ETIP/Consortium Energy Policy Seminar

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Rethinking electricity distribution regulation

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Establishing terminology

What is electricity distribution?

- Distribution is the transfer of electricity *(or gas or water or cable tv…)* between
  - connection points with the transmission network and
  - end consumers
  - local generation
  - other distribution networks
- Distributed generation adds complexity to the "classical" picture

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What is electricity distribution?

- Distribution is a network activity
  - network expansion planning
  - line construction
  - maintenance scheduling
  - maintenance work
  - network operation
- Retailing (commercialization, supply) is a different activity (frequently done by the same entity)

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Regulatory characterization of the distribution activity

- Essentially always treated as a *legal monopoly*, regulated firm or government enterprise
  - Classic public utility: territorial franchise, obligation to serve, quality expectation, limited or no competition…
  - Traditionally a low-risk business
- Why? A "natural monopoly" providing a necessity
  - Economies of scale for provision of service in the same territory ➜ Sub-additive costs: For given outputs X & Y, then Cost (X+Y) < C(X)+C(Y)
  - Inelastic demand ⇒ monopoly price >> cost of service

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Sound approach to monopoly regulation "Incentive regulation"

- Incentive regulation instruments explicitly acknowledge
  - the **viability** of the regulated firm *(the "budget constraint")*
  - the objective of promoting production **efficiency** while preserving **quality of service**, for the ultimate benefit of consumers
  - the uncertainty of the regulator regarding the expected costs of the firm & the possible actions to reduce this **information disadvantage** *(the "adverse selection" problem)*
  - the need to encourage **managerial effort** of the firm by allowing it to capture rents that cannot be clawed back *(the "moral hazard" problem)*

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The challenge

The electric power sector is poised for a transformation

… that will mostly come from **distribution**

- Growth of Distributed Energy Resources (DER)
  - Distributed generation (DG)
  - Distributed energy storage (DS)
  - Electric vehicles (EVs)
  - Demand response (DR) and automated load control
- Infusion of Information and Communication Technologies (ICT)

Some slides for this section have been borrowed or adapted from the EU project THINK, “From distribution networks to smart distribution systems: Rethinking the regulation of European DSOs”, Florence School of Regulation, April 2013

… bringing evolutionary & disruptive changes to…

- Power system technologies, design, and operations
- Electricity sector business models
- Electricity sector regulation

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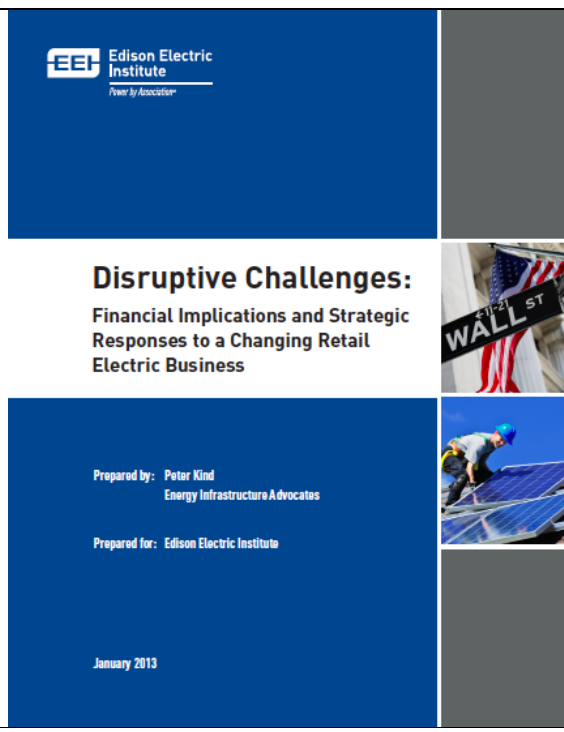

These changes at distribution level may be seen as a threat…

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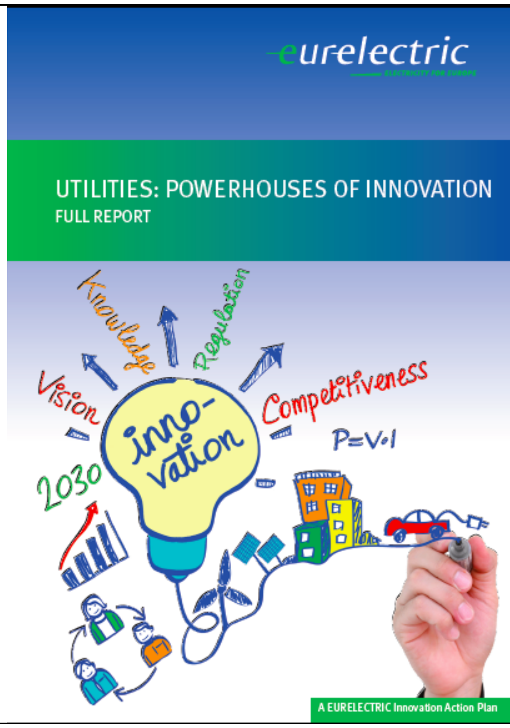

… but also as an opportunity…

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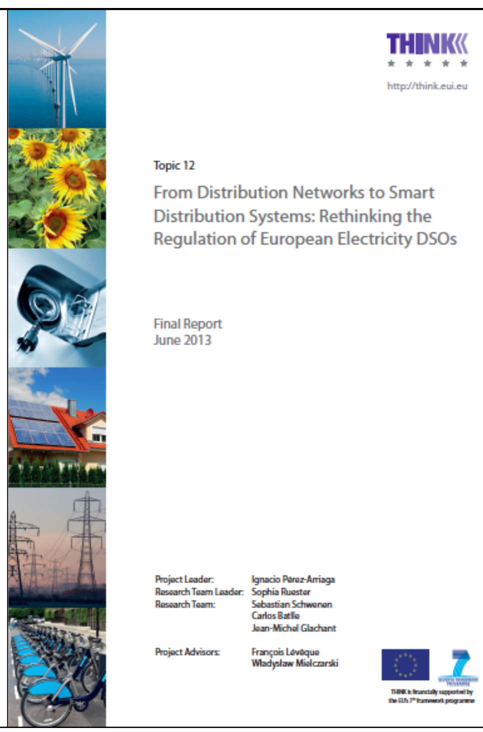

… that requires an adequate regulatory framework

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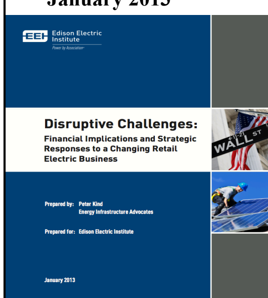
Utilities are expected to tackle a range of emerging issues – such as advanced outage management, integration of renewable generation, and cyber security – *yet they are held to regulatory standards set in the first half of the last century*. In order to modernize our power grid, we should first modernize the regulatory model so that it incentivizes investment, efficiency and innovation.

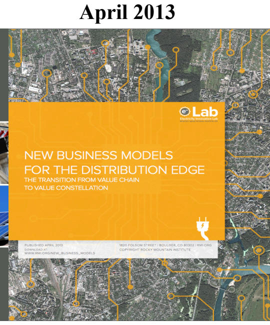
Source: "Results-based regulation", GE & Analysis Group, 2013

What will the utility(s) of the future look like?

January 2013



April 2013



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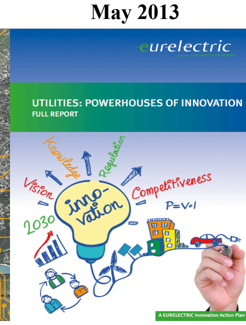

June 2013

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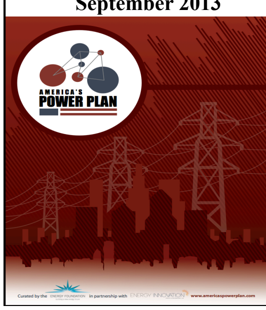

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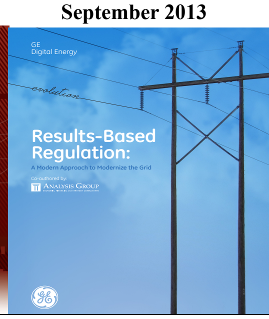
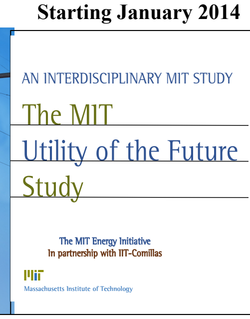


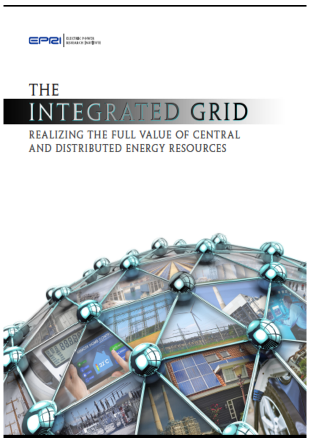
Starting January 2014



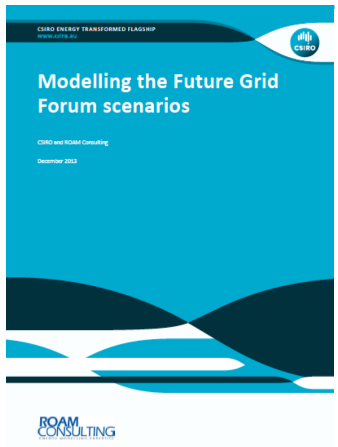
?

And more…

January 2014



December 2013



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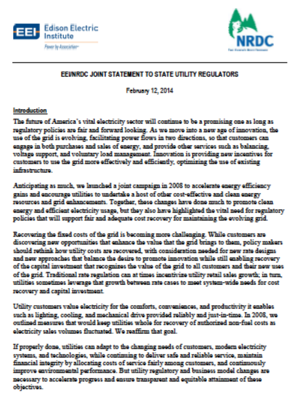
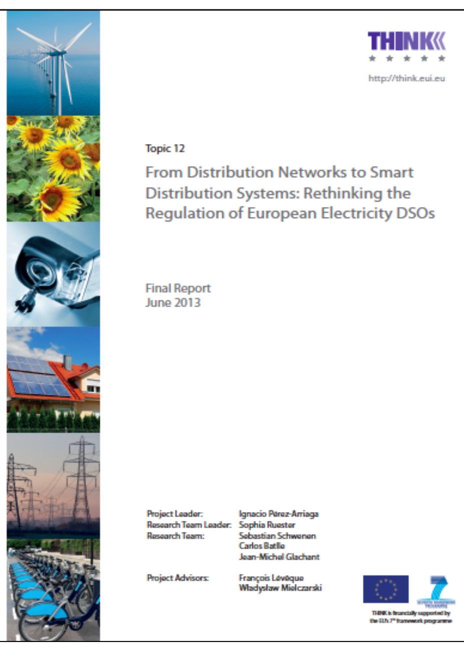
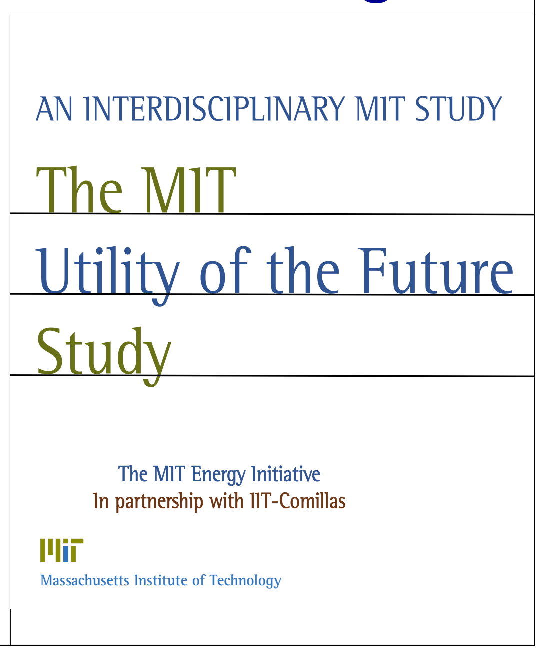


I am *(will be)* also contributing





The game changers

- The combination of
  - Information & Communication Technologies (**ICT**)
  - & various **distributed energy resources** (**DER**s) – including DG *(distributed generation)*, DS *(distributed storage)* & DR *(demand response)*

  will allow the creation and proliferation of new **Distributed Energy Systems** (**DESs**) *(from microgrids and virtual power plants to remote aggregation of controllable loads & smart charging systems for electric vehicle fleets).*
- These DESs will enable a diversity of **new business models** capable of providing value to end-use energy consumers and upstream electricity market actors.

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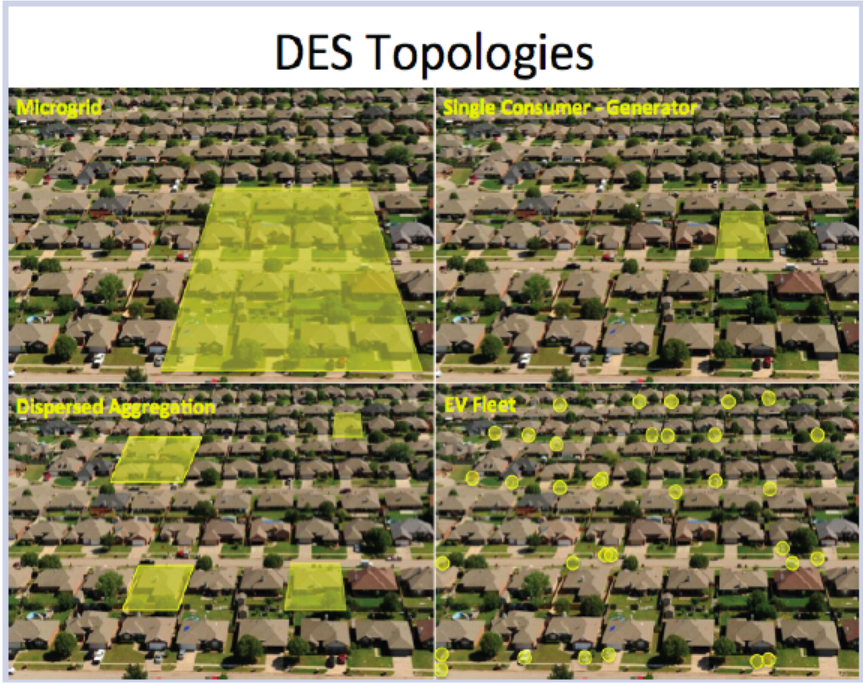
Distributed Energy Systems

DES > DER + ICT

"A *Distributed Energy System* (DES) is a system combining one or more distributed energy resources (DERs), including distributed generation, distributed storage, and/or demand response, with information and communication technologies (ICTs) to enable a business model that provides valued services to energy end users or upstream electricity market actors."

The value delivered by a DES is greater than the sum of the values delivered by individual DES component technologies



Box 2: Examples of different distributed local systems

A DLS could be located within just one physical site, say at the household level: as a combination of active demand response, plus electricity generation (rooftop solar PV, for instance), micro-cogeneration, heat and/or electricity storage and the family EV.

A DLS could also include several agents at one location: a fleet of EVs whose charge is managed from a single control entity in collaboration with the users of the vehicles, who receive an economic compensation for the ancillary services that all together provide to the local DSO and/or the corresponding TSO, plus other benefits in terms of maintenance of the vehicles, parking priorities or car renting could be a DLS.

A DLS could also include several agents at several locations: a company might form a DLS by owning solar PV panels that are installed at the rooftops or the premises of their clients, selling them full electricity services, where the energy may come from the PV panels or from the main grid, but the customers only interact with this company as their only electricity retailer.

A DLS could also include several agents, locations and resources: a DLS may combine some wind or solar PV farms, plus a portfolio of loads of several types and a fleet of EVs and some local storage, all of them sited in the same geographical area under the same DSO, but not all necessarily connected to the same point in the grid, and offer energy services to its consumers and deals to its producers that better the conditions offered by any centralized incumbent utility, the default tariff or the electricity spot market.

Elements for a vision from "the distribution edge"

- New & **unfamiliar technologies** for traditional utilities
- More **sophisticated customers** with unprecedented information & control over their energy use & expanded opportunities to produce their own energy
- Gas-fueled technologies enabling **gas utilities to play an increased role** in serving end-use demand for heat & electricity
- **New market actors** will proliferate: from ICT & DER technology providers to aggregators & operators of DESs
- Changes will be a **threat** to utilities, while also may add them **value** & enable them to better serve customers

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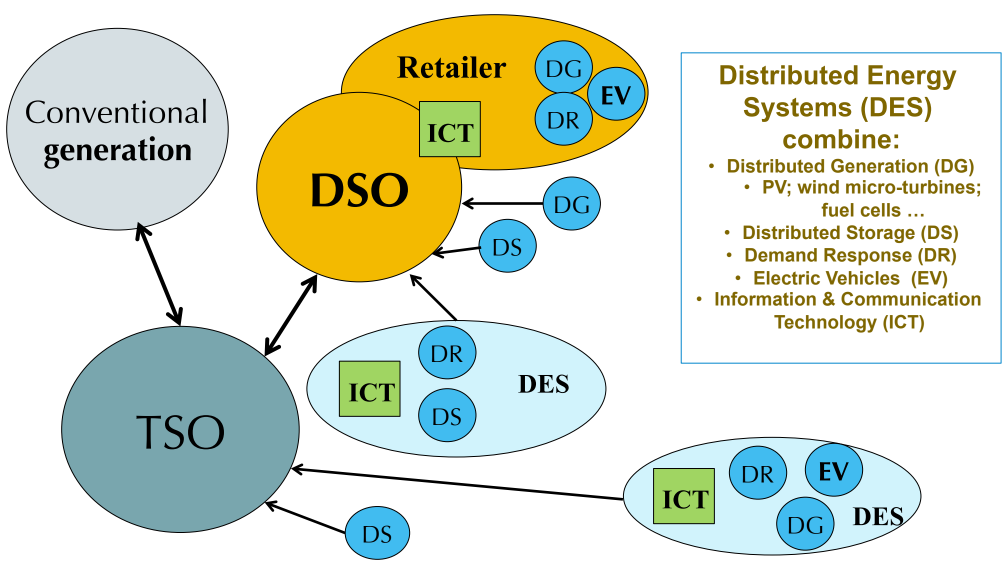
This is how a power sector looks like from this perspective



What is driving the regulatory change?

- New cost drivers ➔ adapt the distribution **remuneration** schemes
- New user profiles ➔ redesign the distribution network **tariffs**
- More information ➔ improve **distribution services**
- New business models ➔ define new functions & may allow **business opportunities** for DSOs
- New forms of value creation within distribution ➔ need for enhanced **interaction between DSOs & TSO**

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Questions of interest

- Which of these DESs could be **viable**?
- How much does this viability depend on the **regulatory framework**?
- How much does the eventual success of the **new** (DES) **business models impact**
  - the **distribution** (wires) business/regulation?
  - the **retailing** business/regulation?
  - the **wholesale generation** business/regulation?

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The different perspectives

- Technological
- Business models
- **Regulatory**

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The technological perspective

The technological perspective

Questions

- What **services** can be provided by DESs to **deliver value** to power system users & stakeholders?
- What technologies can **shift the existing electricity sector paradigm**?
- What is the status & likely evolution *("**tipping points**")* of these potential game changers?

Expected outputs

- Identify potentially **paradigm-changing technologies**, alone or in combination

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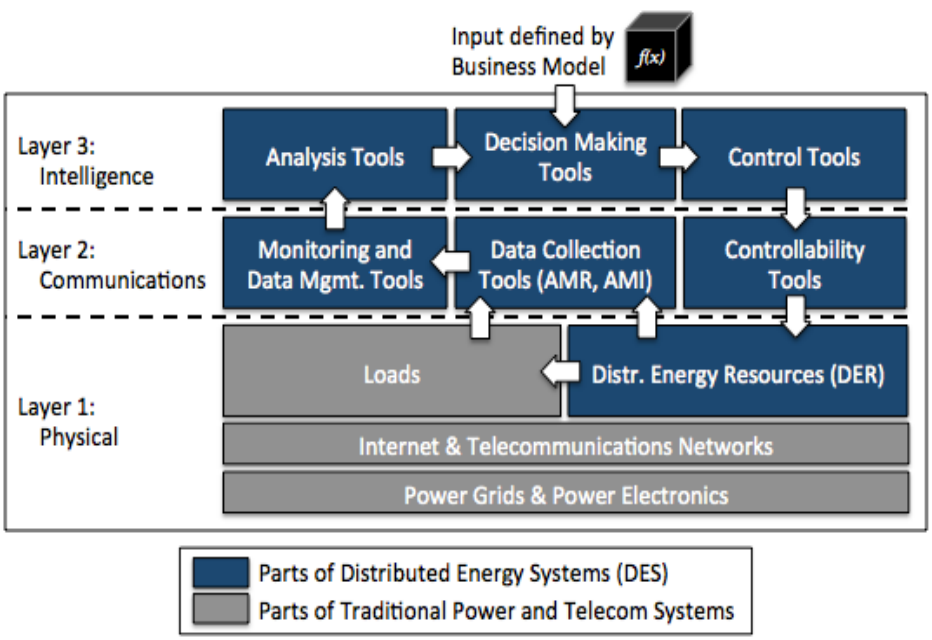
Technologies: 3-level framework for DESs



Examples of emerging DER & ICT technologies that may become building blocks of future successful DESs

DER – "Layer 1"

Distributed Generation (DG)
- Solar photovoltaics (PV)
- Fuel cells
- Microturbines

Distributed Storage (DS)
- Flywheels
- Zinc-air batteries
- Flow batteries

Demand Response (DR)
- Energy management systems
- 'Smart' appliances and automated load controls
- Real-time pricing

Electric Vehicles (EV)
- Plug-in electric vehicles
- EV charging infrastructure

ICT

Communications - "Layer 2"
- Distribution system automation/SCADA
- Intelligent systems sensors
- Advanced metering of generation and loads

Intelligence - "Layer 3"
- "Big Data" analysis software
- Decision support tools
- Home energy management systems

The business model perspective

The business model perspective

Questions

- What BMs are best suited to make use of different configurations of DESs in representative power system contexts to deliver value to all stakeholders?
- Choice or development of the right quantitative evaluation tools

Expected outputs

- Assessment of the viability of each BM
- Insight on how these BMs may impact the significance of the centralized paradigm

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The business model perspective

- **Business Models** (BMs) package available electrical **technologies** into DESs, jointly with **ICT resources**, in a manner that **delivers value** meeting the needs of end consumers, market agents & system operators, while generating a return to the service providers
- This takes place in the context of a specific **power system** & a particular **regulatory framework**

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A question for debate
Potential advantages of DESs

- **Does aggregation (DESs) have any advantage** over individual responses of the different network users, assuming that they receive the right local economic signals?
  - What is the added value (if any) that might be captured by aggregation?
  - Is taking advantage of any regulatory flaws the only reason for aggregation?

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A question for debate
Potential advantages of DESs

- Aggregation of DERs can **reduce the risk** for each individual DER to not meet its market commitments
- Aggregating otherwise relatively inflexible DER products to one DER product bundle furthermore increases the possibility for DER units to **take part in the markets** for system services.
- Aggregating DER can **exploit arbitrage potentials** if existing network charges preferentially treat larger devices from the same type, or aggregations of devices of different types.

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New DESs versus incumbents

- New DESs are/will **challenge the core business** of the incumbent utilities and **create new opportunities** for incumbent utilities to meet end-user needs and operate more efficiently.
- Incumbent utilities have a set of characteristics which present a set of challenges for any project in which they might get involved, but also a set of opportunities and competitive advantages.
- The business model(s) of the incumbent distribution utility must **evolve to capture** these opportunities **and respond** to these threats, and do so at an increasingly rapid pace of change.

The regulatory perspective

The regulatory perspective

Questions

- What are the **limitations of existing power sector regulations** & how are they shaping the emergence od DES-related BMs?
- **How can regulations be improved** to create a level playing field for multiple BMs based on new DESs or on conventional centralized generation?

Expected outputs

- Evaluation of the existing regulatory regimes & **proposal of a level playing field** regulatory framework that can be used as benchmark

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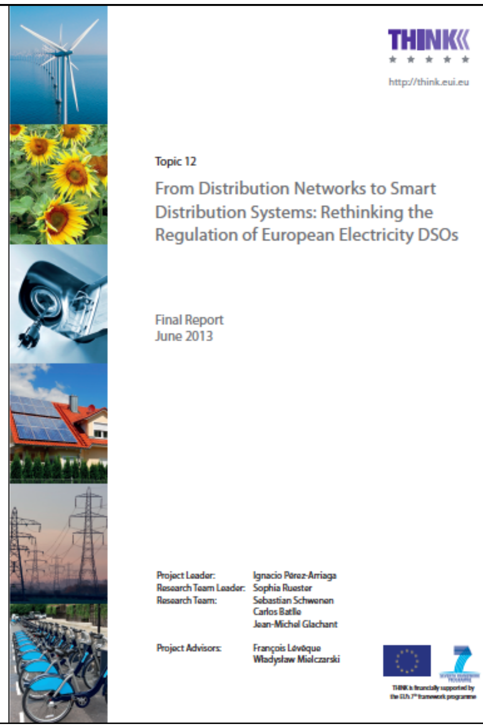
Pace of regulatory change

- The regulatory framework must enable both the distribution system and the regulated utility's business model to evolve at the pace demanded by changing network uses.
- **If regulatory innovation cannot keep pace** with the changing nature of the electric power system, large **inefficiencies** will result.
- The evolution of utility business models can be severely constrained by the lack of proactive regulatory innovation



THINK

http://think.eui.eu

Topic 12

From Distribution Networks to Smart Distribution Systems: Rethinking the Regulation of European Electricity DSOs

Final Report
June 2013

Project Leader: Ignacio Pérez-Arriaga
Research Team Leader: Sophia Ruester
Research Team: Sebastian Schwenen
Carlos Batlle
Jean-Michel Glachant

Project Advisors: François Lévêque
Władysław Mielczarski

THINK is financially supported by the EU's 7th framework programme

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Four areas of DSO regulation need to be reviewed

- **Remuneration** of distribution network companies that better accounts for the costs and savings offered by a high penetration of DESs
- **Allocation of network costs** to its users to provide a level playing field for all DESs – this includes **redesigning network tariffs**
- Identification of the **new role(s) of the DSO** (functions & services with economic value) in a system with larger penetration of DESs
- Reassessment of industry structure and **interactions between network operators** (TSO/ISO & DSOs) and other market actors given increasing penetration of DESs.

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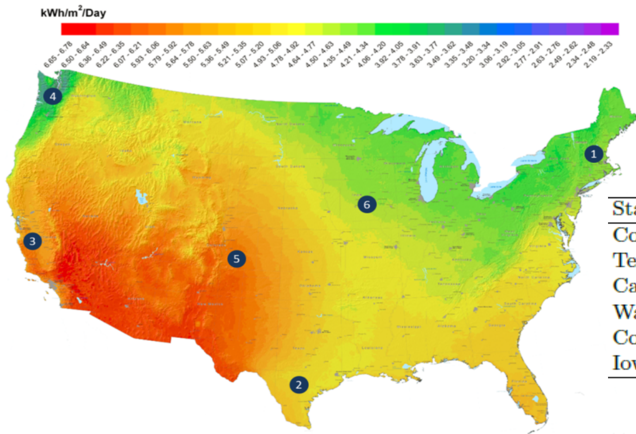
Issue #1
Remuneration of the distribution network

Network remuneration

- Increasing amounts of DER require **substantial investments** to
  - Properly connect all new resources
  - Set up ICT infrastructure that empowers DSOs to employ DER for their daily grid operations

- Therefore, two **regulatory mandates**:
  - Account for increasing total costs related to distribution (investments, operation, losses, etc.),
  - But at the same time also incentivize investments in active system management to cushion those costs

Case example to study the impact of distributed solar PV on total network costs

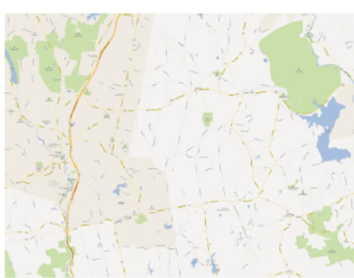


State	Rural	Urban
Connecticut	Torrington	Hartford
Texas	San Marcos	Austin
California	Lancaster	Los Angeles
Washington	Covington	Seattle
Colorado	Eaton	Boulder
Iowa	Altoona	Des Moines

6 locations x 2 cities/location x 3 load hypotheses/city x 8 solar penetration scenarios /load hypothesis = 288 cases

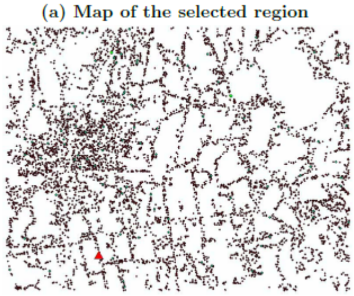
(*) From "MIT Future of Solar Study", with participation of IIT-Comillas

Construction of the reference cases

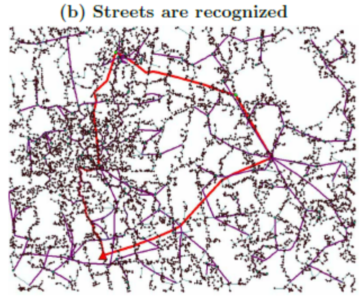


(a) Map of the selected region

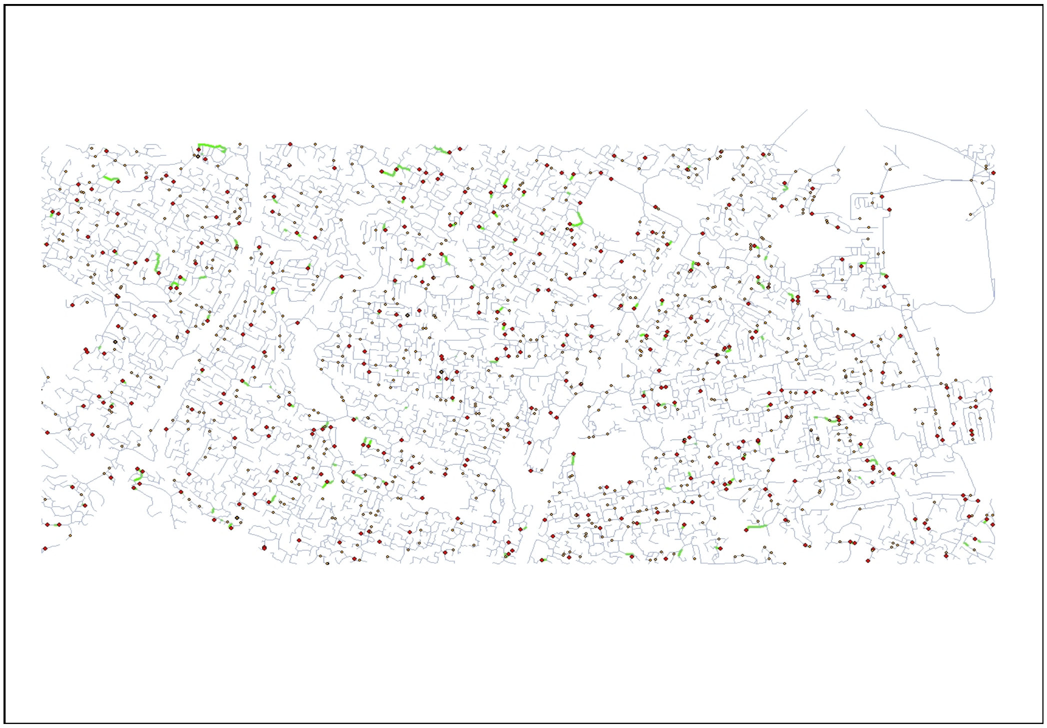
(b) Streets are recognized

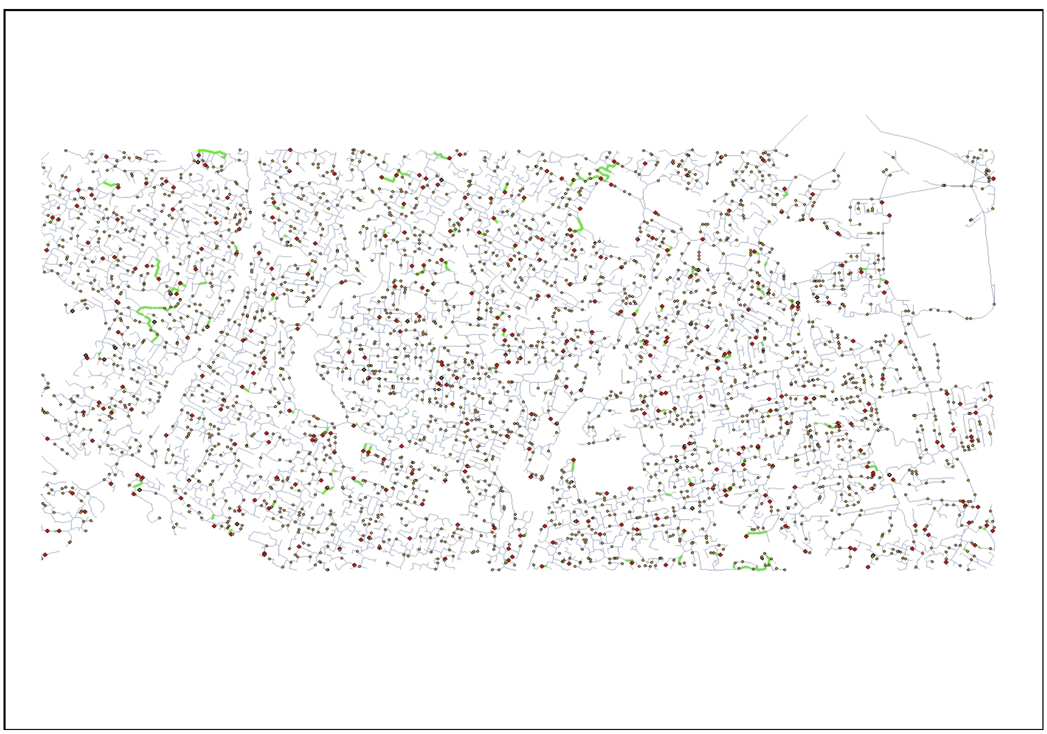


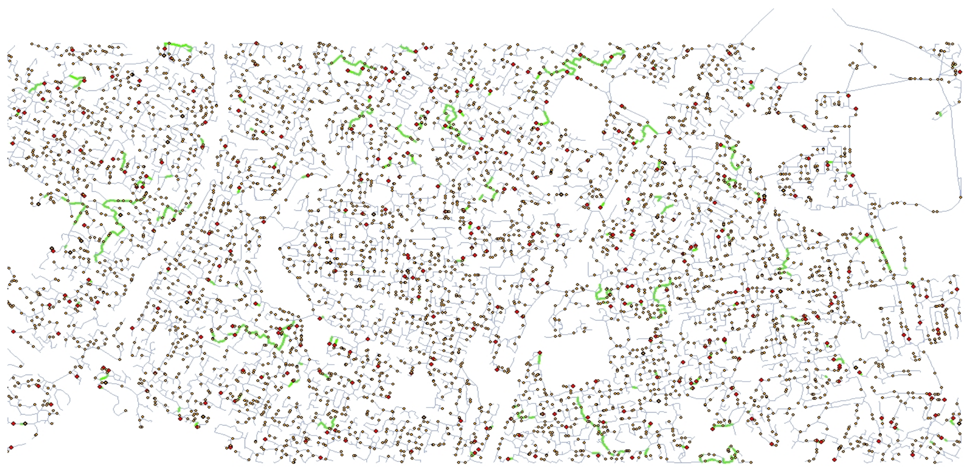
(c) Customers and substations

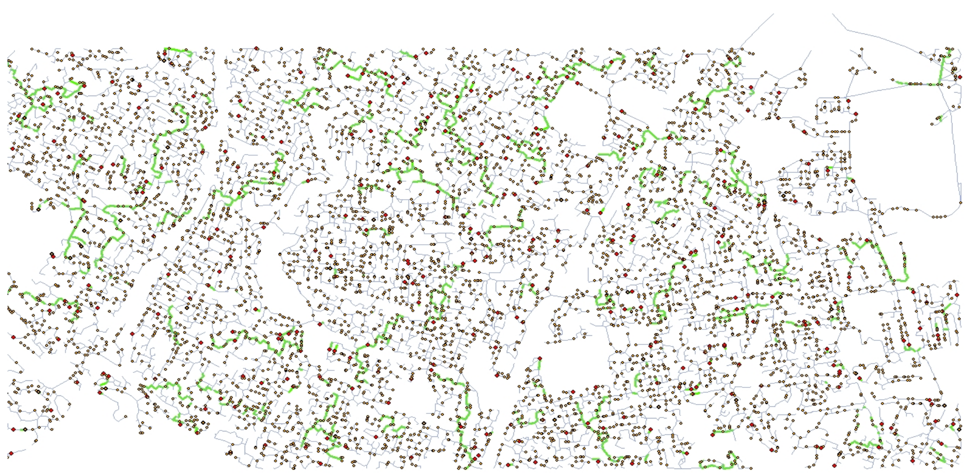


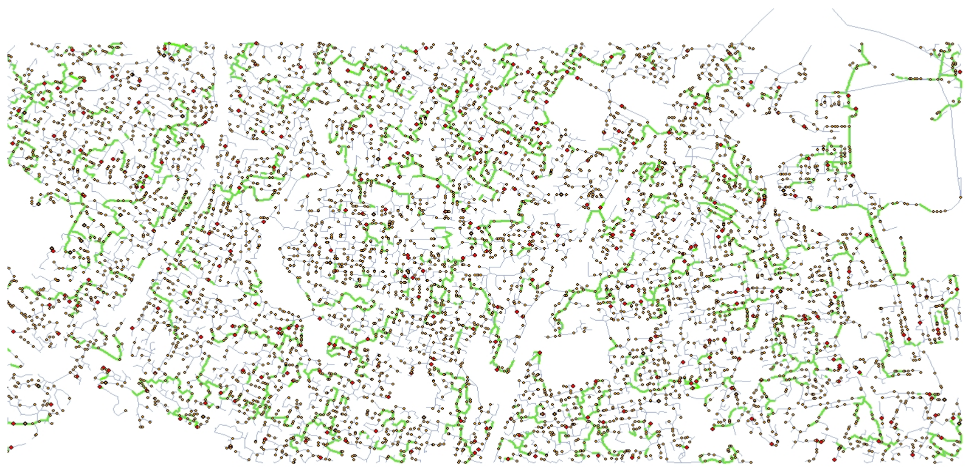
(d) Base network

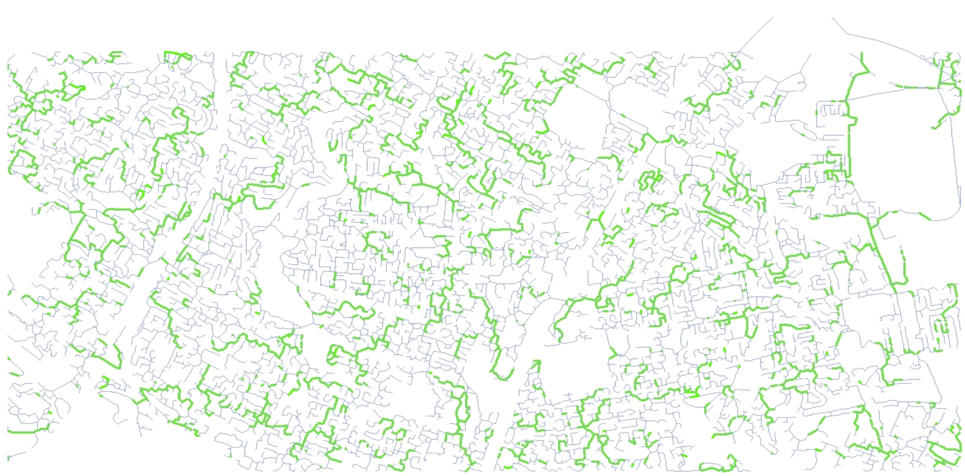




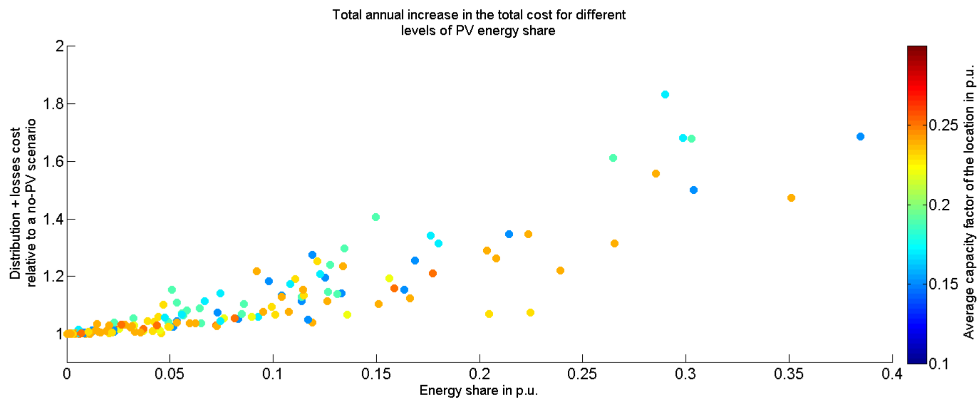






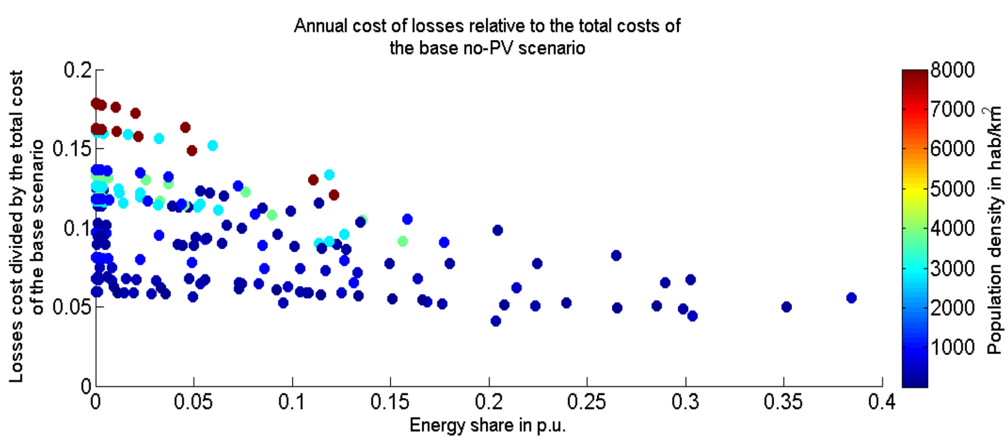


Impact on total cost: A significant PV energy share drives the total cost (distribution + losses) up to maintain the same level of quality of service



(*) From "MIT Future of Solar Study", with participation of IIT-Comillas

Impact on network losses: Losses have a significant, but lesser, importance than investment plus operation costs. Distribution losses decrease as the energy share increases, more in densely populated areas.



(*) From "MIT Future of Solar Study", with participation of IIT-Comillas

Should cost reduction still be the primary regulatory objective today?

- Distribution firms are subject to **new challenges** & must find the most **adequate solutions** to meet any new technical & operating requirements
  - ➜ Regulation must facilitate an adequate response to these challenges
- **How to incentivize the distribution utility to pursue innovation?**

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A new vision is needed *(1 of 2)*

"The **overriding objective of a future regulatory framework for energy network companies is to encourage them to play a full role in the delivery of a sustainable energy sector** & deliver long-term value for money network services for existing and future consumers

"RIIO is designed to promote smarter gas and electricity **networks for a low carbon future**"

(OFGEM, RIIO A new way to regulate electricity networks, Final report of the RPI-X@20 project, 2010)

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A new approach to network remuneration is needed

"It is in the interests of consumers that a company that delivers these outcomes is rewarded. Delivery will require significant investment and **we will ensure that network companies that deliver efficiently are able to raise the required finance at a reasonable cost** to existing and future consumers."

(OFGEM, RIIO A new way to regulate electricity networks, Final report of the RPI-X@20 project, 2010)

A results-based approach as RIIO?

- A results-based model could be based on regulators approving:
  - multiple year revenues to support a forward-looking utility business plan;
  - a mechanism for sharing any cost savings with customers;
  - and output-based performance incentives, such as:
    - A share of the value of outages avoided with grid modernization, savings from energy efficiency programs, social benefits from improved environmental impact, improved cyber security defenses, satisfactory integration od distributed generation or electric vehicles or customer satisfaction

Source: GE Digital Energy and Analysis Group, "Results-Based Regulation: A Modern Approach to Modernize the Grid", 2013.

On-going research at MIT

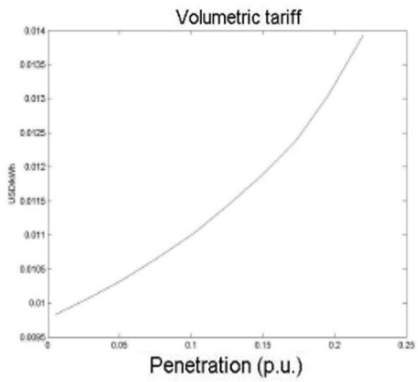
- Combine the best available approaches
  - **Menu of contracts**
    - Regulator offers an incentives compatible menu of regulatory contracts with different cost sharing provisions *(see Laffont & Tirole, 1993; Joskow, 2006; Cossent & Gomez, 2013)*
  - **Network reference models**
    - These are detailed engineering models of efficient networks, as an alternative to statistical benchmarking *(presently not viable due to the large variability in cost driving factors & scarce data)*

Source: Jesse Jenkins, Master thesis, 2014, MIT ESD

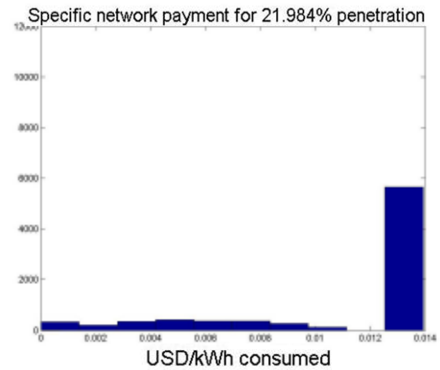
Issue #2
Design of network charges

Ideas for a conceptual approach

Impact on tariffs: When single bi-directional traditional meters (net-metering) are used jointly with volumetric network charges , customers with PV generators are subsidized by the rest of the users of the network.



(a) Changes in the network charge for each kWh consumed



(b) Number of customers that pay a given network tariff for each kWh of load.

(*) From "MIT Future of Solar Study", with participation of IIT-Comillas

The need to redesign distribution network tariffs

- Grid users become complex & sophisticated agents
  - With very diverse consumption and/or production patterns
  - Able (and willing) to react to price signals
- A sound network tariff design should reflect the costs incurred by each user & any hidden subsidies should be removed
- Business models might exploit existing ill-designed network tariffs

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Redesigning distribution network tariffs

- Current network tariff design is **totally inadequate** for the future *(& also present)* network users
- Network charges should be **based on the actual cost drivers**
  - Minimum required **connection** assets
  - Contribution to **grid utilization peaks**
  - Aggregated contribution to **system losses**

& in the **actual profile** of each network user

- Once the amount of network charge has been computed, the **format of the charge** *(€/yr, €/kW or €/kWh)* is also important

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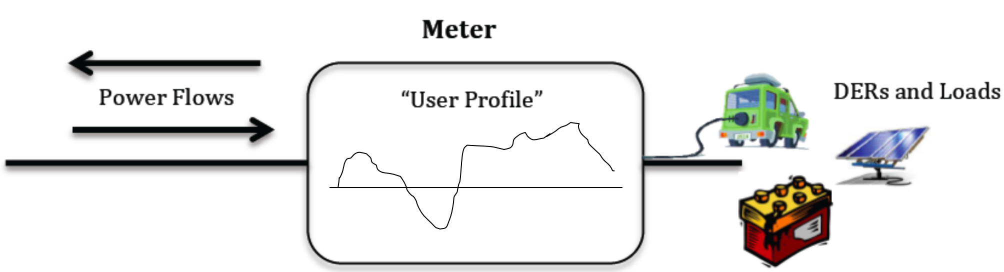
Network charges should be based on the "user profile" & not on the nature of each one of the connected devices



Box 4: Examples for ill-designed network charges

Certain network charging schemes are particularly biasing, as for instance *volumetric network charges together with net-metering*, particularly if old meters (still predominant in most EU countries; these meters only provide the accumulated net consumption over a long period of time until the value is recorded, typically one or two months) are used. Volumetric charges imply that grid users pay according to the amount of energy taken or fed into the system (€/kWh). Net-metering implies that, if at one agent's meter point both load and generation exist, the agent only pays for the net energy fed into or taken from the system during a specified period of time. If, say, the metering interval is 24 hours, then netting energy fed into or taken from the grid neglects that, for instance, during the morning and evening peak hours much load was taken from the system, and during mid-day hours much energy was fed into the system (e.g. from rooftop solar PV). This way, the distribution system is used during most of the time interval. However, the netted amount of energy could be close to zero and thereby reduce the network charge substantially.

This problematic issue also is recognized elsewhere. Different forms of net-metering also exist in many US States, see Yap (2012). EEI (2013) express concerns about US distribution tariff structures typically resulting in non-DER customers absorbing the lost revenues occurring due to net-metering. The authors call for a revision of tariff structures, particularly in states with potential for high DER adoption to mitigate cross-subsidies and to provide proper customer price signals that finally will support an economic implementation of DER.

Yet another example of ill-designed network charges relates to volumetric use-of-system charges that increase in brackets over the energy consumed. Again, if net-metering is applied, by combining load and distributed generation at one meter point, the agent can fall in a lower bracket and significantly reduce his network charges, while the impact of the agent on the network costs probably remains the same. Consequently, high-consumption grid users then fall into the group of low-consumption users and benefit from more favorable tariffs.

Reference framework for the design of electricity distribution grid tariffs

	Allowed DSO revenue		
Cost drivers according to which total cost are allocated	Minimum required assets to just connect the agent (and all others)	Grid user's contribution to peaks	Grid user's aggregated contribution to losses
Format of respective tariff components	Calculated once for each agent, or all agents of a kind in a zone, on top of the strict shallow connection cost Charged in €/year	Calculated for "zones within the D system" and "types of agents"; updated regularly (e.g. monthly) Charged in €/kW	Depending on actual grid usage Charged in €/kWh
Example 1: Household with a typical consumption profile	Subscribes a contract for 4 kW withdrawal	Consumes most during peak hours Relatively high positive charge	Total consumption of 300 kWh per month
Example 2: Household with an advanced hourly meter, an EV, solar PV on the roof, energy storage and "smart" behavior	Subscribes contracts for 10 kW withdrawal and 75 kW injection	Consumes most during night (off-peak) and injects during morning and evening peak hours Negative charge	Total consumption of 600 kWh per month Total generation of 500 kWh per month (yearly average)

Source: THINK project report, Florence School of Regulation

On-going research at MIT

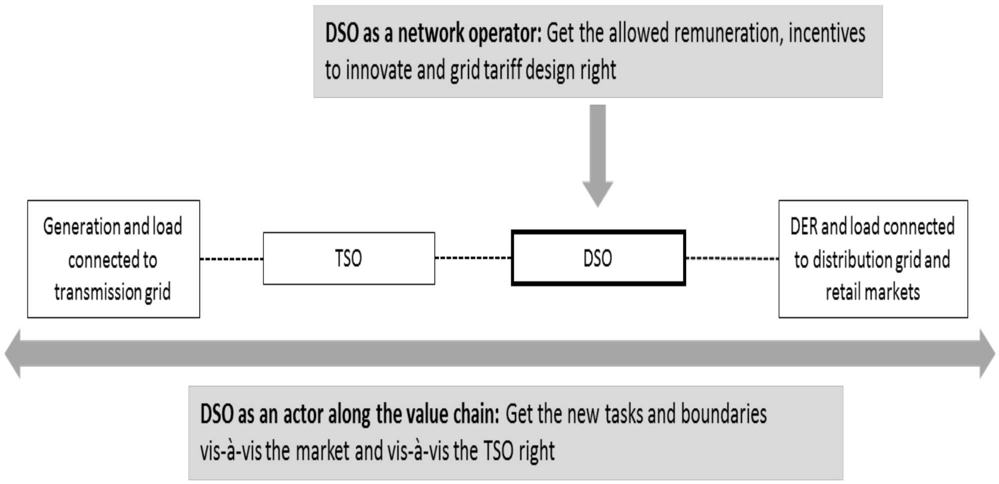
- Use the network reference model to identify the cost-drivers & their weights for each specific network configuration
- Use the individual profiles of the network users to determine their contribution to the network cost associated to each cost-driver
- Find practical & socially acceptable formats of applying the resulting network charges

Source: Ash Kumar, Master thesis, 2014, MIT ESD

Issue #3
New roles of the DSOs

(*) From “MIT Future of Solar Study”, with participation of IIT-Comillas

The new role of the DSO



Issue #4
Interactions among DSOs & TSO

DSOs vis-à-vis the TSO

- General responsibilities of network operators with respect to grid management do not change

… but the set of tools available to perform the tasks is enriched by DER

- Some of the services DER can provide are relevant for either the TSO or the DSO

… whereas others might be of interest for both types of network operators

➔ Regulation needs to guide DSO-TSO interactions: coordination & differentiation of activities

… and do not forget the regulatory challenges for "DSOs" in a totally different context, one that will require specific regulation of the potentially viable business models in massive amounts

Regulatory approaches to universal access to electricity

Related on-going MIT research projects: "Microgrid development in India" & "Technologies & business models for universal energy access"

Isolated rural community in Cajamarca (Peru). Example of dispersed population.
Source: Julio Eisman. Acciona Foundation. Peru Microenergia.

Isolated rural community in Cajamarca (Peru). Example of dispersed population.
Source: Julio Eisman. Acciona Foundation. Peru Microenergia.

Kya Sand, a peri-urban slum near Johannesburg, South Africa, where formal housing has been electrified but informal dwellings exist outside of electricity supply
Source: IFC, "From gap to opportunity: Business models for scaling up energy access"

A plausible taxonomy of business models for electricity access

		Grid Extension	Connected Minigrid	Isolated Minigrid	Single User System	Pico Solar Systems
For profit	Small, decentralized	India (small reseller)	China, Nicaragua, Cambodia (local minigrid)	Cambodia, Ethiopia (local minigrid)	Argentina, Brazil, Kenya… (small retailer)	India, East Africa (local entrep. / international)
	Large, centralized	Argentina, Chile, Guatemala, Uganda (large concession)	Senegal (minigrid concession)	Senegal (minigrid concession)	Bangladesh, Bolivia… (off-grid concession)	Africa, Asia (emerging mkt. / brand builders)
Non profit	Cooperatives	Bangladesh, Costa Rica, USA (large cooperative)		Guatemala (small cooperative)	Guatemala (small cooperative)	
	Social enterprises				Bangladesh, Peru (small & large retailer, dealer)	Mexico (small dealer)
	Other community org.	Bolivia (community gateways)		Brazil, Cambodia … (community microgrids)	Argentina, Nicaragua (community SUS)	
	NGOs				Guatemala (EsF)	
Public	Small, decentralized	Brazil, Colombia (small state utility)		Bolivia (municipal microgrids)		
	Large, centralized	Botswana, Mozambique (large state utility)		Cambodia, Nicaragua (state owned minigrids)	Mexico (state owned SUS)	

THANK YOU FOR YOUR ATTENTION

Reference documents

- "**Challenges in power sector regulation**" , by I. Pérez-Arriaga. Chapter 14 of the textbook "Regulation of the electric power sector", edited by Ignacio Pérez-Arriaga *(focus on sections 14.2.1 & 14.3.2)*
- MIT, "**The future of the electric grid**", December 2011

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- Pérez-Arriaga, Ruester, S., I.J., Schwenen, S., Batlle, C., & Glachant, J.M. (2013). From Distribution Networks to Smart Distribution Systems: Rethinking the Regulation of European Electricity DSOs. Think Project, European University Institute (July 2013).
  http://www.eui.eu/Projects/THINK/Documents/Thinktopic/Topic12digital.pdf
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  http://search.ofgem.gov.uk/search.aspx?aid=6581&pckid=755724950&pt=6018936&sw=riio
- *IEFE, "Changing the regulation for regulating the change. Innovation-driven regulatory developments in Italy: smart grids, smart metering & e-mobility", WP-46, November 2011*

Reference documents

- Edison Electric Institute, "Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business", January 2013
- Eurelectric, "Active Distribution System Management: A key tool for the smooth integration of distributed generation", February 2013
- GE Digital Energy and Analysis Group, "Results-Based Regulation: A Modern Approach to Modernize the Grid", 2013.

Reference documents

- P. Joskow, "Incentive regulation for electricity networks", 2006A
- R. Cossent & T. Gómez. "Implementing incentive compatible menus of contracts to regulate electricity distribution investments". Utilities Policy 27 (2013) 28-38 *(read this paper, rather than the textbook, to understand the menu of contracts)*

A network reference model

- C. Mateo et al. "A Reference Network Model for Large-Scale Distribution Planning With Automatic Street Map Generation", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 26, NO. 1, FEBRUARY 2011

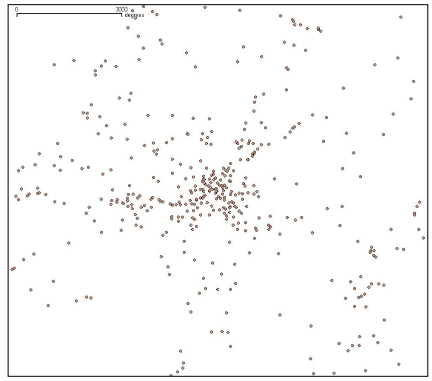
Details
Reference Network Models (RNM)

- A RNM is a network that minimizes the total cost of
  - Investment
  - O&M costs
  - Energy losses in the network

  while meeting prescribed continuity of supply targets *(or explicitly including the cost of non supplied energy)* in the different supply areas *(e.g. urban, suburban, concentrated rural, dispersed rural)*
- RNMs may be used as an aide or benchmark *(with any required adjustments)* when
  - computing the revenue cap for the next period
  - designing incentive schemes for losses or quality of service

Case study: LV networks in Spain

Location of LV customers



Location of MV/LV transformers

Case study: LV networks in Spain

LV lines

Detail: An urban LV network

Street map, LV and MV network, LV customers and MV/LV transformers