Smart Grids: Concept, Progress, Metrics, and the International Smart Grid Action Network

Monitoring Progress Towards a Clean Energy Economy

IEA EGRD Workshop ● 17 November 2011 ● Paris, France

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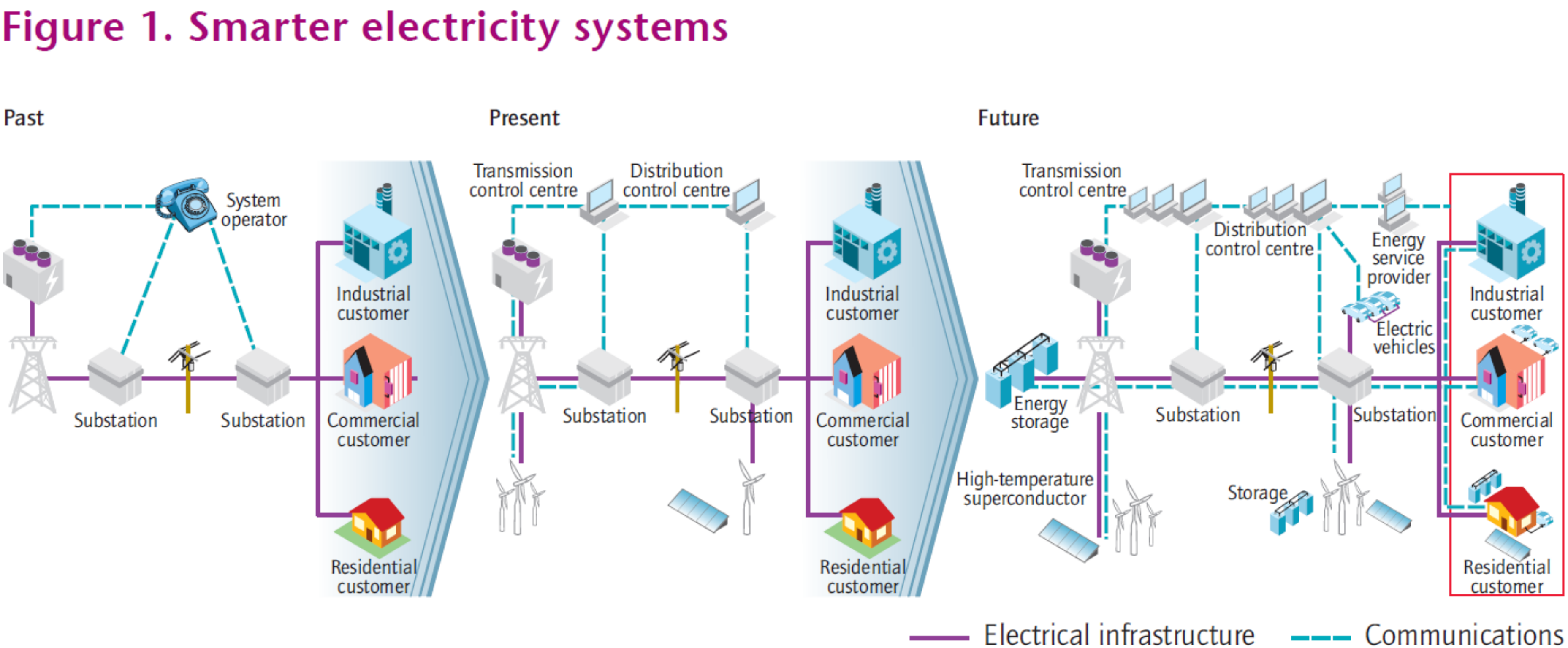
The opinions expressed herein are mine only and do not necessarily reflect the policies or priorities of the U.S. Department of Energy, the U.S Government, or the Participants in the Implementing Agreement for a Co-operative Programme on Smart Grids (ISGAN).

1. **What is smart grid?**
2. Introduction to ISGAN
3. Current Status (Objective 1)
4. Assessment and Metrics (Objective 2)

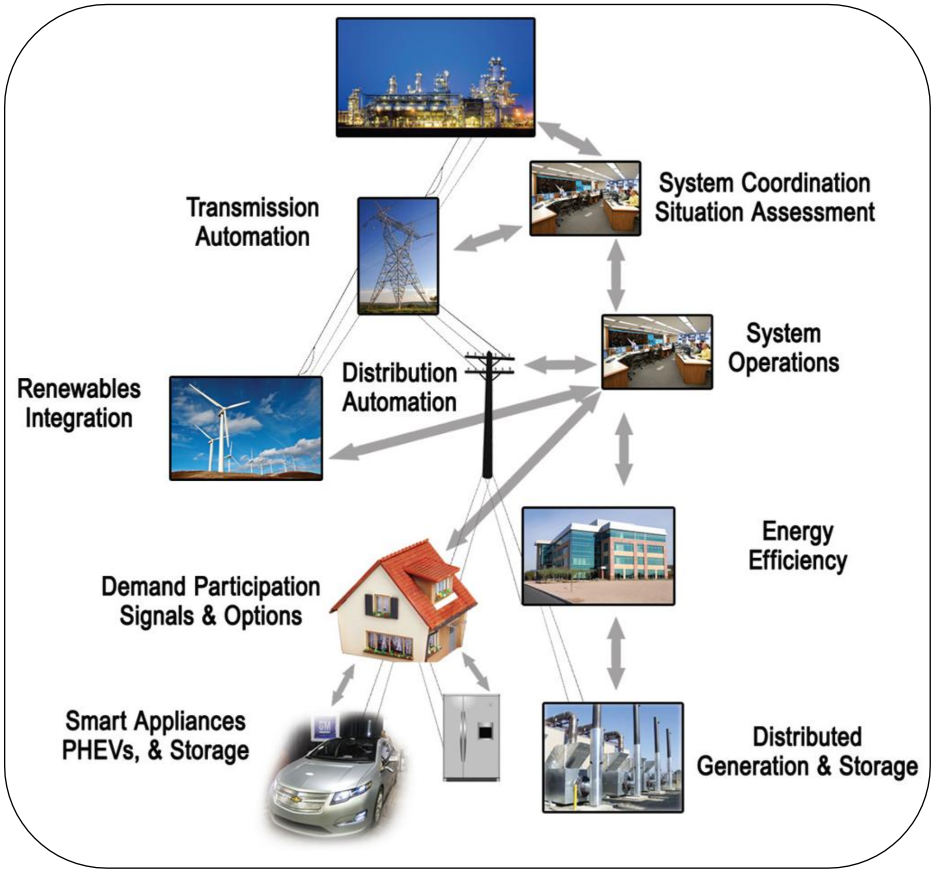
Definitions Differ (Somewhat)

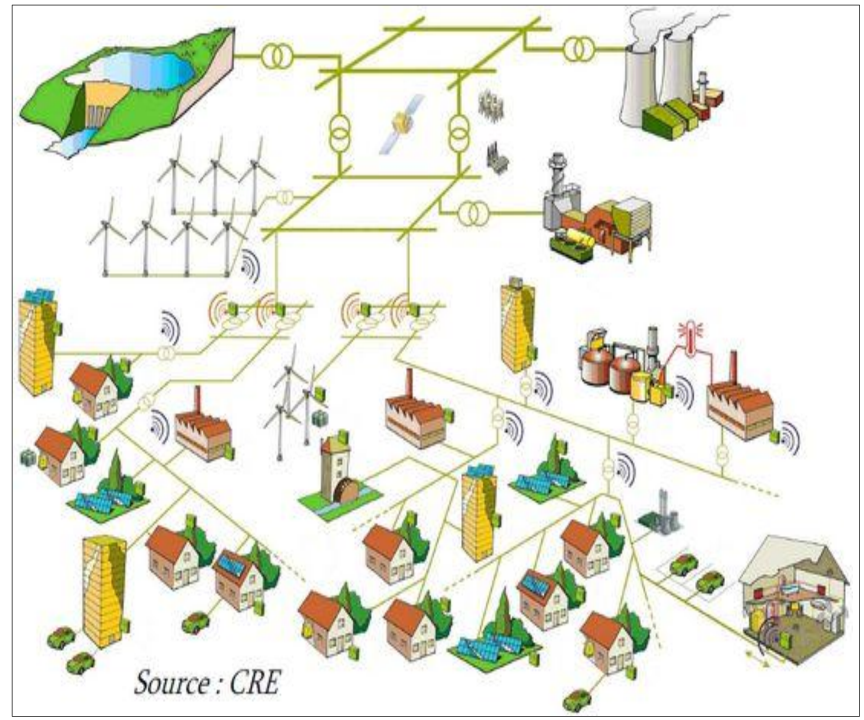
- **E.U. – A Smart Grid is "an electricity network that can intelligently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently ensure sustainable, economic and secure electricity supply" [Smart Grid European Technology Platform]**
- **U.S. – A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources [DOE 2009]**
- **IEA – "A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users." [IEA 2011]**



Source: IEA Technology Roadmap – Smart Grids

Plethora of Similar Diagrams Available

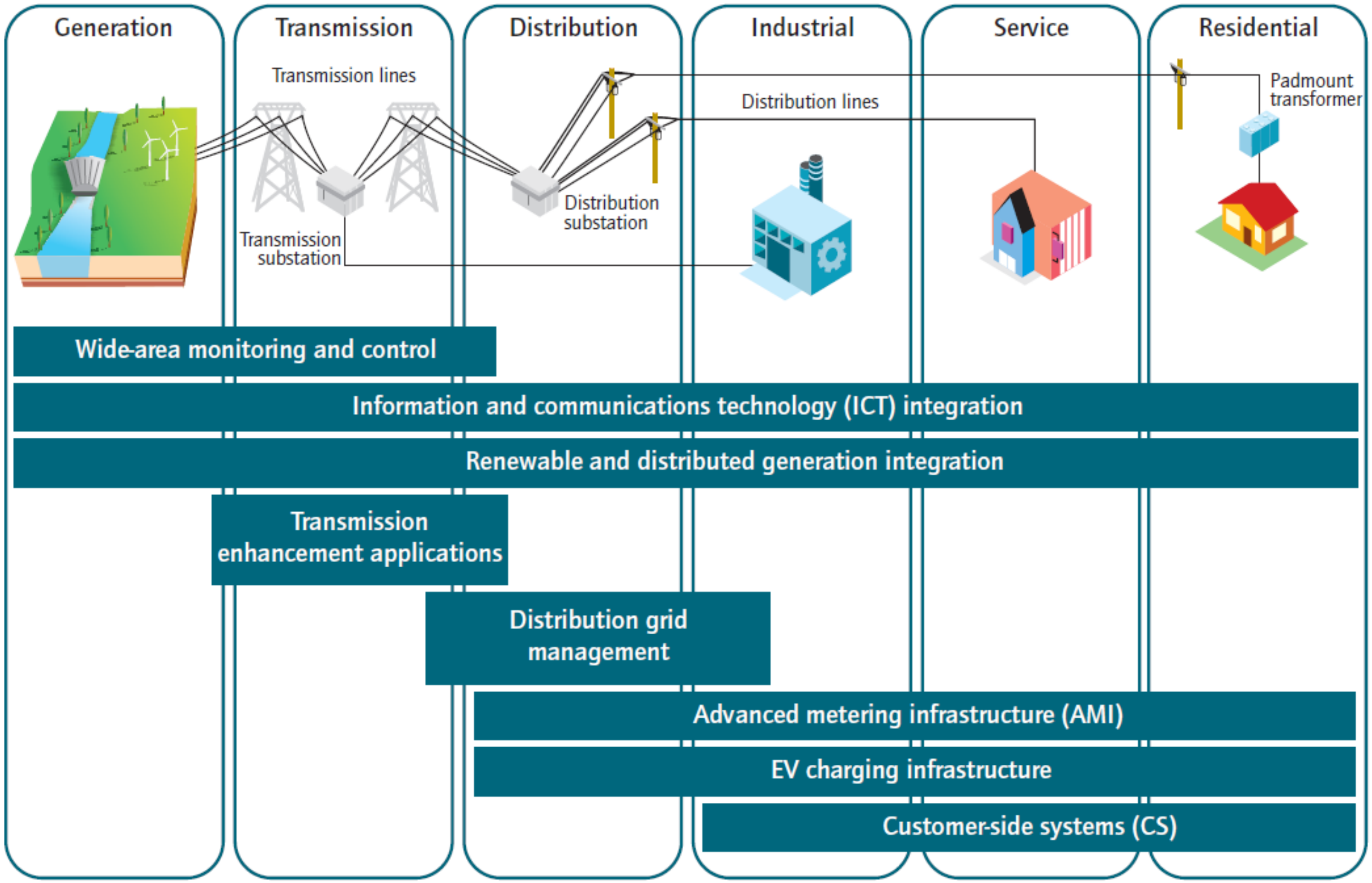




Source: U.S. Department of Energy

Source: http://www.environnement-france.fr

A Wide Range of Technologies and Services Spanning The Entire Electricity System



Source: Technology categories and descriptions adapted from NETL, 2010 and NIST, 2010.

Source: IEA Technology Roadmap – Smart Grids

Perhaps a Smart Grid Can Be Defined by Its Characteristics or Services

Enables informed participation by customers	Accommodates all generation & storage options	Enables new products, services, & markets
Provides power quality for the range of needs	Optimizes asset utilization & operating efficiency	Operates resiliently to disturbances, attacks, & natural disasters

Source: U.S. Department of Energy
Modified versions used in IEA Technology Roadmap – Smart Grids and elsewhere

1	• What is smart grid?
2	• **Introduction to ISGAN**
3	• Current Status (Objective 1)
4	• Assessment and Metrics (Objective 2)

ISGAN
international smart grid action network

A mechanism for bringing high-level government attention and action to accelerate the development and deployment of smarter electricity grids around the world.

ISGAN…

- Fulfills a key recommendation in the Smart Grids Technology Action Plan (released by Major Economies Forum Global Partnership, 2009)
- Was launched as one of 11 initiatives under the Clean Energy Ministerial (in 2010)
- Is organized as an IEA Implementing Agreement (in 2011, under the EUWP and CERT)
- Sponsors activities that build a global understanding of smart grids, address gaps in knowledge and tools, and accelerate smart grid deployment
- Builds on the momentum of and knowledge created by the substantial smart grid investments being made globally
- Will leverage cooperation with the Global Smart Grid Federation GSGF Global Smart Grid Federation and others

Current ISGAN Participants

Australia	India	The Netherlands
Austria	Ireland	Russia*
Belgium	Italy	Sweden
Canada	Japan*	Switzerland
China*	Korea	United Kingdom
Finland	Mexico	United States
France	Norway	European Commission*
Germany		

Plus five other countries invited to join:
Brazil, Denmark, South Africa, Spain, and Turkey

Participate through the CEM, but have not yet signed the Implementing Agreement

One of 11 Clean Energy Ministerial Initiatives

- International Smart Grid Action Network
- Super-Efficient Equipment and Appliance Deployment Initiative
- Electric Vehicles Initiative
- Bioenergy Working Group
- Carbon Capture Use and Storage Action Group
- Clean Energy Education and Empowerment Women's Initiative
- Clean Energy Solutions Centers
- Global Superior Energy Performance Partnership
- Multilateral Solar and Wind Working Group
- Solar and LED Energy Access Program
- Sustainable Development of Hydropower Initiative

Foundational Annexes

Annex 1: Global Smart Grid Inventory

Annex 2: Smart Grid Case Studies

Annex 3: Benefit-Cost Analyses and Toolkits

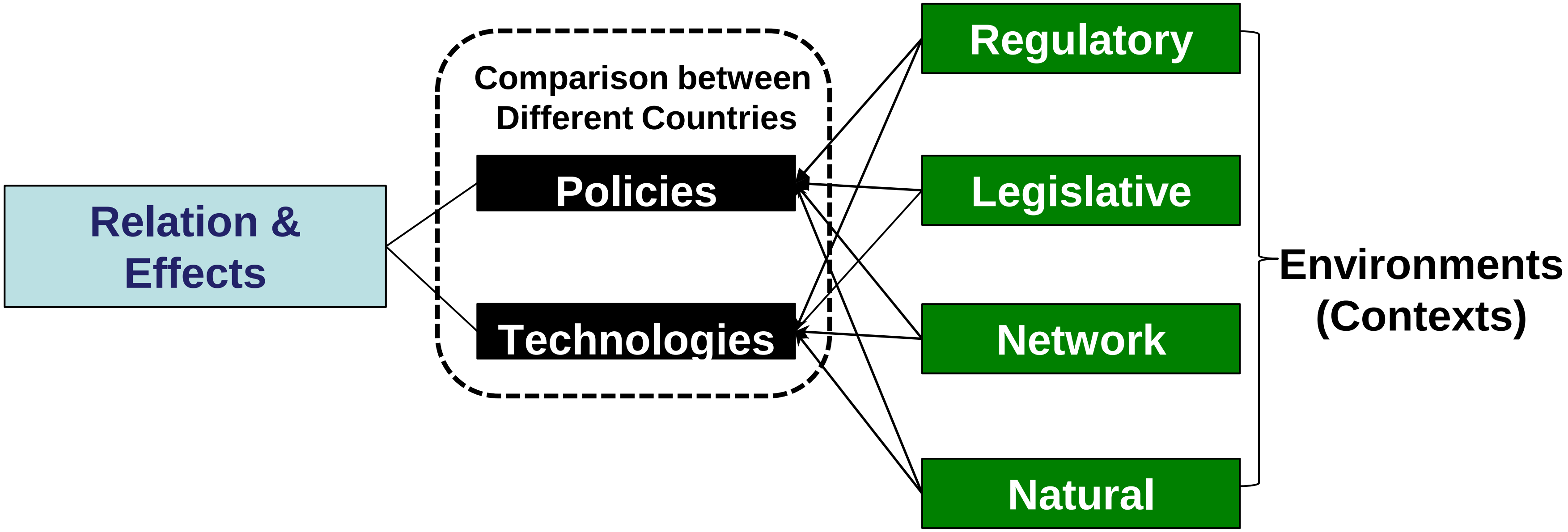
Annex 4: Synthesis of Insights for Decision Makers

Emphases

Objectives and Approach

- **Develop a unified ISGAN framework for assessing smart grid features and technologies**
- **Prioritize this framework for each participating country**
  (i.e., what are the motivating drivers and specific technology interests)
- **Map this framework against existing inventories, surveys, and assessments**
- **Identify gaps, opportunities, synergies, and inconsistencies and make recommendations, if appropriate**
- **Expand framework to take in account key metrics and indicators**
- **Develop appropriate tools for disseminating results**
  (complement, not duplicate existing platforms)

- **Assess best practice examples of case studies**
- **Develop and apply a common case study template & methodological framework**



Objectives and Approach

- **Assessment, modification, and application of methods to measure the present level of maturity of networks (i.e., the “smartness”)**
- **Assessment, modification, and application of existing benefit-cost methodologies and tools, as well as development of new ones**
- **From these analyses, develop appropriate toolkits (including KPI definition)**
  - Range of levels targeted: From high-level, broad-based methodologies to more detailed system-level approaches to project- or technology-level approaches
  - Builds on metrics and data identified by Annexes 1 & 2, and other sources

In short: Knowledge management and info sharing <u>by design</u>

- **Develop a platform that compiles smart grid concepts from high-quality sources and makes them accessible to policymakers (e.g., online glossary)**
- **Produce brief, timely analytical reports that clarify important issues or raise key questions in smart grid policy and deployment**
- **Establish platforms (or augment existing ones) for knowledge management and collaboration among ISGAN participants**
- **Develop other tools for collaboration and information sharing**

Other Activities and Collaboration

Integration of ENARD* Work Programme into ISGAN
(*Implementing Agreement for Electricity Networks Analysis, Research & Development)

Cooperation with Other Implementing Agreements, such as DSM and 4E
(directly through Electricity Coordination Group, End Use Working Party, etc.)

Smart Grid International Research Facility Network (SIRFN) – *proposed Annex*
(to be coordinated with APEC Smart Grid Test Beds Network)

Governance During the Smart Grid Transition – *proposed Annex*
(social sciences focus)

Continuing Dialogue with Other Int'l Efforts, Private Sector, etc.
(e.g., US-EU Energy Council, APEC Smart Grid Initiative, Global Smart Grid Federation, Smart Grid Interoperability Panel)

Smart Grid Interoperability Frameworks – *proposed Annex*
(integration and synthesis exercise)

1. What is smart grid?
2. Introduction to ISGAN
3. **Current Outlook (Objective 1)**
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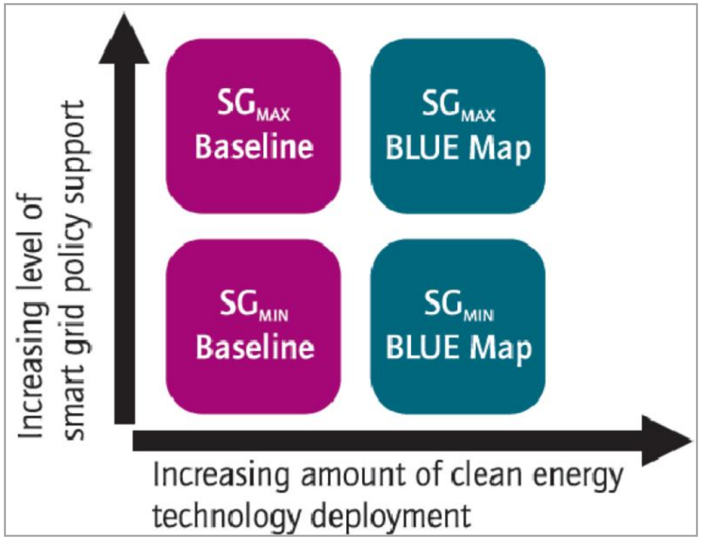
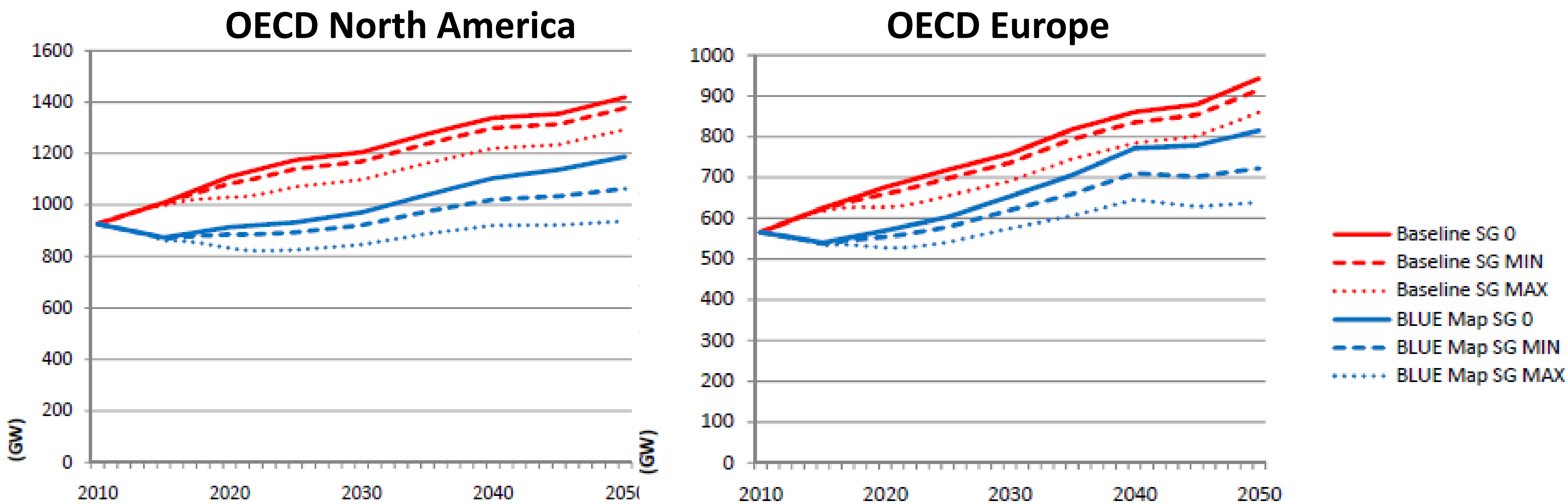
- **BLUE Map assumes smart grids as key enabler, but not considered explicitly in *ETP 2010* analysis**
- **Source for today's discussion is separate 2011 study[1] by IEA**
  - Study used BLUE Map scenario to explore possible declines in peak load due to smart grid-related technologies *and* policies.
  - Three cases:
    - SG 0 assumes no smart grid support or deployment (reference case).
    - SG MIN assumes deployment but minimal policy support
    - SG MAX assumes deployment and maximum policy support.



[1] Impact of Smart Grid Technologies on Peak Load to 2050 (IEA Working Paper)

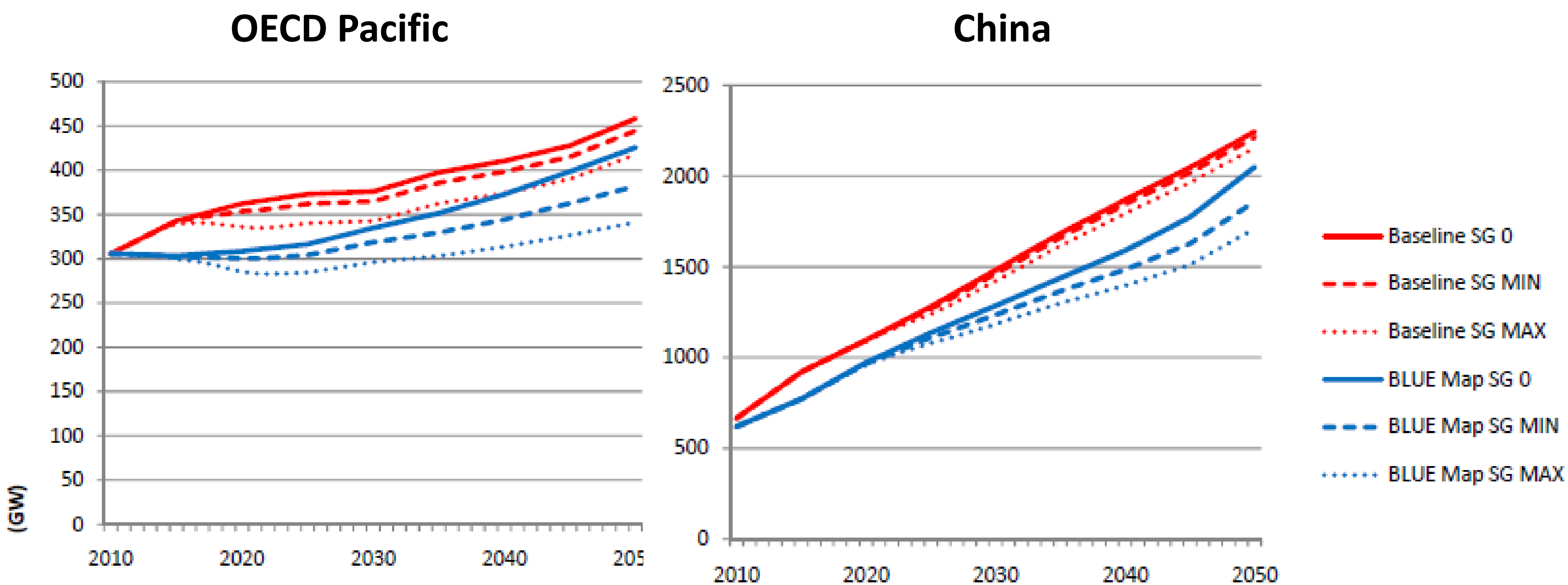
Estimated peak load evolution, 2010-2050



Source: Impact of Smart Grid Technologies on Peak Load to 2050 (IEA Working Paper)

Results: OECD Pacific and China

Estimated peak load evolution, 2010-2050



Source: Impact of Smart Grid Technologies on Peak Load to 2050 (IEA Working Paper)

Or "It Ain't Necessarily So…"

- **Smart meters used as proxy for advanced metering infrastructure (AMI)**
- **Dynamic pricing schemes adopted with smart meters**
- **All regions reduce T&D losses to today's best practice value if smart grid technologies successfully implemented along value chain**
    - AMI deployment penetration rate used as metric for overall smart grid penetration

- **EVs: 90% slow charging (3.7 kW), 10% fast charging (40 kW)**

Share EVs Connected to Grid During Peak		
	Grid-to-Vehicle	*Vehicle-to-Grid*
SG_0	50%	0%
SG_{MIN}	30%	5%
SG_{MAX}	20%	15%

(assumes active management of EV loads…)

- **Grid integration of renewables omitted from analysis (projected for future integration with GIVAR project)**

- **Although "Grid Modernization" has been ongoing for a while… … "Smart Grid" as an integrated concept is relatively new**
- **Frameworks, methodologies and metrics are immature for assessment and evaluation of the…**
  - Present smartness of electricity networks
  - Prioritized technology/policy needs of specific power grids
- **Significant variation among countries/regions in drivers, metrics, and approach**
- **IEA analysis is <u>good start</u>! But it's just a start.**
- **ISGAN and IEA are trying to answer these challenges**
  - Central question:
    *To what extent **can** or **should** we harmonize internationally?*

Good News: Technology is Ready, in General

- **Smart meters are being widely deployed**
  - E.U.: 80% by 2020 (mandated)
  - Japan & Korea: 100% by 2020
  - U.S.: 11% from near-term Recovery Act investments alone…
- **Also being demonstrated and deployed:**
  - Distribution automation equipment
  - Phasor measurement units,
  - EV charging infrastructure
  - Conservation voltage reduction
  - Etc.
- **R&D ongoing in data management, operational analytics and underlying mathematics; power electronics; sensors; transformers; improved conductors; and more…**

Good News: Good Development Trends

Technology area	Maturity level	Development trend
Wide-area monitoring and control	Developing	Fast
Information and communications technology integration	Mature	Fast
Renewable and distributed generation integration*	Developing	Fast
Transmission enhancement applications**	Mature	Moderate
Distribution management	Developing	Moderate
Advanced metering infrastructure	Mature	Fast
Electric vehicle charging infrastructure	Developing	Fast
Customer-side systems	Developing	Fast

* Battery storage technologies are less mature than other distributed energy technologies.

** High Temperature Superconducting technology is still in the developing stage of maturity.

Source: IEA Technology Roadmap – Smart Grids

- **Beyond ISGAN, there is…**
  - Global Smart Grid Federation – private sector
  - APEC Smart Grid Initiative
  - US-EU Energy Council smart grid work
  - Smart Grid Interoperability Panel
  - European Electric Grid Initiative
  - European Energy Research Alliance Joint Programme
  - EC Joint Research Centre mapping efforts (with Eurelectric)
  - EPRI Smart Grid Demonstration Initiative
  - …and many more

Example: Smart Grid Interoperability Panel

- **SGIP is comprised of over 700 member organizations, representing 22 stakeholder categories, with more than 1,800 individuals are participating in SGIP activities**
- **Analysis is provided through the Working Group structure comprised primarily of the Domain Expert Working Groups**
- **Coordination is provided through the origination and oversight of Priority Action Plans – currently 18**
  - Examples: "Standard DR and DER Signals",
    "Common Schedule Communication Mechanism",
    "Harmonization of IEEE C37.118 with IEC 61850 and Precision Time Synchronization"
- **Facilitated by National Institute for Standards and Technology (U.S.)**

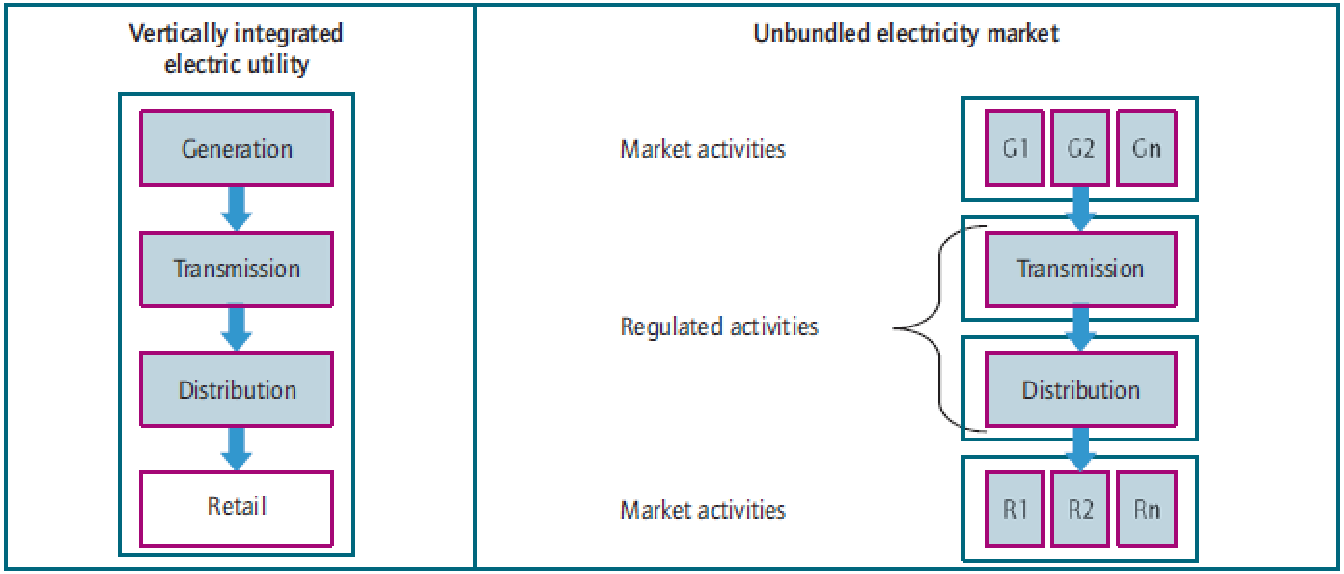
Example: US-EU Workshop Last Week

Comparison of Frameworks

	European Union (Services)	USA (Characteristics)
Smart Grid services/ characteristics	Enabling the network to integrate users with new requirements	Accommodate all generation and storage options
	Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management	Enable active parti[illegible] customers
	Improving market functioning and customer service	[illegible] products, services, and markets
	Enhancing efficiency in d[illegible] op[illegible]	Optimize asset utilization and operate efficiently
	Enabl[illegible]ing of future [illegible]rk investment	
	Ensuring network security, system control and quality of supply	Operate resiliently to disturbances, attacks and natural disasters
		Provide the power quality for the range of needs

Source: EC Joint Research Centre

- **The grid and grid governance are complex and multi-layered, often limiting leverage at any one point in the system**
  - Mix of human/behavioral interactions and automated/instantaneous systems
- **Market structures can impact perception and allocation of benefits and costs – vertically-integrated vs. unbundled**



Source: Enexis, 2010.

ISGAN
international smart grid action network

- **Very broad set of stakeholders –**
  grid touches *everyone* in developed economies

- **Policy, regulation, and business models lag tech innovation**
  - Misalignment between power sector (*long-lived infrastructure*) and ICT sector (*planned obsolescence*)

- **Workforce issues:**
  - Power sector workforce is aging
    (e.g., ½ of U.S. utility work-force eligible to retire within 5 years [Lave et al, 2007])
  - Need workforce with expertise in power engineering *and* ICT

- **Concerns persist about cyber security, data privacy, and data security**

Even More of the Challenges

- **Technology being deployed before establishment of harmonized interoperability standards and conformance testing protocols**
- **Although individual technologies are ready, much less is known regarding combined impacts of suites of technologies** (i.e., systems approach or energy services "platform" concept)
- **Challenge of data management at scale**
- **The methodological and analytical basis for understanding smart grids is still in development**
- **Tech. costs are still too high, especially for emerging economies**

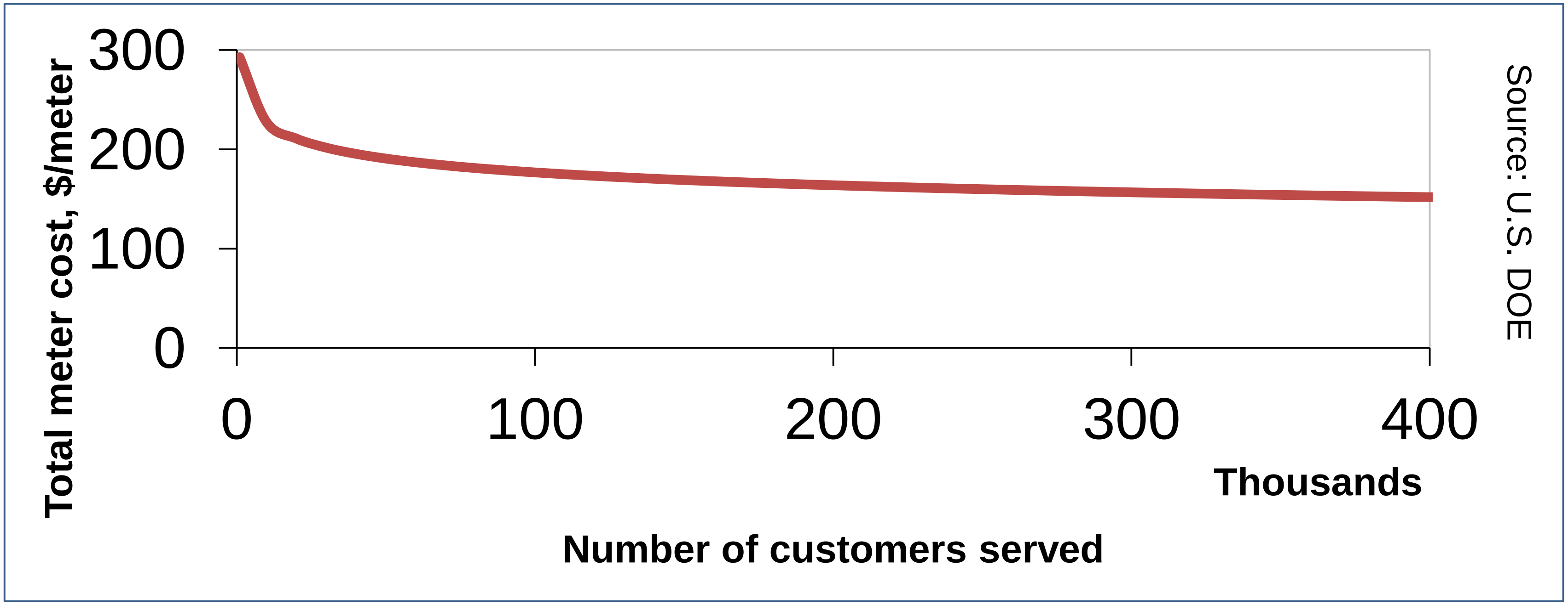
Example: Waiting for Real-world Analysis

<u>DOE Consumer Behavior Studies (funded under Recovery Act):</u>

To provide externally valid results from pilot projects that examine the influence of variable rates, technology, and education on consumer behavior, specifically to understand the factors that influence the acceptance, response and retention rates of customers with respect to alternative rate policies

	2010	2011	2012	2013	2014	2015	2016
Interim and Final Evaluation Reports			**Begin Jan 12** →	→	→	**End Jun 15**	
DOE Cross-Study Analyses to examine: • **Customer acceptance** • **Customer response** • **Customer retention**				**Interim**	**Interim**	**Final**	

- **Analysis of the AMI-related (U.S.) Smart Grid Investment Grants suggest that total price of smart meter is asymptotic at ~$160.**



- **India's target: As low as $25 per smart meter… installed.**

Most Fruitful Areas For R&D Cooperation

- **Testing of technologies, systems, and concepts across a variety of grid technical and policy environments**
- **Interoperability standards development and conformance testing protocols**
- **Grid modelling, analytics, and data management (and underlying mathematics)**
- **Improved power electronics, materials, conductors, etc.**
- **Grid integration of "new" technologies at scale – EVs, renewables and the like – and systems balancing**

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Smart Grids

Sample Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- **Public RD&D investment in smart grids ($/yr) [1]**
- **Private RD&D investment in smart grids ($/yr) [1,2]**

Technology Readiness

- **Electricity capacity of smart grids demonstrations and pilot tests (MW) [3]**
- ***Modeled* power system stability and reliability (CAIDI, SAIDI) [5]**
- Capital and O&M costs of (a) advanced metering infrastructure, (b) customer systems, (c) distributed automation and monitoring, (d) transmission system monitoring and control, and (e) integrated systems [11,12]
- Expected lifespan of advanced metering infrastructure hardware (yrs) [12]

Market Readiness

- **Number of organizations participating in international standards interoperability and/or harmonization activities [12]**
- **Percentage of products conforming to international [illegible] standards [12]**
- Number of G20 countries with performance or pri[illegible]ding tariff structures, for deploying smart grid technol[illegible]
- Stakeholder understanding of the [illegible]nce of smart grid technologies (survey) [4[illegible]
- Number of G20 co[illegible]ding privacy, ownership, and security i[illegible]havior data [4]
- Num[illegible]chanisms that encourage markets to [illegible]ologies [4]
- [illegible]ducts and incentives that encourage deployment of [illegible]g technologies, such as energy use information ($) [4]

Probably too soon to settle on a specific set of metrics.

Market Transformation

- **Percentage [illegible]real-time energy usage information, i[illegible]ing (%) [4]**
- Number of netw[illegible] measurement units deployed (#) [2]
- Change in total ca[illegible]city of automated demand response available compared to baseline (MW) [4]
- Capacity of electricity storage connected to smart grids at (a) transmission scale and (b) distribution scale (MW) [7]
- Distributed generation to total generation (ratio) [3,8]
- Change in Smart Grid Maturity Model (SGMM) scores [9]

Impacts

- Average ratio of peak power demand to average power demand [3]
- Average outage duration (hrs) [8,10]
- Frequency and duration of power outages (CAIDI, SAIDI, SAIFI) [6]
- GHG emissions avoided from smart grid implementation (MtCO2e/yr)
- Reduction in (a) energy demand and (b) T&D line losses from improved volt/VAR control (%) [3,8]

Countries/Regions are Currently Identifying Their Own Metrics Frameworks

- **European Union**
  - Ideal smart grids defined in terms of smart grid “services”
  - Definition of the outcome of the ideal smart grid in terms of “benefits”
  - Metrics to measure progresses and outcomes: *56 Key Performance Indicators (EC Task Force)*

- **USA**
  - Ideal smart grids defined in terms of smart grid “characteristics”
  - Metrics to measure progress and outcomes across nation: *20 Build/Value Metrics (DOE Smart Grid System Report)*
  - Plus more granular suite of metrics to measure progress in individual projects

20 Metrics, Classified as Either "Build" or "Value":

- **Area Coordination**
  - Dynamic pricing
  - Real-time operations data sharing
  - Distributed resource interconnection policy
  - Policy/regulatory progress
- **Distributed Energy Resources**
  - Load participation
  - Load served by microgrids
  - Distributed generation
  - Plug-in electric vehicles
  - Grid-responsive load

Indicators of smart grid deployment progress – not comprehensive measures

- **Delivery (T&D) Infrastructure**
  - T&D system reliability
  - T&D automation
  - Advanced meters
  - Advanced system measurement
  - Capacity factors
  - Generation, T&D efficiencies
  - Dynamic line ratings
  - Power quality
- **Information, Finance**
  - Cyber security
  - Open architecture/standards
  - Venture capital investment

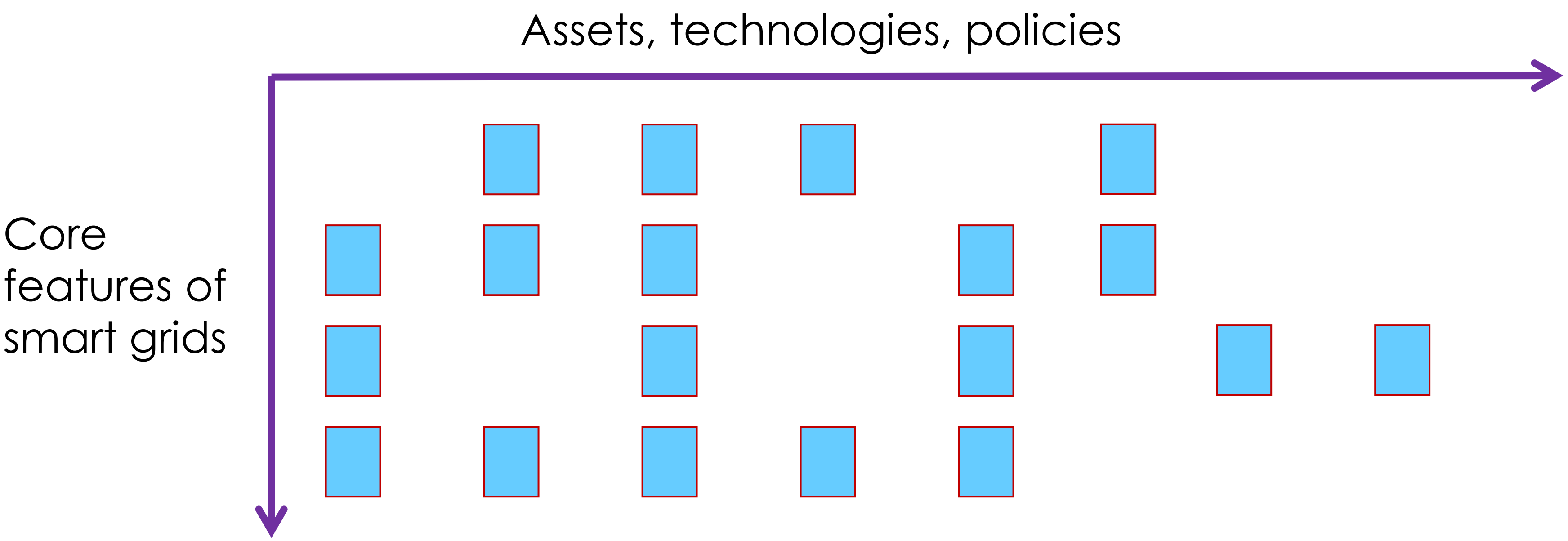
EC Task Force

Services	**Integrate users with new requirements**	**Improving market functioning and customer service**	**More direct involvement**	Total
Functionalities	Facilitate the use of the grid for the users at all voltages/locations	Open platform (grid infrastructure) for EV recharge purposes	Consumption/injection data and price signals by different means	
Benefits				
Increased sustainability				4
Quantified reduction of carbon emissions	1	0,5	1	
Environmental impacts of grid infrastructure	KPI		1	
Quantified reduction of accidents and risks		0,5		
Adequate grid connection and access				2
Grid tariffs			1	
Faster innovation against clear standards		1		
Total	1	2	3	

Source: EC Joint Research Centre

ISGAN Annex 1, Task 1: Framework for Assessment

- Objective: Analyze relationships between core features of smart grids and corresponding enabling assets and technologies, evaluated against the motivating drivers



CHALLENGE: Framework must work for developed and emerging economies.

- **The smart grid transformation is a multi-decadal enterprise.**

- **It will require much experimentation and learning by doing (and in many cases, learning by failing).**

- **Countries and regions must determine for themselves which technologies, applications, and services are their priority.**

  One size does not fit all!

- **However, their decisions can be better informed by common (and rigorously tested) frameworks, methodologies, and tools**

- **The development and coordination of these tools internationally is just beginning!**

Questions? Comments? Concerns?

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Backup: ISGAN Upcoming Schedule

- ***10 January 2012***
  ENARD Power Systems Annex Scoping for ISGAN Integration, Stockholm, Sweden
- ***24-26 January 2012***
  Smart Grid Test Bed Networks Workshop (ISGAN / APEC), Washington, DC and Albuquerque, NM, USA
- ***2-3 February 2012***
  Prep Meeting for 3rd Clean Energy Ministerial, Delhi, India
- ***Week of 26 March 2012***
  ISGAN Executive Committee Meeting and Workshop(s), Mexico City, Mexico
- ***24-25 April 2012***
  Third Clean Energy Ministerial London, UK