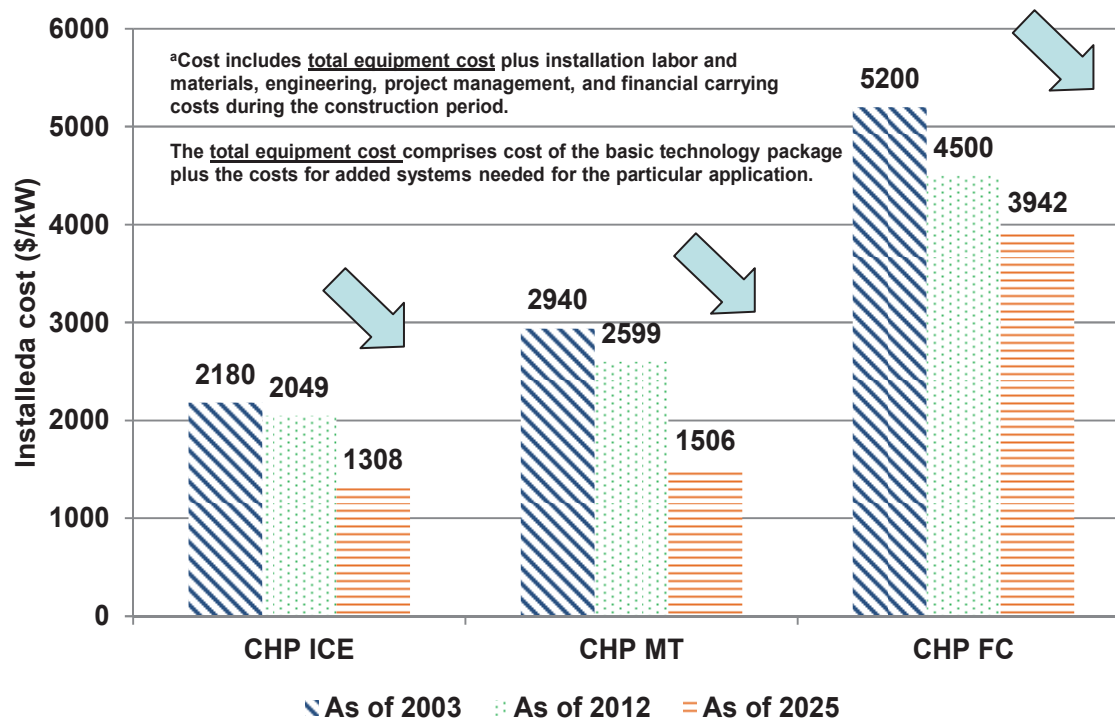


Source: Bloom Energy

Distributed Energy Resources!

Penetration of Distributed Energy Resources - DER

The techno-economic characteristics of DER units went through significant improvements during the last decade

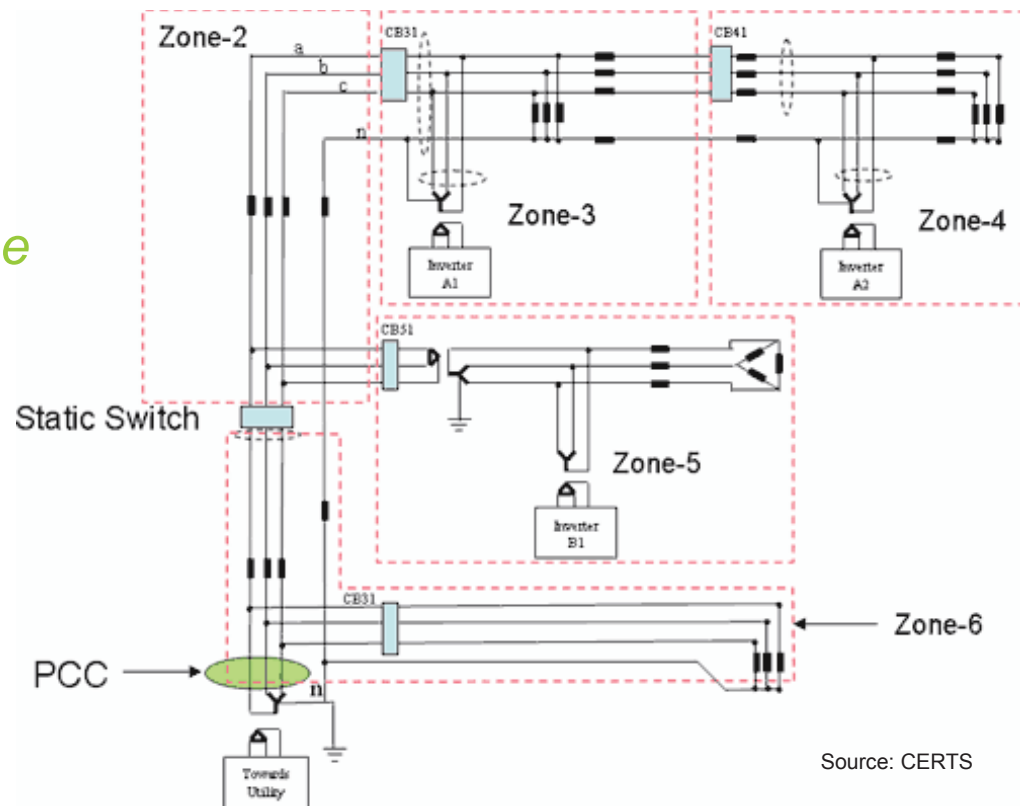


Microgrid concept as a novel alternative

Special attention has been drawn to the microgrid solution

A localized and organized group of interconnected loads and DER, which acts as a single entity with respect to the grid, and is able to operate in both grid-connected or islanded modes.

U.S. Department of Energy
Microgrid Exchange Group



Source: CERTS

Advantages of Microgrids

Microgrids can constitute part of the solution for the current unsustainability of the legacy grid

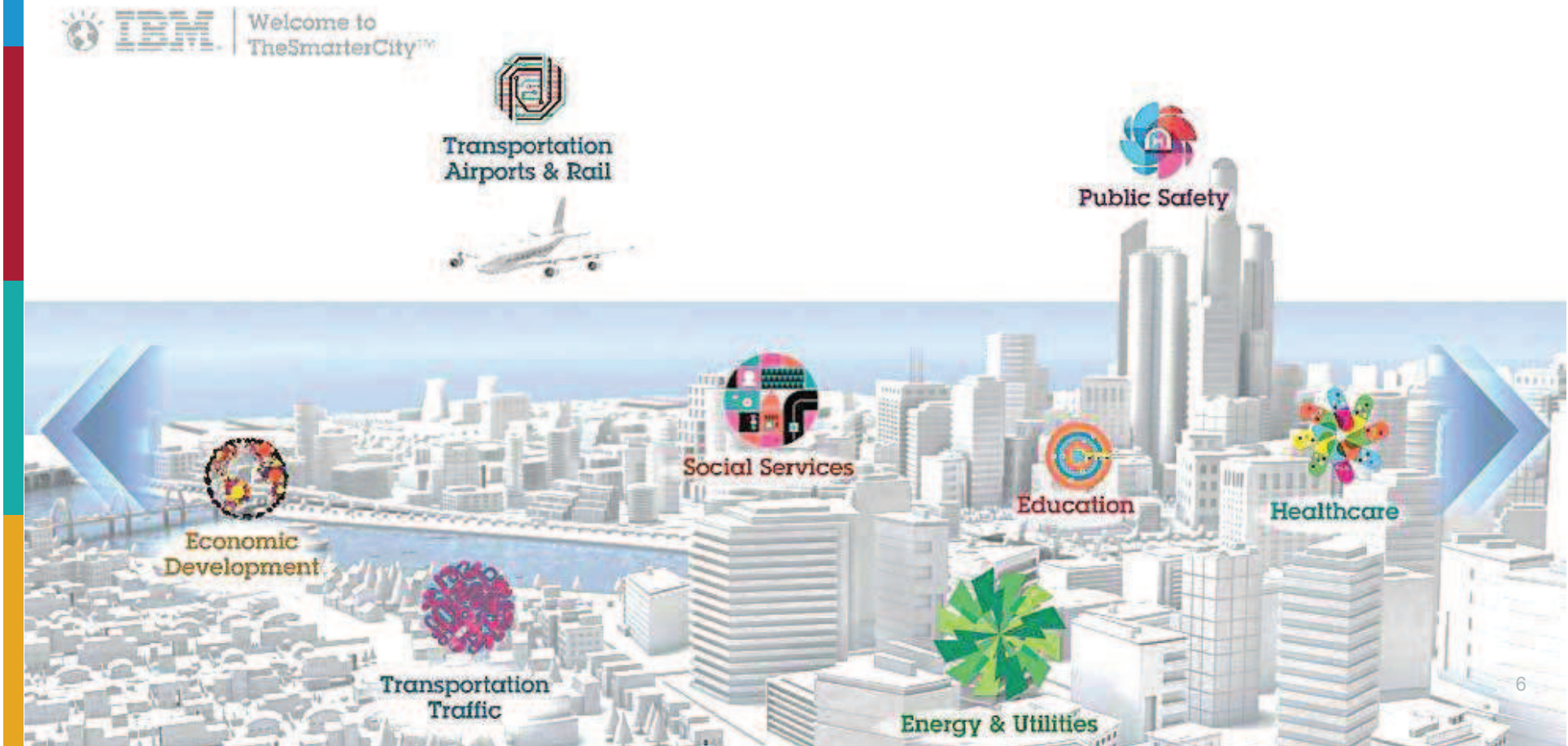
- Provide high PQR to satisfy critical loads of sensitive sites*
- Enhance the resilience of the power system as a whole*
- Increased local control*
- Possibility of usage of waste heat from CHP and CCHP DG*
- Promotion of renewable DGs*
- Reductions in CO₂ ...*



Bob Lasseter said at the time: "Nothing happened." The system moved automatically between grid-connected mode and island-mode without a glitch.

What are Smart Cities after all?

A result of the increasing importance and **integration of ICTs** in the fundamental functions of modern cities



Microgrids as *building blocks* of the Smart Grid

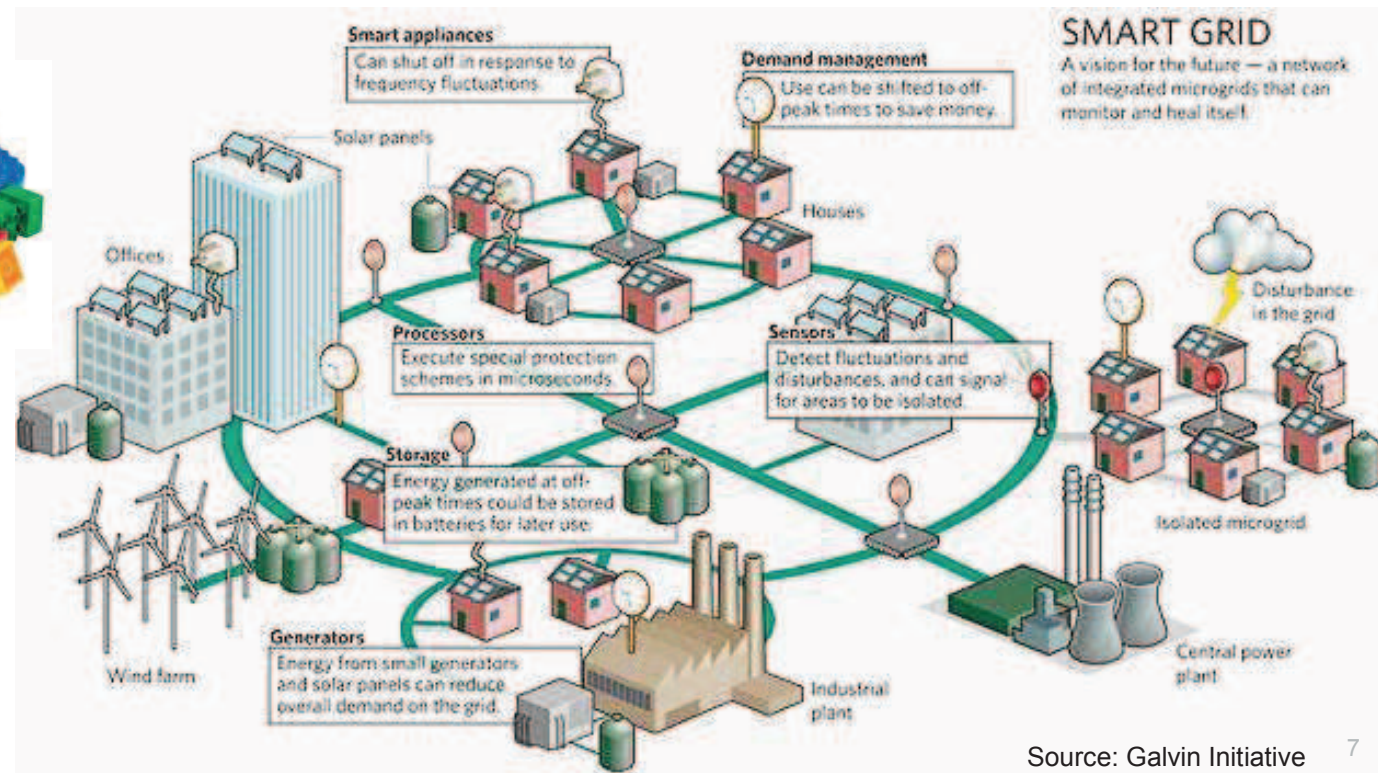
Microgrids are the third element of the Smart Grid, together with

1. improved macrogrid operation, and
2. enhanced grid-demand interaction



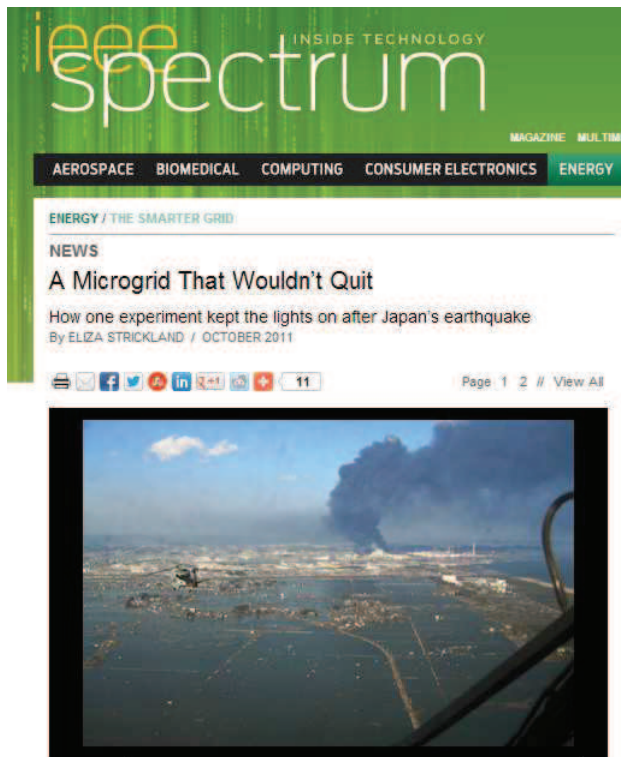
↓
**Legos of the
Smart Grid!**

MITPortugal



Source: Galvin Initiative

Microgrids' increasing popularity



Mesa del Sol unveils Aperture Center microgrid



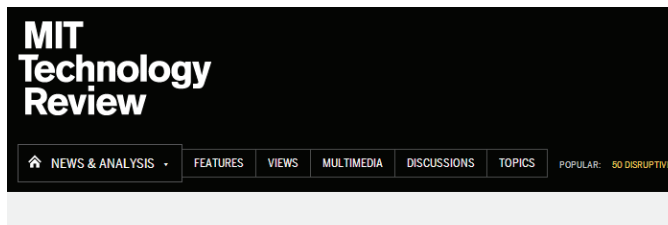
Kevin Robinson-Avila
Senior Reporter-
Albuquerque Business First
Email

Public and private sector officials from Japan joined New Mexico officials and Mesa del Sol representatives Thursday morning to unveil a microgrid that will power the master-planned development's Aperture Center.



Enlarge

Courtesy of Griffin & Associates



VIEW

Martin LaMonica
November 7, 2012

Microgrids Keep Power Flowing Through Sandy Outages

Local power generation with microgrids showed the benefits of reliability during Hurricane Sandy.

The widespread power outages in the wake of Hurricane S completely centralized electric power system and spotlight generation.



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Can Hurricane Sandy spur the adoption of smart microgrid technologies?

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Peter Kelly-Detwiler, Contributor
I write about energy technologies and policies.
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With All Eyes On Hurricane Sandy, A Good Time to Evaluate Micro-Grids

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The Weather Channel this morning reports on a "remarkable" storm "of potentially historic proportions," as Sandy barrels north and the low out west prepares to join the party. It may be another 'perfect storm,' But we just had two historic storms last year in the northeast, with damage exceeding a billion dollars.

Such storms wreak havoc on the electric grid, which is why a workshop I attended in Hartford, CT on "Micro-Grids in New England" seems



Devastating Storms Make the Case for Microgrids

Peter Asmus — November 6, 2012

Hurricane Sandy underscores a compelling reality: today's power grid is wholly inadequate for today's hyper-digitalized economy. With more than 8 million people without power for a matter of days, not hours, momentum is growing for technology solutions, as described on this blog by my colleague Bob Gohn.

Recent evidence corroborates the notion that more severe weather is now business-as-usual. According to the Center for Research on the Epidemiology of Disasters, 100 million to

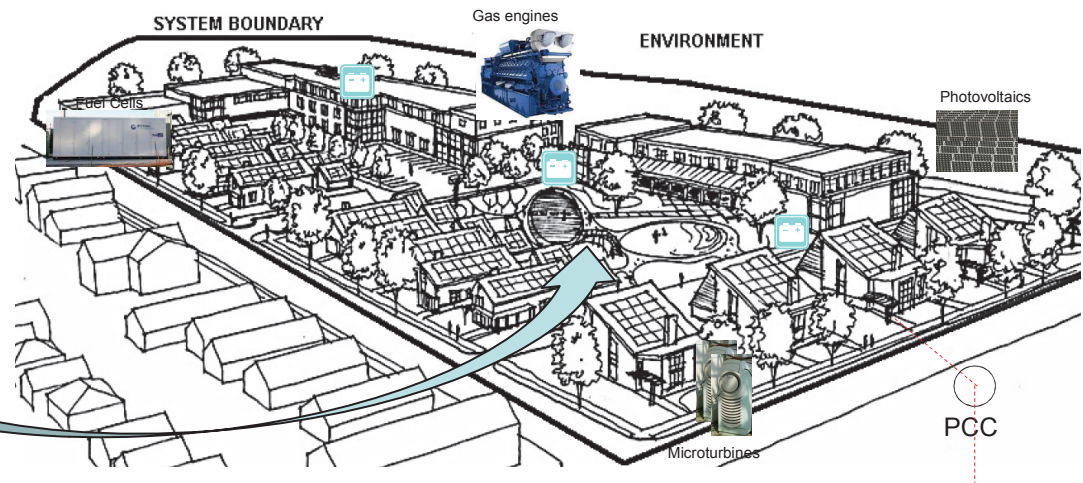
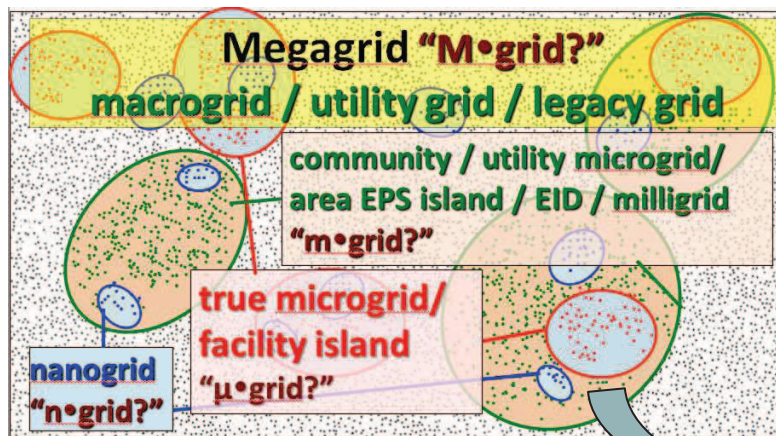


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Focus on “milligrids”, maximizing integration

Community-scale power systems that meet the requirements for a microgrid, or “**milligrids**” where numerous types of demand meet, can potentially increase microgrids’ benefits by making use of **synergies between different kinds of customers**



opportunity to explore demand patterns

About 30% of World microgrid pilots are community-scale

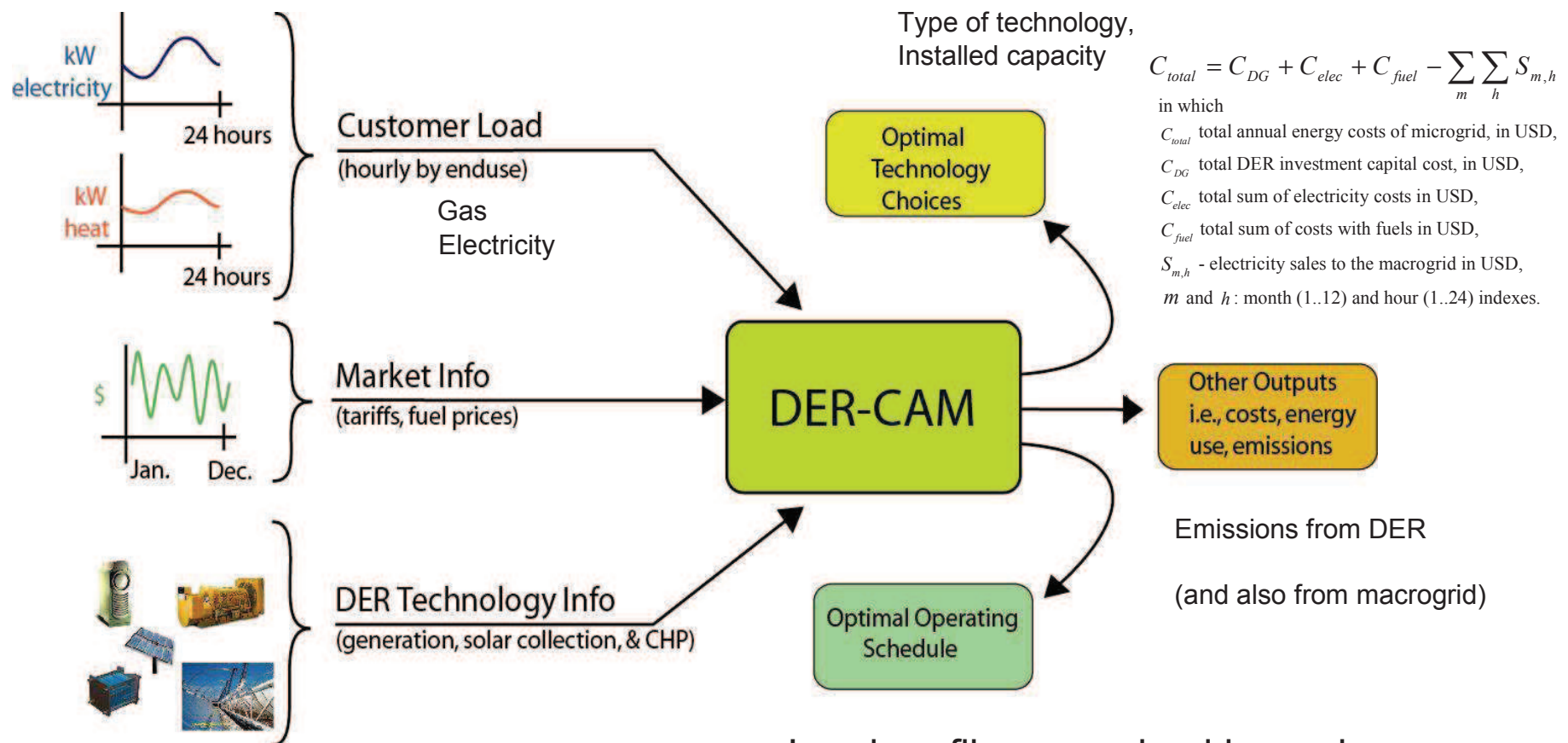
Study of milligrids' adoption patterns

What circumstances can make community-scale microgrids attractive investments in the urban context?

1. analyzing how differently and **under which patterns** distinct building types or its combinations could invest in microgrids
2. identifying **energy costs** and **environmental impacts** under different demand mixes and explore sensitivities to regulatory and environmental aspects (demand, climate, tariff structure

This research intends to fill the gap of sectorial regulatory and policy directions for a rapidly-emerging microgrid market and to sustain future planning and deployment decisions.

Microgrid configuration optimization – DER-CAM



Load profiles organized by end-uses:
electricity-only, space-heating, cooling, water heating and gas-only.

Microgrid configuration optimization

Extension of DER-CAM to accommodate optimization of community-scale, multiple-building microgrids

$$\sum_{i=1}^n Load_{i \in \mathbb{K}} = Load_1 + Load_2 + \dots + Load_n$$

$$\sum_{i=1}^n ElLoad_{i \in \mathbb{K}} = \sum_{i=1}^n ElOnlyLoad_{i \in \mathbb{K}} + \sum_{i=1}^n CoolLoad_{i \in \mathbb{K}} + \sum_{i=1}^n RfLoad_{i \in \mathbb{K}}$$

$$\sum_{i=1}^n NGLoad_{i \in \mathbb{K}} = \sum_{i=1}^n SpaceHeatLoad_{i \in \mathbb{K}} + \sum_{i=1}^n WtHeatLoad_{i \in \mathbb{K}} + \sum_{i=1}^n NGOnlyLoad_{i \in \mathbb{K}}$$

$$CERTScost = \left[(CostM \cdot Switchsize) + \sum_{i=1}^n CostB_i \right]$$

MIT Portugal

Allowing for specific definition of building loads and microgrid critical requirements

UP TO 3 loads

PQR Requirements:

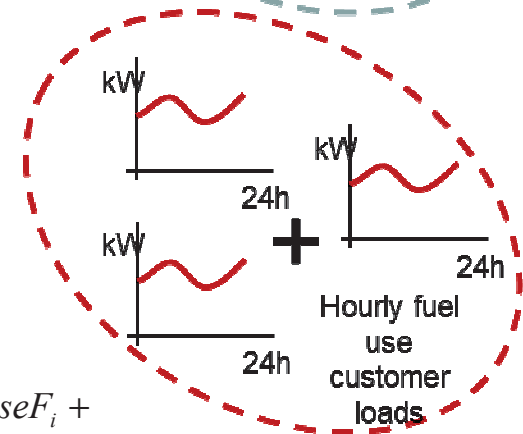
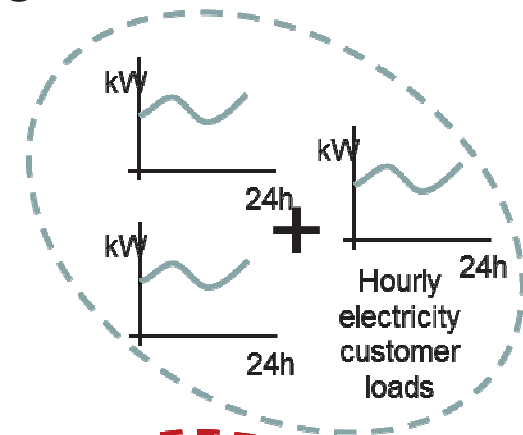
HTL, SCH: 10% critical loads

OFF: 25% critical loads

HOSP: 50% critical loads

Cost of PQR benefits:

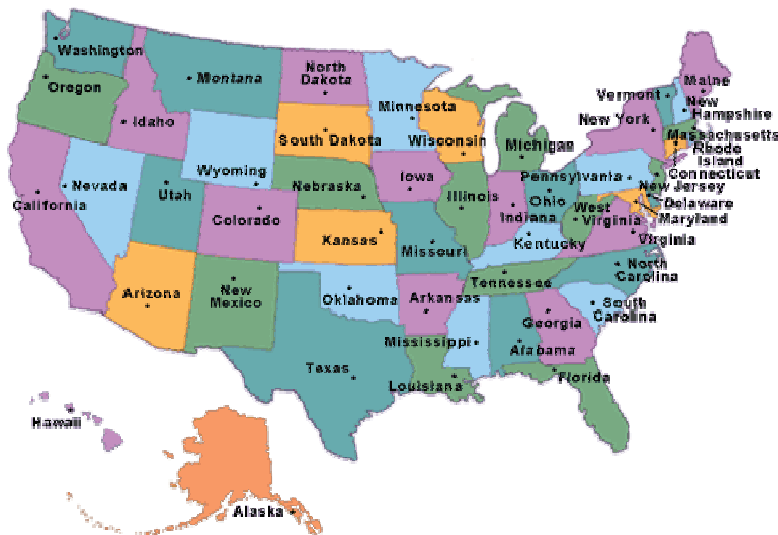
$$Switchsize = \sum_{i=1}^n [\min\{ElLoad_i\} \cdot BaseF_i + (\max\{ElLoad_i\} - \min\{ElLoad_i\}) \cdot PeakF_i]_i$$



Case-study applications

The analysis of microgrids economic adoption patterns is done for different contexts

USA: Load data based on the compiled U.S. Department of Energy (DOE) commercial reference buildings models

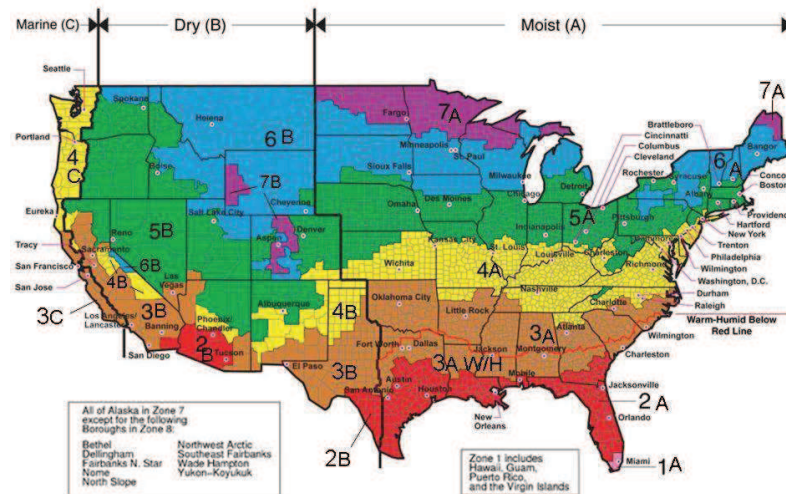


Portugal: Data treatment work in collaboration with several energy services companies



Description of the U.S. case-study

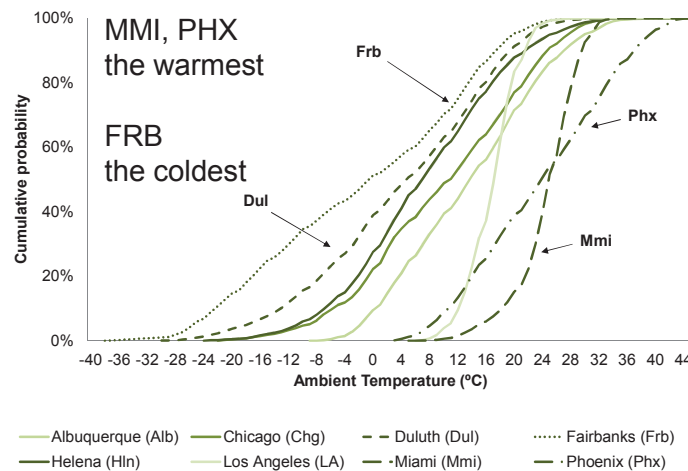
- Runs in 8 representative cities, located in each one of the U.S. climate zones, developed by ASHRAE
- The commercial and residential prototype buildings models were simulated in EnergyPlus in order to obtain the final DER-CAM load profiles



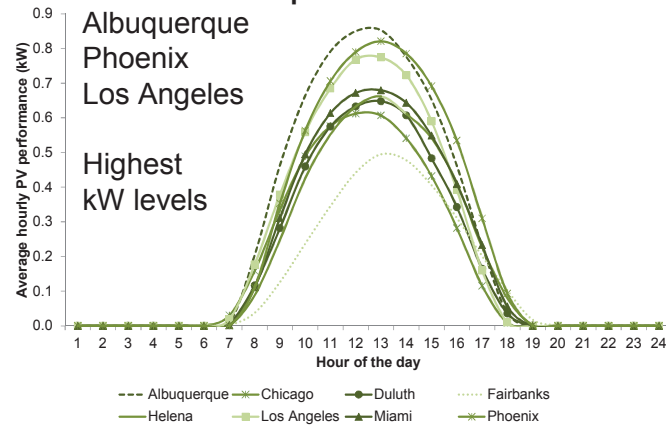
Representative city	State	Climate Zone
Miami	Florida	1A
Phoenix	Arizona	2B
Los Angeles	California	3B – Coast
Albuquerque	New Mexico	4B
Chicago	Illinois	5A
Helena	Montana	6B
Duluth	Minnesota	7A
Fairbanks	Alaska	8A

U.S. case-study, climatic and regulatory diversity

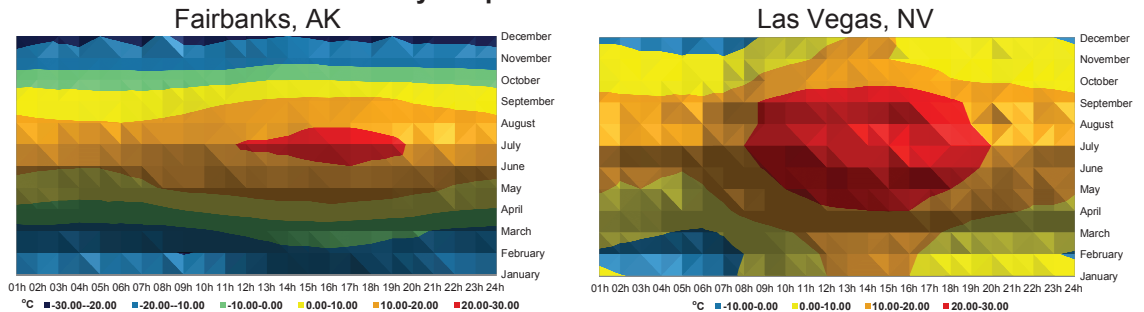
CTD curves



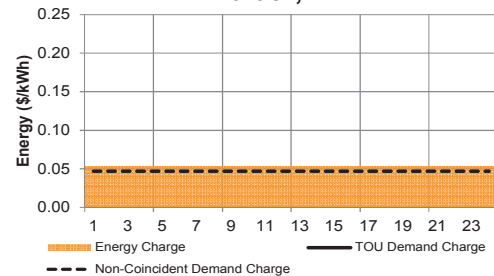
PV performances



Daily temperatures variation

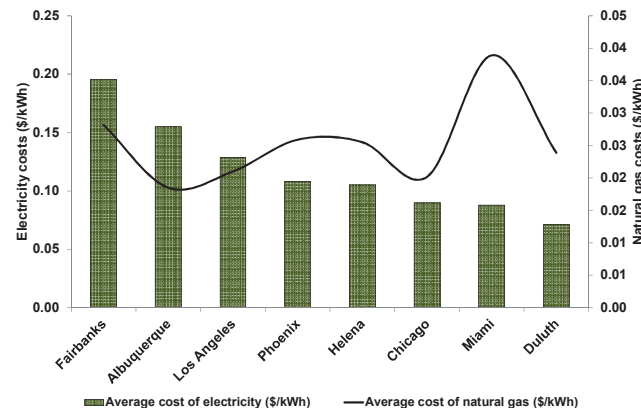
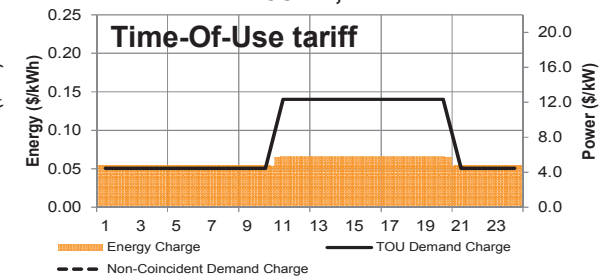


Duluth, MN



Electric tariffs

Phoenix, AZ



L.RES: 30un. Midrise. Apt.,
Secondary school, 10un.
Full-service restaurant;

L.SRV: Small hotel, 10un.
Quick-service restaurant,
5un. Strip Mall;

L.OFF: 2un. Large offices,
5un. Quick-service
restaurant, Small hotel.

U.S. case-study, optimal technology mix

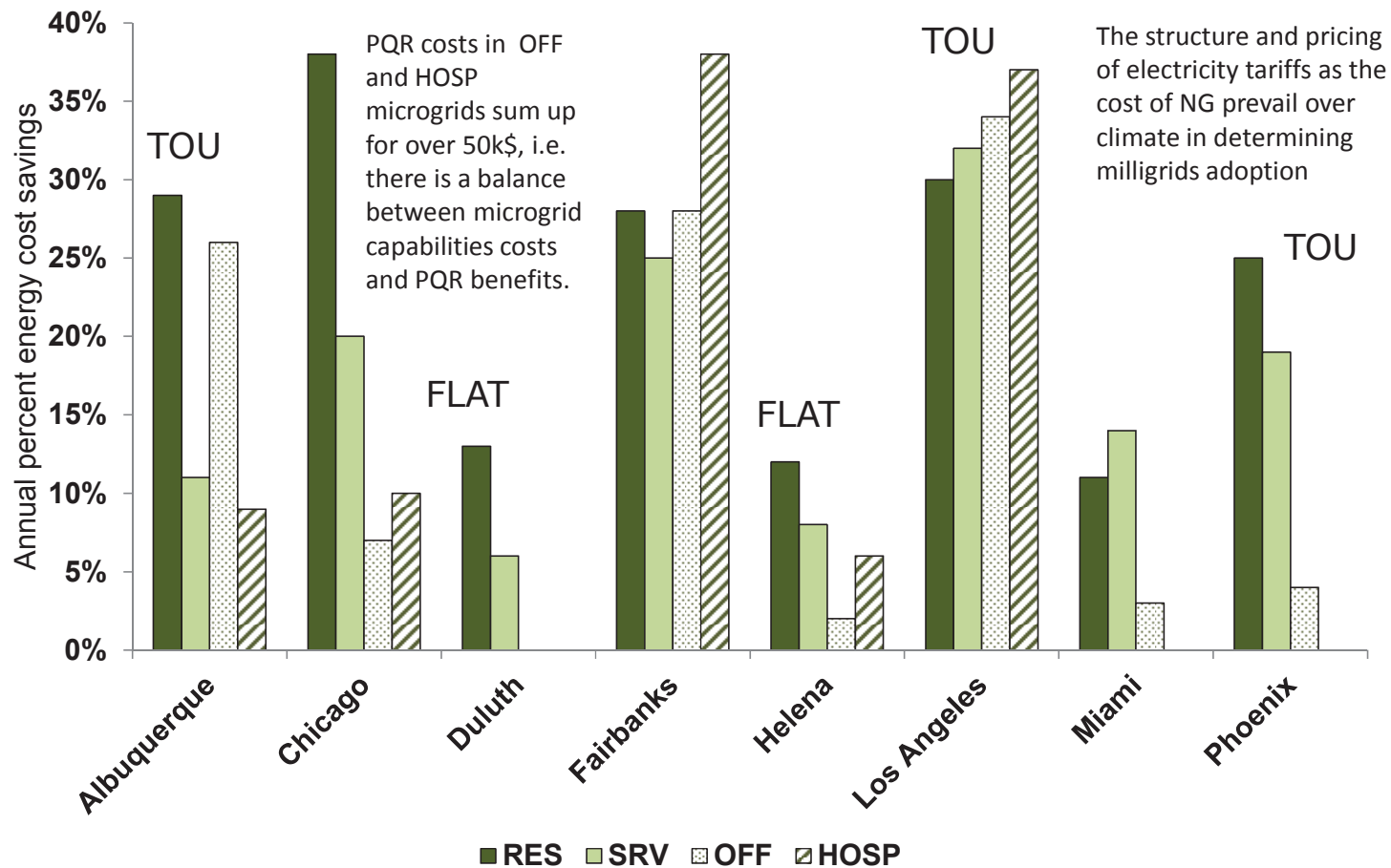
Optimal technology mix of large microgrid adoption solutions in U.S. representative cities

	ICE (kW)	PV (kW)	ST (kW)	ES (kW)	Abs (kW)	Switch (kW)		ICE (kW)	PV (kW)	ST (kW)	ES (kW)	Abs (kW)	Switch (kW)
<i>Albuquerque</i>							<i>Helena</i>						
RES	810 (CHP)	0	0	0	898	130	RES	500 (CHP)	0	0	0	342	116
SRV	310 (CHP)	4	0	0	189	67	SRV	120 (CHP)	0	0	0	0	62
OFF	1000 (CHP)	279	0	0	517	445	OFF	500 (CHP)	0	0	5	293	427
HOSP	500 (CHP)	115	0	0	208	472	HOSP	500 (CHP)	0	0	0	108	441
<i>Chicago</i>							<i>Los Angeles</i>						
RES	500 (CHP)	0	0	0	78	159	RES	1000 (CHP)	0	0	0	662	135
SRV	60 (CHP)	39	0	0	0	67	SRV	370 (CHP)	0	0	0	266	77
OFF	560 (CHP)	0	0	0	124	516	OFF	1120 (CHP)	0	0	0	616	449
HOSP	560 (CHP)	0	0	0	85	525	HOSP	620 (CHP)	0	0	0	208	558
<i>Duluth</i>							<i>Miami</i>						
RES	120 (CHP)	0	0	89	0	128	RES	250 (CHP)	0	53	0	375	167
SRV	60 (CHP)	0	0	54	0	66	SRV	60 (CHP)	0	49	155	104	80
<i>Fairbanks</i>							OFF	250 (CHP)	0	45	138	257	260
RES	810 (CHP)	0	0	0	300	91	<i>Phoenix</i>						
SRV	310 (CHP)	0	0	162	37	54	RES	250 (CHP)	0	0	0	571	174
OFF	1060 (CHP)	0	0	162	377	414	SRV	60 (CHP)	79	0	111	132	93
HOSP	560 (CHP)	0	0	0	130	408	OFF	500 (CHP)	227	0	0	336	535
							HOSP	560 (CHP)	109	0	290	125	606

- All runs invest in CHP ICEs, in RES areas to cover very high heating needs of apartments, schools and restaurants
- OFF and HOSP, reliability-intense areas, invest more in DER capacity and with less climate sensitivity than RES and SRV

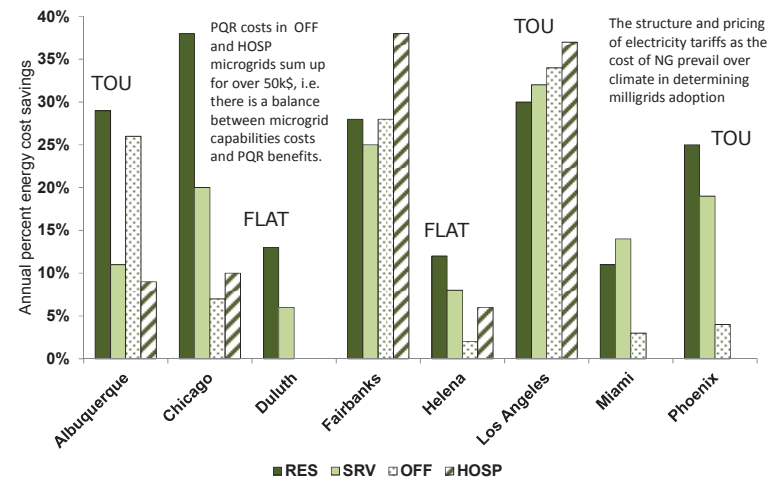
U.S. case-study, annual energy savings

Annual energy savings from milligrids adoption in selected U.S. cities



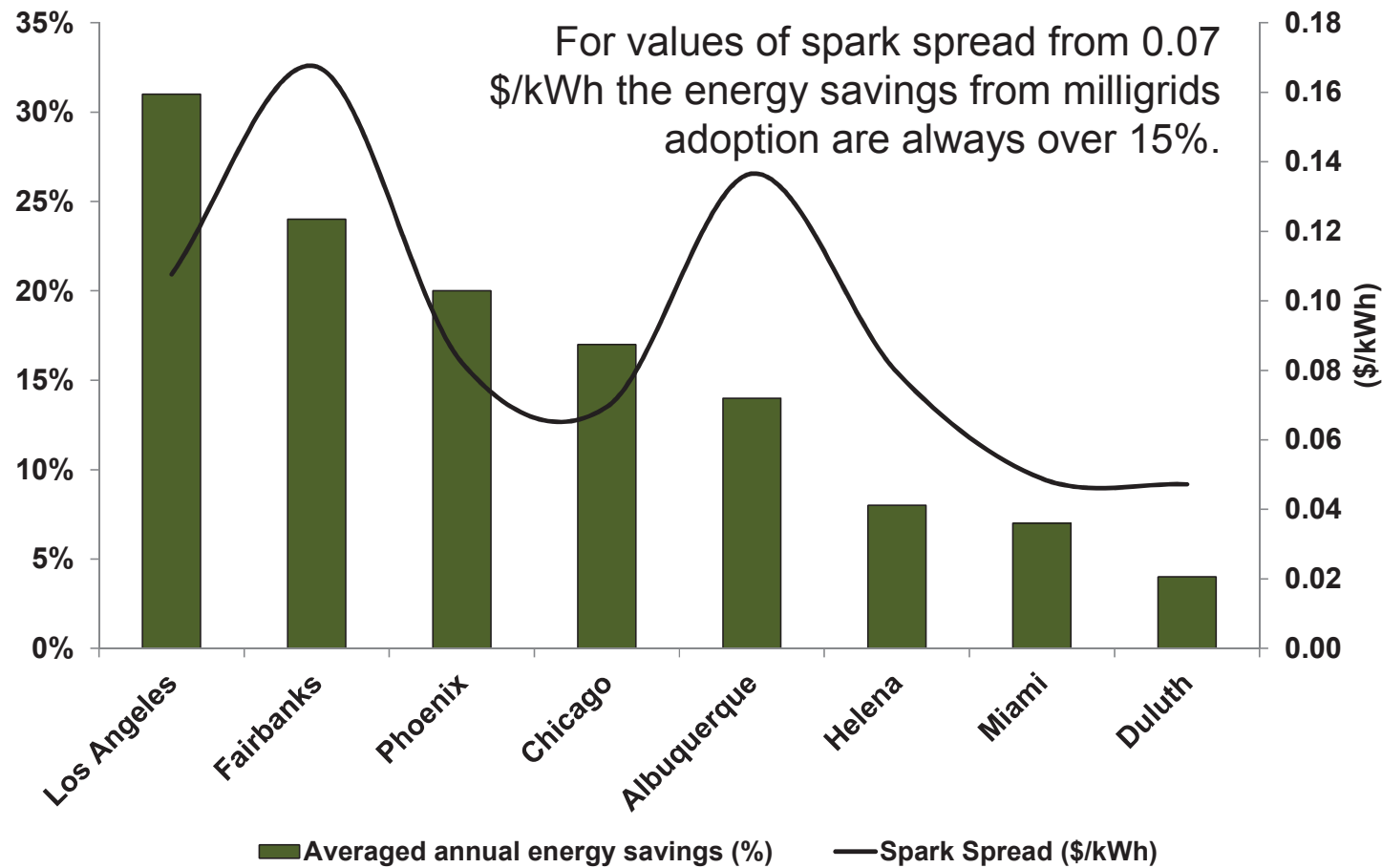
U.S. case-study, annual energy savings

- Limited investments and savings in cities with **cheap electricity, expensive NG** or no **TOU**
- Helena, Miami, Duluth with savings <10%, 5%
- **Warmer vs. colder climates:** Group composed of Albuquerque, Los Angeles, Miami and Phoenix with average energy cost saving of 18% against 13% for the group composed of Chicago, Duluth, Fairbanks and Helena



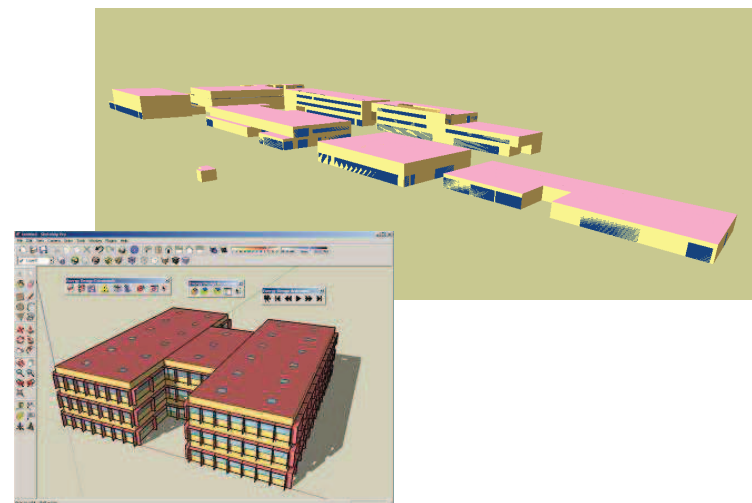
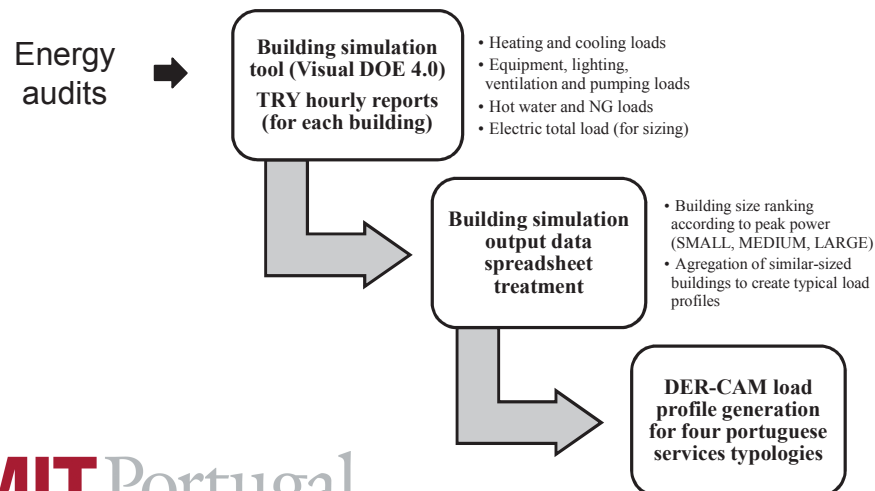
U.S. case-study, spark spread analysis

Spark spread vs. savings analysis for large microgrids adoption in U.S. representative cities.



Description of the Lisbon case-study

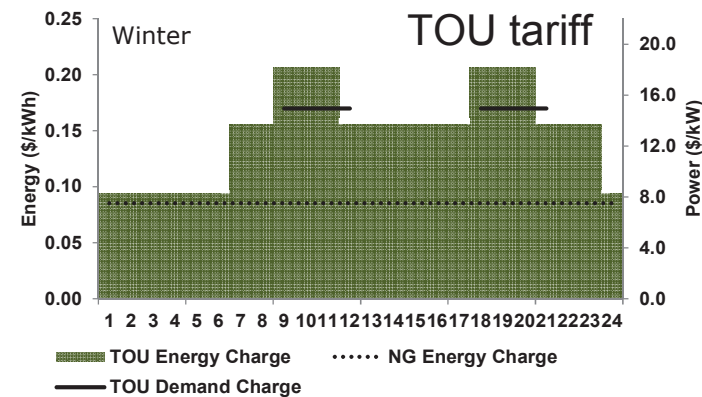
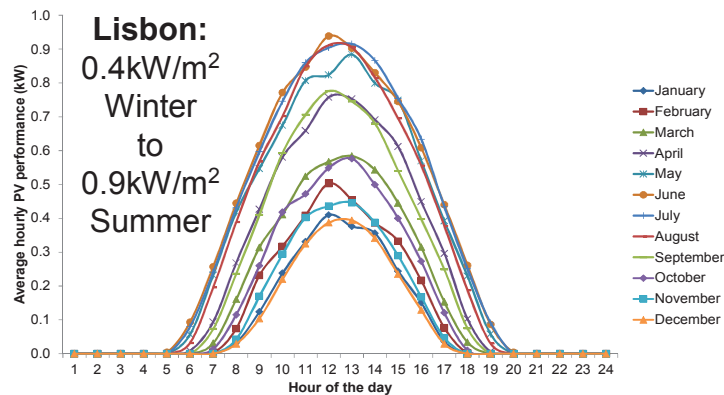
- DER-CAM models were created that reflect technological, environmental and market conditions in Lisbon, Portugal
- Collection of residential and commercial buildings load data in the region of Lisbon and creation of typical building profiles
- The simulation tools Visual DOE 4.1.2 and E+ are used to run building models and obtain hourly reports, inputs to DER-CAM



Lisbon case-study, milligrids' adoption runs

Four distinct building types and a residential area are analyzed in order to access microgrid customer adoption patterns

	RES	HTL	SCH	OFF	HOSP
Electrical peak load (kW)	769	830	896	968	1207
Electrical load factor (%)	12%	33%	20%	36%	50%
HPR (%)	55%	17%	46%	11%	20%
Heat/Elec. Coincidence (%)	27%	13%	20%	11%	20%



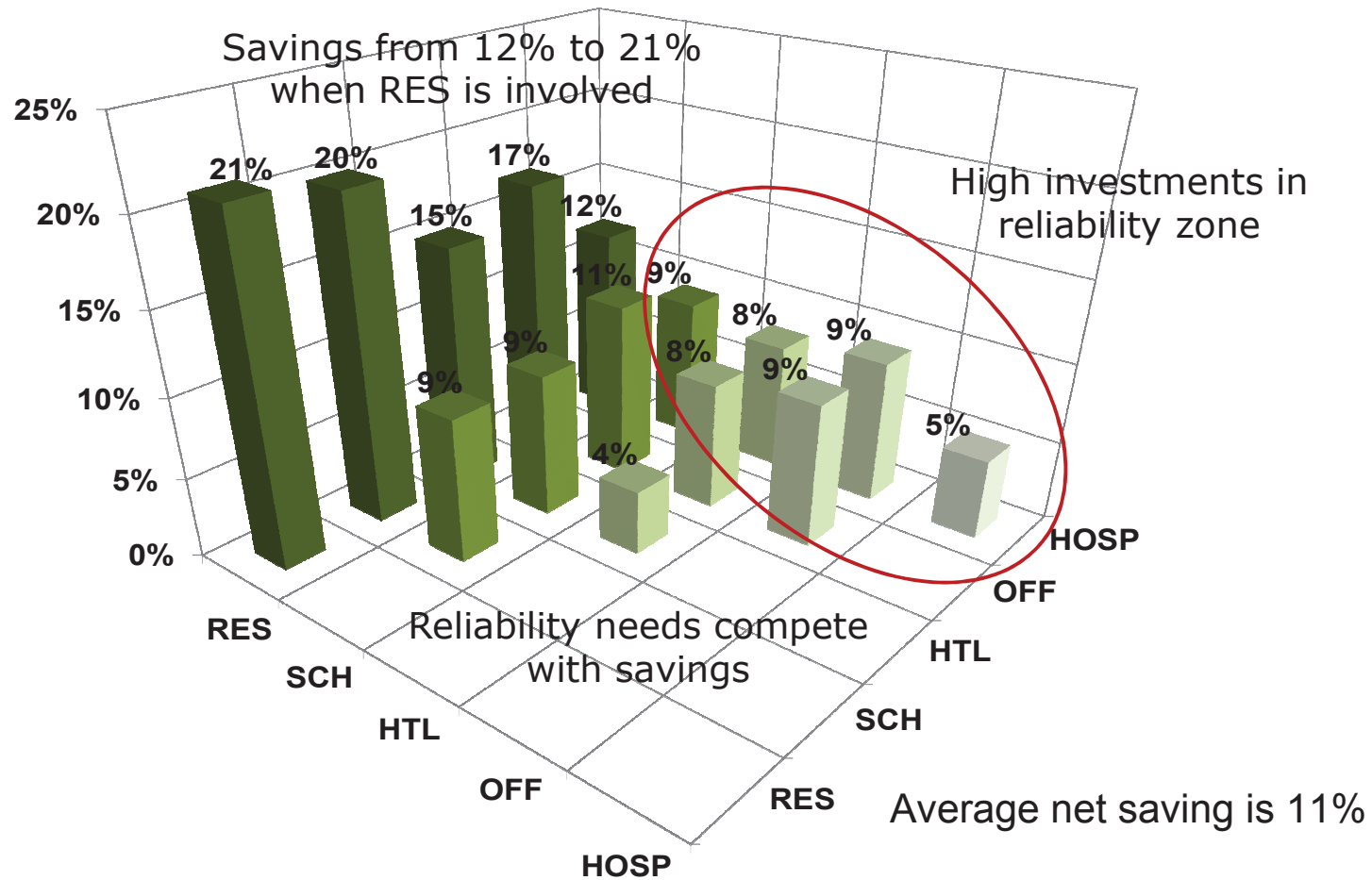
Lisbon case-study, optimal technology mix

Optimal technology mix of microgrid adoption solutions in Lisbon

	ICE (kW)	PV (kW)	ST (kW)	ES (kW)	HS (kW)	Abs (kW)	Switch (kW)
RES	0	51	17	55	0	0	18
RES+SCH	60 (CHP)	335	83	0	0	260	110
RES+HTL	250 (CHP)	222	146	0	449	116	104
RES+OFF	250 (CHP)	489	98	0	455	222	283
RES+HOSP	500 (CHP) + 60	693	200	77	527	140	691
SCH	0	291	73	217	0	249	92
SCH+HTL	250 (CHP)	593	160	0	473	372	178
SCH+OFF	250 (CHP)	697	145	0	553	503	356
SCH+HOSP	750 (CHP)	443	257	0	645	516	765
HTL	0	351	61	359	0	64	86
HTL+OFF	250 (CHP)	701	123	0	490	302	351
HTL+HOSP	750 (CHP)	577	246	0	582	320	759
OFF	250 (CHP)	361	10	0	0	258	265
OFF+HOSP	750 (CHP)	1058	153	0	477	399	938
HOSP	500 (CHP) + 60	433	247	317	868	128	673

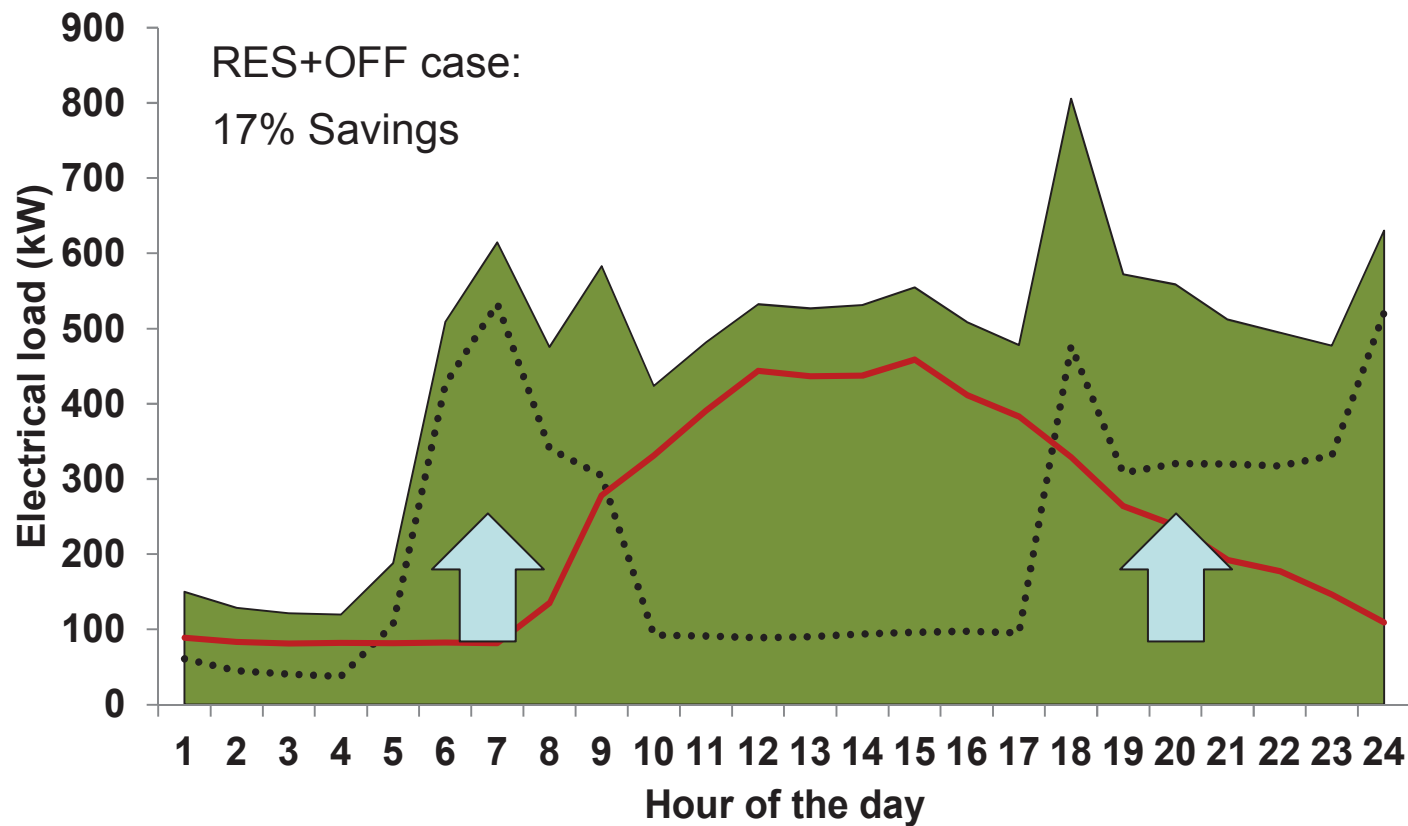
- Investment in CHP ICEs, except for RES, SCH and HTL
- When high-reliability needs exist → investment in ICE capacity

Lisbon case-study, annual energy savings

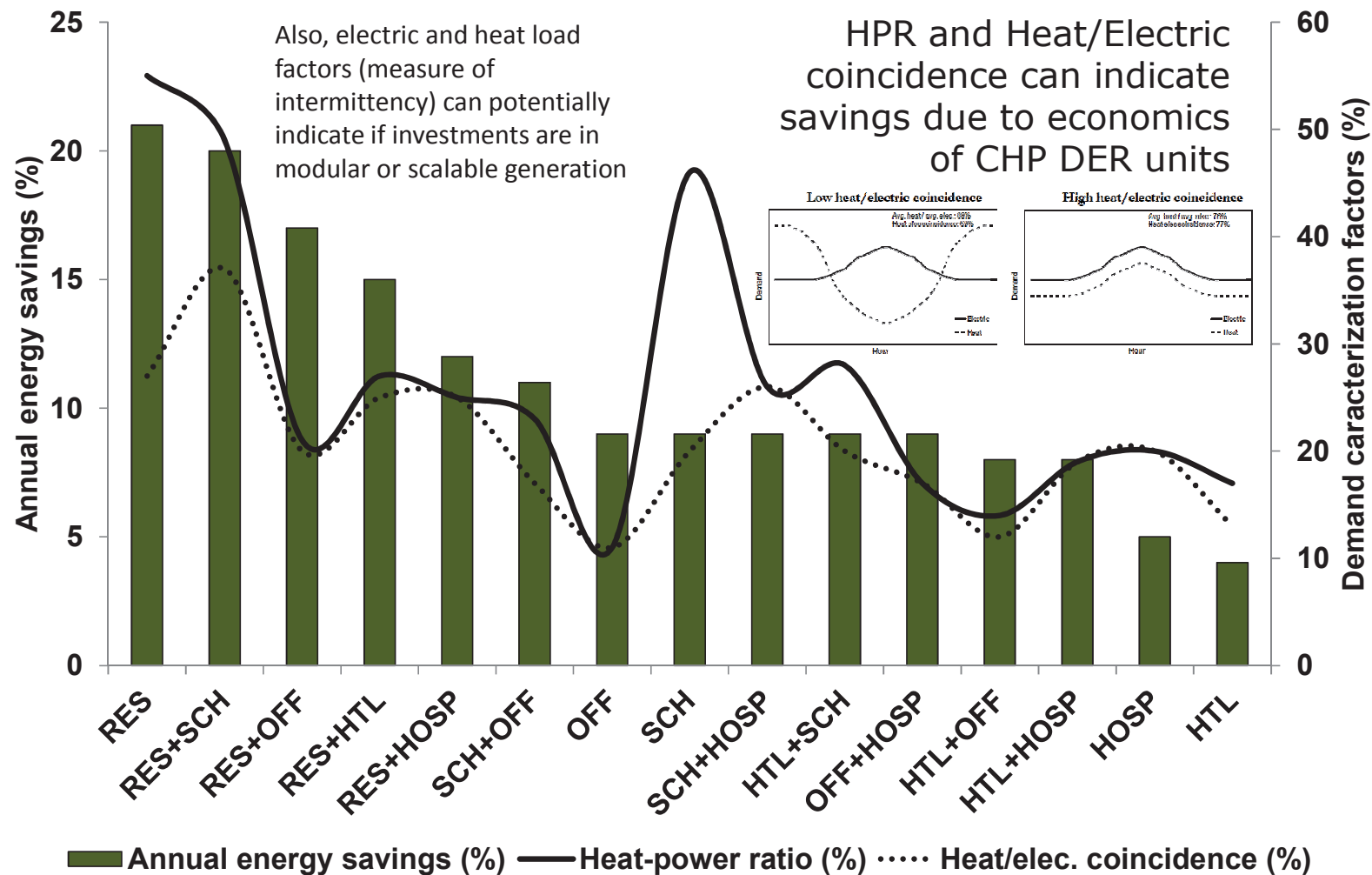


Lisbon case-study, complementarity of loads

- Allows better use of generation assets!



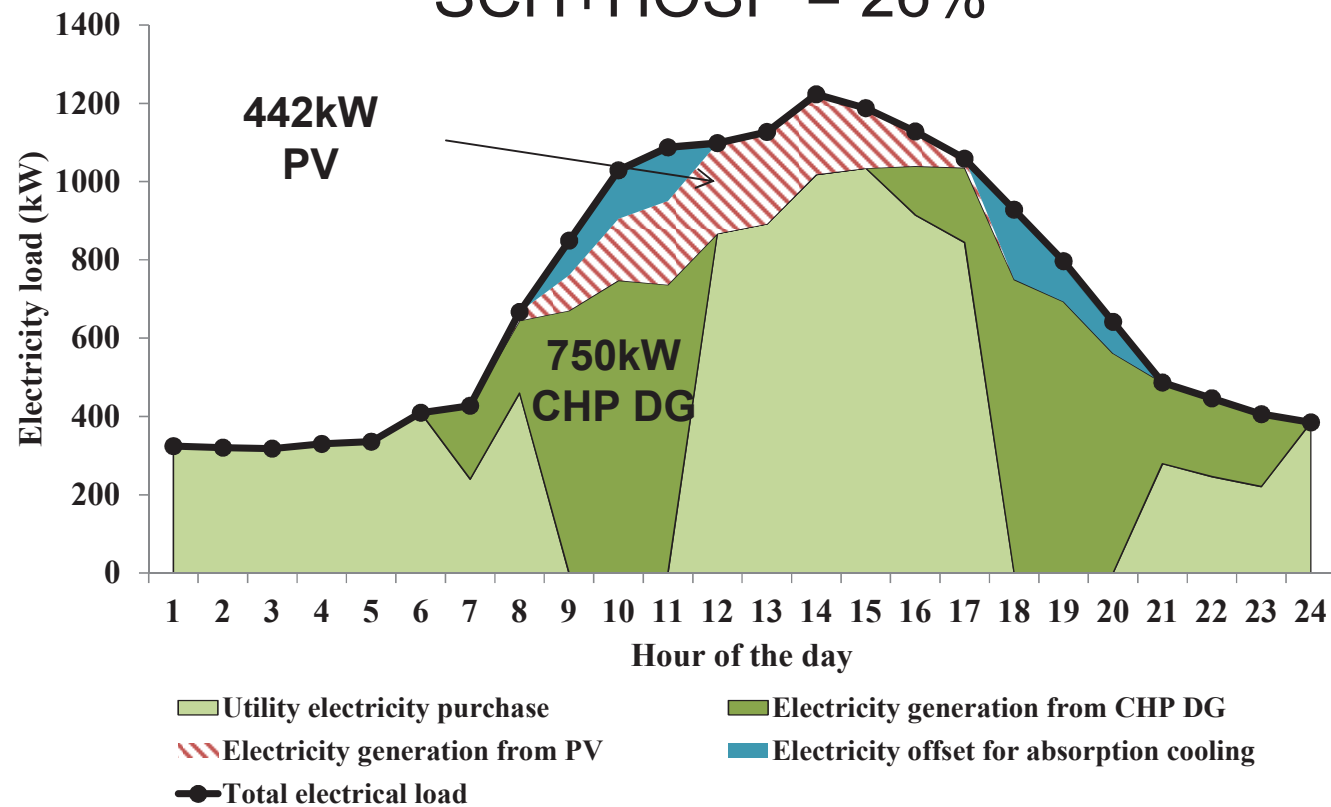
Lisbon case-study, demand characteristics



Lisbon case-study, H./E. coincidence example

TWO peak periods:
Operation is directed to avoid energy and power charging during expensive hours of the early morning and late afternoon.

Heat/electric coincidence
 $SCH+HOSP = 26\%$

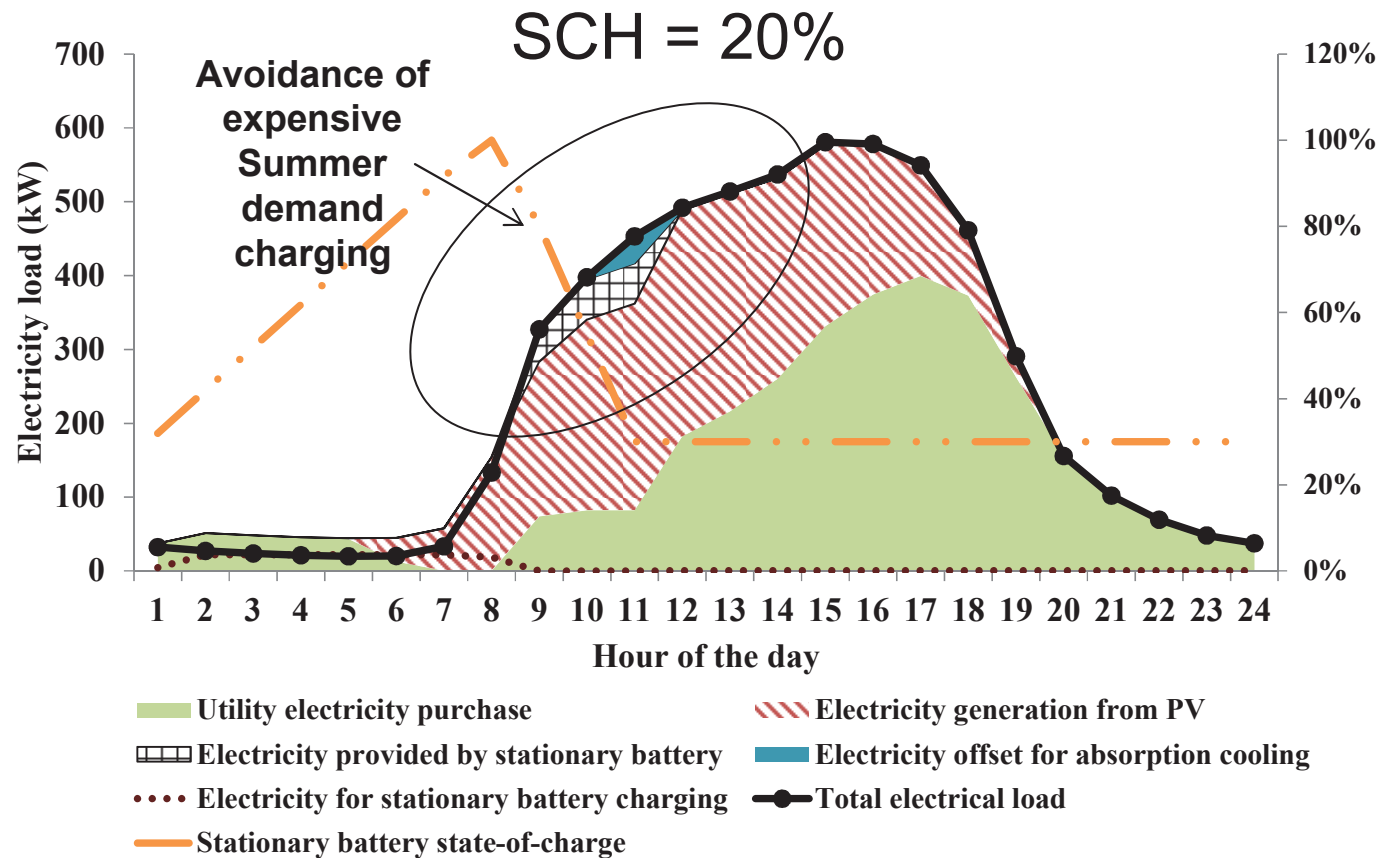


Example December day

Lisbon case-study, electric load factor example

Electric load factor

Example June day

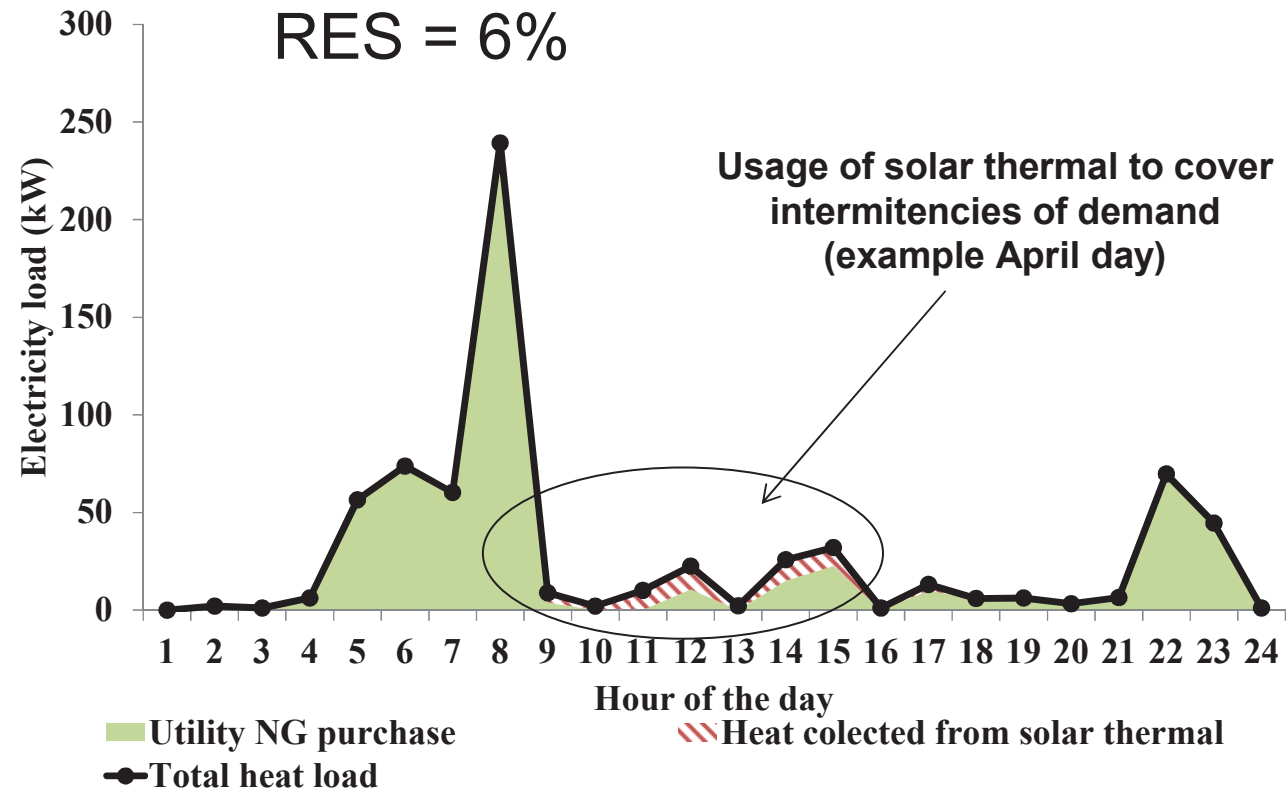


Lisbon case-study, demand characteristics

Heat load factor

	Heat load factor
EDUC+HLTH	13%
OFF	20%
OFF+HLTH	11%
HLTH	20%

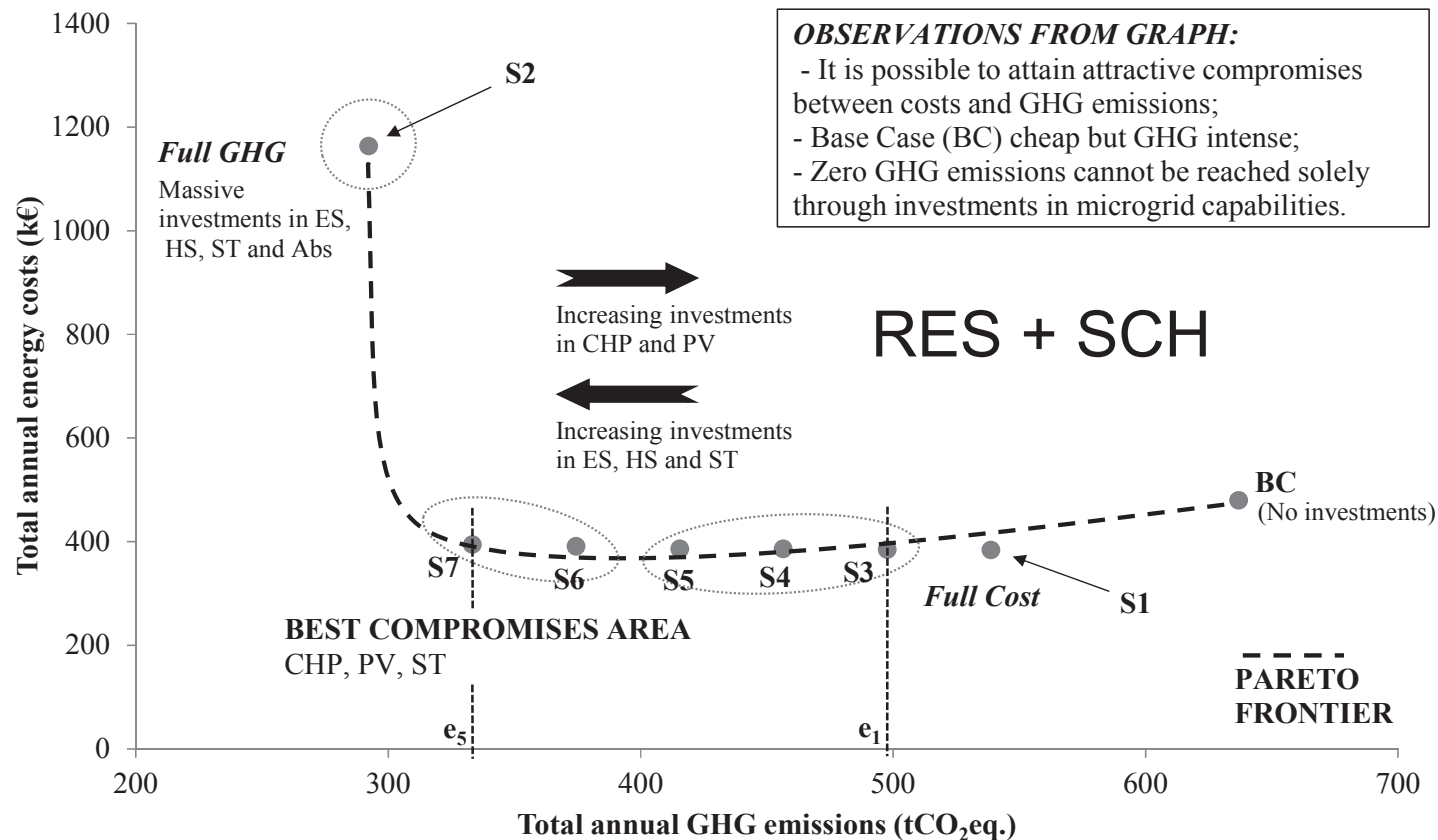
Investments
in CHP



Very small heat load factor of RES does not favor
investments in generation units

Lisbon case-study, demand characteristics

Multiobjective analysis can provide valuable investment insights

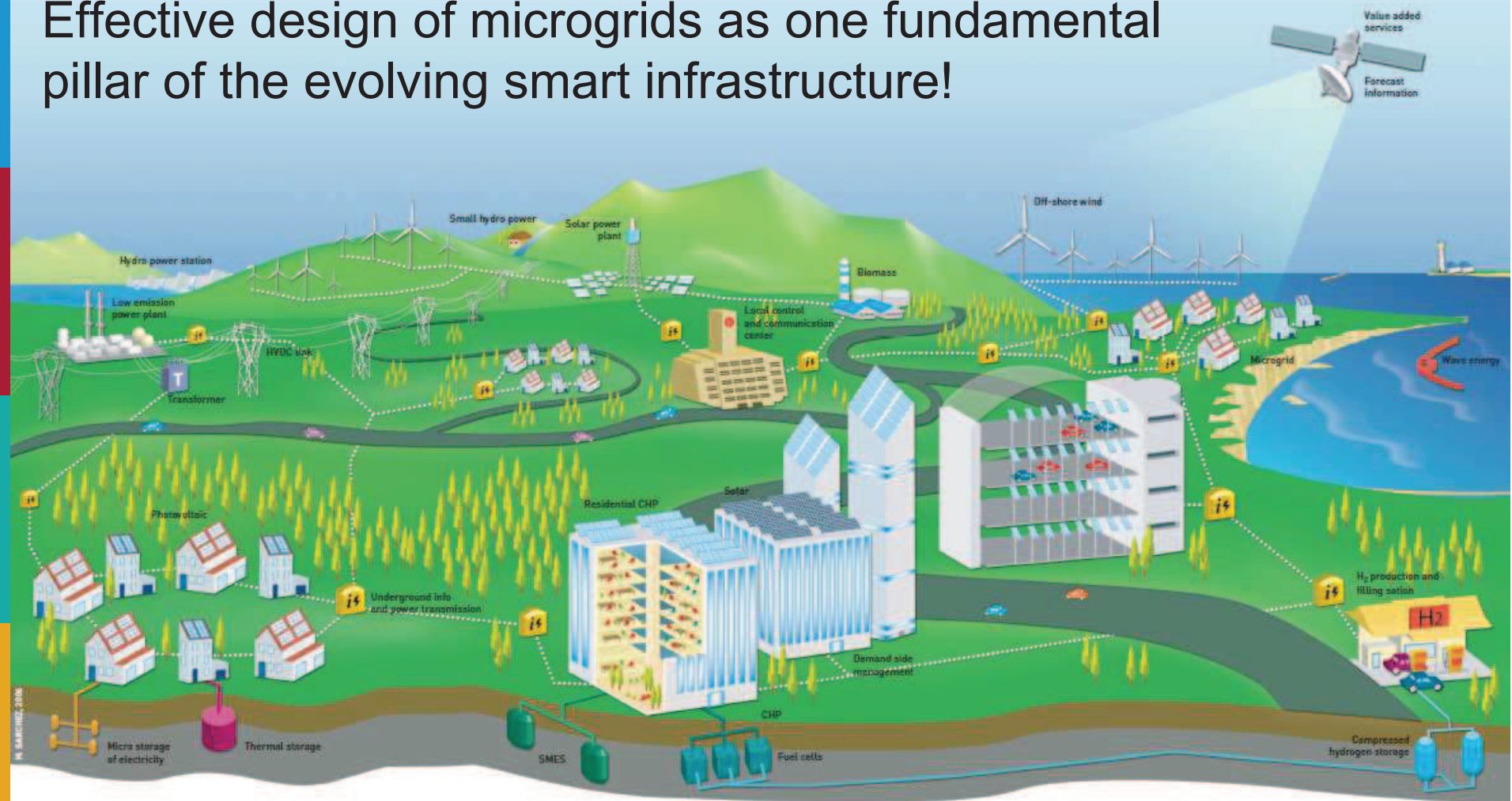


Conclusions

- Microgrids and specifically milligrids can constitute feasible investments in the majority of climates but are generally more attractive in warmer regions, with larger availability of DER.
- The pricing and structure (TOU or flat) of tariffs as well as the energy pricing spark spread prevail over the impact of climate as the factors mostly determining microgrids adoption.
- The PQR requirements of a given urban area are a determinant of the level of adoption of DER prime-movers and infer on the energy savings. Still, there's a balance between costs and benefits of PQR, allowing customers to invest economically in highly reliable microgrids.
- Residential areas show increased sensitivity to climate in relation to any commercial area and bear special interest to milligrids due to the complementary nature of its load profile. Any other aggregation of complementary loads is in principle economically beneficial.
- Office and hospital areas represent demanding, not always appealing, milligrid investments.
- "Lightweight" services areas make generally attractive milligrids investments in all climates.
- Hotel, residential and school buildings, where PQR needs are reduced or non-existent, are prone to microgrid investments characterized by purchase of PV, ST and battery storage. Offices and hospitals in opposition require the purchase of more reliable ICEs.
- HPR as well as H/E coincidence can impact on technology selection and energy savings in microgrid investments. Demand load factors can indicate in which types of DER to invest.

Conclusions

Effective design of microgrids as one fundamental pillar of the evolving smart infrastructure!



THANK YOU

(Questions are very welcome!)

Gonçalo Mendes

C. Marnay, C. Silva, M. Correia de Barros, M. Stadler, P. Ferrão, C. Ioakimidis

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