SMART ENERGY COMMUNITIES:
Insights into its structure and latent business models

Generalitat de Catalunya
Institut Català d'Energia

IREC 10 YEARS
Shaping Energy for a Sustainable Future

eit InnoEnergy
Knowledge Innovation Community

InnoEnergy is supported by the EIT, a body of the European Union

This activity has received funding from the European Institute of Innovation and Technology (EIT). This body of the European Union receives support from the European Union's Horizon 2020 research and innovation programme.

1a edició: Juny 2019.

Editada per:
Institut Català d'Energia

Redacció del document base:
Sr. Xavier Garcia Casals – Institut de Recerca en Energia de Catalunya (IREC).
Sr. Manel Sanmartí – Institut de Recerca en Energia de Catalunya (IREC).
Sr. Jaume Salom – Institut de Recerca en Energia de Catalunya (IREC).

Versió electrònica:
icaen.gencat.cat/publicacions/

Contents

1 Abbreviations 5
2 Introduction 8
2.1 Goal 9
2.2 Scope 10
2.2.1 Geographical 10
2.2.2 Scale 10
2.2.3 Existing versus new neighborhoods 11
2.2.4 Energy and GHG footprint 11
2.3 Trustworthiness and citizens engagement 14
2.4 Social dimensions 15
3 What is a Smart Energy Community? The vision 18
3.1 Overview of SECs structure 19
3.2 Citizens empowerment 20
3.3 Trust between stakeholders 21
3.4 Focus on services 22
3.5 Articulation of distributed resources 23
3.6 Efficient 23
3.7 RES-based 24
3.8 Flexibility 26
3.9 Integration 28
3.10 Governance 29
3.11 Planning 30
3.12 Addressing full social dimension of energy use 32
3.13 Smartness 33
4 Why SECs? The drivers 33
4.1 Transition requirements 33
4.2 Minimize and limit the impact from stranded assets 40
4.3 Limit energy costs 41
4.4 DER integration 45
5 System blocks for SECs 47
5.1 Digitalization 48
5.2 Aggregation 49

5.3 Demand Response ... 52
5.4 Energy Efficiency ... 56
5.5 Onsite and offsite RES generation ... 63
5.6 Distributed Storage ... 65
5.7 Energy system integration ... 67
5.7.1 Transport electrification ... 68
5.7.2 Building services electrification ... 70
5.7.3 Hydrogen and synfuels ... 73
5.8 Energy infrastructures ... 75
5.8.1 Smart meters ... 75
5.8.2 Power distribution network ... 77
5.8.3 District heating & cooling ... 78
5.8.4 EV charging infrastructure ... 79
5.8.5 NG network ... 80
5.9 Virtual power plants for generation and regulation ... 81
6 SEC stakeholders and their interactions ... 82
7 Enabling elements for SECs: Overcoming the barriers ... 84
7.1 Redesigning Regulation ... 84
7.2 Deploying enabling infrastructure ... 90
7.3 Redefining customer experience and role ... 91
7.4 Embracing new business models ... 92
7.5 Markets ... 93
7.5.1 Capacity ... 98
7.5.2 Demand response ... 100
8 Business models ... 102
8.1 Basic vs value-added services ... 103
8.2 Utilities vs third-party providers ... 105
8.3 Sharing economy ... 106
8.4 Revenue streams ... 107
8.4.1 Energy Management ... 107
8.4.2 EE as capacity expansion ... 107
8.4.3 DR as flexibility service ... 108
8.4.4 DS as flexibility service ... 108

8.4.5 DG as generation and integration service ... 109
8.4.6 Offsite community RES generation ... 109
8.4.7 Energy services provider ... 109
8.4.8 Mobility services and its energy integration ... 110
8.4.9 Local social welfare ... 111
8.4.10 Transition responsibility articulation ... 111
8.4.11 Fair transition management ... 112
8.5 Case example: Flexibility from HPs ... 113
9 Roadmaps ... 118
10 References ... 126
11 Annexes ... 133
11.1 RES for SEC: technologies and costs ... 133
11.2 Storage for SEC: technologies and costs ... 147
11.3 EVs & charging infrastructure ... 169
11.4 DR and aggregation ... 171
11.4.1 Iberia (Spain & Portugal) ... 182
11.5 Smart Grid & smartness ... 184
11.6 Services for SECs ... 188
11.6.1 SEC audit ... 188

1 Abbreviations

A-CAES	Adiabatic Compressed Air Energy Storage
AEC	Alkaline Water Electrolisis
AHU	Air Handling Unit
AMI	Advanced Metering Infrastructure
B	Biomass
BoS	Balance of System
BAU	Business as usual
BM	Business model
BMS	Building Management System
BRP	Balancing Responsible Party
CAES	Compressed Air Energy Storage
CAGR	Compound Annual Growth Rate
CCGT	Combined Cycle Gas Turbine
CAPEX	Capital Expenses
CF	Capacity Factor
CHP	Combined Heat and Power
COP	Conference of the Parties to the UNFCCC / Coefficient of Performance (HP)
CSA	Community Sustained Agriculture
CSP	Concentrating Solar Power
D-CAES	Diabatic Compressed Air energy Storage
DEM	Distributed Energy Management
DER	Distributed Energy Resources (DG, DS, DR,…)
DG	Distributed generation
DH	District Heating
DHC	District Heating and Cooling
DHW	Domestic Hot Water
DR	Demand response
DS	Distributed storage
DSF	Demand Side Flexibility
DSM	Demand Side Management
DSO	Distribution System Operator
EDLC	Electric Double-Layer Capacitors
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EF	Energy Flexibility
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FC	Fuel Cell
FF	Fossil Fuels
FFR	Fast Frequency Response
GDP	Gross Development Product
GHG	Greenhouse Gases
HHV	High Heating Value
HP	Heat Pump
HVAC	Heating, Ventilating and Air Conditioning

ICE	Internal Combustion Engine
ICT	Information and Communication Technologies
IEA	International Energy Agency
IoT	Internet of Things
IREC	Catalonia Institute for Energy Research
IRENA	International Renewable Energy Agency
LAES	Liquid Air Energy Storage
LCOE	Levelized Cost of Energy
LCOSE	Levelized Cost of Stored Energy
LED	Light Emitting Diode
mCHP	micro CHP
MPC	Model Predictive Control
MPP	Maximum Power Point
M&V	Measurement and Verification
NDC	Nationally Determined Contributions (under Paris Agreement)
NWA	Non-Wires Alternatives
NZEB	Net Zero Energy Building
nZEB	nearly Zero Energy Building
NG	Natural Gas
NZEC	Net Zero Energy Community
O&M	Operation and Maintenance
OPEX	Operation Expenses
PBR	Performance-based regulation
PCM	Phase Change Material
PEC	Plus Energy Community
PEM	Proton Exchange Membrane (electrolysis)
PES	Primary Energy Savings
PHS	Pumped Hydropower Storage
PPA	Power Purchase Agreements
P2G	Power to Gas
P2L	Power to Liquid
P2X	Power to Gas or Liquid
PV	Photovoltaics
RBC	Rule Based Control
RES	Renewable Energy Sources
RoCoF	Rate of Change of Frequency
SC	Space cooling
SCOE	Social Cost of Electricity
SEC	Smart Energy Community
SEM	Smart Energy Management
SDG	Sustainable Development Goal
SIR	Synchronous Inertial Response
SH	Space heating
SM	Smart Meter
SMES	Superconducting Magnetic Energy Storage
SNSP	System Non Synchronous Penetration
SO	System Operator
SOEC	Solid Oxide Electrolyzer Cell

SOFC	Solid Oxide Fuel Cell
ST	Solar Thermal
TES	Thermal Energy Storage
TRL	Technology Readiness Level
TSM	Thermochemical Storage Material
TSO	Transmission System Operator
UNFCCC	United Nations Framework Convention on Climate Change
UTES	Underground Thermal Energy Storage
VAS	Value-Added Services
VPP	Virtual Power Plant
V2G	Vehicle to grid
V2H	Vehicle to Home
V2L	Vehicle to Load
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VRES	Variable Renewable Energy Sources (wind and PV)
WACC	Weighted Average Cost of Capital

2 Introduction

The transition towards a sustainable socio-economic system is a must, and the alignment with the environmental boundary conditions (climate change) has introduced a very strong evidence of urgency[1] on effectively undertaking this transition and deploying high enough transition rates as for completing it within the following decades.

The required transition is not small potatoes. Fundamental and deep changes need to be introduced throughout our systems and structures. Talking about the energy system, the transition requires a full and radical transformation of it, from the very technologies used to generate and regulate final energy supply, to the markets and BMs used to articulate the economic interactions between the different stakeholders, and putting completely upside-down its current structure by bringing the demand side of it to an empowered governing position for its definition and operation.

And tough astonishing as it may seem, as a society we and our institutions still seem far from internalizing how urgent the transition is: At the current level of GHG emissions the available carbon budget to have a minimally acceptable[2] likelihood to stay within a 1.5ºC global warming would be completely exhausted, as we write now at beginning 2018, in just three years! (CarbonBrief, 2017) That is, by 2021 we will already have exhausted the available carbon budget unless we manage to articulate a very deep and fast transition right now.

Articulating such a radical transition in the relatively short available periods provided by the current environmental boundary conditions it is a monumental challenge[3], tough still feasible, but it requires effectively addressing structural changes in our socio-economic systems (Garcia-Casals X., 2017b).

This kind of transition won't be top-down driven, as the evidence of already several decades of institutional climate negotiations with extremely limited effective impact has already shown us. In fact, several of the required structural changes to underpin the transition clearly favor a bottom-up driven transition, and is just here where SEC become a fundamental transition cornerstone.

---

[1] *Alignment with other socio-political-economical boundary conditions is also becoming really urgent, but the perception of this urgency is less evident than that imposed by the overwhelming evidence of climate change impact on the very physical environment where we live and where our socio-economic system strives.*

[2] *66% likelihood, which for any other socio-economic activity (like a loan concession by a bank for example) is still an extremely low likelihood that would not support undertaking this action.*

3 *The absolute lack of effective climate action during the last decades has brought about a very tight situation where almost the entire available carbon budget for avoiding unlocking high impact climate change has already been used.*

In fact, in spite of still as of today assisting to national level retrograde climate change political action[4], we are already assisting to bottom-up disruptive action undertaken at city level, like the recent announcement by New York city of its divestment form FF companies and its filing of a lawsuit against five oil majors (Klein N., 2018). SECs complement this city-level financial and judicial transition line of action by articulating and materializing the required alternative to build from bottom-up the transition energy system.

The three components of the SEC name deserve some preliminary mention:

- Smart:
    - Smartness deployment is a fundamental component from the pursued transition, and it goes far beyond 'smart' technology gadgets, to fully embrace a context where interactions between the different stakeholders are enabled by available technology but driven and defined by the kind of intrinsic smartness that allows unlocking the full evolution potential. Therefore, besides smart technology gadgets and the IoT, smartness involves regulation, markets, BMs, governance, consciousness and involvement.
- Energy:
    - The focus of our analysis is the energy system, which constitutes a very important component of the required structural transformation. However, the transition needs to go beyond the energy system itself, which becomes evident by the explicit interconnections between the energy and economic system when the adequate BMs are explored.
- Community:
    - The community level is the appropriate starting point to articulate the bottom-up energy system transition. Close to the available DER and with the capacity to weave the appropriate stakeholder interactions, providing simultaneously prosumers governance and appropriate aggregation levels to interact with the energy infrastructure and to put in value the potential from local synergies.

2.1 Goal

The scope of this report is to dive into the SEC concept to gain insight into its structure and explore the latent BMs that can contribute to the SECs deployment within a transition context.

4 *Like in the USA and Spain.*

2.2 Scope

2.2.1 Geographical

The report is mainly focused on Iberia, tough many of the concepts are universally applicable and existing preliminary experiences are more often found outside Iberia.

The report's scope is primary urban, where most of the population in Iberia lives as a result of last decades demographic migration trends. Also is in urban areas, more densely populated, where energy networks and aggregation of consumer's participation into the energy system operation has its biggest potential. However, most of the SCE concepts herewith addressed are also applicable to most of Iberia's rural areas.

2.2.2 Scale

We consider the neighborhood as an adequate community scale providing balance between two opposing trends:

- Big enough to reach some economies of scale[5] and synergies (efficiency deployment, flexibility, integration,…) and significant aggregation size[6].
- Small enough to provide governance in distributed resources and to foster communities' involvement.

Still there will be instances that require to go beyond the neighborhood boundaries up to the city scale in order to enable the associated business models (like with mobility services).

But in general terms, the neighborhood scale fits very well with the smartness imperative of exploiting all the potential from collaborative approaches, and we can appreciate how this trend is already advancing along the different transition fronts. For instance, when focusing on buildings, the current trend is to transcend the energy and flexibility performance of a single building and start considering the aggregated performance from a cluster of buildings (Pernetti R., et. al., 2017), since aggregation articulates synergies and discloses a significantly higher potential for smart interaction.

5 *In (A. Manyes, et al., 2013) these potential economies of scale, tough not quantified, are already pointed out as a means to overcome the barriers that prevent the deployment of ESCO BMs to* **tackle the energy** *refurbishment of the built environment. A case study for Santa Coloma de Gramanet (Barcelona) is presented in this reference.*
6 *The neighbourhood scale easily goes beyond the MW size which allows for an efficient integration into energy and regulation markets. Current regulation also points at this scale for enabling efficient integration of DER into the system.*

2.2.3 Existing versus new neighborhoods

Tough new neighborhoods development provides more degrees of freedom with regard to the potential deployment from some of the transition dimensions, like EE in the building stock, DER integration, and transition-friendly energy infrastructure, the fact is that new neighborhoods will constitute in Iberia a tiny fraction of the whole urban environment, and therefore the main transition target are existing neighborhoods.

However, with regard to the SEC concept and articulation, most of what we'll address in this report is fully applicable to both existing and new neighborhoods, the only difference being that in a new development the portfolio of potential 'hardware' actions[7] is more diverse and some of these actions can be deployed more straightforward. But with regard to the more 'software' transition components, like everything that has to do with smartness deployment and BMs, both situations are much alike.

In fact, one of the main differences between an existing and new neighbourhood is associated to the articulation of social participation. In a new development, no specific prosumers are still linked to it, so that planning and decisions are taken from a top-down approach just setting most of the context that future community prosumers will have to adhere to. On the other hand, articulating a SEC apparently involves a far more sociologically involved process, since planning and decision making has to be community based from the very onset, and deep governance has to be embedded in the process. Therefore, from this perspective a SEC seems far easier to implement in a new than in an existing neighbourhood. However this is a false impression, since the essence of a SEC is by far more closely linked to empowerment and governance than to specific hardware, and in the planning and execution process of a new neighbourhood, tough the deployed hardware can certainly be far more fit for the transition, but all the sociological work is completely pending until later phases when people go actually living and working in this neighbourhood, and in fact even latter than this point in time, because building community links takes a significant amount of time.

In this sense, we could say that working with existing communities, not only addresses the main share of the transition, but also allows starting to build resilience from the very onset, with resilience being one of the main SEC attributes.

2.2.4 Energy and GHG footprint

The starting point in sustainable community planning is to evaluate the communities' energy and GHG emissions overall footprint, and from there to decide the portion of the

7 Like EE actions in the built environment and EVs infrastructure deployment.

footprint assumed within the targeted scope and to explore the mitigation options to deploy.

The footprint from an urban community expands significantly beyond the most obvious component, which is the operational energy consumption from its buildings and public services, since all the society's economic activity gravitates around supplying services and products to the communities' inhabitants. An important smartness component from a SEC is to get awareness of the overall community footprint and explore the means for a full mitigation.

Indeed, often just a portion (usually that which is regulated) of the building's operational energy is perceived as the urban community footprint, and we go to the extreme of talking about NZEB when we manage to mitigate this part of the footprint, while in fact that is a relatively small portion from the overall communities' footprint. Indeed, to the regulated building's operational energy (HVAC, DHW) we should add the rest[8] of the building's operational energy (plug electric loads and lighting) and the building's embodied energy to get the overall energy footprint from buildings, and to that we should add up the energy implications from the rest of services with energy implications enjoyed by the community members (transport, food production, public services[9], infrastructure and industry).

Figure 1 presents the results from an overall final energy footprint evaluation for sustainable urban developments in Denmark planned in years 2010 and 2011. Although both cases are associated to sustainable urban planning exercises, the targeted footprint portions of the corresponding benchmark conditions differ, which leads to different structures of the final 'efficient' neighborhood overall final energy footprints. We can appreciate in this figure how even in neighborhoods planned under sustainability criteria and incorporating NZEB[10], the remaining of the community energy footprint keeps on being very significant, and requires an important mitigation effort to neutralize its associated GHG emissions footprint.

8 Which for efficient buildings tends to be the dominant part.
9 These are also often captured under the neighborhood's conventional energy footprint (public illumination, water supply and treatment,…)
10 Or nearly NZEB.

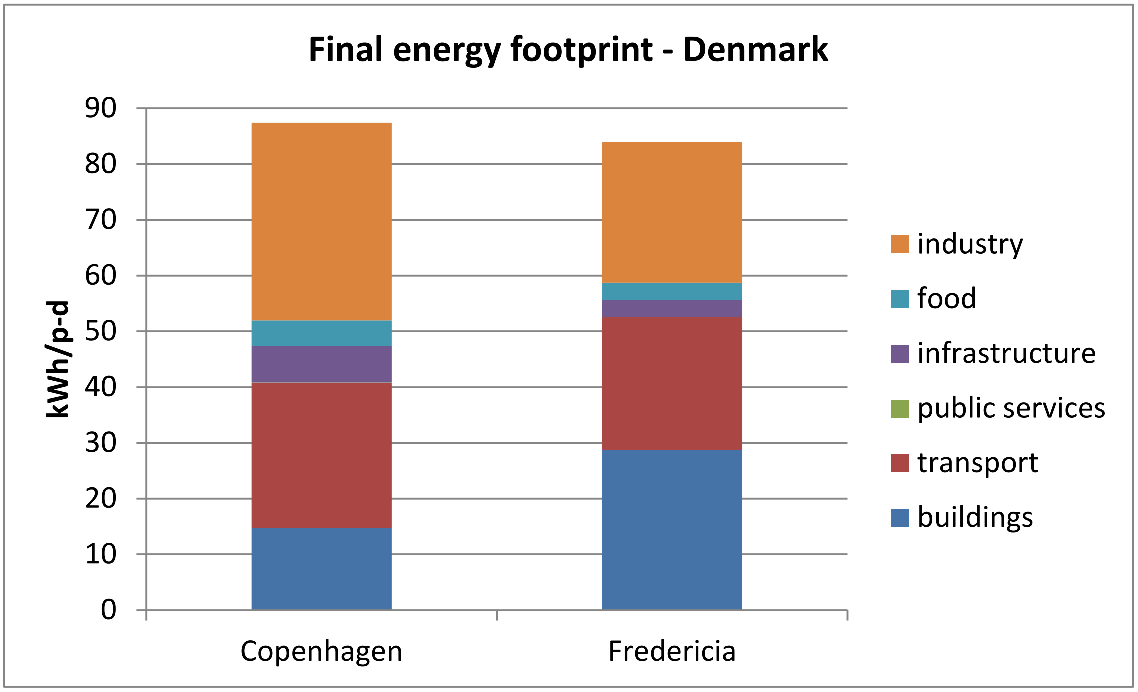


Figure 1: Per capita total final energy footprint from sustainable neighbourhood urban developments planned in Denmark the years 2010 and 2011. The different categories include both operational and embodied energy. Under 'food' just the production component is presented, with the rest of food associated energy consumption (packaging, post processing,…) being included under industry and transport. Public services makes reference to public lighting, water supply and sewerage. (Garcia-Casals, X., 2017a)

Full smartness requires awareness, visibility and mitigation of the overall communities' footprint, which still gets more magnified when equity and fair transition global considerations are included (see §8.4.11). Still it is a common practice that sustainable urban planning only targets that part of the overall scope more easily influenced by urban planning and managing. However, the balance of the footprint not targeted for direct on-site improvement should be mitigated through off-site action.

We should highlight here that tough the GHG footprint could be reduced to zero through RES deployment, even without attempting to reduce the associated energy footprint, this approach, besides becoming a very expensive energy transition, would still lead to a high requirement for the resources extraction required for RES equipment manufacturing, and its associated socio-economic and environmental impacts. Therefore the reduction of the energy footprint is also a goal from a SEC.

The scope of this report is limited to the following portions of the neighborhood's overall footprint:

- Residential buildings energy services
- Commercial buildings energy services
- Public services (city infrastructure)

- Passengers city transport
- Freight city transport

Other parts of the overall footprint could be addressed by different or the same strategies and business models, but are not herewith considered in detail.

One of the footprint dimensions not addressed in this report but with a significant impact on the overall community footprint is food production and consumption. Initiatives like CSAs are already flourishing to address in a distributed manner part of this footprint's dimension.

2.3 Trustworthiness and citizens engagement

The way utilities and electricity retailers have run their electricity supply BMs up till now, often imposing their unilateral terms and ways to provide electricity as a commodity, and disregarding any effective participation of customers in the definition and operation of the electricity system, not only is at the complete opposite extreme of the governance that a SEC requires, but also has led to very low levels of social trust.

Under this context utilities and electricity retailers face a huge challenge to recover the social trust that would enable them to be a part of the SEC puzzle.

Indeed, the same technology that enables DG, DS DR and SEM in the distribution network also enables grid defection[11]. In fact the future trend for electrification in huge parts of the world to reach the energy access SDG, mainly driven by economic arguments, is based on stand-alone and micro grid electricity systems not connected to a centralized distribution and transport networks. Therefore grid defection is becoming an option in the global North, where distribution and transport infrastructure already exist.

Existing distribution and transmission grids are valuable assets which offer technological flexibility to facilitate the transition and integration potential. However, system governance and citizen's empowerment are stronger transition components. Unless current utilities and retailers are able to actively evolve bringing their BMs into the shared economy sphere, providing meaningful added-value services, contributing to empower customers and regaining social trust, a tend towards grid defection could be initiated producing stranded distribution and transmission assets.

The rules of the game are changing and the captive customer context is over, requiring an active role of current utilities and retailers to convince that they can become appropriate active elements of SECs.

---

[11] Grid defection means that a consumer or group of consumers disconnect themselves from the main grid, and self-generate the required electricity to satisfy its demand through a stand-alone energy system or micro grid.

We should note that although citizen's grid defection is nowadays a very real[12] alternative evolution pathway enabled by the technology currently becoming available (low cost RES-based DG, DS, EM,…), and stimulated by historic utilities and retailers low track record in social performance and fair treatment of customers, it does not seem to be the socio-economic optimal transition pathway. Grid connectivity can provide important additional flexibility elements when smartly planned and managed, facilitating a faster overall society's access to the transition, and when aiming to go beyond current electric loads[13] grid connectivity could allow reaping all the benefits from energy system integration. Indeed, covering the integrated overall (ie, including for instance transport with EVs) energy needs from a household with a rooftop grid isolated PV system with storage, besides being very expensive (and therefore socially exclusive) it seems to be far away from a techno-economical optimal transition solution, which by itself implies a rather limited smartness deployment.

Therefore, when we talk about SECs we assume that the 'S' from 'Smart' also extends to business smartness and socio-techno-economical smartness, which by default[14] seeks to get all the transition benefits from grid connectivity and all the shared economy benefits that can be enabled by it.

2.4 Social dimensions

The reduction of the energy and GHG emissions footprints are two important social contributions of SECs:

- The reduction of the energy footprint minimizes the resources used by the society to provide its energy services, and therefore the environmental and distributive impacts associated to the extraction of these resources.

---

[12] For instance in Australia, the combination of very opaque utilities' economic management, very high electricity retail tariffs, and increasing availability of low cost DG (PV) and DS, is incentivizing grid defection under the current context, where current electricity loads can be satisfied at lower cost and without having to put up with the nuisance to deal with utilities and retailers without a connection to the distribution grid. Also in Spain, the current trends to tax behind the meter RES generation, and to increase the fixed or power fraction from the retail tariff (therefore increasing the overall kWh cost) without acknowledging the value from the services that the customer can provide to the system with its contracted capacity, together with the very low social track record from utilities, is also setting the scene for grid defection.

[13] Which certainly could in the near future often be economically covered even while being isolated from the grid.

[14] Under specific contexts and circumstances, often found in other parts of the world where T&D grids are not as developed as in Iberia, main grid isolated solutions based on micro grids (with a potential evolution towards higher connectivity contexts) are likely to be the optimum transition pathway.

- The reduction of the GHG emissions footprint contributes to mitigate climate change and reduce the huge socio-economic impacts (both within and beyond the community physical boundaries) that would be associated to it if we continue along a BAU pathway.

But beyond today's contribution to energy and GHG footprints there are additional components from the social dimension that should be addressed by SECs:

- Co-benefits
- Historic responsibilities for a global fair transition.

Co-benefits make reference to those additional local community benefits beyond the reduction of plain energy costs. As part of its smartness attribute, SECs should strive to acknowledge, provide visibility and reap all these benefits, which often, once internalized, also bring about its associated positive economic impact. A clear co-benefits illustration is the implications of buildings' energy refurbishment beyond its obvious EE impact in reducing operational energy costs. Indeed, community buildings' energy refurbishment, besides its EE impact in reducing demand and peak loads, and therefore reducing both community's energy operational costs and utility's grid and generation infrastructure costs, also provides additional social benefits and their associated economic savings, like the reduction of sanitary, medicine and labor costs associated to the improvement in the building's thermal comfort conditions. In (Ortiz J., Salom J., 2016) IREC shows how even under very conservative assumptions, building's energy refurbishment payback times are reduced to less than half its current conventional value by capturing within the economic analysis other costs (sanitary, medicine and labor costs) beyond direct energy savings and EE investment costs.

Other local co-benefits associated to SECs deployment are:

- Air quality improvement, both locally because of the reduction in pollutant distributed energy conversion technologies (ICEs, boilers,…), and beyond the community physical boundaries because of the reduction of centralized electricity generation facilities or their operational requirements. This air quality improvement has a direct effect on wellbeing and health, as well as its associated economic impact.
- Noise quality improvement. At urban community level, mainly associated to the substitution of ICE vehicles by EV vehicles as part of the energy system integration and EE deployment. Noise reduction also has a direct effect on wellbeing and health, with its associated economic impact.
- Congestion, security and use of public spaces. Mainly associated to the implementation of smart mobility services, with its very strong reduction of the number of vehicles in the public transport infrastructure, as a direct consequence of the shift from individually-owned and inefficiently-operated to collectively-owned and efficiently-operated vehicles. Indeed, the very sharp increases in vehicle occupancy and utilization factor when moving from individually-owned to

collectively-owned and smartly operated vehicles, bring about a reduction of one order of magnitude in the vehicles occupying and moving through the community's public transport infrastructure, which has a proportional impact on the congestion reduction, vial security improvement and increase in the availability for public spaces. All these directly speak of an improvement in the wellbeing and have positive associated economic impacts.

- Reduction of the burden, space requirements and inefficient economic costs associated to private ownership of extremely inefficiently used transport vehicles, which is brought about by the deployment of smart mobility services.
- Dramatic reduction of traffic accidents and increase of urban security for all, recovering the use of public spaces for people[15]. Smart transport systems – by directly addressing mobility service demand with flexible, safe, and optimized resources –, drastically reduce the amount of vehicles circulating through the community, and increases its vial security level.
- Reduction of the social, political and environmental impacts beyond the community physical boundaries, associated to the extraction of resources needed to cover the community's energy demand.
- Smart articulation of local resources (energy, materials, work capacity, …), aiming to reinforce the circular economy and optimize material and resources flow from and to the community.

It is important to note that although the bottom-up community based transition approach is the only one that provides chances to tackle the global challenges, a SEC won't be of any use by itself if the global transition does not come to a good end, and therefore it is of paramount importance to articulate the means to materialize an effective contribution of the community members to their share in historic responsibilities and fair transition.

Even when there is a wish from a community's individuals to contribute their fair share to the transition, two barriers often exists that prevent materializing this potential:

- Lack of an adequate and effective channels to articulate these contributions
- Lack of a clear social accountability providing visibility of individual contributions

These are all additional services that could be offered by the entities implementing SEC business models, providing significant additional value, so that customer's engagement in the overall business model could be facilitated.

[15] *Instead of being mainly devoted to vehicles.*

3 What is a Smart Energy Community? The vision

The energy system is bound to undergo a fundamental evolution, which is clearly illustrated by the evolution of the power system, which is called to become the backbone from the overall energy system. Power systems are already evolving from FF-based centralized up-down non-integrated systems, towards RES-based decentralized bottom-up integrated systems with much higher diversity and size, and bidirectional information, economic and energy flows (Figure 2).

SECs are called to become a cornerstone to articulate and facilitate this transition.

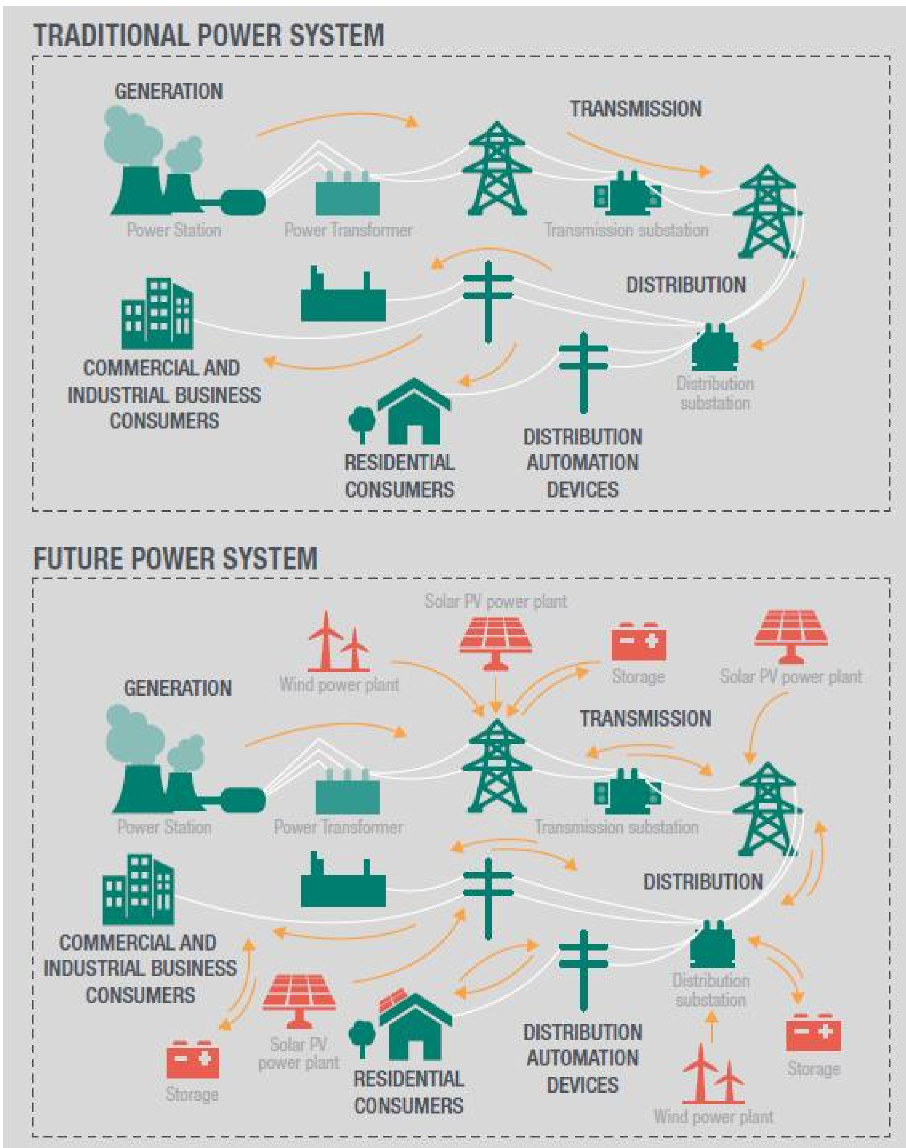


Figure 2: A traditional, centralised power system and a future, lower-carbon, decentralised power system (van der Burg L., Whitley S., 2016)

3.1 Overview of SECs structure

The SEC integrates, aggregates and coordinates distributed energy services users and providers at neighborhood level, facilitating the full and direct involvement of citizens in the configuration and operation of the energy system, and enabling the flow of smartness in such a way that the full potential from DER can be reaped for the shared benefit of the community and the rest of the energy system.

The SEC positions the citizen at the center of the energy system, and articulating a network of smart links builds a bottom-up energy system structure with full social governance and the capability to materialize the transition towards sustainability by enabling the full potential from DER.

The SEC facilitates the full and effective flow of information between the community and the rest of the energy system, articulating citizens' energy system governance, and allowing for the proper allocation of resources from the different stakeholders (consumers, prosumers, utilities, third party providers,…) in the configuration and operation of the energy system. Therefore adequate and coordinated decisions can be taken about energy system investments, optimally allocating the DER (DG, DS, DR, EE) and its ownership structure, facilitating the means for the participation from all the community members, and optimizing its operation.

In the planning dimension the SEC facilitates that:

- Prosumers (DG, DS, DR and EE) and consumers (DR, EE) get the right information to decide on their behind-the-meter investments, taking into consideration their own needs and responsibilities, the community needs, the network needs and the beyond-the-community energy system needs and possibilities (articulated through energy markets).
- Consumers get informed options to participate on beyond-the-meter community owned DG and DS, which can be placed on-site within the community or off-site beyond-the-community depending on the optimal techno-economic conditions taking into account the community and energy system contexts.
- Utilities, retailers and third-service providers receive information that allows them to get insight about their appropriate energy system investments (both at community and beyond-the community levels), the aggregate demand for services and the aggregated and coordinated offer of services to participate in the energy system planning (DG, DS, DR, EE).

In the operational dimension the SEC facilitates that:

- Prosumers and consumers get access to smart DEM, allowing for the optimization of both behind-the-meter and community EM, enabling the full potential of their bidirectional interaction with the energy system.
- The aggregation at community level produces a nodal VPP that facilitates the DER integration into the energy system, as well as reaping the full potential from energy system integration by allowing the complete incorporation of EVs into the local DER resources, and optimizing its interaction with the rest of the energy system (V2G).

In the social dimension the SEC facilitates that:

- Full coverage of community level energy co-benefits (health, energy poverty,…) is achieved, optimally distributing resources to maximize the social benefit of EE deployment and guaranteeing minimum levels of energy services demand coverage.
- The articulation of the community members co-responsibility on a global fair transition, through an efficient implementation of the mitigation compensation concept (see §8.4.11).

3.2 Citizens empowerment

The supply of energy services is one of the dimensions from our socio-economic system with higher environmental and economic footprint.

Effectively addressing current global challenges like climate change requires articulating structural changes on how socio-economic systems address the supply of energy services, evolving from the current context with corporate energy supply structures and passive consumers, where BMs gravitate around the supply of energy units disconnected from the energy services they are supposed to fulfil (and therefore without any driver for EE), in a top-down structure where consumer's role is limited to paying their bills. This top-down commodity structure for the energy system was the easiest to articulate from a corporate point of view, but it's extremely inefficient and has a huge room for improvement by deploying smartness through the energy system.

Realizing that the final goal are not the energy units itself but the energy services, and that citizens are not an outlying element from the energy system but a central part of it, discloses a huge potential for improvement through the articulation of these structural changes into the energy system.

However, accessing this huge potential for improvement requires the articulation of effective governance, empowering citizens in such a way that their contributions can be fully integrated in the energy system planning, deployment and operation, materializing a shared economy context where benefits from these improvements can be fairly shared between all the stakeholders with full acknowledgement of its social share.

SECs provide the means for an adequate articulation of this bottom-up energy system architecture, facilitating the distributed governance and direct involvement that allows accessing the full potential of smartness deployment.

In a SEC, citizens fully participate into the definition, configuration and operation of the energy system, exploiting the full potential of DER (DG, DS, DR,…), and sharing the benefits of effective DER articulation with the rest of energy system stakeholders. Their aggregation at community level brings them to a VPP level that allows for an efficient participation in the overall energy system while maximizing their DEM in such a way that the local use of DER is optimized and the SEC's net requirements on the rest of the energy system are minimized: The community's behind the (communal) meter needs are minimized while maximizing the beyond the (communal) meter services it can provide to the energy system.

3.3 Trust between stakeholders

Solar leasing companies routinely enter into 20-year contracts with customers, whereas demand response companies rely on customer participation during demand response events. The success of these BMs rests firmly on the ability of these providers to maintain good, long-term relationships with their customers.

In general terms, articulating the full potential for transition structural changes, reaching full active involvement and integration of prosumers in the energy system operation, and unlocking all the DER capabilities, requires building relationships between the different stakeholders based on trust and clear open accountability.

But basing relationships in trust is by itself a big structural change, moreover within the energy sector where the track record of the relationship between utilities, retailers and big energy companies with their customers has often followed a pattern of maximizing corporate benefits, not paying much attention to end customers, and externalizing as many costs as possible for the society to take care about them later on[16]. Electricity market liberalization in Europe has introduced some changes based on competitiveness between retailers, but still the relationship they stablish with customers has more of a commercial empty shell than anything close to be based on building trust.

The situation with regard to the lack of trust is much the same with other stakeholders like politicians and regulators. In Spain this has been felt quite strongly along the last decade,

[16] *That's just what we are trying to fix now…*

when after getting the RES deployment started off, retroactive regulatory changes and aggressive position from politicians defending corporate interests have let consumers and prosumers down, people that had invested in DG RES believing that in that way they were providing their contribution to the s much needed energy system transition. Still as of today, DG behind-the-meter is persecuted with the so called ‘taxes to the sun’, and there is no mechanism at all for articulating the participation of consumers in the energy system operation through DR or DS.

This damaged trust landscape is a very important transition barrier, and the community level (through the SEC concept) is likely to be the most adequate level to start rebuilding it, though the other stakeholders also have to evolve away from the only-corporate-benefit-at-whatever-social-cost attitude towards the socially responsible paradigm in a very clear and noticeable way if the full transition potential is to be materialized.

3.4 Focus on services

In the current top-down energy system structure the focus is on corporations selling energy to consumers (unidirectional interaction), with all the BMs and investment decisions revolving around this. In this context it is no strange that EE or behind-the-meter DG are having a very hard time to find its way, with lots of barriers on their way, since anything that would reduce energy consumption (as EE and behind-the-meter DG do), would undermine corporate energy BMs by reducing its incomes and benefits.

Still, energy units (like electricity kWh, petrol liters or NG cubic meters) are by themselves of no use to consumers. Therefore consumers, after buying the energy units from its corporate energy suppliers have to invest themselves in energy conversion infrastructure to convert these energy units into the ultimate energy service they seek, very often by using extremely inefficient equipment, like the ICE in extremely underused personally-owned vehicles to cover their mobility demand in extremely congested transport infrastructure.

All these cumulative inefficiencies positively feed the GDP used as main indicator to measure the economy’s evolution, which reinforces this perverse scheme forcing to sell still more energy units, as much as possible, even if this is killing the real social economy through local pollution, global climate change and many other social and environmental impacts.

All this directly speaks to an extremely lack of smartness deployment through the energy system, and therefore through the socio-economic system supported by it.

In a SEC the focus is shifted from energy to services, which are the ultimate product that consumers demand, and bi-directionality is introduced in the services supply, with citizens both consuming services and providing services to the rest of the energy system.

By focusing on services a huge untapped potential for EE is articulated, aligning EE with the economic drivers, since in this context the most successful BM will be that which supplies the same service with less energy requirements. Indeed, under this context, energy moves from being the ultimate tradable product to being a production input for the services provider, and therefore the more efficiently that it can produce, the higher the benefit margin for a given service price.

Many services can be offered under this context (see §8.4), with added-value services gaining momentum under SEC MBs, but the two that directly map the currently dominant energy and emissions related BMs at community level (energy supply and transport) are the following ones:

- Building energy services
- Mobility services

3.5 Articulation of distributed resources

SECs provide the means to smartly and efficiently articulate the DER (DG, DS, DR,…), introducing a meaningful scale of smart DEM through the aggregation of grid-edge technologies with citizen's governance.

Local integration of RES DG, supported by the on-site flexibility provided by DS and DR, allow for an efficient extension of the consumer's behind the meter concept to the community level, increasing the self-consumption at community level by locally sharing the DG, DS and DR resources through the local distribution grid or micro grid, and significantly alleviating the 'beyond the community' grid requirements.

Therefore, considering a virtual or physical meter at community level, with a SEC one reaches a very powerful behind the meter concept with significantly higher self-consumption levels from those achievable at individual consumer scale, and at significantly lower costs thanks to the articulation of shared economy elements. Moreover, the aggregation at SEC level provides the means to constitute a VPP with capability to provide regulation and ancillary services to the rest of the power system.

3.6 Efficient

EE is a transition cornerstone with the potential when deployed in a smart context to reduce final energy demand from the diffuse sectors (buildings & transport) down to a 20% of their BAU value (Garcia-Casals X., 2011).

A SEC enables and facilitates smart EE deployment by providing an adequate aggregation and management level that facilitates individual prosumer involvement.

Indeed, not only can the community level significantly reduce the costs of EE deployment by the involved economies of scale and synergies, but it also allows making a business case for EE deployment by its participation in different markets (for instance capacity markets) through its aggregation.

One social issue with EE measures is that they have significantly less visibility than other transition contributions: Indeed, having a PV rooftop installed at your place has up till now looked far more cool than insulating your façade, and no need to mention the comparison with having your EV charging at home. However, the potential contribution from EE can be far more important to the transition than rooftop PV or individually owned EVs, since for the cooler actions there are in fact even better alternatives from a transition point of view, and nothing else can substitute the EE deployment. Moreover, almost each one of us can participate in the EE deployment, while only few can install PV in their rooftop or have an own EV, hence the potential impact from EE deployment is significantly higher, both with regard to its cumulative effect into the energy system and with regard to citizens empowerment.

The SEC also allows providing a clear visibility of EE actions, putting them side by side with other transition actions by keeping a clear social accountability of community member's involvement.

Still, a SEC looks for the optimum balance between EE deployment and other transition contributions, like EF and RES deployment.

3.7 RES-based

The transition energy system is a RES-based energy system, and therefore deploying RES through the system and facilitating its integration is one of the main SEC pillars.

Communities have the capability to become frontrunners and catalyzers of RES deployment.

As of today the means are already available for a community to offset its entire final energy footprint with RES generation. We already see that approach followed with the targeted share of the final energy footprint in several new urban developments in Europe. But the same can also be articulated in already existing communities.

In fact, along the last years we are seeing pledges from cities all around the world to transition towards a 100% RES supply along the following years to decades (Bringault A., et al, 2016), (ICLEI, 2018), (Go 100% Renewable Energy, 2018), with few of them already having attained their goals (Sierra Club, 2018). Although one has to be cautious with the verification of what these claims really mean, and often they are still far from full transition requirements, but they indicate a clear trend showing that 100% RES-based energy supply is already starting to be felt as feasible at city level.

A SEC is based 100% on RES for the targeted part of its energy footprint, and articulates the means for the RES coverage to go beyond that until covering the whole of the community's energy footprint.

On the one hand, a SEC facilitates the evaluation, quantification, communication and internalization by its members of the targeted and full energy and emissions footprint, and on the other hand facilitates the means for the community as a whole and each community member to offset their emissions footprint through RES-based generation.

Of course, the RES-related SEC goals go far beyond just the offsetting with RES of its emissions footprint, by actively contributing to facilitate the RES integration into the overall energy system through its EF. But still, RES generation constitutes an important component from a SEC.

In fact, a SEC RES-linked generation can go significantly beyond its own current emissions footprint because of the articulation of compensatory mitigation associated to fair transition considerations (see §8.4.10).

However, SEC-linked RES generation does not have to be exclusively on-site generation, because there may be more techno-economic-social efficient and transition aligned ways to cover this RES generation requirement. Indeed, already going from the single building to the neighborhood scale, on site-generation possibilities are significantly widened, avoiding some of the implicit inefficiencies linked to the NZEB or nZEB concepts. But SEC-linked RES generation can also be sited beyond the community physical boundaries, opening the door to unlock synergies with other communities[17] that allow reaching significantly higher overall transition efficiency levels and potentials, which by itself it is already an articulation of the smartness SEC attribute.

Integration is one of the key transition components, and in this context it is important for a SEC to internalize and articulate around the concept that a SEC is nothing by itself[18] but can be everything through its positive and synergic interaction with the rest of the world.

Therefore, in a SEC we'll find both on-site distributed and off-site community-based generation.

---

[17] For instance strengthening the urban-rural links.

[18] Climate change is a strong reminder of this fact: A SEC is not able on its own to avoid climate change and experience its impacts, and can only contribute to avoid it through its synergic interaction with the rest of the world.

3.8 Flexibility

Flexibility is one of the main attributes from a smart energy system, encompassing all the system components from generation to demand and storage.

The SEC is the appropriate scale to unlock the full flexibility potential by accessing and aggregating the capability of DER and its interactions.

The flexibility attribute requirement has been highlighted by the transition itself through the EF needs to operate a power system with increasing shares of VRES.

Indeed, the stiffness from the current energy system structure (non-integrated, disregarding the demand as an active component of the system, and relying exclusively on centralized generation to regulate the system's operation), is completely unable to manage the system as VRES are being introduced through policy and economic drivers. But this fact, far from being an indicator of the unfeasibility of RES-based energy systems, is the simple consequence of the current energy system missing to articulate the EF potential. Smartness deployment seeks to articulate the full EF potential, facilitating VRES integration and leading to an extremely improved energy system.

A smart energy system counts with many different flexibility sources:

- DR: The active participation of demand to operate and regulate the system, with the capability to configure VPP through its aggregation. All energy demand sectors are capable to contribute to DR, but in the SEC context that we are focusing the main components are buildings and transport.
- Storage: With the capability to provide all the system's regulation requirements, from very fast response for SIR and FFR services, to other ancillary services requiring slower regulation. Storage can be articulated through many system components: batteries (static and from vehicles), building's thermal mass and hot/cold water storage, pumping hydro, CSP,…
- Generation. Up till now VRES have been operated at MPP because of the requirement to maximize its production in order to reach economic viability. With this operation strategy the entire regulation burden falls on the rest of the system. However, VRES are capable of operating in other more flexible modes, in such a way that they can provide upwards and downwards regulation services, assuming their share of responsibility on the energy system operation.
- Integration. By integrating different parts from the energy system, not only additional flexibility resources become available (like V2G), but also new options for very high flexibility are unlocked, like the introduction of hydrogen or hydrogen based synthetic fuels to cover the needs from other parts of the energy system not susceptible of being electrified.

The techno-economic optimization from all these flexibility contributions provides the adequate share from each one of them, but what is clear is that there are many tools available for operating a RES-based energy system, and SECs can contribute to articulate a big part of the flexibility required to support the transition.

There is a smart balance between EE and EF deployment, which is now beginning to be acknowledged. Up till now, transition or sustainability efforts have focused mainly on EE deployment[19]. But as we progress along the transition pathway and the different fronts like EE and RES deployment start to interact with each other, the need for a holistic approach and the role from EF on it becomes evident.

Indeed, in order to integrate high RES generation and operate a RES-based energy system limiting its costs, demand needs to take an active role in the energy system management, which means articulating its EF potential. In fact that is precisely what we can call smartness: getting all the parts of the system actively involved and working collaboratively to reach the overall goals. This active involvement providing EF can sometimes conflict with what would be a strict EE approach aiming at the minimisation of energy consumption. But the EF approach can deliver significantly better overall performance than the narrow EE approach. In fact the EE approach focuses on a small part of the overall system without taking into account the interactions between the different system elements, and without explicitly addressing the overall system's goal, implicitly assuming that the local EE goal will automatically contribute to the overall goal, which is not always the case, while the EF approach has a more holistic view searching to optimize the interactions between the different system elements in order to achieve the overall goal.

A typical example to illustrate this point is that of a building, or group of buildings, attempting to provide the comfort service to its occupants. A strict EE approach would implement a control system aiming to continuously stick at the lower end of the space's temperature comfort band. However, this is an approach that does not allow unlocking the flexibility potential from the building stock, and the resulting system stiffness can seriously compromise the capability to operate a RES-based energy system. Indeed, an EF approach would implement a control system that modulates the spaces' temperature set point so that, while always being within the comfort band (and therefore providing the requested comfort service), mobilizes the flexibility associated to the building's thermal inertia in order to respond to the RES generation capabilities: When there is excess RES generation capabilities, in order to avoid RES curtailment, the control system increases the space's temperature set point so that the excess RES generation capacity is stored into the building's structure; on the other hand, when there is RES generation shortage, the control system curtails the energy demand from the HVAC system and allows energy being transferred from the building's structure (the energy accumulated when there was RES excess generation capacity) to the space, therefore contributing to the energy system regulation and allowing a RES-based energy system to supply all the demand.

[19] *Tough without much success on its implementation.*

This same approach can be applied for reaching other goals, like the one of minimizing GHG emissions while the energy system is still not completely RES-based, and therefore having the building's EF contribute to minimize the energy demand on those periods where energy is delivered by CO_2-intensive technologies (Pernetti R. et al, 2017). Indeed, as shown in (Patteeuw D. et. al., 2015) by optimizing both EE and EF in buildings, significantly higher CO_2 emission cuts - around 15% - (and lower societal CO_2-savings costs) could be achieved at community level than when each individual building focuses only on minimizing its energy use, even with an overall higher (3-5%) energy use: Offering EF to the grid might increase the local energy use of a building, but lead to overall reduced CO_2 emissions.

3.9 Integration

Energy system integration is another smartness dimension, since it unlocks a huge efficient transition potential and it provides access to significantly higher transition rates.

Energy system electrification is one of the main means for energy system integration.

The main transition values provided by energy system integration are:

- Facilitates and accelerates the transition from the diffuse sectors (buildings and transport), which up till now are significantly lagging behind in the transition pathway, and compromising the transition itself because of its high GHG emissions weight in the overall energy sector. Indeed, the highest RES penetration rate up till now is that achieved in the power sector, where many RES technologies have already progressed along their learning curves till the point of reaching the doors of economic competitiveness. Electrification of diffuse sectors (through HPs and EVs), besides providing by itself a very important EE improvement, allows these sectors to access the full RES potential from the power sector.
- Unlocks huge amounts of EF through the smart interaction between the different energy sector components. Indeed, one of the main barriers for increasing the RES fraction into the power sector is the lack of EF for regulating a RES-based power system. By integrating the building and transport sector within the power sector through its direct electrification, a whole bunch of EF becomes available to the power sector through elements like building's thermal inertia and V2G interactions. Moreover, when indirect electrification of the portions of the energy system not susceptible of direct electrification[20] is also used as an integration measure, though RES-based hydrogen and synthetic fuels generation, EF is

[20] *Like air transport, marine transport, some industrial applications, and to some extent heavy freight road transport, tough for that last one the first EVs are already becoming available.*

brought to another dimension due to the decoupling achieved by the hydrogen and synfuels energy vectors.

- In a transition context where EE is being deployed, some of the energy infrastructures traditionally deployed in the building sector become redundant, because the final energy footprint becomes dominated by the original electricity services (lighting, appliances, cooling,…) while the other services traditionally satisfied with additional energy infrastructure (like heating and DHW served by NG networks or other FF[21]) are reduced to a small share of the overall energy footprint and can efficiently be satisfied through its electrification[22]. Hence, integration can contribute to minimize the energy infrastructure deployment.

A SEC pursues energy system integration within its boundaries, as well as the best integration of the SEC itself into the overall energy system.

3.10 Governance

The energy system is ultimately meant to provide services to society. However, in the historic and current setup, due to the lack of social capability to provide input for its definition and operation, the energy system has been deployed and managed by corporations, driven by the corporate benefit goal while supplying final energy as a commodity to society.

Under this current setup there is a very important misalignment between social and corporate goals, which ultimately have led to environmental and social limiting constraints. Indeed, corporate management has systematically externalized environmental and social costs, while focusing on maximizing the delivery of energy as a commodity[23] instead of on delivering the services really required by society.

Turning this situation around, so that the energy system provides the services needed by society minimizing social and environmental impacts while accounting for all[24] the social costs, requires fostering and articulating the energy system governance, which is another of the main smartness attributes.

Increasing the energy system governance also favors the active involvement of prosumers in the energy system definition and operation, which is a transition requirement to articulate all the DER potential needed to manage a RES-based energy system, since the centralized top-down approach used by corporate energy system management up to date is not able to cope with this new energy system paradigm.

---

[21] *But also DH or biomass installations.*
[22] *While simultaneously increasing the EF potential.*
[23] *And hence missing any meaningful efficiency driver.*
[24] *No more externalities.*

Therefore, governance and demand side involvement come hand by hand, and a SEC provides the right context and scale for articulating them.

3.11 Planning

The transition we are undertaking means a complete overhaul and restructuring of the current energy system, with changes reaching the structural level to modify the underlying paradigm, and with very short time periods available for successfully completing the transition. Moreover, up till now we as society do have a relatively bad track record on effectively articulating the transition requirements[25]. In this context, it really seems *smart* to foster in-depth and appropriate planning to guide the transition.

We should take into account that the time window to unfold the transition is in the order of magnitude of just few decades, and this is also the order of magnitude of the lifetime associated to most of the technological options we may choose to deploy. Hence, making today the wrong choices because of limited or inadequate planning means generating stranded assets[26] in the near future, and therefore significantly increasing the transition costs, perhaps beyond our capabilities, and therefore compromising the transition itself.

A typical example to illustrate the planning implications is the use of CHP installations, which in the past, during the FF-era, were a very good energy efficiency measure that provided many benefits to the countries that fostered it (like Denmark). However, there seems to be a time lag between the collective[27] internalization of EE measures and the moment when they are appropriate, since as of today, already stepping away from the FF-era and into the RES-era[28], CHP installations are still proposed in planning exercises and incentivized by regulations[29]. And the fact is that in a fast changing context as corresponds to a transition process, there is need to think out of the box when undertaking a planning exercise, because it is quite likely that what hold for the past won't be any more the right position as of today and as the transition unfolds. In Figure **3** we present this situation for the case of CHP. The figure presents the primary energy saving (PES) associated to the use of CHP in an energy system where the reference heating technology is a HP[30] and where the reference electricity generation system

---

[25] *This is true at all the scales, up to national energy planning, which in Spain and as of today still does not have a vision of where we should be heading, which constitutes an important transition barrier.*

[26] *A stranded asset is an asset that becomes under-utilized and devaluated before being able to generate an economic value that recovers its investment, therefore becoming a liability.*

[27] *Or at least within the planning environments.*

[28] *So that today new installations will spend most of their lifetime within the RES-era.*

[29] *As is the case in Spain.*

[30] *Currently the reference heating technology would be a NG boiler, but already as of today, and each time by increasing difference as the transition progresses, the HP significantly outperforms*

evolves from being a coal thermal power plant (blue line), to a combined cycle NG power plant (red line), and ultimately a 100% RES-based power system. As it can be seen in the figure, what in the past was a good option (CHP provided PES > 0), as of today is already neutral and along the transition becomes a really bad option (PES <<0).

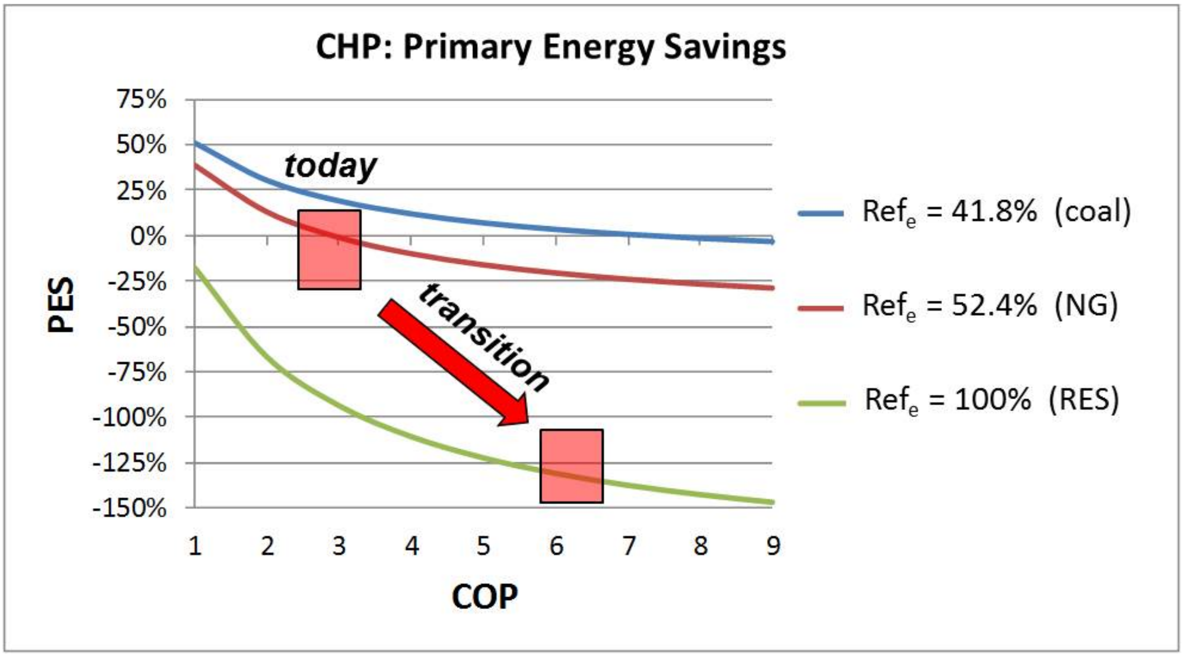


Figure 3: Primary energy savings from CHP when HPs are used as reference technologies and the power system evolves towards being RES-based. Ref$_e$ is the reference electricity generation efficiency (for the electricity coming from the grid), with the cases corresponding to a coal power plant, and combined cycle NG power plant, and a 100% RES based power system are presented (Garcia-Casals X., 2011).

Another illustration for the relevance of appropriate planning is the requirement to attempt to optimize the transition from a techno-economic point of view, which is a must in order to avoid the deployment of additional transition barriers, like would be economic or financing constraints associated to choosing a too expensive transition path. Indeed, a whole bunch of technological options are currently available for undertaking the transition in almost any part of the system. A clear example is the built environment, where once one decides to deploy EE measures one has a myriad of available different possibilities[31], providing thousands of potential combinations and among all of them has to choose the

---

the NG condensing boiler (see (Garcia-Casals X., 2011) for the details), and therefore in a transition context becomes the reference heating technology to evaluate a CHP installation.

[31] Different levels and typologies of façade and roof insulation, improving windows, passive natural ventilation and solar protection options, daylighting, improving controls, different thermal distribution systems, different heat generation equipment, storage options, distributed generation options, improving lighting and appliances efficiency, smart meters, education and sensitization campaigns,…

best combination. Cost optimization analysis are part of the planning activity contributing to guide the transition decisions, as shown in (Ortiz J., et al, 2016b) for the building refurbishment sector.

It is worthwhile to insist on the fact that smart planning is that which plans for the transition. Too often this fact is forgotten, and we find very elaborated planning analyses that are developed taking as input the current context (emission coefficients, primary energy factors, cost structures,…), which invariably lead to the wrong conclusions, because under a transition process if we can be sur of something is about the fact that the current context will change. Indeed, a transition planning process concluding that technology-A is the appropriate one to support for the transition on the basis of the current electricity emission coefficients, when within the lifetime of this technology-A investment the power system will evolve towards a zero emission coefficient situation, is very likely to lead to the wrong transition choices.

So yes, planning in a transition context is a complex task, and therefore has to be done as smartly as possible. Nevertheless this complexity should not lead to 'paralysis by analysis'. We need to get started in the transition process, and will get changes to adapt along the way. But it is important to be aware about this situation in order to devote enough resources and effort to get as close as possible to the right planning as we advance along the transition path.

A SEC is therefore underpinned by smart transition planning processes, which also strive for the mobilization of local resources in a holistic planning approach aiming at getting the social best from the synergies that unfold during the transition within the techno-economic systems.

3.12 Addressing full social dimension of energy use

Beyond supplying the locally demanded energy services, the energy system, and in general terms the energy use, has other social implications. A SEC makes its best to address the full social dimension from energy use.

Some of these other parts of the energy use dimension that a SEC should care for are:

- Addressing local inequalities with regard to the basic energy services (not the consumed energy itself), and specifically energy poverty.
- Striving to maximize co-benefits within the SEC.
- Environmental and social impacts produced by the energy system beyond the SEC physical boundaries.
- Addressing, articulating and facilitating the materialization of co-responsibilities for a fair transition.

From a transition perspective, it is very important that a SEC underpins all its structure in the certainty that only a successful global transition provides local success to the SEC, and consequently contributes to it in its fair share.

3.13 Smartness

Smartness is often confused with the gadgets (SMs, distributed monitoring, ICT,…) that enable the deployment of real smartness.

But real smartness has more to do with all the other characteristics of SECs that we described above. The smartness enabling gadgets have become available in recent times and hence stopped being a barrier for smartness articulation, but whether or not smartness will be deployed through the energy system depends more on how these gadgets are used than on the gadgets themselves: Just deploying AMI, as we have already verified, does not bring about any advance in smartness deployment.

Therefore, if we would distinguish between smartness hardware (sH: SM, sensors, ICT,…) and smartness software (sS: planning, markets, BM, socio-economic structure,…), now that sH became available the focus has to be on sS to avoid missing the full smartness potential.

Smartness is mainly characterized by the facilitation of bidirectional information, services and monetary flows, as well as for the articulation of those elements as social governance, shared[32] economy and trust between stakeholders that enable deployment of the full potential, and a clear view of the way ahead and the interrelations between the SEC and the rest of the world. These constitute the backbone of a SECs, and the underlying BMs the main means for its materialization.

4 Why SECs? The drivers

Herewith we present several drivers for SECs deployment.

4.1 Transition requirements

[32] *Sharing is a sign of smartness, and when dealing with the economic system in a transition context this becomes specially true.*

The current socio-economic system, and particularly the structure of its associated energy system, is completely misaligned with the boundary conditions from the climate system on Earth. So far we have already warmed the Planet just about 1 degree Celsius, and we are already witnessing strong impacts going beyond the forecasts from climate models and having very serious environmental and socio-economic consequences. Continuing along the current BAU path we are set to warm the Planet between 4 and 6 degrees Celsius within this century, and we know that four degrees of warming is incompatible with any reasonable characterization of an organized, equitable and civilized global community. Even 2 degrees Celsius of warming (twice the current value) would unleash huge socio-economic impacts, and we are heading for it extremely fast, with barely one decade time window or less before we can avoid it with high likelihood. Figure 4 shows the years countdown since beginning 2017 until exhausting the full carbon budgets for different likelihoods to stay within different levels of global warming at the end of this century. The currently considered 'save' level of global warming is 1.5ºC, and for a 66% likelihood of staying under that temperature threshold we would have just 3 years if we keep on emitting at the current rate.

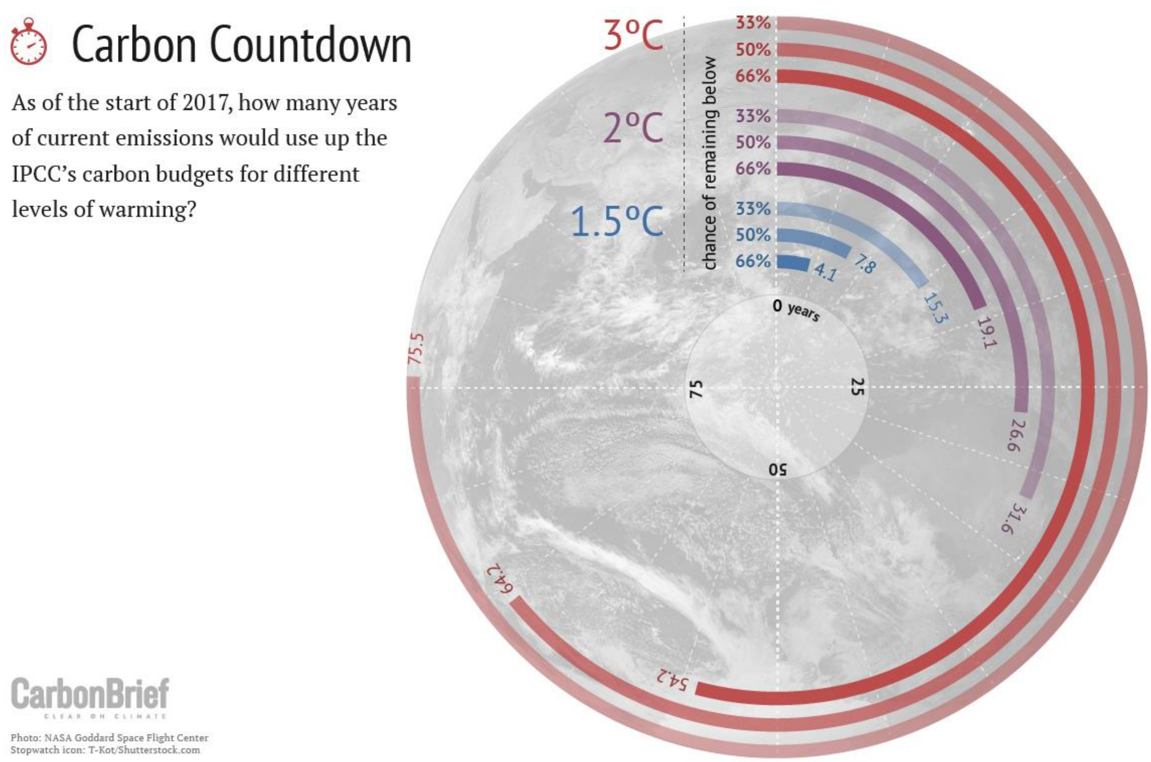
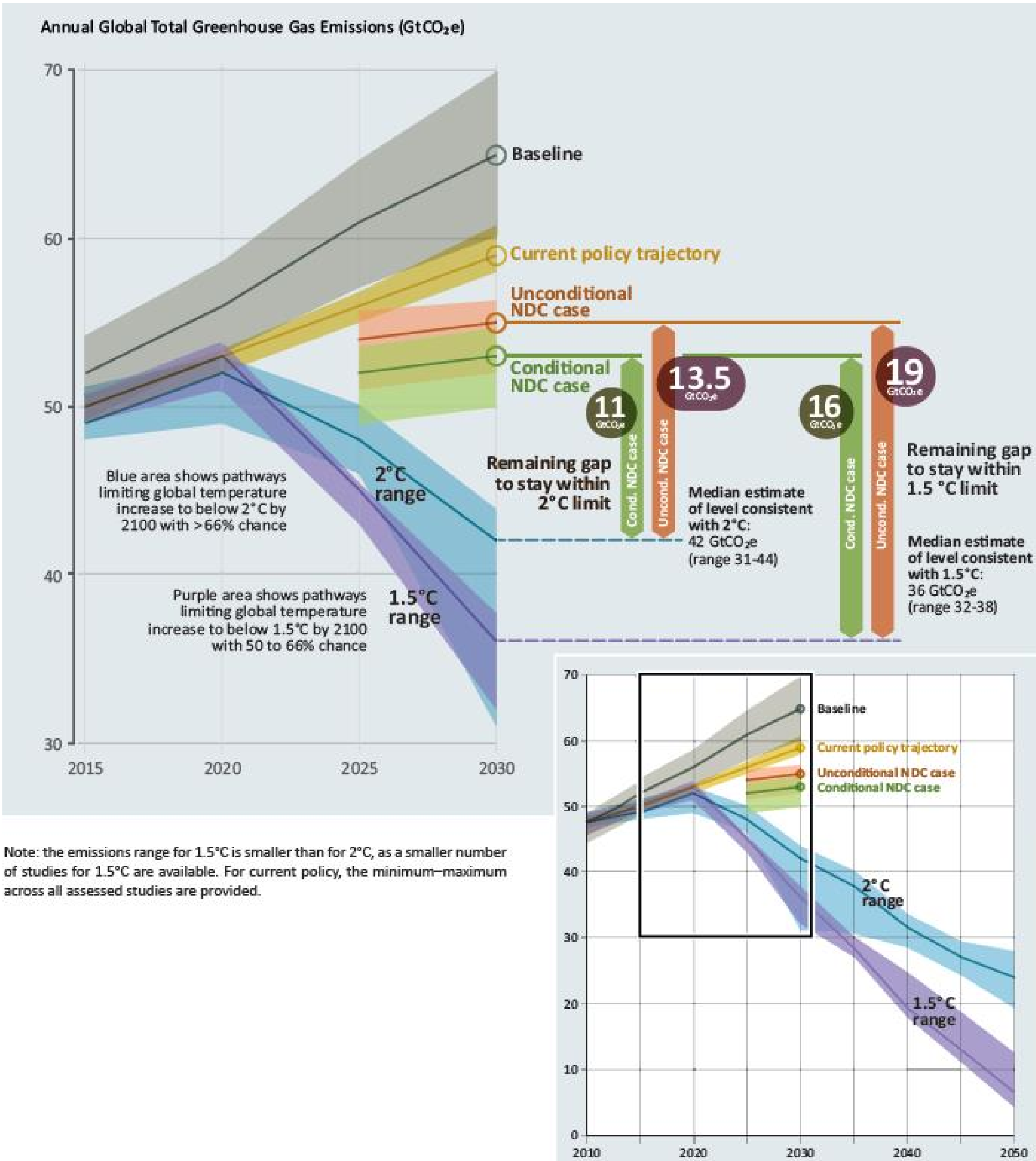


Figure 4: Countdown of the years left until the full carbon budgets (with different likelihoods to stay under the specified global warming) as of beginning of 2017 for different global warmings would be completely exhausted if GHG emission rates would be kept constant to its 2016 value (in 2017 global GHG emissions were even higher). Since we are already in 2018, we should subtract one year from the numbers indicated in the figure (CarbonBrief, 2017)

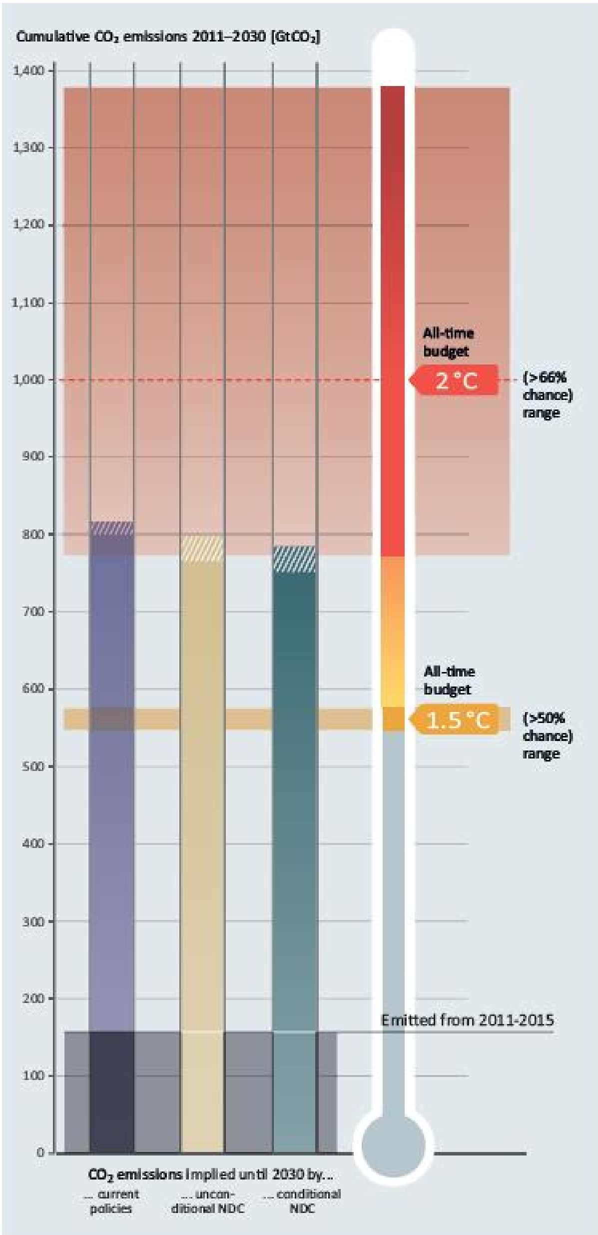
The 2015 Paris Agreement from COP21 adopted the climate goal of stabilizing global warming in 1.5 degrees Celsius as a limit of what could be considered manageable climate change impacts. The challenge posed by a transition from our socio-economic and energy systems that leads us towards a 1.5 degrees Celsius climate stabilization is huge as a consequence of the enormous delays on effective transition undertaken up till now. In fact, already back in 2015 there were significant doubts of whether a transition consistent with the 1.5 degrees Celsius climate goal was feasible at all because of the accumulated delays. Now, two years later and starting 2018 without having managed to articulated any meaningful transition along these lines, the challenge is even higher.

In (UNDP, 2017) the gap between GHG emissions in year 2030 according to the current pledges from the different countries, and the requirements of a transition path that would be aligned with the Paris Agreement goal (1.5ºC global warming by 2100) is presented, amounting to an astonishing 16-19 $GtCO_{2eq}$/y, with the transition still needing to go significantly beyond that by eliminating the remaining 36 $GtCO_{2eq}$/y from the transition path by 2030 (Figure **5**). In fact, as Figure **6** shows, the cumulative emissions by 2030 associated to the current policies, the unconditional NDCs or even the conditional NDCs do already significantly overshoot the available 1.5 ºC carbon budget, indicating that a much faster transition is required if we want to keep global warming below 1.5 ºC. In this context, where such huge emission gaps arise from what national and international institutional approaches can deliver, a bottom-up approach articulated from the SEC level seems to be an imperative to align our evolution with the planetary boundary conditions.



Note: the emissions range for 1.5°C is smaller than for 2°C, as a smaller number of studies for 1.5°C are available. For current policy, the minimum–maximum across all assessed studies are provided.

Figure 5: Global greenhouse gas emissions under different scenarios and the emissions gap in 2030 (median estimate and 10th to 90th percentile range) (UNDP, 2017)

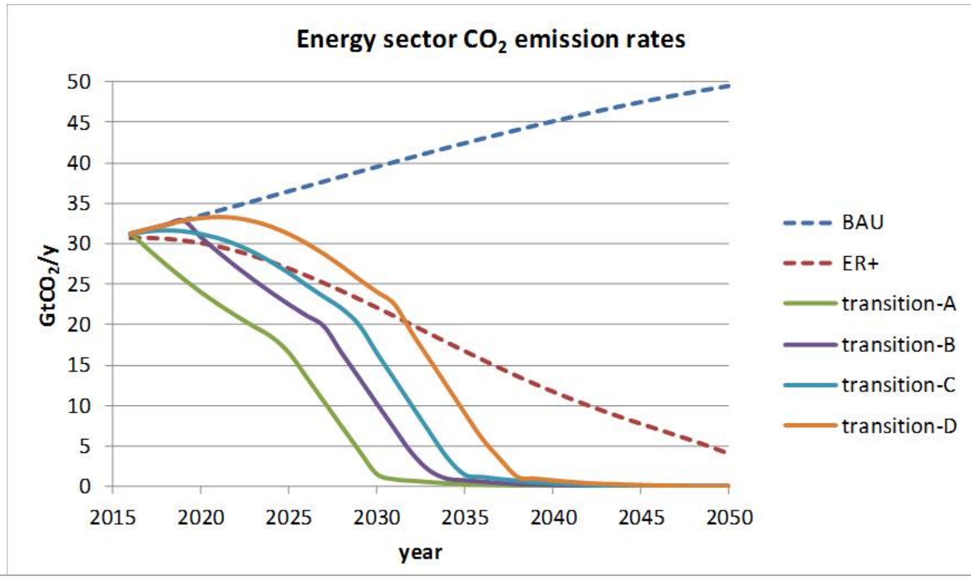


Note: The figure shows cumulative global total CO_2 emissions for the conditional NDC case, the unconditional NDC case and the current policies scenario, and carbon budgets from the Fifth Assessment Report of the IPCC (IPCC AR5) (IPCC, 2014a). The carbon budget ranges show the values based on the range of scenarios assessed by Working Group III (IPCC, 2014b). The solid horizontal line at 1,000 $GtCO_2$ shows the estimate based on complex Earth-System Models, assessed by Working Group I (IPCC, 2014a). Historical emissions until 2015 are based on Le Quéré *et al.* (2015).

Figure 6: Comparison of projected emissions by 2030 and all-time 1.5°C and 2°C carbon budgets (UNDP, 2017)

In (Garcia-Casals X., 2017b) a global transition analysis was undertaken to evaluate the feasibility and implications to articulate a transition aligned with the 1.5 degrees Celsius climate goal. The outcome of this analysis was that it is still feasible to articulate such a transition, but that structural changes should be addressed to unlock the potential for the required transition rates. Two of these structural changes are the deployment of smartness, and the articulation of social direct involvement in the energy system's planning, operation and governance, which directly speak to the deployment of SECs.

Figure **7** from (García-Casals X., 2017b) presents the results for the overall energy sector from a worldwide transition rate analysis aimed at checking the feasibility to stay within 1.5ºC global warming, in terms of the evolution of yearly CO_2 emissions (top) and the resulting cumulative CO_2 emissions (bottom). Four transition paths (A, B, C, and D) are presented, all of them based on the maximum attainable component transition rates, and differing on when is the transition started (year 2017 for A and C, and year 2020 for B and D),and how are the maximum transition rates deployed (from the very onset for A and B, and linearly increasing along a 10-years time window for C and D). The transition results are in this figure compared with the BAU evolution and with the advanced Greenpeace energy revolution scenario (ER+), which was by this time considered one of the most progressive world transition scenarios. As we can see from the comparison of the cumulative emissions with the available carbon budget, only transition-A manages to be slightly below the available carbon budget, and CO_2 emissions from other sectors (forests and agriculture) still have to be added on top of the energy sector emissions. This result provides a clear idea of how tight the transition requirements are. Fortunately two additional components, namely natural negative emissions and mitigation of other GHGs provide, if properly articulated an additional buffer that makes the transition still feasible tough certainly tight: See (García-Casals X., 2017b) for more details.



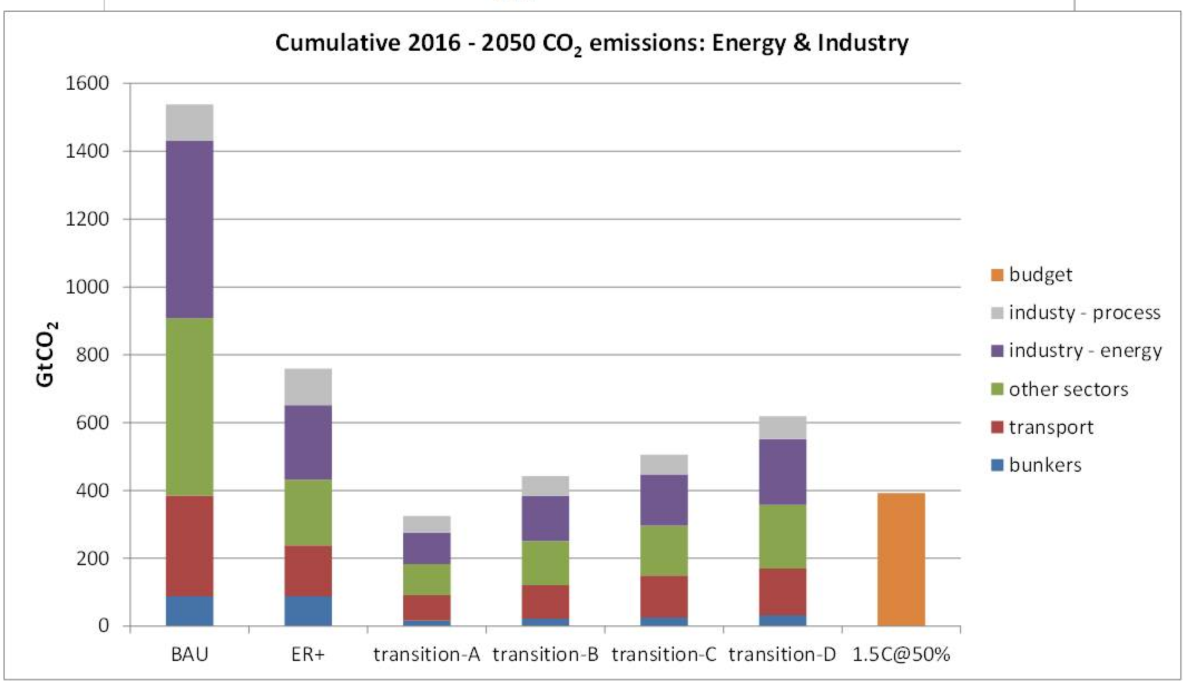


Figure 7: Top: Different transition paths from the world overall energy sector in terms of CO_2 annual emission rates. Bottom: Cumulative CO_2 overall energy sector (and breakdown for different subsectors) worldwide emissions for different transition paths, compared with the available carbon budget for a 1.5ºC global warming with 50% likelihood. Transition A, B, C and D correspond to four different transition scenarios varying in how soon the transition gets started (in 2017 or in 2020) and how the maximum transition rates are deployed (from the onset or linearly growing along a 10 years time window). ER+ designates the Greenpeace advanced energy revolution scenario. (García-Casals X., 2017b)

4.2 Minimize and limit the impact from stranded assets

Stranded assets on the one hand are an economic inefficiency that limit our available resources for materializing the transition. Moreover, stranded assets often generate transition barriers that compromise the transition itself. Therefore we should aim to minimize stranded assets and develop social governance to manage its barriers in such a way that they don't block the transition. SECs can significantly contribute to these goals.

Due to the delays on undertaking an effective transition, today's needed climate consistent transition will lead to stranded FF assets.

Indeed, just from the FF production side, compatibility with the climate goal requires that all new and undeveloped FF reserves stay in the ground (Muttitt G., et al., 2016). This means that trillions of dollars' worth of proven reserves – currently propping up share prices from FF companies – should lose their value overnight if we want to keep chances of materializing the required transition. This is already a transition barrier, and will generate more significant transition barriers as time goes by. Any new investment in FF extraction will increase the associated transition barriers. Overcoming these barriers requires increasing the energy system's social governance for overcoming its current corporate dominance. SECs facilitate this process.

Also from the generation side, the fact that FF infrastructure (power plants, thermal plants, DH networks,…) have a life-time cycle of around 40 years, means that basically each new FF infrastructure development will become stranded before the end of its economic lifetime if we manage to articulate the required transition. Therefore, in order to minimize stranded assets and its economic impact no new FF generation infrastructure should be developed. In fact, even without developing new FF generation infrastructure, since we currently have a FF overcapacity issue, a climate consistent transition will lead to stranded FF generation assets, since they won't be able to complete their economic life cycle (García-Casals X., 2017c). On the basis of its increased social governance and its capability to optimize energy resources by articulating distributed participation and involvement in the energy system, SECs can contribute to minimize FF generation stranded assets and properly manage those that already exist minimizing its associated transition barriers.

The risk also exists for grid (both distribution and transmission) stranded assets. Indeed, the same technology options that can contribute to articulate the deployment of smartness throughout the grid (DG, DS, DR, EM, micro grid,…), can also enable consumer's grid defection if the current trend on customer's utilities and retailers distrust is not reversed, and the contextual and regulative framework for incorporating citizens into the energy system is not modified.

Distribution and transmission power grids can be a significant transition flexibility provider, especially where they are already deployed as is the case in most of urban

Iberia, allowing for lower overall transition costs, fastest transition, and providing mechanisms for transition social inclusiveness. But in the current context, the main network stakeholders need to actively convince consumers to take advantage of these potential benefits and stay grid-connected, which requires reversing the current situation where consumers do not have a clear view of these benefits because in the past none of these have been shared with them and they had to put up with significant hurdles associated to the way how utilities and retailers have been treating them up till now.

SECs and the BM for added-value services they enable provide a unique opportunity to revalue the social value of the grids, completely redefining the relationship between consumers and other stakeholders and fully integrating them into the broad energy system, which would allow optimizing the transition's socio-economic dimensions and avoid additional stranded assets.

Also with regard to RES generation capacity there could be risks of transition stranded assets if smartness is not deployed throughout the energy system. Indeed, on the one hand missing to articulate the potential from EE, DR and DS would lead to RES overcapacity, which in turn would require significant RES generation curtailment to operate the power system. And on the other hand the transition dynamics themselves could lead to mid transition peaks in electricity demand as a consequence of the evolution of EE deployment and electrification (Garcia-Casals X., 2017b) which ultimately would require RES curtailment after the peak and therefore generate RES stranded assets. SECs could significantly contribute to minimize or even eliminate these RES stranded assets.

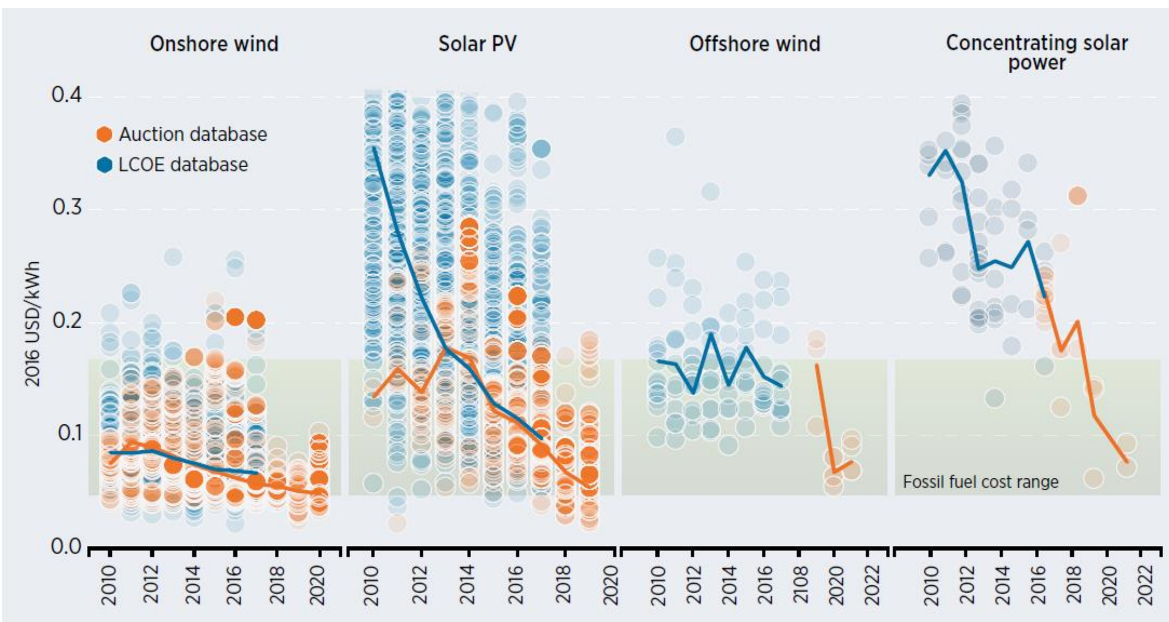
Another dimension where transition stranded assets could be produced is in the deployment of distributed non-electric RES (like ST), and associated energy infrastructure (like DH and DHC). Indeed, currently we have regulations pushing for the deployment of non-electric RES distributed technologies in the consumer, building and neighborhood levels, lacking a transition's integration perspective. Due to the integration potential of electrifying the energy system (including developing the flexibility associated to DR) and the non-electricity demand reduction associated to EE deployment, non-electric RES could become a redundant infrastructure and therefore become stranded. SECs, by distributing the energy planning and adapting it to local contexts could help to minimize these stranded assets.

4.3 Limit energy costs

The advancement of RES technologies along its learning curves has provided impressive cost reductions in just few years and relatively limited deployment. These last years we have already witnessed results of RES auctions in different parts of the world providing PPAs and LCOEs for PV and Wind below 30 US$/MWh, with some even going below 20

US$/MWh (Dipaola A., 2017), (Deign J., 2017), (IRENA, 2018). Even for dispatchable RES like CSP with a significantly lower progress along the learning curve, along 2017 we saw PPAs around 70 USD/MWh (New Energy Update, 2017). At these costs, RES already become economically competitive with new FF generation, and even start beating O&M costs of existing FF plants, meaning that investing on these plants is already becoming a better economic option than keeping on operating existing FF plants, and this even without economically internalizing the climate change impact associated to maintain operation of FF energy plants.

Figure 8 presents the LCOE and PPA evolution for onshore wind, offshore wind, PV and CSP projects since 2010, showing both individual project values and the global weighted average values for each year. Looking at the global weighted average evolutions we see how projects from all four technologies auctioned the last year (and to be commissioned in 2019 – 2022) are already hitting the lower boundary of the FF cost range. However, we can also appreciate in this figure how, at least until 2017, there is significant cost dispersion between the different projects commissioned[33].



Source: IRENA Renewable Cost Database and Auctions Database.

Note: Each circle represents an individual project or an auction result where there was a single clearing price at auction. The centre of the circle is the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, the real WACC is 7.5% for OECD countries and China, and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Figure 8: The levelised cost of electricity for projects and global weighted average values for CSP, solar PV, onshore and offshore wind, 2010-2022 (IRENA, 2018)

[33] *Associated to project specific characteristics like project size, available renewable energy resource, project geographical localization and project specific financial conditions.*

The transition analysis developed for Spain in the Energy 3.0 study (Garcia-Casals X., 2011) provides clear evidence that a transition towards a smart, efficient and RES-based energy system leads to significantly lower overall energy costs that following along the BAU pathway (Figure **9**), even without factoring into the economic evaluation the internalization of the BAU evolution externalities, like the associated climate change impact and its adaption requirements. Figure **9** presents the evaluation from the whole Spanish energy system LCOE along different evolution pathways to 2050: In the top graph LCOE values at the beginning (2007) and end (2050) of the considered time-window are shown, and in the bottom graph the corresponding average values for the whole of the time-window are provided. As we can see, all transition scenarios (E3.0) provide significantly lower average LCOE during the transition period (2007-2050) than following the BAU pathway, but the economic benefits are significantly higher than that after the transition is completed, because from year 2050 onwards the transition scenario provides a LCOE that is less than a quarter of what the BAU would require[34].

[34] *And the BAU would keep on escalating costs from 2050 onwards, to which we should add all the externalities associated to the huge climate change unfolded by following the BAU pathway.*

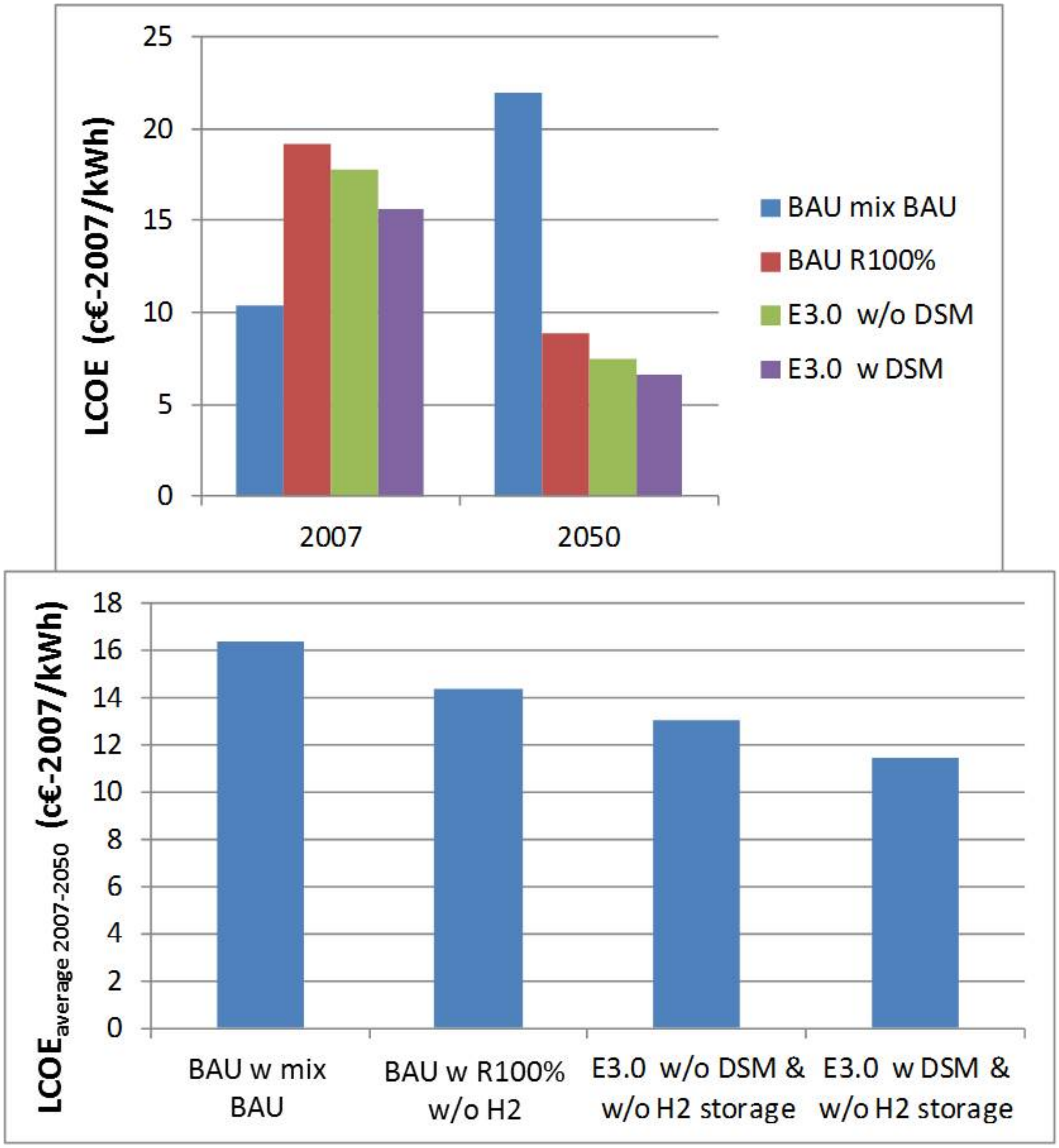


Figure 9: LCOE from the overall Spanish (peninsular) energy system for different scenarios to 2050. Top: LCOE at the scenario's beginning (2007) and end (2050). Bottom: Average LCOE along the 2007-2050 period. BAU with mix BAU is the BAU evolution; BAU R100% represents a transition scenario where the demand evolves along a BAU pathway but all the generation is transitioned to RES (somehow represents the incipient transition pathway we are currently following); E3.0 designate the transition pathways, without including DSM (w/o DSM) and including it (w DSM). (Garcia-Casals X., 2011)

The plumbing costs of RES generation along the last years has brought to the forefront the concept of 'base-cost renewables' to replace the traditional concept of base-load and peak-load centrally operated power grids (Bhavnagri K., 2017), with some utilities around the world already embracing and planning for this concept (Parkinson G., 2017a), foreseeing an evolution from fully centralized networks to basically DER-based networks, shifting to a future of distributed energy, built around low-cost renewables and enabling technologies like storage and smart controls to fill the gaps: a massive shift from the conventional view that all customers should be served by centralized generation and fed by long networks of poles and wires.

Plumbing RES generation costs have added momentum to the economic driver for the transition towards SECs, which is proving useful in a context of immature socio-economic systems that still pretend to externalize a big deal of full social costs. However, the economic case for the transition towards SECs is significantly stronger than the one shown by plumbing RES generation costs falling below costs of today's new FF generation and approaching O&M costs of existing FF generation, and one dimension from the 'smartness' attribute is making this fact explicit. Indeed, internalization of externalities through monetary valuation strongly supports the economic case for the transition towards SECs. In the global dimension, tackling climate change through the SECs' mitigation potential, beyond saving huge amounts in adaption costs, would provide the unevaluable benefit of allowing our socio-economic systems to keep on thriving in this Planet: There is no Planet-B. And in more local community-based dimensions, the internalization of externalities discloses huge socio-economic savings associated to SECs deployment, like clearly illustrated in the IREC's study (Ortiz J., Salom J., 2016) dealing with building stock energy refurbishment and showing how payback periods are reduced to less than half its value based solely on energy saving evaluations, once other social costs (sanitary, medicines, labor,…) associated to the comfort level improvement are factored in.

4.4 DER integration

DERs are being deployed through existing network systems driven by its cost reduction and increasingly seamless interaction with end-users. DERs often provide already an economic case for end users, besides empowering them to take their own transition actions even if the main energy system does not follow.

In grid interconnected systems, a massive non-coordinated deployment of DERs could impose serious technical challenges (beyond economic ones by impacting retail tariff structures), eventually leading to higher network costs to integrate and manage these new resources and system players.

Introducing smartness at community level like a SEC does is by far the best approach for turning around this potential problem and transforming it in a very powerful transition solution.

Systems with high DG and DS penetration, like some parts of Australia with very high rooftop deployment, are already actively testing how to introduce distributed management in order to properly tackle this DER deployment in such a way that instead of being a problem to the grid becomes a solution. In Melbourne the DSO and aggregator have successfully and seamlessly switched off and on a neighborhood from the grid and operated it in islanded mode served solely by its own DER in a mini-grid configuration, which allows them to integrate DERs without any limit and get their full advantage to the system without escalating integration costs (Vorrath S., 2017).

In fact, in the current context of increasing DER-based DG, retailers themselves have a strong driver to articulate demand side flexibility through DR (deploying smartness through the system at community level) in order to balance their portfolio and avoid having to pay for their unbalances.

Unlocking the flexibility associated to SECs, besides its direct contribution to on-site RES integration also provides significant indirect contributions to increase the overall RES penetration and reduce the transition costs. One of these indirect contributions is associated to the power system frequency regulation, and specifically to the sub-second very fast regulation to control RoCoF after a system fault. Ireland, with its current SNSP of 60% and aiming to increase it up to 75% in 2020 complying with its RES deployment plans, provides a clear illustration of this situation (Reynolds P, et al, 2017). As elsewhere Ireland's electricity system currently gets its RoCoF control characteristics from the inertia provided by its spinning thermal power plants (kinetic energy). However, as RES penetration increases, the contribution of conventional thermal power plants to electricity generation reduces, and in order to keep enough inertia in the system to face RoCoF issues, these thermal power plants have to operate at part load, which means lower efficiency, reaching situations where CCGT plants have equivalent emission coefficients to coal power plants. Moreover, because the inertial contribution to RoCoF issues is just a small percentage (around 10%) of the nominal thermal power plant output, big quantities of them need to be connected to the grid in order to provide the required RoCoF control. By using the 'digital' inertia[35] from batteries, all the thermal power plants can be substituted[36] while simultaneously improving RoCoF and frequency regulation capabilities, and reducing the system costs and GHG emissions (in Ireland eliminating the SIR regulation service provided by thermal power plants would lead to a €19M/y savings and 1.4 MtCO_2/y emission cuts).

---

[35] "Digital Inertia" is actually a misnomer. Batteries have no physical inertia – they do not move. Instead, they can provide inertial-like response via super-fast active power injection and import, but the origin of this power is a modification of chemical energy instead of kinetic energy in the case of spinning thermal power plant's turbomachinery.

[36] Because thermal power plants contribute to SIR with just around 10% of their nominal capacity while batteries can deploy up to 100% of their nominal capacity in fractions of a second, just about 10% of battery capacity needs to be deployed to substitute 100% of the thermal power plant capacity providing the SIR services.

5 System blocks for SECs

Herewith we present the different system blocks available to articulate a SEC.

We attempted to differentiate between already existing blocks and blocks still under development to provide a sense of the current availability of these system blocks. However, in the current transition context, the boundary between the 'existing' and 'under development' classifications is rather blurry.

Indeed, we have blocks (like DR) that are conceptually and technologically already available but that in many places still encounter barriers (regulatory, organizational,…) that prevent them from being operational.

Although a gradual approach to SECs deployment can be pursued, where available system blocks are articulated foreseeing the gradual incorporation of the other system blocks still not available, the smartness attribute from SECs requires, at least in the planning stages, aiming at the full incorporation from all the system blocks, pursuing a systemic and integral approach to capture all the potential that SECs offer. That is why institutions working with the development of the SEC concept should pursue an integral approach like the IREC's presented in Figure 10.

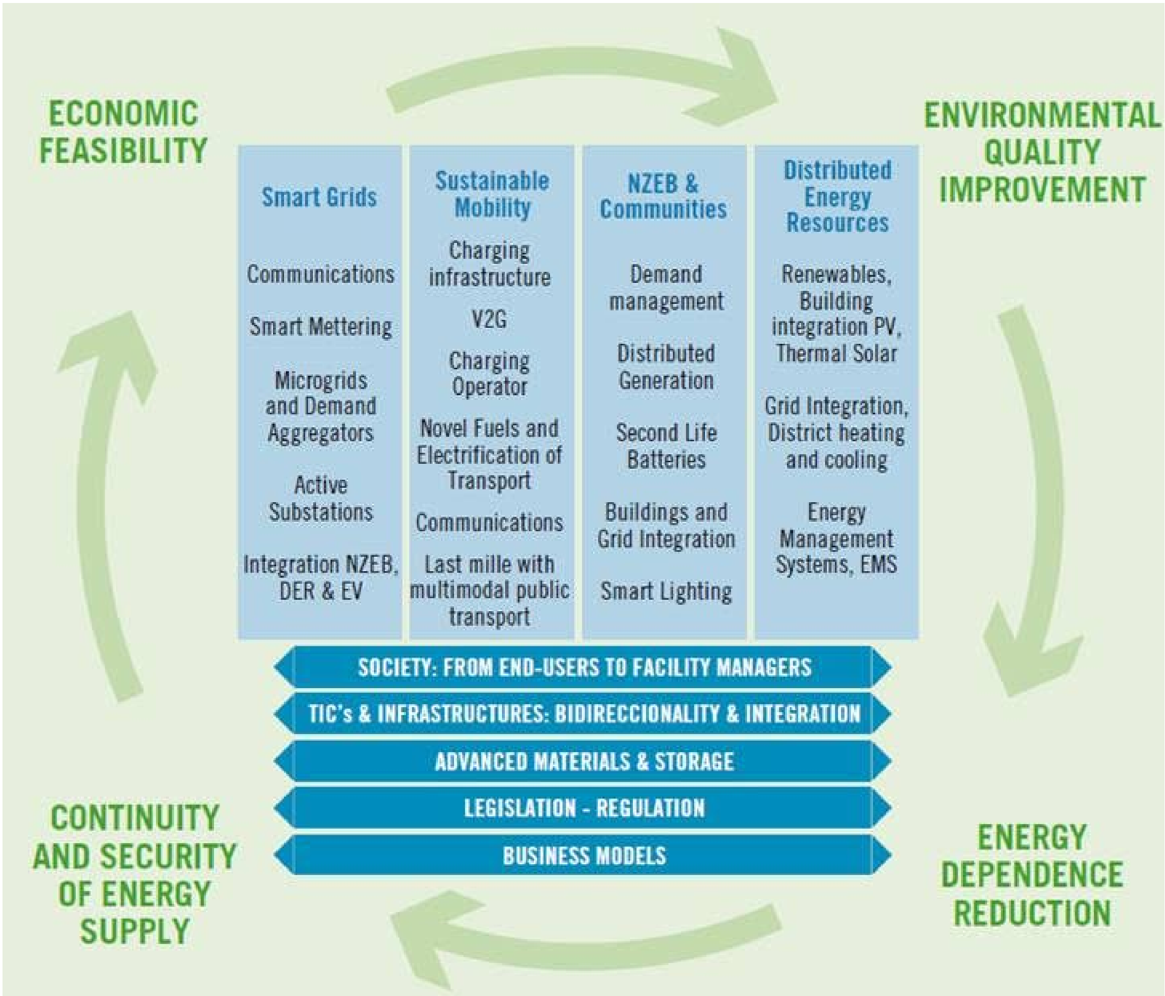


Figure 10: IREC's SEC integral approach

5.1 Digitalization

A larger number of resources at the customer side, providing a range of services to the grid (including energy, capacity, voltage control and frequency response) and likely willing to make transactions with other distributed resources, will result in the need of a digitized network that can enable real time management of those resources, as well as support to qualification, verification and settlement of the DER-related services.

Digital technologies increasingly allow devices across the grid to communicate and provide data useful for customers and for grid management and operation. Smart meters, new smart/IoT sensors, network remote control and automation systems, and digital platforms that focus on optimization and aggregation, allow for real-time operation of the network and its connected resources and collect network data to improve situational awareness and utility services.

Data from smart devices and DERs in general will be critical to new BMs and to facilitate customer engagement and adoption of grid edge technologies.

Properly shared and detailed, data has the potential to improve customer experience on several dimensions, such as improving customer service through better access to more information and by enabling automated operations that will help customers flexibly manage their electricity demand and optimize costs.

Though market penetration of smart, IoT-enabled devices, including refrigerators, microwaves and dishwashers, is currently low at 3% to 5% of major customer appliances, this share is forecasted to dramatically grow, with the number of sensors in power consuming devices multiplying by six by 2020 (WEF, 2017).

5.2 Aggregation

Aggregation of DERs provides the means to facilitate its full integration into the energy system by at one end of the value chain enabling the painless and convenient incorporation of consumers and prosumers into the energy market, and at the other end shaping the distributed resources into a convenient VPP structure that facilitates its interaction with the market and SO. Smart aggregation of mobility demand also enables energy system integrated mobility services. In this sense, aggregators often become one of the cornerstones from the SEC smartness structure.

The goal of the aggregator is to maximize the value of the flexibility by providing it as service to the energy actors that have the most urgent need for it. An aggregator is foreseen in the energy market to act as an intermediator and facilitating agent between prosumers and traditional market players.

The independent aggregator represents a new role within European electricity markets. The introduction of this role into a market creates critical momentum around the growth of DR, attracts private investment, and fosters competition between service providers[37] (SEDC, 2017).

In (SEDC, 2017) the results from an assessment of the development of the regulatory environment for DR in the different EU Member States are presented, which includes the

[37] For example, in some markets in the USA today, over 80% of demand-side volumes are provided through independent aggregators, even though suppliers are able to offer the same services. Similar patterns occur wherever independent aggregation is allowed, including Ireland, Western Australia, and New Zealand.

regulatory enablement of independent aggregators' market participation in these countries[38].

The main conclusions from the (SEDC, 2017) analysis (see §11.4 for more details) about the state of DR and aggregation development and deployment in Europe are:

- The regulatory framework in Europe for DR is progressing, but further regulatory improvements are needed.
- Restricted consumer access to DR service providers remains a barrier to the effective functioning of the market[39]. Regulatory frameworks in the majority of EU member states do not yet acknowledge the role of independent DR aggregators, or they require aggregators to conclude bilateral contracts with retailers/BRPs – whose business is often competing – in order to sell consumers' flexibility.
- Significant progress has been made in opening balancing markets to demand-side resources.
- The wholesale market must be further opened to demand-side resources. The issue of access for independent aggregators to the wholesale market is prevalent across the majority of Member States. In most cases, the framework only allows for BRPs or retailers to aggregate and sell their own consumers' flexibility. At best, some large consumers and VPP can sell their electricity directly on the market. This, alongside the further opening of the balancing market and ancillary services, needs to be addressed in order to allow for further competition between market actors in the electricity market.
- Local System Services are not yet commercially tradeable in European countries. With the exception of Great Britain, incentive structures for DSO in Europe do not encourage the use of market-based flexibility resources today. No effective market structures have been implemented in any of the analysed countries for DSOs to be able to source flexibility, including from DR, for optimised local system operations.

In (Barbero M., 2017), the IREC, within the framework of the REFER project, provides an analysis of how aggregators could articulate the flexibility supply from the buildings sector. A review of DR status in different European countries is provided, which is rather unequal throughout Europe, in spite of having the 2012/27/EU Energy Efficiency directive

[38] We need to recall that the articulation of DR and the enablement of aggregators is a requirement already set in the 2012/27/EU Energy Efficiency Directive.

[39] France and Switzerland are still currently the only countries to have a clear framework on the status of independent aggregators and their role and responsibilities in the market, while the UK, Ireland and Finland enable aggregator access at least to some markets and products. Progress can be seen in Belgium and Germany, where the definition of frameworks is under development, and discussions have started also in Austria and the Nordic countries.

that already required since 2012 the facilitation of DR and independent aggregation[40]. The study reviews the activity of many different aggregator companies[41] that are already operating in different European countries[42] offering different services[43]. Among these, three different groups of aggregators are found:

- Aggregators managing small consumers and offering fast frequency control to the SO.
    - They mainly use the inertia of DHW tanks for the control of electric or HP heaters, the building's inertia for the HVAC control, and DS installations.
- Aggregators that are also electricity retailers
    - For these, the main and often single aggregator's goal is to balance its own portfolio for not having to pay penalties. Indeed, unbalances are rather expensive for retailers, and the increasing DG based on RES makes demand side flexibility an important asset.
- Aggregators managing big commercial and industrial consumers and selling their services to the TSO.

In (Lipari G., et al, 2017) IREC's implementation of a real-time commercial aggregator (Figure **11**) that pools the generation and/or consumption flexibility offered by its customers to provide energy and services to actors within the system is presented and analysed, including the flexibility procurement and activation processes dealt with by DSOs on one hand, and the bidding and allocation processes carried out by aggregators on the other hand. In this case the flexibility product or service is defined as an energy curtailment for a defined time interval. A methodology is proposed that coordinates automation systems located at customers' premises with aggregator's systems operation in real-time. A flexibility activation and delivery workflow is tested in which individual customers report current operational status to the aggregator, so that flexibility allocation can be done based on updated and particularized volume forecasts. The methodology

---

[40] *Indeed, the 2012/27/EU already in 2012 stated that 'Member States shall ensure the removal of those incentives in transmission and distribution tariffs...that might hamper participation of DR, in balancing markets and ancillary services procurement', and 'Member States shall ensure that national energy regulatory authorities encourage demand side resources, such as demand response, to participate alongside supply in wholesale and retail markets'.*

[41] *RESTORE, VERBUND, Hybrid-VPP4DSO , DANSKE COMMODITIES, ENERGIDANMARK, SEAM, FORTUM, ACTILITY, ENERGY POOL, SMART GRID ENERGY, VOLTALIS, ENTELIOS, DONG ENERGY DE, DONG ENERGY UK, FLEXITRICITY, KIWI POWER, TEMPUS, VPS, OPEN ENERGI, ENECO GROUP,…*

[42] *Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Netherlands*

[43] *Energy and flexibility potential audits, consumer's real time energy monitoring including the impact of their DR contributions, network congestion management, VPP including those based on DS, guidance and facilitation of consumer's participation in the different DR markets, EE optimization, electricity costs minimization through response to price signals and tariffs, grid's frequency regulation (primary, secondary and tertiary), capacity reserves for the SO, RES integration,…*

fits well with customers' managing automation systems, which generate energy schedules ex-ante such as energy planners with optimization algorithms.

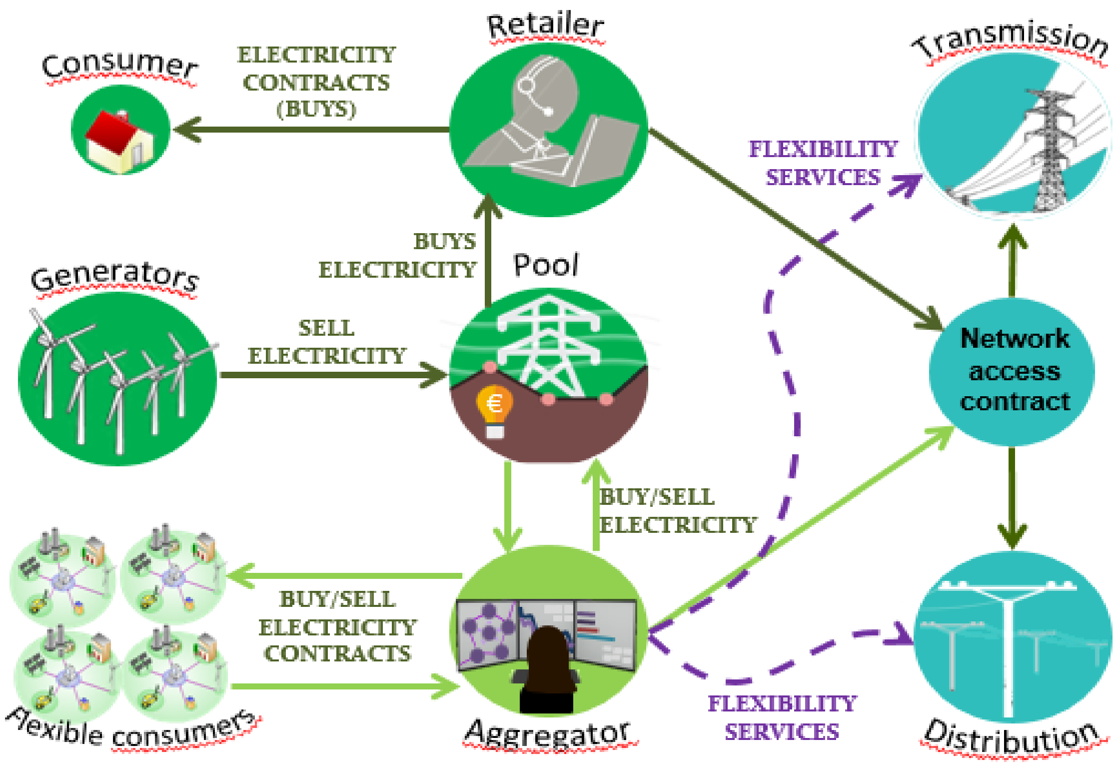


Figure 11: Commercial aggregator concept as per (IREC, 2017)

5.3 Demand Response

DR or DSM or DSF is a very powerful distributed flexibility resource to enable a fast and efficient transition towards a sustainable RES-based energy system, while providing the key for structural involvement of citizens into the energy system definition and operation.

Both above mentioned aspects of DR are closely related to each other, since the development of its full flexibility potential requires the direct involvement of consumers with complete social governance and shared economy approach. There is no way that utilities, retailers or third party providers access the full potential from DR without appropriate trust from the consumers, which requires governance and a fair economic approach. DR potential fully sits behind-the-meter, in the consumer's premises, and deeply interacts[44] with how the consumer makes use of energy services. This is one of the points where it becomes very clear that smartness articulation goes far beyond smart meters deployment, and involves other dimensions like governance and business models.

DR is now widely recognised as an important enabler of security of supply, RES integration, improved market competition and consumer empowerment.

DR can be seen as a grid management technique where retail or wholesale customers are requested either electronically or manually to reduce or adjust their electricity consumption, and rewarded for this flexibility supply.

DR is one of the main tools[45] to unlock the potential for flexibility in the energy system, and flexibility is one of the main transition enablers.

Targeted DR programmes could also be an alternative to investment in network capacity upgrades to address congestion. In the case of the United Kingdom, it has been estimated that the cost of network reinforcement could be around one-third less in a system with optimal demand response combined with 100% penetration of electric vehicles and HP space heating. The benefits of demand response for network investment could be reflected in the network tariff.

DR at community level can be mobilized at both behind-the-meter and beyond-the-meter levels, through different load components:

- Behind-the-meter DR (residential and commercial buildings or installations):
    - Building thermal loads like SH, SC and DHW. Thanks to the inertial attribute of these loads, energy can be stored as thermal energy in the building structure (SH, SC) or storage tank (DHW, distribution SH and SC tanks) for later use, and with electrification as integration tool this provides DS for the electrical system. In (Péan T.Q., Joana Ortiz J. and Salom J., 2017) an analysis is presented of a plausible control strategy to implement DSM with SH and DHW in a residential nZEB electrified with a HP in Mediterranean climate, exploring the potential for flexibility, as well as the implications in terms of comfort, overall energy consumption and cover of electric load by the local PV system.
    - Refrigeration loads. Both in residential and commercial buildings, refrigeration electrical loads from fridges and freezers can be smartly modulated to store and release thermal energy.

---

[44] *In (Péan T.Q., Joana Ortiz J. and Salom J., 2017) an analysis of building's DSM with SH and DHW loads is presented, illustrating and quantifying the trade-offs between the flexibility service provided and the resulting comfort level, overall energy consumption and self-coverage of electric load with local PV generation.*
[45] *Although not the only one: Storage, RES generation, and integration with the rest of the energy system (V2G and hydrogen-based fuels) are other very important flexibility sources for a smart energy system.*

    - Cooking (electrical) loads. Electric cooking loads from residential and commercial buildings can also offer some flexibility for DR by slightly modulating its set points while in operation or by shifting them during short periods when feasible.
    - Building lighting loads. Building lighting loads, both in residential and commercial buildings, also offer potential for contributing to DR by downwards modulation of set points.
    - HVAC components whose operation can be modulated while maintaining the basic service within the required parameters, like fans, pumps and AHU.
    - Building appliances loads. Electric appliances offer many options for DR. One example are washing machines and dishwashers which can provide smart DR options both by modulating its current washing cycle and by slight time shifts of the different washing phases within a given washing cycle.
    - EV charging. Behind-the-meter EV charging offers a very powerful DR mechanism articulated through the storage capability of EV's batteries.
    - Many different industrial equipment can be modulated to offer DR services without affecting its main function. Indeed, often inertial characteristics from equipment and processes allows for DR participation without going outside the required operating parameters, providing additional income sources for the business.
- Beyond-the-meter DR:
    - Community lighting. Temporary dimming of community public lighting offers downward DR capabilities.
    - Community's public infrastructure, like water supply and waste water treatment offer DR capabilities through the modulation of electric motors in pumping stations and treatment plants.
    - Community EV charging infrastructure. Beyond-the-meter EVs charging infrastructure, whether public or privately operated, provides a huge potential for DR.
    - Community transport infrastructure (underground, trams, train,…). Electric community transport infrastructure provides additional DR capabilities by slight electric motor's modulation.

Two types of DR can be distinguished depending on whether the DR has an explicit or implicit interaction with the market (SEDC, 2017). It is important to understand that neither form of DR is a replacement for the other: it is necessary to enable both Explicit and Implicit DR to accommodate different consumer preferences and to exploit the full spectrum of consumer and system benefits:

- In Explicit DR schemes (sometimes called "incentive-based" or "incentive-driven") the aggregated demand-side resources are traded in the wholesale, balancing,

Capacity Mechanisms, system support and reserves markets. Consumers receive direct payments to change their consumption (or generation) patterns upon request, triggered by, for example, activation of balancing energy, differences in electricity prices or a constraint on the network. Consumers can earn from their consumption flexibility individually or by contracting with an aggregator[46], but is usually facilitated and managed by a commercial aggregator.
- In Implicit Demand Response (also called "price-based"), prosumers react to dynamic market or network pricing signals. Prosumers can adapt their behaviour (through automation or personal choices) to save on energy expenses.

Demand flexibility creates value for customers and the grid by shrinking customer bills (by as much as 40%), reducing peak demand and shifting consumption to lower price, off-peak hours. Demand flexibility also can help providers, in some cases, to avoid or defer investments in central generation, transmission and distribution, and peaker plants. The global DR market is estimated to be around 70 GW by 2018 (WEF, 2017), although estimates oscillate widely: In EU we are currently tapping in to around 20GW of activated DR, but the Commission places the potential at 100GW, rising to 160GW in 2030 (SEDC, 2017).

However, there is as of today still a striking contrast between the requirements of the European Energy Efficiency Directive (2012/27/EU) with regards to DR articulation and the effective means at the disposal of consumers wanting to access the day-ahead, intra-day, balancing or other markets with their DR capabilities (SEDC, 2017):

- Participation of demand-side resources in all electricity markets should be authorised. This very basic condition is still not fully met in the majority of EU Member States. For example, in several markets demand-side resources are only allowed to participate in a small number of programmes and certain markets are as of today still entirely closed to DR (such as balancing markets in Italy and Spain, or re-dispatching markets in Germany).
- Aggregated load must be allowed and encouraged to participate. For a significant quantity of demand-side flexibility resources to be available to the system, TSOs and market operators should open the markets to aggregated load. Most countries which have opened their product requirements to DR have also enabled aggregated load to participate (e.g. France, Belgium, Switzerland, Great Britain, etc.). On the contrary, other European countries opened some of their markets to load participation, but not to aggregated load, therefore disqualifying all except the largest industrial consumers from accessing these markets (e.g. Slovenia, Poland).

[46] *Either a third-party aggregator or the customer's retailer.*

In (Barbero M., 2017), the IREC, within the framework of the REFER project, provides an analysis of how the flexibility supply from the buildings sector DR could be articulated. In this reference, among others, we find a discussion about the appropriate methodologies to define the baseline needed to provide M&V of the really delivered DR service, which is an issue of paramount importance for enabling DR. An appropriate baseline determination methodology is still pending even in those European countries where DR participation is more advanced.

According to the IEA, DR can be used for different objectives (as illustrated in Figure 6.2) and can increase the flexibility of the load in different dimensions:

- Peak shaving: reducing peak consumption during tight system conditions so as to release pressure on generation and grid capacity needs. This also reduces the need for investment in peak generation assets
- Valley filling: increasing or shifting consumption to hours of ample generation of wind and solar power
- Ramp reduction: reducing the steep ramping needs at peak time with the shifting of load at a time when the system is under less constraint.

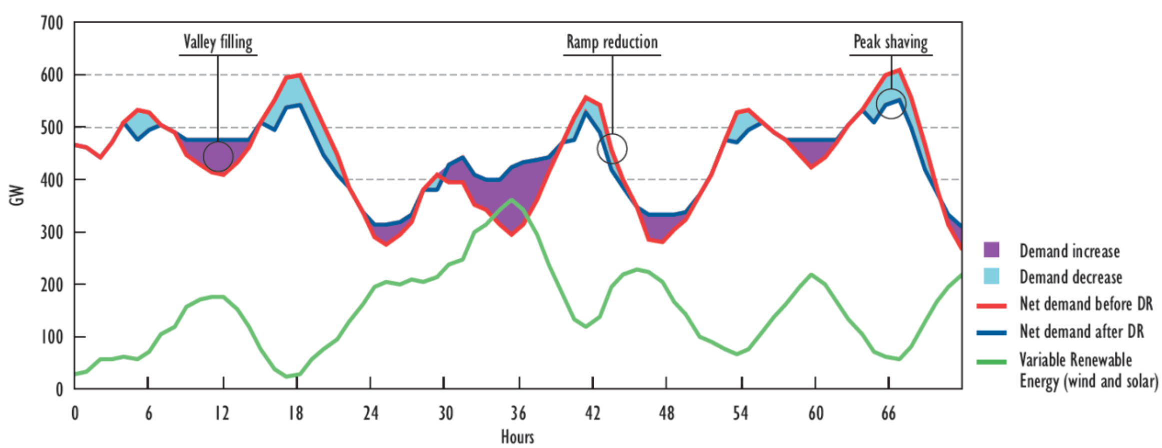


Figure 12: The different roles of demand response with high share of renewables (Baritaud M., et al, 2017)

5.4 Energy Efficiency

With an average price of about 2 to 3 cents per kWh including participant costs, EE is a cost-effective resource and is significantly less expensive than investing in additional generation. The IEA estimates that every dollar spent on energy efficiency avoids more than $2 in supply investments (WEF, 2017).

EE deployment also enables SEC blocks. For instance, an energy-efficient building also allows the end-user to shift its heating or cooling demand: well-designed and efficient buildings maintain the desired indoor temperature better and over a longer period, which makes them more appropriate for pre-heating or pre-cooling, allowing energy consumption shifts to other time periods.

There is a huge potential for EE throughout the whole energy system, and its deployment is just a consequence of smart evolution. Moreover, synergies exist between other smartness components and EE deployment, in such a way that the very integration of the energy system offers very important EE potential, including that for the diffuse sectors, illustrated by the deployment of HPs in the buildings sector and collective-property service-oriented operated EVs in the transport sector.

In fact, from a transition perspective, not articulating the EE deployment is a waste of resources we cannot afford, since the cost of EE is often significantly below the cost of RES deployment, which becomes especially true when we are considering the whole energy sector transition. Moreover, primary materials requirements and scarcity could constraint RES deployment on a global scale unless EE is properly articulated. In fact, in a transition context, the EE savings go beyond the avoided costs for additional RES deployment requirements, since RES deployment at these scales also has land and environmental impacts that should be minimized in the framework of a smart transition.

With regard to EE it is important to highlight that the so-called diffuse sectors (buildings and transport) are the ones that offer the highest potential, which is really good news since these sectors are the ones that have been traditionally harder to tackle.

In (García-Casals X., 2011) transition scenarios for the whole Spanish energy system were developed, exploring the sectorial potential for EE in a detailed bottom-up analysis. Figure **13** presents the resulting energy efficiency potential for the whole energy system and its subsectors for a scenario completing the transition in year 2050. The first think that is important to remark from these results is that the BAU evolution up till year 2050 would lead to significantly higher final energy demand than the current energy demand, and is against this baseline that the post-transition scenario (designated as E3.0 in the figure) has to be compared. As it can be seen, deploying the EE potential allows reducing total final energy demand in year 2050 to 28% of the BAU value (a 72% reduction), with diffuse sectors being able to reduce the final energy demand to 20% of the BAU value (a 80% reduction). These high reduction potentials for final energy demand make a huge difference in the techno-economic-environmental transition implications.

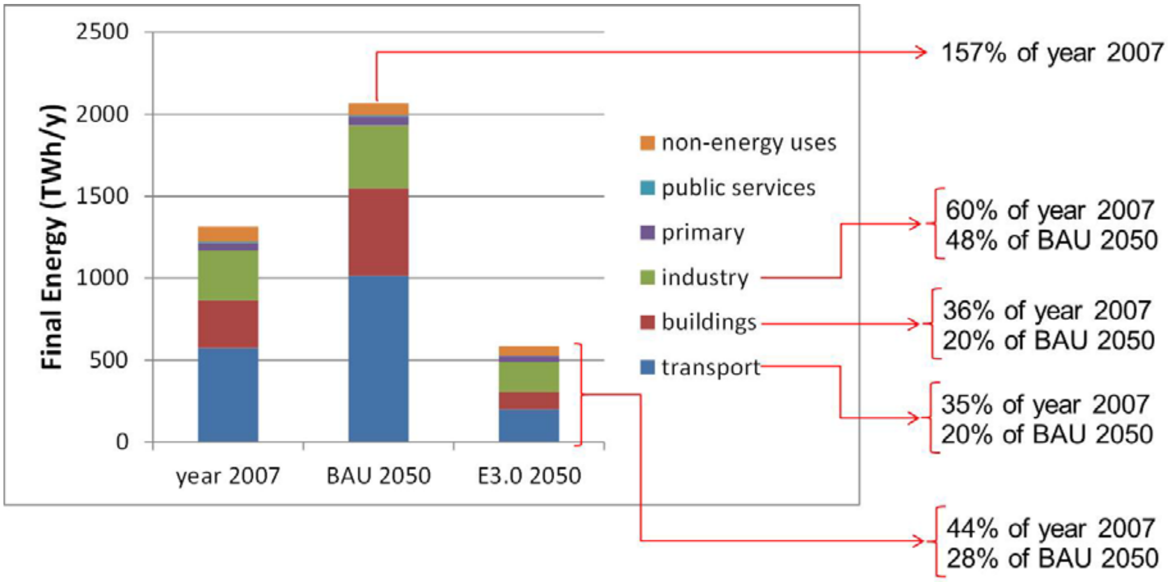


Figure 13: Efficiency potential in Spain for the whole energy system after completing the transition in year 2050, comparing with current condition (year 2007) and BAU for year 2050. E3.0 is the post transition situation in year 2050. (García-Casals X., 2011)

Indeed, as we can appreciate in Figure 14 the total life-cycle energy system costs are significantly lower when following a smart transition pathway that deploys the EE potential than what they would be under a BAU evolution, even if BAU demand would be covered exclusively by RES generation. We should note that a BAU demand covered with RES (BAU w R100% in the figure) is the king of generation-only minded transition that we are currently trying to follow and headed to, where the emphasis on EE and smartness deployment is extremely limited. The huge difference in overall costs between the 'BAU w R100%' scenario and the smart transition scenarios (E3.0 in the figure) is a clear indicator of how far from true smartness would be a transition that just focuses on deploying RES into the energy system.

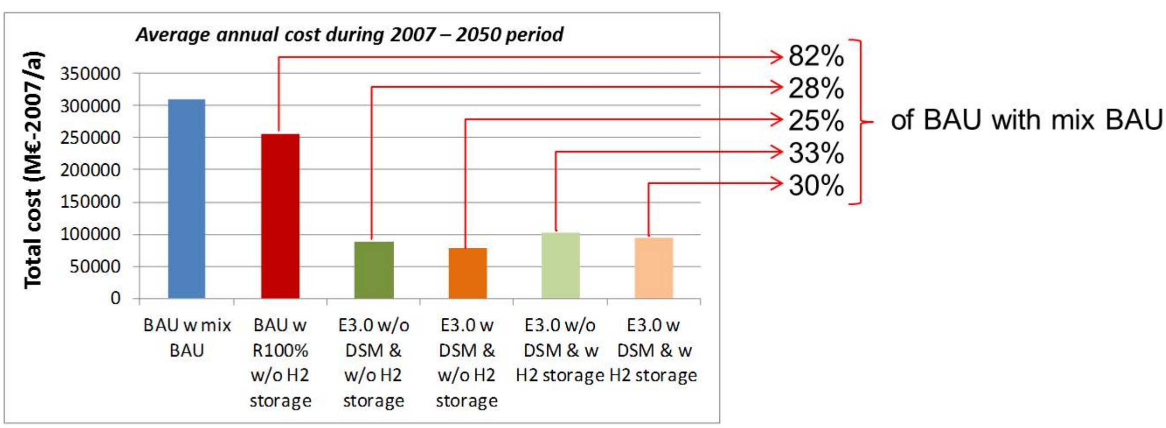


Figure 14: Total average annual costs for the whole energy system during the 2007-2050 period. E3.0 is the transition scenario. BAU with R100% is a scenario with BAU demand fully covered by RES generation. DSM and hydrogen storage are transition options that improve system integration and operation. (Garcia-Casals X., 2011)

But as we indicated above, EE deployment has positive impacts that go beyond the energy system costs, like land occupation and environmental impacts. Indeed, RES deployment does have environmental and land use impacts, and therefore minimizing its use in a 100% RES-based energy system also minimizes all these impacts. Figure **15** illustrates the case of land occupation by the energy system[47] for different 2050 scenarios (E3.0 in this figure designates smart transition scenarios). If we first focus on the BAU scenarios, we can see how the BAU with generation mix-BAU ('BAU w mix-BAU' in the figure) would, by 2050 occupy more than 10% of the Spanish peninsular territory, significantly above the around 2% today's value, as a consequence of the significantly increased electricity demand and the increased use of biomass (even under the BAU). If we would keep on following an only-generation side transition and supply all the BAU demand with a 100% RES-based generation system, the required land occupation would increase to around 24%[48] ('BAU 100%R' in the figure), more than doubling the direct land occupation from the 'BAU w mix-BAU', which is an astonishing high use of the land devoted to the energy system. Still, this not a fair comparison, because the 'BAU w mix-BAU' besides the direct land use represented in Figure **15**, also has a huge (around 270% of the total peninsular Spanish land) indirect land use because of its carbon ecological footprint, which is reduced to zero in the 'BAU 100%R', hence the 'BAU 100%R' is a significantly better scenario than the 'BAU w mix-BAU' in terms of total land use, but still it requires a huge use of the land for the energy system. If efficiency and smartness are applied for the transition, the resulting scenarios land use requirements are indicated in Figure **15** as E3.0[49], where we can see how the total land use requirements are between half to one fifth of the 'BAU 100%R' requirements[50], with the big variation depending on the quantity and origin of the biomass used for the transition energy system. In a transition context, taking into account the Spanish biomass resource limitations, there are two extreme options for covering this part of the energy demand that does not allow for a direct electrification: biomass (including biofuels) or RES-based hydrogen (and/or synfuels derived from hydrogen). Depending on the balance between these two options adopted in the transition scenario, total land occupation oscillates between 4% and 15% of the Spanish peninsular land, the higher figure corresponding to the case of making an extensive use of land-based biomass (but within the available potential). The 'balance H_2' E3.0 scenario is one where all the parts of the energy system not able to be directly electrified are supplied through RES-based hydrogen (or synfuels obtained from this hydrogen), which is an indirect electrification of these end energy uses, and where no biomass at all is used. The 'residual & marine biomass' E3.0 scenario is one where all the required biomass is sourced from marine or residual origins (which do not have land use implications).

---

[47] We should note that the land occupation values presented in this figure

[48] The same order of magnitude of today's total Spanish surface with some degree of environmental protection.

[49] Note that all E3.0 scenarios presented here are without DSM. The deployment of DSM does reduce total land requirements, but only slightly.

[50] We should note that non-energy uses of biomass (for instance as input to manufacturing processes like plastics) are included in the total values presented in this figure.

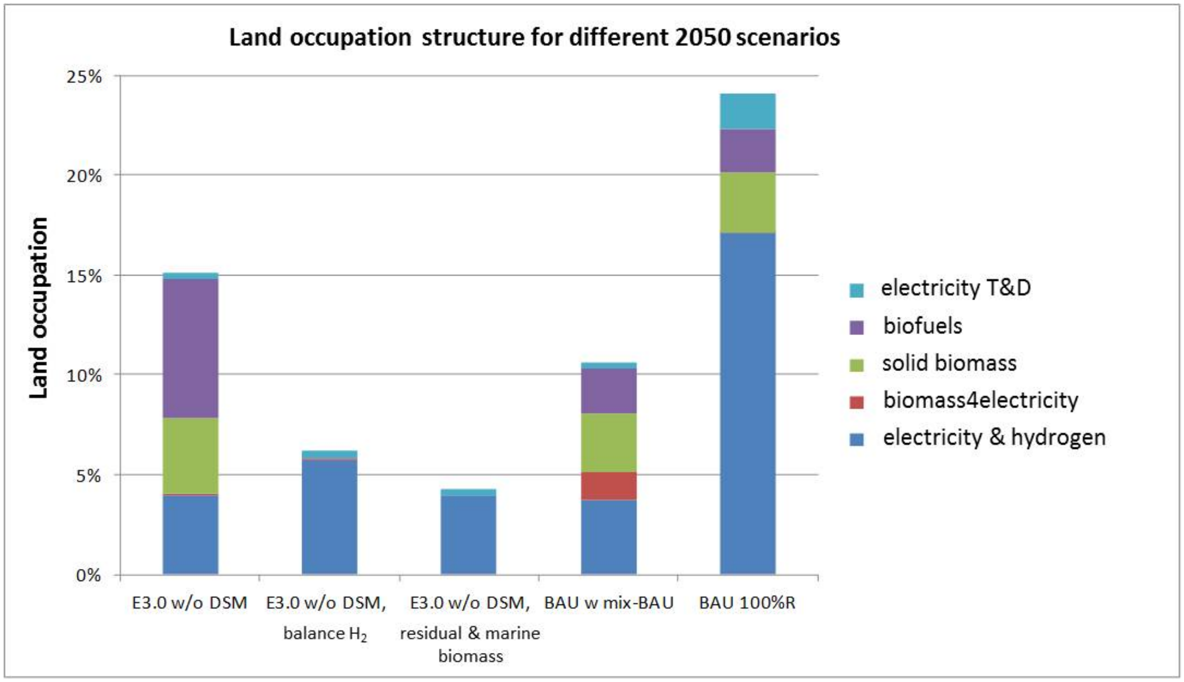


Figure 15: Structure of land occupation by the energy system for different 2050 scenarios. E3.0 are smart transition scenarios. BAU 100%R is a BAU demand scenario with 100% RES generation. 'residual and marine biomass' makes reference to the origin from all the biomass used in this scenario. 'balance H_2' makes reference to the fact that in this scenario all non-electricity final demand is covered by RES-based hydrogen. (Garcia-Casals X., 2011)

The EE potential and its cost-effective deployment has been extensively analysed along the last years. In (Ortiz J., et al, 2016) and (Ortiz J., et al, 2016b) we find the results of an IREC cost-effective analysis for selecting EE measures for refurbishment of residential buildings in Catalonia.

In Catalonia, the energy renovation rate of the building stock is very low, around 0.2% dwellings per year, and it is in the renovation of the built stock where most of the building sector EE potential resides. A similar situation can be found in Spain and in the rest of European countries. Therefore significant effort has gone to define the techno-economical optimum of EE deployment potential in the existing building stock with the aim to facilitate its articulation.

(Ortiz J., et al, 2016) and (Ortiz J., et al, 2016b) present a method to determine the cost-optimal measures for the energy renovation of residential buildings, considering three main criteria: thermal comfort, primary energy use and global economic costs. The method consists of a two-step evaluation. In the first step the passive measures are evaluated using thermal comfort and investment cost as performance indicators, and selecting among all of their combinations those that provide the best balance between thermal comfort and investment costs. In the second step, the active evaluation, all the EE measures combinations obtained from the selected passive measures and the considered active EE measures[51] are analysed using global cost and primary energy consumption as performance indicators, and from the resulting Pareto frontier the cost-optimal combination of EE measures and the most economic deep renovation combination are determined (see CO and DR in Figure **16**), which provides the best combinations among all the potential EE to be applied[52]. The results obtained in this analysis show a high potential for existing buildings' energy performance improvement, even providing a significant life cycle user economic costs reduction from the current value (CO versus BC in Figure **16**), tough deploying the limit of the EE potential would lead to higher life cycle user costs than the current situation (DR versus BC in Figure **16**).

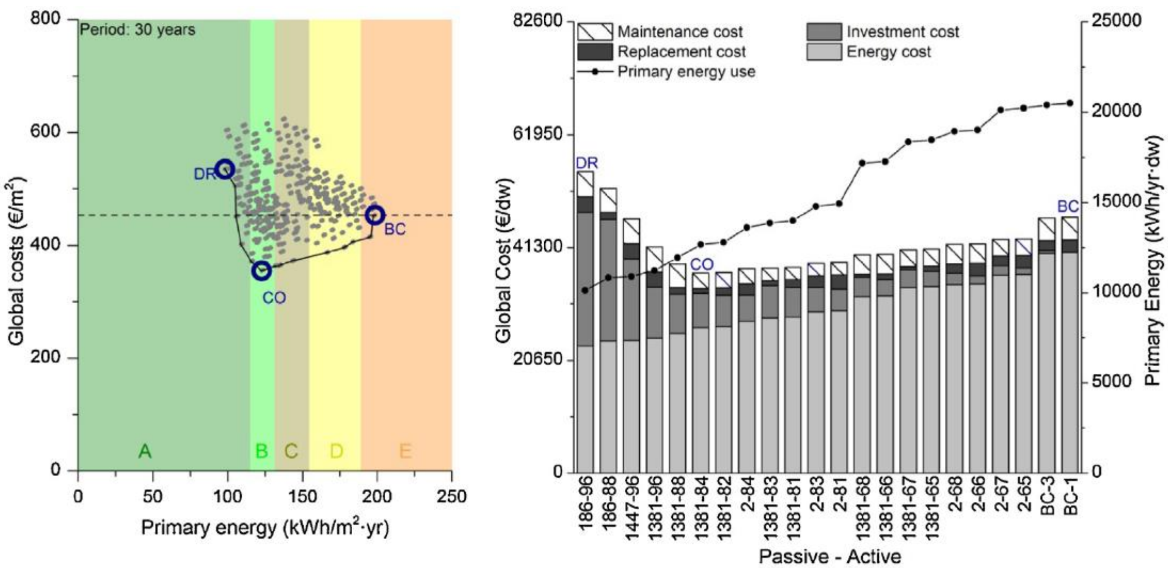


Figure 16: Cost-energy evaluation: primary energy consumption vs. global cost over 30 years (colour background: energy label scale of Total consumption of dwelling). Building located in Barcelona (C2) with natural ventilation. Right: Energy efficiency measures of the Pareto frontier, detailing the global cost distribution: energy cost, investment cost, replacement cost and maintenance cost (The x-label rep-resents the code of the measures implemented in each scenario (passive-active)). BC represents the base case (the building without any measure); CO the cost optimal measure; and DR the deep renovation scenario, which provides the maximum energy saving with the lowest global cost. (Ortiz J., et al, 2016b)

Tough it is very important to undertake analysis that provide guidance about the best EE measures combinations among the huge available portfolio, it is also important for the

[51] It should be noted that this study included smart meter supported awareness campaigns among the different considered EE measures, and concluded that the development of awareness campaigns has a high potential to reduce the energy consumption. In fact, the awareness campaign represented the most effective measure, in terms of energy savings by euro invested.

[52] The EE measures considered in this study were: façade and roof insulation, natural ventilation, solar protection, natural lighting, improved windows, condensing NG boiler, efficient AC equipment (EER=4.55), better H&C control, LED lighting, smart meters-based awareness efficiency campaign, together with ST for DHW and PV as RES DG.

application of these results to keep in mind that the results from cost-optimal EE deployment present a high sensitivity to several factors:

- The EE measures portfolio considered in the analysis. For instance, the possibility to use HPs for heating and DHW, or the deployment of efficiency measures throughout the building's appliances[53].
- The economic context under which the analysis is performed. A consumer's current microeconomic context, where externalities are not captured, tough it provides indication of the EE deployment that can be expected without support mechanisms or the required level of support to incentivize a given EE goal, cannot be the main transition driver. Indeed, the transition is required just because of the externalities associated to the current economic context, and therefore, the overall social costs internalizing all the externalities is the appropriate indicator to guide the transition pathway. Cost-optimization analysis based on current consumer costs or on overall social costs can lead to significantly different but complementary results.
- The scenario under which the cost analysis is undertaken. Indeed, current conditions are not an appropriate characterization of the post or mid-transition context. With regard to costs, beyond the inflation driven cots evolution, costs will also evolve because of structural changes (RES deployment, power market evolution,…) and evolution along learning curves. Primary energy factors and emission factors also evolve along the transition (because of the RES integration in the power system and the increasing availability of RES-based fuels).
- The degree of integration captured in the analysis. As already mentioned, one important transition component is the energy system integration. Therefore, cost optimization analyses are better transition-aligned if they also consider an integrated approach. For instance, from the overall energy system point of view, the optimum EE deployment could be significantly different from that corresponding to an analysis of the building sector on its own. Indeed, not all the EE measures provide for instance the same degree of EF, and it is already known that from the overall energy system point of view sacrificing EE in favour of increased EF could lead to a better overall result. When aiming at optimizing the transition, system components like buildings or transport should better be considered including their interactions with the rest of the energy system, since this can unlock synergies that allow reaching significantly higher overall performance.

[53] *Electricity use by appliances, in a transition context, becomes the dominant part of the building's energy footprint.*

5.5 Onsite and offsite RES generation

A SEC has to be fully supplied by a RES-based energy system. A gradual approach to the full coverage of a SEC's final energy footprint with RES can be pursued as a roadmap, tough always keeping and communicating a very clear balance from the current situation. However, the final SEC goal is to cover the whole of its final energy footprint with RES generation, and even beyond that in order to internalize its compensatory mitigation requirements steaming from fair transition considerations (see §8.4.11 for more details).

However, taking into account that the primary SEC's goal is contributing to articulate the overall transition, and that on this regard its interaction and integration in the overall energy system is of paramount importance, a SEC should not be limited to onsite RES generation, using its smartness attribute to allocate its related RES generation in such a way that the overall transition impact is optimized.

Therefore, we can distinguish two kinds of SEC-related community-based RES generation:

- Onsite RES generation, which can be building integrated or in common public spaces.
- Offsite RES generation[54], which can be connected to the power grid where the SEC is integrated, or beyond that even in other continents (for fair transition considerations).

Different considerations are to be taken into account when deciding the right split between onsite and offsite SEC-linked RES generation:

- Available RES resources, incorporating local siting constraints as shading and orientation.
- Environmental and land impacts associated to RES deployment.
- Power system and distribution grids requirements to integrate RES.
- Value of regulation and flexibility services that can be provided to the T&D grids
- T&D losses.
- Costs of RES generation, which can be quite sensitive to the restrictions and constraints on technology and size imposed by different siting contexts.
- Type of RES and T&D infrastructure constraints. For instance, for thermal RES generation as that from ST, biomass or geothermal, onsite generation (whether at building level or in community spaces through a DH network) is the only feasible option.

[54] It is important to note that in the case of offsite RES generation, clear offsetting rules are required to stablish a clear link between the SEC and the associated RES generation.

- The demand targeted by RES generation. For instance, the SEC-linked RES generation associated to fair transition and mitigation compensation considerations, targets a demand that takes place outside the SEC physical boundaries (even in other continents), and therefore has to be addressed by off-sit RES generation.
- Availability of hydrogen T&D infrastructure. When the SEC-linked RES generation targets to cover that part of the overall SEC final energy footprint that cannot be directly electrified (air transport, marine transport, freight road transport), the electrolyzes to produce the hydrogen could be based both onsite or offsite, depending on the options to access hydrogen T&D infrastructure[55]. In any case, the RES-based electricity generation needed to produce the RES-based hydrogen can, as with the rest of the SEC-linked RES generation, be sited onsite or offsite depending on the right balance between the above mentioned criteria.

In typically densely populated urban spaces from Iberia even when considering building integrated RES, this is not at individual dwelling level but rather at communal building spaces (PV, ST,…). This concept of communal space use for RES integration can be extended beyond the individual building boundaries. In the case of electricity generation RES this level of aggregation brings about cost advantages (investment and O&M), and opens the door for a better techno-economic integration with the local distribution grid, tough property and licencing issues should be properly managed. However, when communal thermal RES installations are considered (DH & DC), considerations about piping distribution losses, redundancy in distribution energy infrastructure, and integration capacity with the rest of the energy system, could lead to disregard these options for a SEC.

Onsite RES generation, besides its energy contribution to the electricity system, can also provide community-based regulation and ancillary services[56]. Some of the DER aggregators that are currently already working in Europe, aggregate a portfolio of DG equipped with controls that allow automatic upward[57] and downward contributions even to the primary (the fastest) frequency regulation. In these systems, if the system

[55] *For instance, if the hydrogen is distributed through the existing NG network, hydrogen generation can be onsite.*

[56] *Offsite RES generation can also provide these services, but probably would be managed by other stakeholders than the SEC aggregator.*

[57] *In order to have upwards regulation capability in normal conditions the DG resources must be operating below its nominal point (typically at 95% of its nominal capacity). Otherwise, the system can provide only downwards frequency regulation. The issue is that currently many frequency regulation markets require symmetry in the offers, and therefore an only downwards regulation resource is not allowed to participate in the market. But in a smart system upwards regulation would be reserved for other resources (like DS) in order to minimize the curtailment associated to normally operating below the nominal point.*

frequency reduces, the aggregated DG resources increase their generation, and if the frequency increases the aggregated DG resources reduce their generation, which all together becomes an automatic frequency control from a VPP sitted at the SEC location.

5.6 Distributed Storage

DS achieves its greatest value at the system level when it is connected to the grid and a full set of services can be realized at various levels, such as network management services (frequency regulation, voltage support), utility services (resource adequacy, congestion relief) and customer services (backup power, demand charge reduction, energy arbitrage).

DS storage can be aggregated to become a VPP offering different regulation services, from fast frequency regulation (primary control) and slower frequency regulation (secondary and tertiary), to peak shaving and energy arbitrage. For primary frequency regulation applications, a fraction (typically 10%-20%) of the battery capacity is reserved to automatically offer this service, and grid frequency is monitored: If grid frequency reduces below the low set point the battery is discharged, and if grid frequency increases above the high set point electricity is charged into the battery. Therefore the aggregated system operates like a VPP with automatic frequency control.

The aggregation of DS to provide fast frequency regulation services (SIR and FFR) has one of the keys[58] to fully eliminate conventional thermal power plants from the power system, getting rid of this regulation requirement for spinning thermal inertia to keep connected to the power system, displacing RES generation and with ever decreasing efficiencies and increasing specific emissions[59] as RES penetration increases. Indeed, 'digital' or 'synthetic' inertia provided by batteries not only can cover for the SIR and FFR services nowadays provided by the inertia from spinning thermal power plants, but in fact can improve the grid frequency control capabilities (Reynolds P. et al, 2017).

Energy storage is becoming a very clear enabler transition technology that facilitates energy system integration. In power systems, the storage modularity allows for its deployment through the different levels (transmission, distribution, and low voltage networks) providing a variety of services.

---

[58] *Indeed, there are other keys to eliminate the requirement for spinning conventional power plant inertia: One of them would be using the DR capabilities, tough only very fast sub-second DR could provide SIR and FFR services. The other is to increase the amount of CSP connected to the grid.*
[59] *Because of the requirement for thermal power plants to work at part load in order to keep enough inertia connected to the system, which makes that CCGT GHG emissions come close to those from a coal plant.*

[Figure 17] summarizes the roles that storage can play along the transition up till the 2030s in five different fronts: Off-grid and isolated grids, grid services, VRE integration, self-consumption and electro-mobility.

The modularity and performance of storage systems allow them to provide very valuable services to all the voltage levels of the T&D system: Transmission network, Distribution network and low voltage network ([Figure 18]). As of today we are already witnessing the development of batteries both in grid connected applications like the 'big' (100 MW) South Australian utility-scale battery commissioned by Tesla at the end of 2017 and surpassing the expectations it had generated already one month after its commissioning (McConnell D., 2018), and household grid-connected applications in several parts of the world.

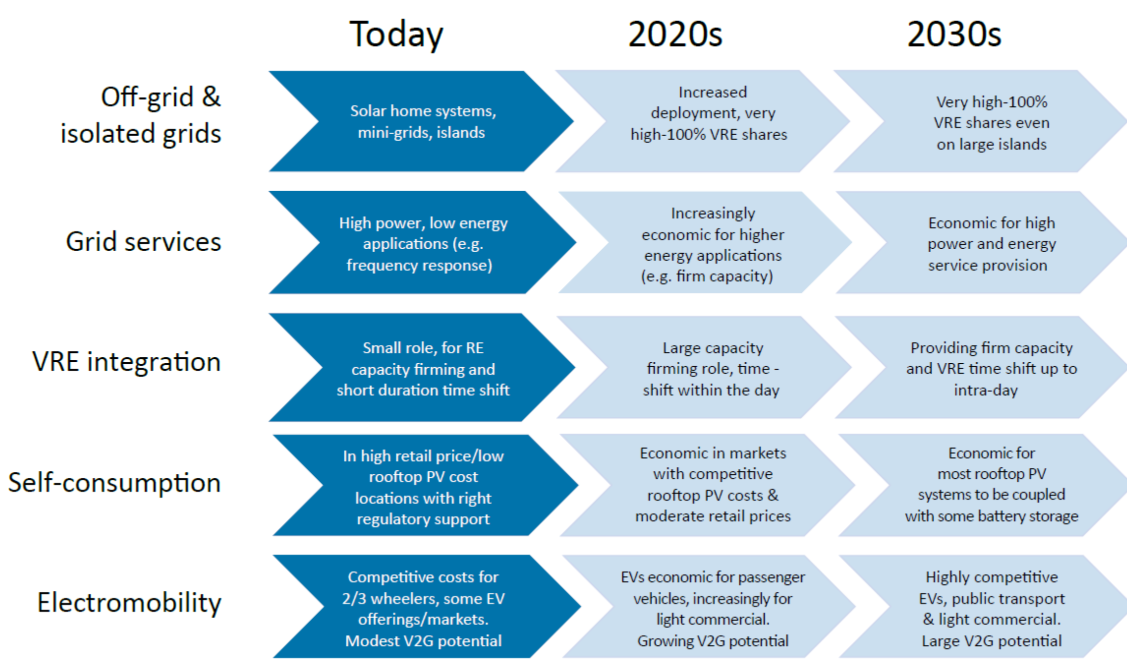


Figure 17: Electricity storage needs in the energy transition (Ralon P., 2017)

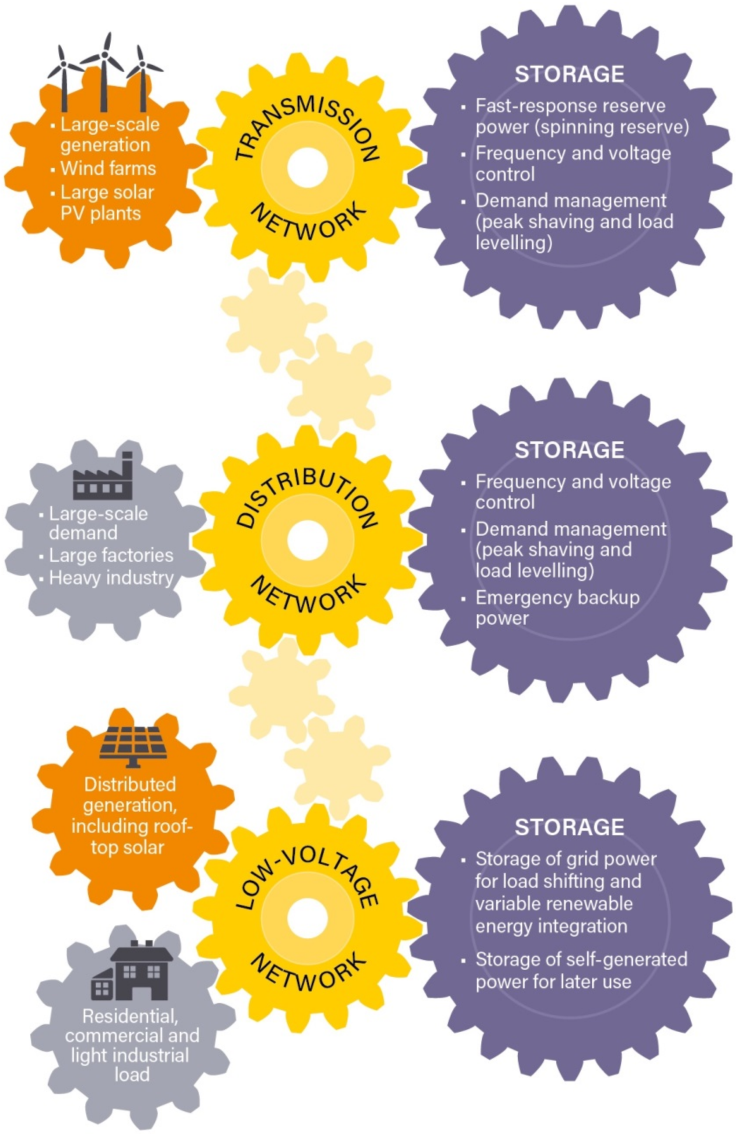


Figure 18: Storage Applications in Electric Power Systems (REN21, 2017)

5.7 Energy system integration

Energy system integration is another of the main transition and SEC blocks, for it allows unlocking synergies and the full potential from the different energy system components, which by itself constitutes already a big share of the smartness content.

Since electricity can supply most of the energy services demanded by society (while some of these services can only be provided by electricity), and RES penetration into the electricity sector is the highest throughout the energy system (with many technological options available and mature enough), it has become the main electrification vector.

Other aspects also converge on providing this outstanding transition role to electricity:

- Electrification is often linked to EE deployment. That is the case in both diffuse sectors, where HPs in the building sector and EV in the transport sector offer a huge efficiency potential together with its integration with the rest of the energy system.
- Avoiding redundancy in energy infrastructure by eliminating this parts that in a transition context are devoted to an ever shrinking demand.

5.7.1 Transport electrification

The electrification of transport offers a huge EE and EF potential to support the transition by tackling this up to now so problematic subsector from the point of view of primary energy consumption and GHG emissions.

Both direct and indirect electrification form part of the transport sector integration.

Direct electrification can be used to cover a significant share of the mobility services needs through EVs (cars, busses, urban freight transport,…), trams, metro and trains: These are mainly the urban mobility services, and therefore its electrification not only provides huge EE and EF potential, but also brings about a drastic reduction of pollution levels in urban areas. The transition in this portion of the transport sector has seen low deployment rates along the last decades, but during the last years we are assisting to very high increases in EV deployment, while many regions of the world have issued along the last couple of years official pledges to completely substitute the ICE by EVs in the following decades, unlocking what could be a fast death spiral for petrol cars aiming at completing the process as soon as 2030 (Parkinson G., 2017g): Norway by 2025 (Staufenberg J., 2016), India by 2030 (Mahapatra S., 2017) , China (McDonald J., 2017), France by 2040 (Chrisafis A., Vaughan A., 2017), UK in 2040 (Asthana A., Taylor M., 2017), Netherlands, Germany,…

Long haul road freight transport could in principle seem more difficult to be directly electrified, but we are already assisting to the commercial deployment of competitive electric trucks (Parkinson G., 2017f).

Beyond that, there are significant shares from a SECs overall energy and emissions footprint related to transport and that cannot be directly electrified: Air transport, sea transport, and the part of road freight transport not suitable for electrification (if any). Indirect electrification through hydrogen production with RES-based electricity can tackle[60] this part of the energy and emissions footprint while simultaneously providing a very powerful energy system integration strategy.

Direct electrification of transport provides a very straight forward energy system integration strategy, where not only are mobility services efficiently covered with RES-based electricity, but the EVs themselves can provide EF services to the buildings where they are connected to, and to the whole power system (V2X). Figure **19** shows how the V2G services are expected to expand as EVs deployment increases.

The deployment of EVs brings about a parallel deployment of DS and huge DR capacities. In fact, the very deployment of battery based stationary DS is being spurred by the batteries' cost reduction associated to mass EVs deployment.

Moreover, EVs deployment in a smart transition context also facilitates the articulation of mobility services BMs with a huge potential to reduce the number of vehicles in the roads by introducing smartness and aligning BMs with the final goal: Supplying satisfactory mobility services instead of selling EVs as a product. This evolution from individually-owned and inefficiently-operated to collectively-owned and efficiently and smartly operated EVs would reduce congestion, release a lot of urban space for people's use, and very significantly reduce the industry sector energy and material requirements that currently go into vehicles manufacture.

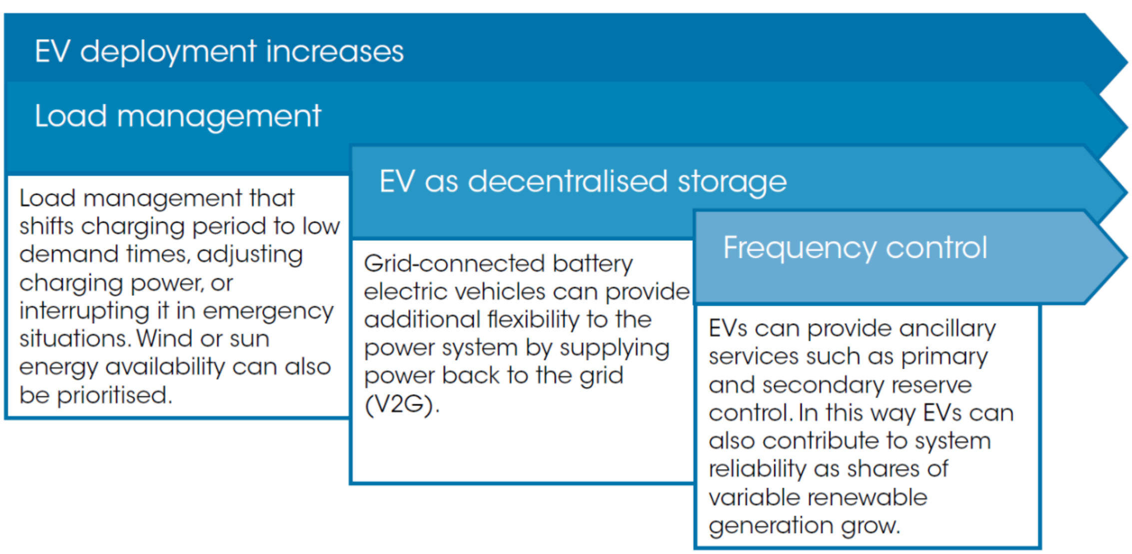


Figure 19: V2G service expansion as EV deployment grows (Ralon P., et al, 2017)

---

[60] *Another option to tackle part of this share of the transport emissions footprint would be the use of biofuels, however, the limited sustainable biomass resource on the one hand, and the environmental and social impacts associated to an extensive use of biomass for energy purposes, will probably limit its use during the transition (Garcia-Casals X., 2011), (Garcia-Casals X., 2017b), requiring other means to tackle this ever growing share of the energy and emissions footprint.*

5.7.2 Building services electrification

In the current non-integrated and FF-based energy system, buildings' energy services are covered by different energy carriers, with electricity typically representing a relatively small share (below 50%) of the final energy demand. In fact, in the current context, electricity is mainly used for those energy services that can only be satisfied with electricity (lighting, appliances, fans, pumps,…), which we could call 'structural electricity services'. Indeed, in the pre-transition energy system context, 'non-structural electricity services' (heating, DHW,…) were better satisfied both from efficiency and economic points of view[61] through the use of FFs. In fact, in the pre-transition energy system context, the use of a high exergy resource like electricity to satisfy energy services requiring low exergy supply (low temperature heating) was considered a heresy, and since most of the electricity was generated with FF plants, its use to cover low temperature heat demand would ultimately lead to higher overall FF consumption and GHG emissions.

However, as the transition unfolds this picture changes completely. On the one hand electricity is generated with RES, and on the other hand EE deployment makes that the final building's energy footprint is strongly dominated by structural electricity components.

Indeed, in (Garcia-Casals X., 2011) scenarios for the evolution of the Spanish building energy stock final energy demand in the 2050 time horizon were developed for both the BAU evolution and a climate aligned transition[62]. The building stock was represented by 10 building typologies and uses[63] in the 47 peninsular Spanish provinces. Figure **20** and Figure **21** present the evolution of the final energy demand structure when moving from the BAU[64] to the transition scenarios (E3.0), for both the multi-family house and office buildings sitting in Burgos. These figures illustrate the general result found for all climate zones and building typologies, which is that structural electricity consumption strongly dominates the final energy demand from the building stock in a transition context[65], which

---

[61] And also from a GHG emissions point of view.
[62] Evaluating and deploying the full transition potential.
[63] Single family house, multi-family house, office, warehouse, supermarket, commerce, hotel, hospital, school and restaurant.
[64] We should note that the BAU is significantly more efficient for non-structural electricity final energy demand than the current building stock, since the only current efficiency requirements on buildings mainly target the non-structural electricity final energy demand. Therefore, in the current building stock the relative share of structural electricity demand is still smaller than for the 2050 BAU.
[65] With this regard, it is important to highlight the relevance of improving the building's structural electricity demand characterization, so that appropriate tools are available to analyse the implications of the building stock interaction with the grid. In (Ortiz J., et al, 2014) an IREC contribution on this front is presented, proposing a stochastic model aimed at describing the electricity consumption of building clusters and neighbourhoods (also applicable to individual households), based on a probabilistic approach and tuned to the Mediterranean region of Spain, introducing a significant improvement over the traditional fixed consumption profiles derived from
statistical data completely unable to support any prospective underpinned by structural changes like the energy system transition.

is a natural consequence of the deployment of efficiency measures with higher energy reduction demand potential in the non-structural electricity energy services (heating, DHW…).

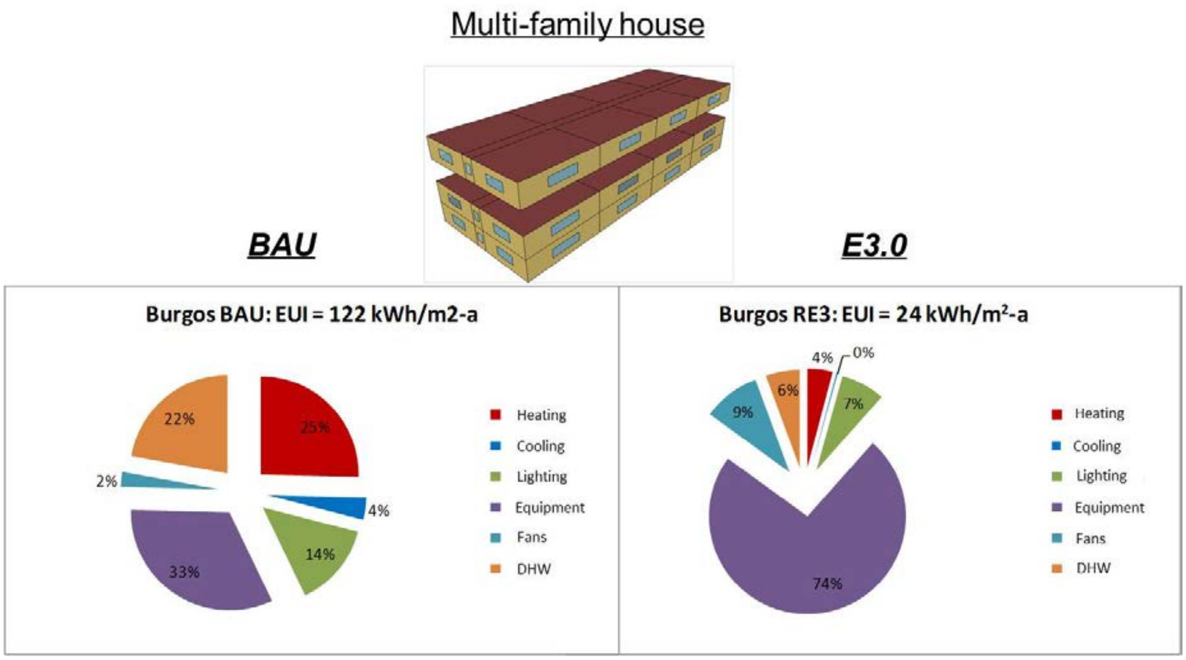


Figure 20: BAU and transition (E3.0) final energy demand structure for a multifamily house building in Burgos (Spain) by 2050 (Garcia-Casals X., 2011)

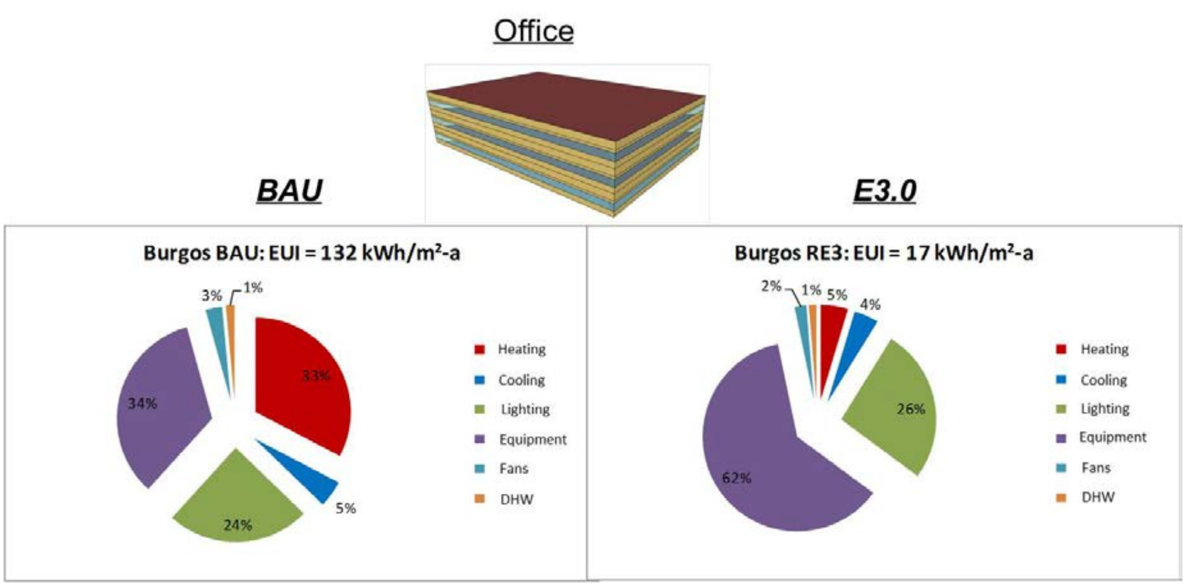


Figure 21: BAU and transition (E3.0) final energy demand structure for an office building in Burgos (Spain) by 2050 (Garcia-Casals X., 2011)

The facts that on the one hand the final energy footprint from a post-transition building stock is strongly dominated by structural electricity, and on the other hand that ALL the building's energy services can be efficiently covered with electricity, makes it redundant (and difficult to justify from an economic point of view) to invest in additional building's energy infrastructure beyond the building connection to the electricity grid.

Moreover, by fully integrating the building into the energy system through all its demand electrification, the full potential of EF and DR from the building stock can be articulated by incorporating all the DER capabilities into the power system.

With this regard it is relevant to see how fast the main focus regarding the building stock transition is shifting towards EF and integration issues, going beyond the typical building's share of energy demand to include even a significant part of transport demand (V2X)[66]. Indeed, just few years ago the main focus with regard to the building sector transition was on EE and DG deployment, through the NZEB concept[67], with a rather egocentric approach where the building sector seldom looked beyond its conventional boundaries to see what was going on with the rest of the energy system. At most, there was some activity looking for appropriate indicators that allowed beginning to characterize the interaction of NZEB with the surrounding grid (Salom J., et al, 2014) through indicators as the dimensioning rate[68] and the connection capacity credit[69].

Nowadays the focus shifted away from NZEB to nZEB stressing EF as one of the main building performance indicators, and therefore focusing on the impact of the building stock in the whole integrated energy system, searching for indicators appropriate to characterize this EF (Pernetti R., et al, 2017), and explicitly acknowledging that the best contribution of the building stock to the overall transition passes through its EF optimization, facilitating overall energy system operation and RES integration, even if this means increasing its energy demand[70].

---

[66] Through distributed P2X the building's integration role of the transport sector could go well beyond V2X to embrace the remaining of the transport sector energy demand through the distributed production of hydrogen and synfuels.

[67] The NZEB concept by itself has a very narrow perspective by focusing only on a net balance at building level without taking into account whether this leads to an improvement or to additional burdens into the overall energy system.

[68] Dimensioning rate is the maximum absolute value of the net exported energy normalized with the nominal design connection capacity between the building and the grid.

[69] Connection capacity credit, or power reduction potential is the percentage of grid connection capacity that could be saved compared to a reference case.

[70] For instance due to the impact of storage losses.

5.7.3 Hydrogen and synfuels

Chemical storage of electricity (P2X), where electricity is stored within the chemical bounds of different gaseous or liquid molecules (hydrogen and/or different synthetic fuels - synfuels), is called to play an important role in RES-based energy systems.

Indeed, P2X provides:

- Means to store huge amounts of energy
- Very high specific energy compared to other storage technologies (up to the 10000 Wh/kg from FFs), which makes this stored energy very easy to transport.
- Huge flexibility to an integrated energy system, since generation and consumption are completely decoupled through the chemical storage.
- Means to address the transition from those parts of the energy system not easy to be directly electrified (part of the long distance freight transport, air transport, sea transport, industry,…)
- Optimization of the use of existing infrastructure (FF distribution and storage facilities)

In fact, in the framework of a RES-based integrated energy system, P2X can be considered as an indirect electrification, where the demand is covered through RES-based electricity which is used to produce hydrogen and synfuels.

When gaseous fuels are obtained we talk about P2G, which involves water electrolysis to obtain hydrogen, and if required, a subsequent methanation where the hydrogen is combined with CO_2 or CO to obtain methane. Both hydrogen and methane can be used to provide the final energy service through combustion equipment or FCs. Figure 22 presents the P2G process chain.

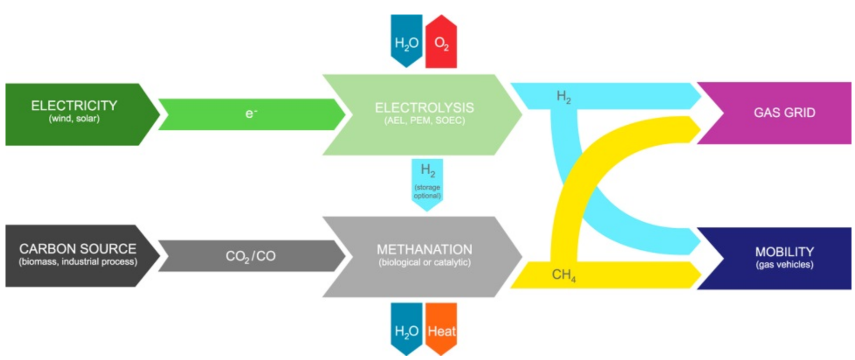


Figure 22: Power-to-Gas process chain (Götz M. , et al, 2016)

But starting from hydrogen and CO_2, chemical processes are also well known[71] to synthesize liquid fuels, providing the P2L overall process with the capability to produce RES-based fuels that can be integrated in parts of the energy system that do not render themselves for direct RES-based electricity use, like air transport (Figure **23**).

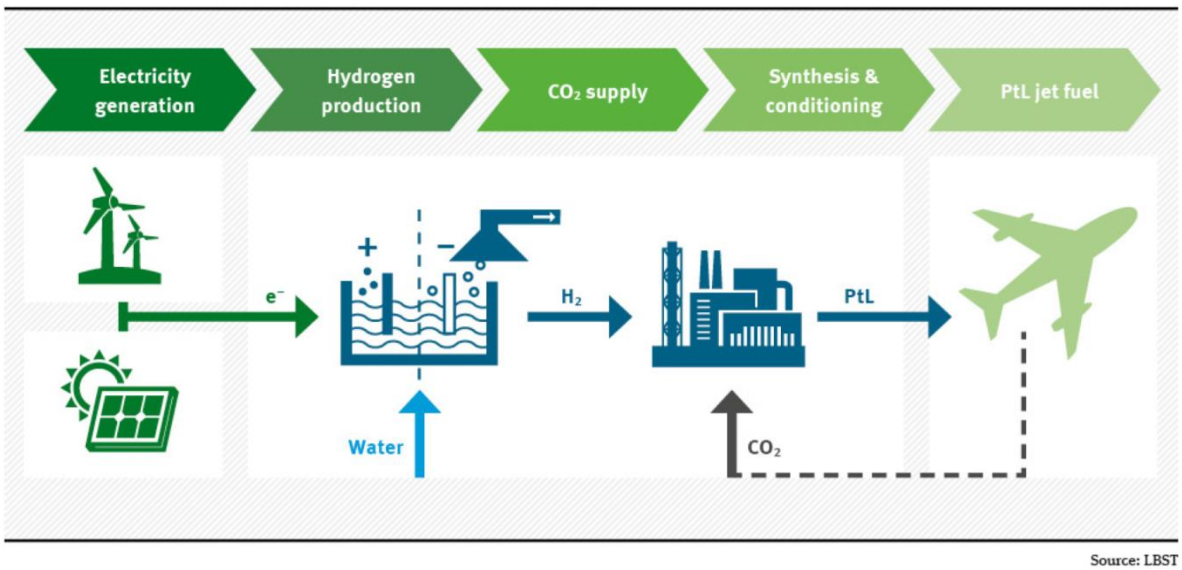


Figure 23: Generic scheme for P2L process chain (Schmidt P., et al, 2016)

At first view it may seem that air transport or sea transport have little to do with a SEC's energy and emissions footprint. But that's just an often applied 'convenient' illusion at the community or individual level, and a very 'inconvenient' one at the global level, because it has traditionally left in no man's land this part of the GHG emissions footprint, which is currently rocketing up and bound to become the dominant part from our overall emissions footprint in a transition context, capable on its own to blow up the full available carbon budget for climate compatibility (Garcia-Casals X., 2017b).
But in fact there is a significant part from the overall SEC emissions footprint that is associated with these transport modes: Most of the goods consumed within the community have been transported long distances (here, the smartness from a SEC should also act to minimize this in favour of local consumption), and community members and businesses in Iberia do make a significant use of air transport, whether directly or indirectly through their interactions with the economic system.
Recognizing this responsibility and contributing to tackle its implications is part of the SEC smartness deployment, and a recognition that without a successful global transition there won't be any meaningful local transition.

Picking up the SEC's responsibility for this part of the SEC emissions footprint it also introduces additional flexibility at community level through the onsite or offsite hydrogen generation from RES-based electricity, which opens up the door to a huge amount of DR and DS.

[71] *For instance the Fischer-Tropsch synthesis and the methanol synthesis.*

If T&D networks like the pre-transition NG network are locally available within the SEC, the produced hydrogen can be injected into this grid by prosumers, just as they do with locally produced RES-based electricity.

If local T&D networks for hydrogen are not available, the community can choose to produce its hydrogen offsite (or at least participate in the required RES-based electricity generation), or even opt for a community level DS and regulation facility based on the use of FCs to convert back the locally generated hydrogen into electricity.

5.8 Energy infrastructures

5.8.1 Smart meters

A smart meter is an electronic device that records energy consumption and should enable a two-way communication between the consumer and the utility or aggregator, as well as allowing dynamic price signals responding to the energy system and market status to reach consumers, and capabilities to access and manage the consumer's loads.

Accurate measurement of the energy consumption to provide real-time data on the energy used is a requirement to valorise DR services. Without smart meters allowing end-users – in particular residential and commercial users – to be compensated for the validated savings achieved through DR actions, the full potential from DR participation into markets cannot be articulated.

Smart meters can also fulfil an important task in articulating consumer's responsibility about their consumption patterns, by providing them with accurate and straight forward information about the implications from their consumption patterns, as well as the means they have to improve them, in such a way that synergies with the energy system can be unfold.

Figure 24 presents the current state of the smart meter roll-out across EU Member States (see more about it in §11.4).

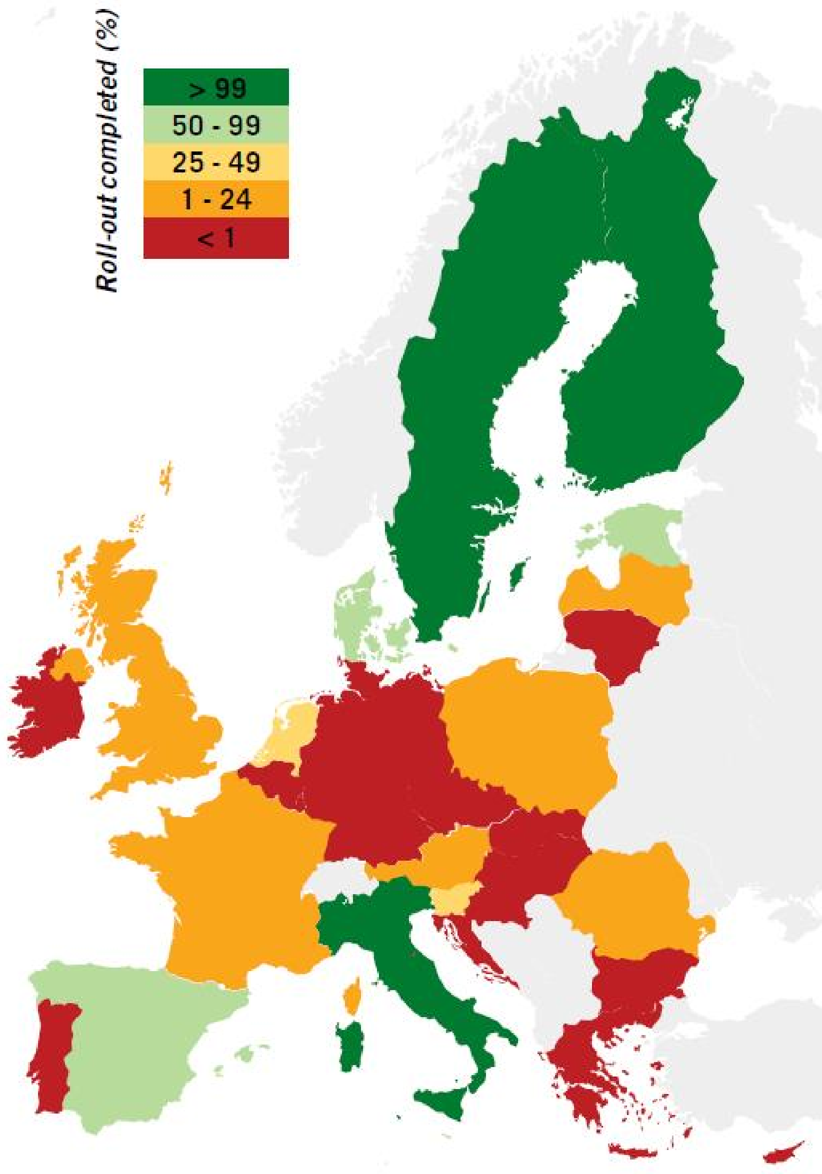


Figure 24: Share of household customers equipped with smart meters for electricity in 2016 (Source: The EU Building Stock Observatory [2] and ACER [12]) (De Groote M., et. al, 2017).

However, it is not enough just deploying SMs: Appropriate regulation and markets need to be in place to allow DR to be articulated through smart meters, and the appropriate BMs to materialize all their potential should be deployed.

Far too often the SMs deployment has been confused with smartness deployment, perhaps expecting that smartness would spontaneously grow around the SMs, and very often with utilities pretending to access by free (no sharing economy mechanisms) the data and resources from their customers. But in fact it is everything else that has to be deployed around SMs and deep into the SEC structure what constitutes smartness, with the SM just being a gadget that enables smartness to flow throughout the system.

5.8.2 Power distribution network

Electricity networks are a key transition component, since they enable cost-effective and manageable RES generation to supply the demand, by increasing the power system flexibility through geographical interconnection of non-correlated generation and demand while granting access to other EF sources, and allowing to access good RES resource sites.

Moreover, the electricity networks are (at least in Iberia) an already existing infrastructure, since the current power system has been based on a centralized production model that required of this infrastructure to deliver the electricity to end users. Therefore, it certainly would be smart to make the best use of this existing infrastructure to facilitate the transition.

In fact, electricity networks have already played a major transition role by facilitating the onset of mass RES deployment, which has allowed RES technologies to advance along their learning curves up to a point where they are not only transition-competitive but also cost-competitive.

In fact the fast deployment rate of RES through the power sector has shaped the very transition concept that we have as of today, enabling a way to fast decarbonisation, facilitating the transition from the complex diffuse sectors, and providing the means for energy system integration through its electrification.

And this energy system integration opens the door to huge EF resources arising from the synergies between all the power system elements (generation, demand, storage,…).

All of this makes of electricity networks a relevant asset to facilitate the transition.

However, the very development of RES technologies providing DG at competitive costs, altogether with the availability of smartness-facilitating hardware and DS technology, makes that prosumers are no longer captive of electricity networks, and therefore the electricity network (and the BMs associated to it) has to convince prosumers that it constitutes the most appropriate transition path for them.

Indeed, as of today grid defection is becoming an alternative transition path, and the bad track record of how utilities, retailers and regulations have and are treating prosumers (specially in Spain), constitutes a strong driver for searching alternative transition pathways to those linked to electricity networks. In fact, globally speaking energy access improvement, and therefore transition onsets, are already relying mainly on grid-isolated RES deployment in stand-alone or micro grid applications. Even in the global North, micro grids are also being pursued as a climate change adaption element to increase a community's resilience by allowing a community to be disconnected from the main grid when harsh environmental conditions compromise centralized electricity supply, like in the case of the blockchain enabled Brooklyn micro grid (Spector J., 2017)

Hence, electricity grids could keep on being a cornerstone of the energy system, but they have to win this status by convincing prosumers. In fact this is healthy competitiveness, and will force networks to face the dilemma of giving the best of them and become still far more relevant for the energy system of what they are today, or lose relevance.

The distribution level is the one more closely related to the SEC, together with the potential low voltage own community microgrid. However, the SEC can also have interactions with the transport part of the grid through the services offered by its aggregator to the wholesale market or through its offsite RES generation.

With regards to the distribution grid, the smartness deployment related to the interaction between the SEC and the DSO requires an evolution of the DSO regulation and BMs that incentives them to go beyond CAPEX pole & wire investments in order to reap the benefit of its synergies with what the SEC can offer.

5.8.3 District heating & cooling

DH and DHC is another energy infrastructure at community level.

In the past, while we were completely within the FF-era, these infrastructures offered huge efficiency potential by enabling more efficient FF-based heat generation than what could be reached at household or building level. A clear example is the use of efficient CHP to supply the thermal load from buildings, extensively used by Denmark since the 1980s.

However, in a transition context a careful evaluation is required to evaluate if this energy infrastructure is the best transition option or if it can become redundant and other options based on distributed electrification would be more efficient and provide better EF and integration.

Indeed, there are several elements to consider in order to evaluate the suitability of DH or DHC infrastructure in a transition context:

- Heat distribution losses by unit of useful energy delivered. In a context with highly efficient buildings, the relative heat losses from DH or DHC networks increase significantly, and their economic performance is reduced.
- Advantages from centralizing heat generation at community level, like the possibility to use more efficient HPs, to integrate more techno-economically

efficient ST generation or seasonal thermal storage, or to improve the DR management.

- Techno-economic performance of the additional distribution infrastructure (heat distribution network). Indeed, the electricity network will have to be deployed anyway because it is the one that provides by far the dominant part of the final SEC energy demand to final users, electricity is rather efficiently distributed through this network, and all the energy services provided by DH or DHC network can be electrified.

The Danish case is an interesting one to analyse because their early and extensive adoption of DH and CHP. When analysing Danish transition it can be concluded that their heavy reliance in DH and CHP, tough it was very positive in the past, it has introduced significant barriers in the transition towards a smart and RES-based energy system because of the stiffness associated to these energy infrastructure, which led to almost a decade of transition stagnation (Garcia-Casals X., 2017c).

Nowadays Denmark is trying to tackle this situation through and extensive use of biomass for low temperature heat generation, which can introduce significant sustainability problems as analized for the Spanish transition in (Garcia-Casals X., 2011), and for the world transition in (Garcia-Casals X., 2017b). Moreover, biomass burning is not carbon neutral in the short to medium term[72], and therefore just in the following decades when we need to revert the atmosphere's GHG content it can play against the transition (Garcia-Casals X., 2011).

In Europe the issues associated to biomass use are finally becoming evident when we have reached a situation where a very significant share of all the forest wood we use is for energy purposes, and momentum and consensus are growing to eliminate the EU incentives that allow counting burned wood towards RES goals accounting (Beddington J., et al, 2017). And globally, the first voices start pointing out the non-neutrality of biomass (Spratt D., 2018),and the risks to rely on it for the transition.

5.8.4 EV charging infrastructure

The integration of the transport sector into the energy system requires the deployment of smart and bidirectional EVs charging infrastructure. The limited availability of this infrastructure has been up to now, together with the regulation limitations and the EV cost levels, one of the main barriers for the deployment of integrated EVs.

EVs costs are decreasing fast and regulations are bound to evolve also fast in view of the pledges made by many countries to eliminate ICEs in one or two decades. Therefore the

[72] *When in the best scenario new plantations offset the CO_2 released when burning the wood, but not that for processing it.*

deployment of appropriate EVs charging infrastructure needs to be properly addressed in order to avoid that it constraints the transition.

SECs could play an important role in facilitating the deployment of these infrastructures.

5.8.5 NG network

Currently there exists a significant NG infrastructure both in the power sector and urban buildings sector.

NG has been in the past[73] pointed out as a 'transition' or 'bridge' FF because of its in principle lower GHG emissions than coal and oil.

The interest for this approach can be easily understood from a FF corporate point of view, attempting to extend their business few decades ahead as the evidence was settling about the need to stop using coal and oil. And indeed in the last years this approach has spurred investments in fracking to extract shale gas and oil, with strong social and environmental impacts.

NG could indeed have played a significant 'brige' role if we would have started substituting coal and oil with NG several decades ago[74]. However, as of today that is not anymore the case, and in recent years the myth of NG as a transition fuel has been fading as evidence about its life cycle impact and real transition implications has started to settle down (Hausfather Z., 2016), (Vorrath S., 2017c).

Moreover, RES and DER development, together with their capacity to unlock EF, are completely eroding the main argument to support NG as a transition fuel in the power sector: The need for flexible centralized generation.

There are many reasons for not considering NG an appropriate transition fuel,, among which we could mention the following ones:

- NG infrastructure deployment produces strong transition barriers by locking in investment interests that risk to become stranded. In (Garcia-Casals X., 2017c) the transition processes in several countries are analysed, with the results highlighting a strong impact from FF barriers: Spain is a clear case where NG overcapacity in the power sector has effectively stopped and even inverted the transition process.
- New NG infrastructure deployment is inconsistent with the available transition time frame. Indeed, any new investment in NG would have to become stranded before the end of its economic life time in order to align our socio-economic evolution

[73] *Still as of today this argument is heard from time to time, tough with decreasing intensity as climate constraints become evident.*
[74] *Just as CHP was an appropriate EE strategy in the FF-era but not anymore right now.*

with the climate boundary conditions: These investments are incompatible with the available carbon budgets.

- Today transition's requirements are to stop emitting GHG as fast as we can (Garcia-Casals X., 2017b). Therefore, locking-in additional GHG emissions for the following 30-40 years[75]it is certainly not the appropriate transition strategy.
- Life cycle emissions from shale NG can be significantly higher of direct combustion emissions, and approaching these from coal (Hausfather Z., 2016).
- Financial, economic and technologic resources should focus completely on deploying the required transition. Distractions on intermediate steps will inevitable delay the transition, increase its costs, and compromise its capability to stabilize the climate.

Currently NG is also significantly used within the urban environment, supplying final energy used to cover heating, DHW and cooking loads. We often find therefore an existing T&D NG infrastructure to supply this demand.

Within a SECs transition context NG does not have a place in the urban environment, since all the services it currently provides can be provided free of GHG emissions, more efficiently, in a more integrated way, and avoiding redundant urban infrastructure, with RES-based electricity. Therefore, new NG infrastructure development has no place within a SEC.

But in many existing urban spaces, the NG distribution infrastructure is already in place, and therefore in a SEC context we could anticipate a NG defection process leading to stranded assets.

However, this grid defection process and the associated stranded infrastructure assets could be avoided if the NG T&D and storage infrastructure are converted for its use with RES-based hydrogen and synthetic fuels.

5.9 Virtual power plants for generation and regulation

A VPP is built through the smart aggregation of DER.

VPP can provide generation (through the DG aggregation), but beyond that one of their main transition roles is bound to be providing regulation and ancillary services to the power system, efficiently articulating the EF available from DER.

[75] *The economic life time from new investments.*

6 SEC stakeholders and their interactions

The main stakeholders involved in the articulation of a SEC are:

- Consumers
- Prosumers
- Utilities
- DSO
- Retailers
- Aggregators
- Smart mobility services providers
- Energy services providers and facility managers
- Other third-party providers
- Investors
- Administration (local - municipality, regional, national)
- Regulator

The grid edge trends (decentralization, digitalization and electrification) are paving the way towards a system where traditional boundaries between producers, distributors and customers are blurred, increasing the complexity of system governance, but simultaneously opening the door to much higher levels of system social governance.

The aggregator is one of the more outstanding SEC stakeholders, tough the articulation of appropriate links and relationships between the different aggregators (which has quite a lot to do with regulation, markets and BMs) is the glue that enables true smartness deployment.

The aggregator gathers the flexibilities and the contributions provided by prosumers to build active-demand-based products relevant and interesting for flexibility market players such as DSOs. With regard to DR, the aggregator sells a deviation from the forecasted level of demand. The aggregator should use specific tools to perform the following typical functions (Al-Jassim Z., et al, 2017):

- Consumption forecast: based on historical consumption data as well as demand models, this tool is used to estimate the baseline consumption used for flexibility services quantification.
- Consumer segmentation: this tool clusters the prosumers portfolio in groups with shared key characteristics.
- Flexibility forecast: simulation of the behavior of the consumers under different price and volume signals
- Market forecast: forecasting of the market prices
- Optimal planning: optimal incentive and bidding policy to maximize its profit

The proper integration of DER could become a complex process. If handled unilaterally from the DSO or TSO it will require a huge effort from their side in order to establish communication channels to all available DERs in the network and properly manage them so that the full EF potential is enabled. It is therefore important that a third party (the aggregator) takes care of the communication with DERs in the network. Hence it is important to focus on the DSO functionalities that enable communication between the flexibility market and the aggregator, and the aggregator role and the functionalities required to be a successful business entity.

In (Al-Jassim Z., et al, 2017) a discussion about optimal approaches for the interaction between DSOs and aggregators to activate DER flexibility in the distribution grid is presented, based on smart grid distributed automation systems. In this reference a combination of two different approaches to manage distribution grid congestions through the mobilization of the EF potential is proposed: dynamic tariffs passed from the DSO to customers through retailers in order to activate their DR capabilities[76], and the procurement of EF through flexibility markets provided by aggregators that share their economic benefit for DR articulation with end users.

A flexibility market algorithm from the controller in the distributed automation system is proposed in (Al-Jassim Z., et al, 2017) for MV grid congestion management through the use of DER and demand-side flexibility, which is responsible for the communication between the DSO, the aggregator, and the flexibility market for flexibility purchases, finding an optimal solution that minimizes the cost of the purchased flexibility products.

In some countries the aggregator role is being played by other stablished actors in the electricity system (retailer, DSO,…), in what is sometimes called 'supplier led aggregation'. The UK is a typical example, because the independent aggregators have up till now met barriers such as not being able to trade on the intraday markets, and no access to balancing mechanism.

There are arguments that favour a clear separation between the novel aggregator role and other stablished roles in the electricity market (retailer, DSO,…): In the very beginning of the monopolistic structure, the whole electricity system was operated by the same party. Breaking up the monopoly, market liberalisation is to separate monopoly into several roles. That means each of the roles has their own responsibility... If you mix the roles of suppliers and aggregators, this means an aggregator is also a supplier, implying internal trading in a black box. Therefore, the aggregator should be a new independent entity (Lajgaard Pedersen M., Karentius Freund M.S., 2017).

---

[76] Note that tough this scheme may look more straight forward and with lower costs for DSOs, since the benefit for EF articulation is not shared with end consumers, its capacity to articulate the full EF potential is far more limited, and it could be difficult to clear all congestion situations or achieve all the energy system goals (like RES integration).

Another option for implementing the aggregator role is that an energy services provider also plays this role, like could be a HP-operator, a mobility services supplier or a DG/DS supplier.

But as a transition roadmap, a progressive transition towards the independent aggregator could allow an earlier articulation of the EF potential depending on the specific policy, regulatory, market and technological contexts in each specific country. For instance, in (Lajgaard Pedersen M., Karentius Freund M.S., 2017) different options have been chosen for analyzing EF business models in each of the three targeted countries (France, UK and Denmark), using an independent aggregator for France, a supplier led aggregation with the retailer assuming the aggregator role in UK, and an energy service provider (HP operator) assuming the aggregator role in Denmark.

7 Enabling elements for SECs: Overcoming the barriers

The current regulatory paradigm hinders distributed resources from providing their full value to the system, and uncertainty around rules prevents key stakeholders from deploying enabling infrastructure that could complement the grid as the backbone of the future energy system.

7.1 Redesigning Regulation

Often, current regulation constitutes a barrier for the transition itself, since it was thought and implemented for a context very different from the one we have today, and it often struggles to keep pace with contextual evolution. This can be illustrated by many cases, but perhaps one of the more evident is how current markets restrict the participation of the very same resources that are needed to articulate the transition. This case is very clearly illustrated by the Australian 'big battery' connected to the grid in December 2017, where day by day the fast regulation capabilities demonstrated by the 100 MW/129 MWh grid-connected battery leaves rule-makers struggling to catch up (Parkinson G., 2017d), while the current Australian electricity market rules do not reward, and even do discourage, the participation of such flexible fast responding resources, and even just do not allow them to participate in the market itself. Indeed, from the 20 different services that grid connected batteries can provide to the power system, in the Australian electricity market they can basically only get paid for one: time-shifting the output of wind and solar.

For utilities to evolve towards the role of transition facilitators and away from being a transition barrier, they need greater flexibility and options for revenue and earnings as they transition away from the traditional cost of service regulatory model that is based primarily on capital investment: capital investment should not anymore be the primary means of driving utility earnings.

Deployment of digital technologies in the network can be hindered by outdated regulation, when the remuneration model creates a bias towards capital investments in network infrastructure at the expense of potentially cost effective alternatives in digitalization and exploitation of distributed resources. The lack of a clear legal structure around customer and distributed resources data limits growth in this area (WEF, 2017).

The key regulatory changes to be addressed in order to advance in the alignment of utilities and other stakeholders with the transition and redesigning the regulatory paradigm are (Blansfield J., et al., 2017), (WEF, 2017):

- Evolve the revenue model around two main principles[77], reaching revenue decoupling[78]:
    - Outcomes-based or performance-based regulation, so that policies reward players for reaching policy goals using adequate transition performance indicators (EE, peak shaving, data sharing, customer engagement, DER deployment …). By rewarding outcomes instead of inputs, PBR better aligns the behaviour and financial interests of regulated utilities and other stakeholders with public interest objectives and consumer needs and benefits.
    - Total expenditure approach, removing the incentive for utilities to invest only in additional network infrastructure and encouraging them to invest also in NWA, including network digitalization or procurement of services from DERs. This means optimizing incentives for capital expenditures and operating expenses. Various forms of NWAs rely on services that, in many cases, can effectively replace utility capital expenditures. As an example, consider the case where a distribution transformer is reaching its capacity limits due to load growth. Instead of replacing the transformer, the utility could have:
        - A contract for dispatch rights on a battery owned by a customer during the summer peak demand hours. The customer can make use of the battery during the other hours for energy arbitrage, enhanced reliability and demand charge savings. This allows the utility to avoid purchasing an expensive transformer, in essence

[77] An example is the UK's RIIO (revenue = incentives + innovation + outputs) programme, which requires transmission and distribution operators to submit revenue proposals tied to specific performance metrics along with introducing the Totex model. With Totex, companies in the UK are considering innovative solutions such as demand-side response or batteries as alternatives to building more capacity. Moreover, they are shifting towards purchasing services (for instance IT cloud-based solutions) rather than the traditional model of owning assets. Network companies that try innovative approaches to the goals set by policy can exceed the baseline return on regulatory equity.

[78] That is: Mitigating the incentive for utilities to sell more electricity to drive up revenues.

replacing that equipment and capital investment with a service contract for dispatch rights.
    - A contract with a demand response provider, which can pay its customers to reduce peak demand and offset the need for the new transformer investment.
- Enable Platform Service Revenues: develop and offer new basic and VAS based on operating the grid as a platform.
- Articulate shared savings mechanisms, which grants the utility a share of the estimated net benefits from implementing solutions that result in customer savings. Normally, such actions would simply lead to lower utility revenue and earnings. Shared savings mechanisms can counteract this utility disincentive. Shared economy mechanisms also work all the way around: If utilities pretend to access customer DERs to operate the system, the benefits should not solely go to the utility, since this is a recipe for disaster because very strongly restricting the amount of DREs that will be effectively mobilized.
- Integrate DERs into markets and monetize their services. Adequate market design is to be enabled, allowing:
    - Independent aggregation: A key dimension for the market design for DERs is to facilitate the possibility of aggregation of resources by third party service providers, and access to wholesale markets under fair conditions[79].
    - Network operators to procure services from distributed resources: Full integration also requires allowing distribution network operators to procure services from distributed resources to solve issues in specific locations of the network (e.g. voltage and power flow control).
    - Time and location-based valuing of distributed resources and
    - Improved connection speed and economics.
- Modernize system planning around three main dimensions:
    - The role of distribution network operators: enable distribution system operators to shift from network operator to platform providers.
    - Overcome regulatory siloes (geographical[80], value chain[81], technologies[82], industries[83],…). Breaking siloes is fundamental to ensure efficient, secure and safe operation of the network, performing tasks such as cost optimization, congestion management, balancing, use of flexibility, real-time monitoring and control and network planning.
    - Regulation that can reassure investors while keeping the pace of technology evolution, which requires regulators to have the key qualities of

---

[79] *An example of market design integrating DERs comes from France, which is consistently one of the largest demand-response markets in Europe, and allows for aggregated demand response by opening both ancillary services and wholesale markets to demand response and independent aggregators.*

[80] *e.g. between cities/regions/countries*

[81] *e.g. between TSO and DSO*

[82] *e.g. between EVs and storage*

[83] *e.g. between ICT, energy, transport*

pro-activeness, adaptability and stability. These qualities would materialize in longer regulatory periods and flexible review cycles. A long-term approach reassures investors, facilitating their investment decisions. This approach must be accompanied by periodic reviews, to adjust to changing market dynamics, new technologies and changed costs. Consistency in regulatory principles, policies and processes will provide stability, while flexible and shorter review cycles provide the proactivity and adaptability.

- Use price signals by redesigning rate structures. Time-sensitive dynamic pricing is an essential component of a decentralized energy system, as it provides an economic signal for customers to interact with the grid, enabling the development of more sophisticated VAS comprising different DERs. Essential components of this rate design restructuring are:
    - Price differences between peak and non-peak hours, or between excess and deficit RES generation, need to be large enough to make customers care and react to the price signals.
    - Enrolment method (opt-in vs opt-out)
    - Enabling technology (automation vs manual operation)

To enable independent aggregators to enter the market at scale, it is critical that the role and responsibilities of these new entrants are clarified. In particular, it is important that the relationships between retailers, BRPs, and independent aggregators are clear, fair, and allow for fair competition between market parties. A regulatory framework should be put in place that ensures that aggregators can access the market without depending on the agreement of the consumer's retailer. Such a framework should define standardised processes for information flows on a need-to-know basis, as well as volume and financial settlements between the different market parties, with a view to avoiding any significant distortive impacts on the retailers/BRPs (SEDC, 2017).

In (SEDC, 2017) an assessment of the regulatory conditions for DR and aggregation in Europe is presented (see §11.4 for more details). The overall result of the SEDC review still reveals multiple remaining barriers to the establishment of consumer centred DR services. The European countries that currently provide the most conducive framework for the development of DR are Switzerland, France, Belgium, Finland, Great Britain, and Ireland. Nevertheless, there are still market design and regulatory issues that exist in these well-performing countries. In the countries where DR has traditionally been almost non-existent, such as Estonia, Spain, Italy, there has recently been at least some regulatory interest in exploring its potential. The following main conclusions were drawn from this analysis:

- The regulatory framework in Europe for DR is progressing, but further regulatory improvements are needed.
- Restricted consumer access to DR service providers remains a barrier to the effective functioning of the market. Regulatory frameworks in the majority of EU member states do not yet acknowledge the role of independent DR aggregators,

or they require aggregators to conclude bilateral contracts with a customer's retailer/BRP to sell a consumer's flexibility.
- Significant progress has been made in opening balancing markets to demand-side resources in Europe. However, Iberia lags behind significantly.
- The wholesale market must be further opened to demand-side resources. In most cases, the framework allows only for BRPs or retailers to aggregate and sell flexibility on the wholesale market, or at best, VPPs and large consumers to sell their electricity directly on the market. Access has to be opened to independent aggregators.
- Local System Services are not yet commercially tradeable in European countries. No effective market structures have been implemented for DSOs to be able to source flexibility, including from DR, for optimised local system operations.

In (Barbero M., 2017) the IREC points out that besides the need for DR and independent aggregator specific regulation, other regulatory aspects must be addressed in order to eliminate those barriers that steam from the current regulatory and market set-ups:

- Eliminate specific regulation that was thought for the past (an energy system governed by centralized generation) and that today introduces barriers for DR:
    - Consumer incentives to maintain a flat consumption profile in Germany
    - High availability periods
    - Need to offer the same time of regulation all the year through, which for instance eliminates the DR potential from electric heaters in Finland
    - Requirement for individual instead of aggregated prequalification to participate in a market
    - Too high minimum power requirements (like the 10 MW in Finland)
    - Symmetry requirements in DR bids (upwards equal to downwards regulation capabilities)
- Lack of appropriate price signals to activate DR
- Low prices in markets opened to DR
- lack of capacity payments that provide BMs viability by not having to rely exclusively in generation payments with very limited and often uncertain volume
- Requirement for the DSO, with its conflict interests, to provide its authorization for the aggregator to be able to offer its services to the transport grid (like in Ireland, Germany, Belgium)
- Inadequate share of retributions between aggregator and retailer (for instance, in UK the retribution for demand reduction goes to the retailer instead than to the aggregator that managed this DR).

We should point out the feedbacks existing between some of these regulatory paradigm change dimensions, which if properly managed can help accelerating the transition. For instance, the capability to introduce adequate price signals to articulate consumer's active participation is often hindered by a retail tariff structure that strongly masks and dilutes wholesale market prices behind high fixed network services costs. Evolving the utilities' revenue model towards a performance based total expenditure approach, on the one hand would reduce fixed network costs by limiting oversized capex pole&wire expenditure whereby the wholesale market price signal would become more visible, and on the other hand would enable end consumer's revenue streams by selling their DERs services to the electricity system.

The early evolution of the revenue model towards a performance based total expenditure approach would avoid sunk pole&wire investments that introduce long lasting impacts on retail tariffs, masking the price signal from wholesale markets to final consumers. The Australian case is a clear illustration of this point: In Australia (Parkinson G., 2017) a demand management incentive scheme – touted as the biggest game-changer in network spending seen in Australia because for first time it will be as profitable for network business to undertake cost-effective demand management as it is to invest in poles and wires – has finally been approved by the country's regulators in December 2017. Tough these regulatory changes are very well welcomed, they could have been introduced a decade earlier, and thereby prevented the huge binge on network spending that caused Australian electricity bills to double.

The very design of regulation often introduces transition barriers just because of being wrongly framed for today's context. Indeed, these regulation framing mistakes could be irrelevant in the past, but as new technologies and needs arise they uncover these shortcomings.

One clear example is ancillary services regulation in the power system, as clearly pointed out for the case of Ireland in (Reynolds P., et al, 2017) when stating that it's time to stop framing ancillary services around the incumbent technology, and create a genuinely level playing field.

Indeed, one of the main market and regulatory design limitations is conflating 'what is needed' with 'how it is delivered'. In Ireland, rather than framing SIR regulation services around system needs (namely RoCoF management), the market specifies the physical mechanisms by which technologies must provide this support -namely via kinetic energy, which is not technology neutral, and in fact prescribes a mode of operation that fails to take advantage of the full flexibility of batteries (which respond to RoCoF and FFR with a power output from another origin than the kinetic energy modification). Therefore, in Ireland's regulation market SIR is closed to providers of synthetic inertia, which means a missed opportunity for delivering cost effective RoCoF management.

The fact that up till now the fast (sub-second) power response to tackle RoCoF issues has been provided through kinetic energy, it doesn't mean that what the system needs is kinetic energy, because the system's need is active power injection within the required time windows, and if instead of coming from kinetic energy it comes from chemical energy (batteries) or electrical energy (DR), it fulfils the same regulatory service. Ultimately the flexibility of control offered by batteries is even superior to conventional analogue alternatives (spinning inertia), but the bias from market and regulation prevent this benefit to be reaped.

7.2 Deploying enabling infrastructure

The role of the grid is evolving beyond supplying electricity, and becoming a platform that also maximizes DERs' value.

New infrastructure is critical to accelerate the roll-out of DERs, increase customer convenience and capture the full value of grid edge technologies such as storage, DR and EVs.

Enabling infrastructure is for example:

- EVs recharging stations
- broad-band telecom
- smart meters
- network remote control and automation systems

EVs charging technology and pricing signals capable to enable flexible and smart charging are needed to foster energy system integration. EVs charging infrastructure currently lags far behind the number of gasoline stations. Reallocating EV subsidies from vehicles to charging stations over the next five years could enable the deployment of two to eight times as many charging stations compared to the number of EVs subsidized. Public infrastructure is also lagging behind mostly due to uncertainty related to the model of deployment, including costs, ownership and technical requirements. High-power charging infrastructure (greater than 150kW) positioned along highways would be a good choice for this public infrastructure (WEF, 2017).

As digitalization continues and more digital devices are deployed, communication among them will be vital. Broadband communication infrastructure supporting a broad set of services – both network and customers services – is the backbone enabling digitalization. A lack of technology standards may hinder the development of this communication infrastructure and could slow innovation in the space (WEF, 2017).

Following (WEF, 2017) several actions can be taken to ensure that the necessary infrastructure is in place to enable new BMs and the future energy system:

- Define a model to deploy enabling infrastructure that is flexible, open and interoperable.
    - Removing uncertainty by deciding rules on ownership and cost-recovery of enabling infrastructure.

- Convening open standards and requiring interoperability for DERs and communication infrastructure to ensure multiple services can be combined
- Defining clear ownership and the cost recovery mechanisms.

- Ensure customers and third parties can benefit from data generated by DERs and the digital grid. Smart meters, sensors, remote control and automation systems, DERs and connected devices are all generating large amounts of new data. Sharing this data will be essential to realize greater value from these technologies, but policy-makers and regulators will have to define the rules for who can own, access and share data. Blockchain registries hold promise for data sharing, although a detailed model has yet to be worked out.

For the deployment of enabling infrastructure, both private and regulated approaches could in principle be followed. However, in some cases, there currently might not be any clear business case for the private sector to invest in physical infrastructure such as charging stations, where initial failures of private companies have led to limited interest by others to invest. In contrast, the regulated business model where a return could be earned based on these new rate base assets do provide a clear business case and interest by utilities.

Industry collaboration or public-private partnerships can offer viable alternatives. For example, a group of competing EV manufacturers has recently unveiled a plan to invest over €1 billion in building an ultrafast charging network in Europe (WEF, 2017).

7.3 Redefining customer experience and role

Customer preferences and expectations are shifting towards fewer carbon emissions, greater choice, real-time interaction and sharing, always-on connection, higher transparency, experiences and learning opportunities through services more than products, better reliability and security. The goal is, through encouraging collaboration and openness, to incorporate the new reality of a digital, customer empowered, interactive electricity system, facilitating customer engagement by making the experience easier, convenient and economical (WEF, 2017).

Following (WEF, 2017), three ways to redefine the customer experience and simplify customer engagement are to:

- Create a seamless customer experience by overcoming the complexity
  - Successful products make it easy for customers to engage, offering simple customer interfaces that incorporate automation, self-learning and multi-device applications[84].

[84] Nest's thermostat, for example, learns customer schedules and automatically adapts and programmes itself.

  - Customer choice is important, but opt-in schemes create obstacles for new technologies. Making participation the default while allowing for opt-out provides customers with the same options while facilitating adoption.
- Shift the customer experience by combining multiple services
- Recognize sophisticated customer segmentations[85] and tailor offers accordingly

7.4 Embracing new business models

The three disruptive energy system trends (decentralization, digitalization and electrification) and their associated technologies enable innovative BMs built around empowered customers.

Revenue models will see a smaller share of income derived from centrally generated electrons, but could be compensated by revenue from new distribution and retail services.

The network becomes a platform that maximizes the value of distributed resources and enables them to exchange services with others across the grid.

Cross-sector partnerships will be critical to success as technologies converge and boundaries blur[86].

Utilities and other organizations in the electricity system will pursue new revenue sources from innovative distribution and retail services by (WEF, 2017):

- Shifting BMs towards alternative and complementary services. Integrating and exploiting DERs in the electricity system will open up new revenue streams, at both the distribution and retail levels.
  - DSO: qualification, verification and settlement of DERs services – compliance obligations that are required and similar to traditional generators.
  - Retailers: services related to DERs management, provision, operation and installation
- Equipping organizations with the new capabilities required in the grid edge world
- Developing innovative financing schemes. Financing in the electricity sector has not evolved as quickly as grid edge technologies, as it has remained focused mostly on large power infrastructure projects. Distributed energy projects are smaller and more numerous. Questions that will need to be answered:

---

[85] The IREC aggregator implements a prosumer segmentation that clusters the prosumers portfolio in groups with shared key characteristics (Al-Jassim Z., et al, 2017).

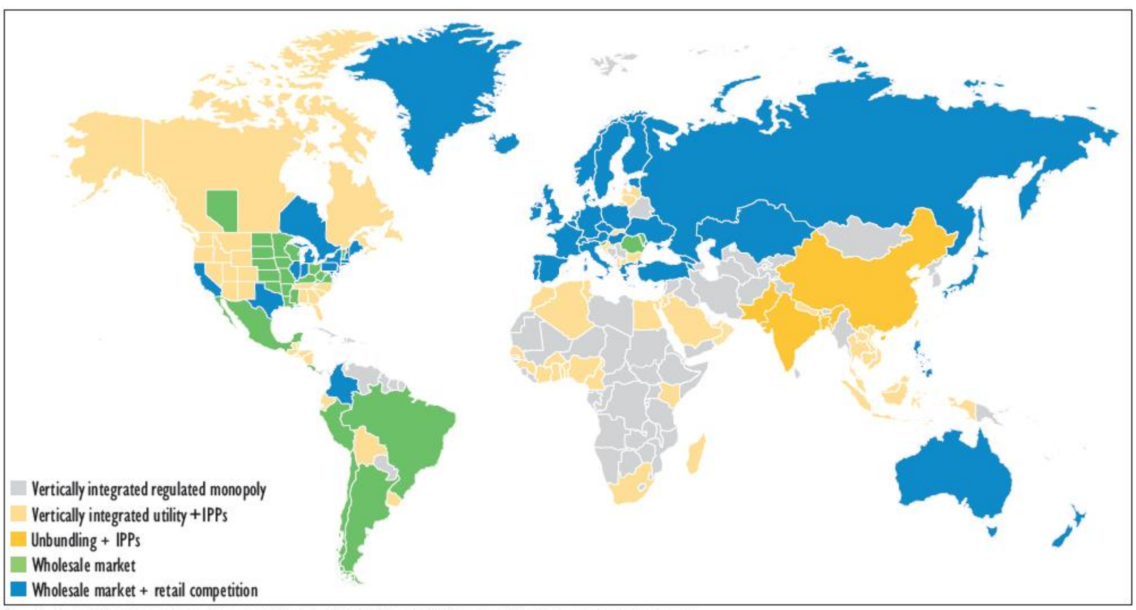
[86] In Europe, automakers and utilities are partnering to develop new business models, such as the development of energy storage facilities that rely on used EV battery modules, or ancillary services provided by V2G.

- What are the implications on the risk and return profile of investments in energy assets in the future?
- Should small grid edge transactions be aggregated to facilitate financing?
- Will new energy assets have access to low cost institutional capital?

Three examples of emerging business opportunities attracting cross-sector partnerships are storage-as-a-service (which can be attractive for commercial and industrial customers), transportation-as-a-service (which can improve fleet utilization with the advent of autonomous driving) and blockchain technology. All three support the shift from asset-intensive business models to service provider platforms. Their BMs require a new set of digital capabilities and internal operating models that embrace the digital transformation.

7.5 Markets

Electricity markets have been an important component for introducing techno-economic efficiency in the power sector, and they are currently operating in many parts of the world, tough there are also many regions that still operate under vertically integrated utilities or regulated monopolies (Figure **25**).



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Sources: IEA and *Renewable Energy and Energy Efficiency Partnership (REEEP) Policy Database 2012-2013.*

Figure 25: Map of the status of liberalisation in electricity markets. Electricity markets have been restructured in most jurisdictions, with different degrees of competition being introduced. (Baritaud M., et al, 2016)

There are currently many different electricity markets, depending on the grid level where they operate (wholesale and retail markets), the services and products that are traded in them (energy, capacity, reserves,…), or the time windows they consider (long term, medium term, short term – day ahead, intraday, balancing). Figure 26 presents an overview of different electricity markets.

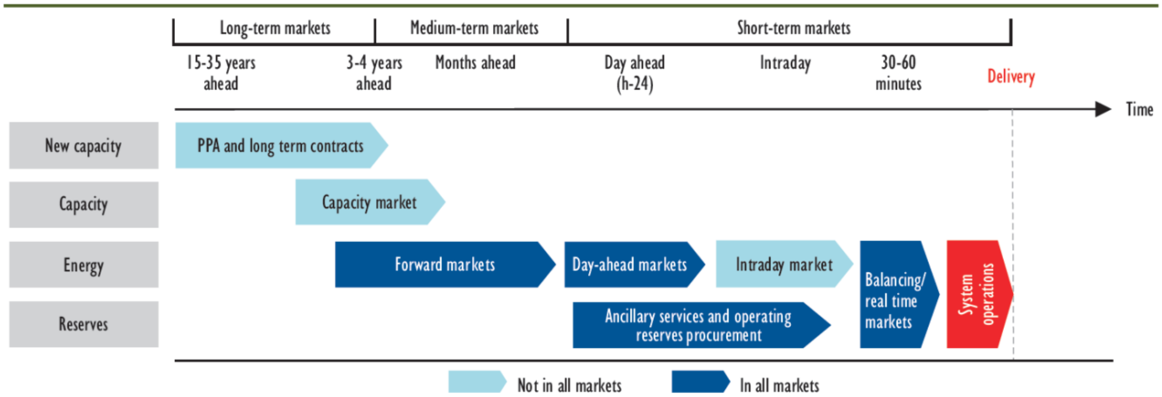
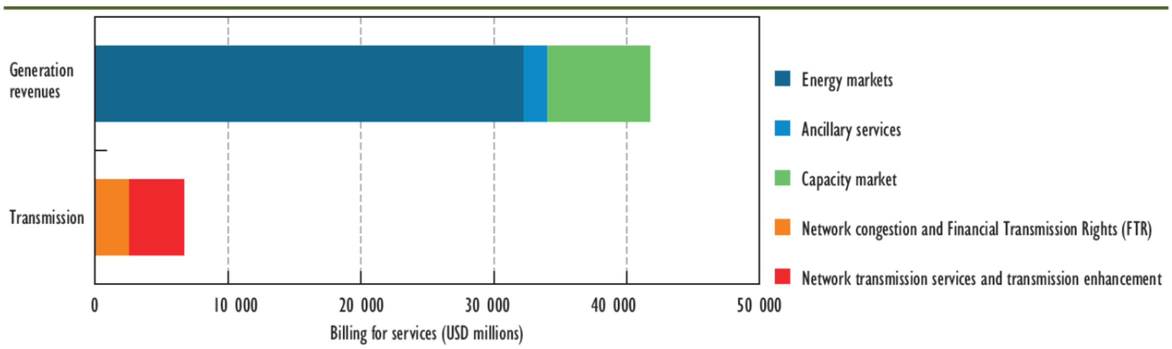


Figure 26: Overview of different building blocks of electricity markets. A suite of interrelated markets is used to match generation and load in the short, medium and long term. (Baritaud M., et al, 2016)

The current revenues from these markets are rather different, and clearly dominated by selling energy in the energy markets (Figure 27). Capacity markets are also providing an increasing revenue share, tough they do not exist everywhere.



Source : PJM (2015)

Figure 27: PJM (Pennsylvania Jersey Maryland Interconnection) billing for services (2014). Generators' revenues come mainly from the energy markets and, where they exist, capacity markets. (Baritaud M., et al, 2016)

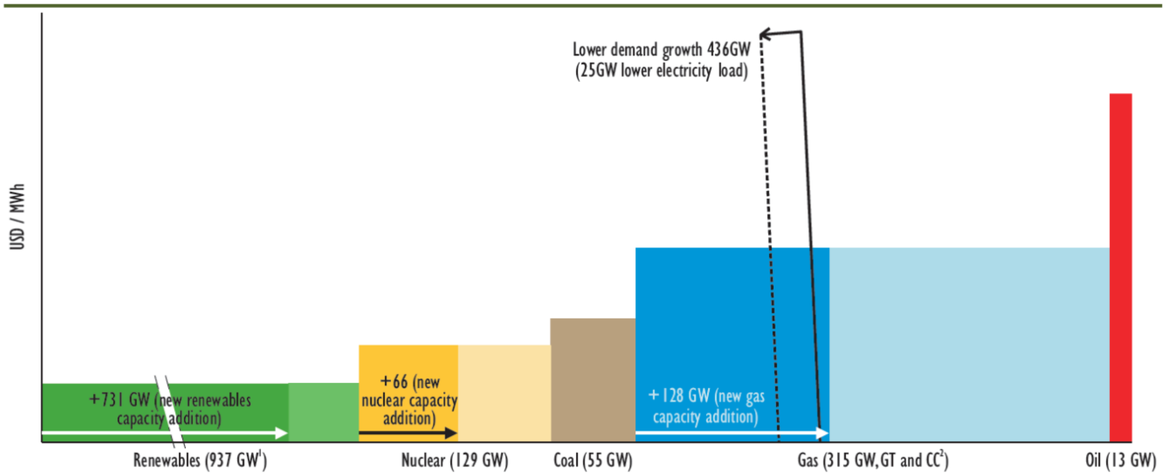
However, for becoming a useful transition enabler, markets need to evolve significantly beyond their current status. Indeed, in their current configuration markets often constitute a transition barrier by limiting the participation of different stakeholders and/or the technologies that can supply these services. This is especially true when it comes to enable prosumers' participation through aggregation, or opening the floor for the so much needed additional EF technologies.

The need for electricity markets evolution in order to get transition aligned is becoming evident even through the very shacking of fundamental underpinning components of current markets by the increasing RES deployment. Indeed, the deployment of VRES with low marginal costs and priority of dispatch is already altering the merit order of generation used to determine the electricity price in wholesale markets, in such a way that lower clearing prices are obtained because of the displacement to the right of the generation/offer curve (Figure **28**).

This effect of RES deployment, leading to lower wholesale markets is often celebrated by RES supporters arguing that RES deployment leads to a reduction of electricity price for customers. But this is not so positive as it might look at first sight:

- On the one hand the customer only receives a diluted effect from this wholesale price reduction, since the customer gets its electricity from the retail market, and retail tariffs include many other things beyond wholesale electricity price.
- But above all, this points out a fundamental flaw of current markets to deal with the transition electricity system. Indeed, if VRES would completely dominate the generation and IF their only revenue[87] would be that from the current price clearing mechanism based on marginal costs, there would be no way that this market allows to recover the associated investment, and therefore it would not enable a sustainable electricity system.
- Moreover, supporting the required development of EE and DR in a market context would require higher energy prices (and not lower), probably complemented by adequate capacity mechanisms.

[87] *Note that currently this is not the case, because VRES revenue is mostly regulated through FITs or PPA, and therefore VRES investors get a return on their investment whatever happens with the wholesale electricity price. In some cases a mixed situation exists, where VRES generators get a regulated premium on top of the wholesale price, which makes them at least a bit sensitive to this market price.*



Notes: The GW values in parenthesis represent the electrical capacity in 2040 under 450 Scenario. As the average load factor is 29% for wind and 13% for solar photovoltaics, this represents the de-rated capacity that reflects the average contribution of these technologies to the supply slack. CC = combined cycle; GT = gas turbine; USD/MWh = USD per megawatt hour.

Figure 28: Impact of decarbonisation on the merit order of generation (450 Scenario, EU 2015-40). Decarbonising the power system entails a major evolution of the merit order that constitutes the foundation of electricity market prices. (Baritaud M., et al, 2016)

Therefore electricity markets need to evolve for:

- Providing adequate return on investment mechanisms for sustaining the required RES investments. In a completely non regulated framework this could be partly achieved by introducing additional revenue streams for RES, like capacity markets do. However, perhaps other approaches with some degree of regulation are worth exploring and prove to be more appropriate, like auction-based premiums or other strategies that lead to electricity offers that more closely mirror the associated LCOEs.
- Opening the floor for other technologies and participants, properly addressing those elements required to underpin the transition, like is the case for EF services.

With regard to retail markets, tariffs re-structuration seem the appropriate doorway to articulate consumers' market participation through appropriate price signals. Beyond that prosumer's participation in other markets (like wholesale markets) can better be articulated through their aggregation.

One aspect directly linked to retail price is behind-the-meter-generation or storage. Unlike generators connected to the transmission or distribution grid, the development of behind the-meter generation or storage depends on retail prices, not wholesale electricity prices. From this perspective, it is the design of retail prices that matters most, including 1) the possibility to net electricity generated and consumed (net metering), 2) the tariff structure (fixed, capacity charge, variable charge), 3) the surcharges to cover energy policy costs and 4) the taxation of electricity. A key element is that price signals between retail and wholesale markets need to be co-ordinated (real-time price, dynamic pricing) in order to balance the contribution of centralised and decentralised resources.

The term “socket parity” is used to describe the point at which the LCOE of a given technology (e.g. solar PV) falls to, or below, the per-kilowatt hour retail price of electricity obtained from the grid, i.e. the variable part of a consumer’s electricity bill. This socket parity would be the one incentivizing prosumer behind-the-meter investments in the absence of additional revenue streams like FITs or net metering, and therefore it is very sensitive to the retail tariff structure.

During the last years, due to the reducing costs of VRES and specially PV, utilities have perceived the risk of not recovering their fixed costs, arguing that up till now a share of the fixed costs was embedded into the variable part of a consumer’s electricity bill, and that therefore the tariff structure should be reformulated to reduce the variable part and increase the fixed part in order to avoid that non-prosumer consumers cross-subsidize prosumers. This leads to reducing the socket parity and therefore makes it more difficult for DG to deploy.

It is true that the retail tariff structure needs to be revisited to include the above considerations and provide an appropriate recovery of grid fixed costs[88]. But doing this tariff reformulation without a holistic transition view would lead to additional transition barriers, like discouraging behind-the-meter investments that could and should contribute to provide the overall required generation and flexibility capacity.

In fact, just increasing the fixed retail tariff term and decreasing the variable term it has negative effects beyond discouraging DG. Indeed, DR and even EE are discouraged too.

The right share between distributed and centralized RES and EF deployment has to be reached (Figure **29**) for materializing a smart transition, and this includes more elements than the fixed grid costs. Indeed, a prosumer’s fixed term should not only be a liability but should also reflect the value asset associated to the EF services it can provide: If a prosumer increases its connection power, this should lead to increased fixed costs while he consumes while the system is constrained to provide, BUT it should also open the door for rewarding its increased DG and DR services when the system needs it. Just focusing on the punitive part for the prosumer (increasing its fixed tariff term without acknowledging the increased value this can provide) constitutes an important transition barrier.

---

[88] Tough it is also true that other incentives have to be provided to utilities so that they optimize the overall costs transcending the ‘just capital cost’ expenditures they have been following up till now.

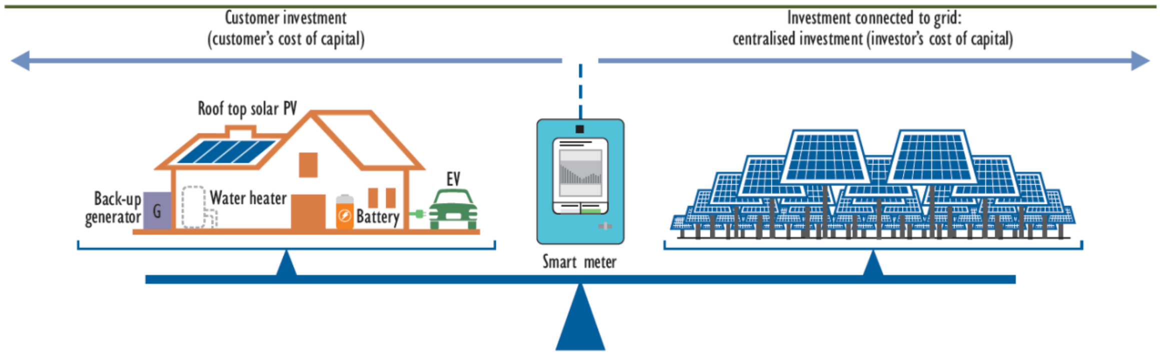


Figure 29: Finding the right electricity price and structure to optimise distributed resources. (Baritaud M., et al, 2016)

7.5.1 Capacity

Capacity electricity markets are lately in the spot light, as the first transition effects on the installed FF overcapacity has led to a reduction of incomes for its investors. Indeed, the displacement of the merit curve associated to RES penetration, on the one hand reduces the need for FF generation (which is just the transition aim) leading to reduced plant capacity factors, and on the other hand can reduce also the wholesale clearing price, which altogether generate a significant reduction of incomes for conventional power plants. In this context, FF power plant operators have started to request capacity payments in order to guarantee that they are there to complement RES generation[89], since the energy market itself no longer provides their required return on investment, and therefore would no guarantee that the required capacity is deployed.

This is indeed a thorny subject, because while it is true that a holistic markets review needs to be undertaken, and perhaps capacity mechanisms (for RES) are a required component of it, but fostering it to support the current FF overcapacity[90] can easily become a transition barrier instead of a transition enabler.

In theory, an energy-only market design with sufficient demand response can clear at all times. However, even with scarcity pricing in place and a certain level of demand

---

[89] *Implicitly assuming that they will always be required to complement and regulate RES generation, which is equivalent to neglect the other available EF mechanisms.*

[90] *Stranded assets are the natural consequence of a transition process when appropriate social planning is not deployed. In many cases, and Spain with its NG CC plants is a clear example, the FF overcapacity is the result of speculative corporate investment done with the pretension to generate corporate benefits by externalizing to the environmental costs. These investment were no needed from a social perspective, and tough is true (and politicians fault) that an adequate social transition planning was not available (and it is still not today), the sole responsibility for these stranded assets lies on those that tried to speculate with them, and a capacity mechanism in this context is pretending to make society pay for these stranded assets, which certainly does not look right.*

response, a capacity market might be necessary. This is highly dependent on both the level and the nature of the reliability standard. If the reliability standard is just an indicative target and policy makers can accept high prices and lower reliability over limited periods of time (for example, a couple of years), then an energy-only market with scarcity pricing is likely to be sufficient. But if the standard is defined as a resource adequacy floor that must be met at all times, then a capacity mechanism will be necessary. Figure **30** presents a simplified decision tree to decide whether a capacity market is needed or not.

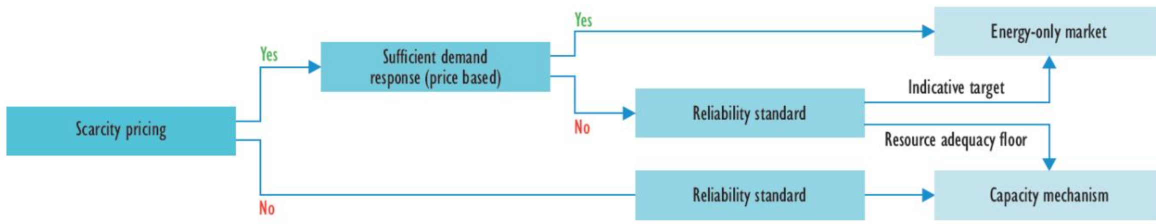


Figure 30: Simplified decision tree, energy-only market versus capacity mechanism. (Baritaud M., et al, 2016)

Some question why resources that are already earning sufficient revenues from the wholesale markets should receive an additional benefit in the form of a capacity payment. One answer is to recognise that the provision of capacity is a service, just as the provision of energy is. By participating in the capacity market, the resource in question is committing to be available for reliability needs, regardless of what happens in the wholesale market. It is therefore reasonable that these resources should also receive capacity revenues.

Another way to look at it is to ask what would happen without a capacity market and with no cap on wholesale market prices. In that case, during times of scarcity, the wholesale market price would rise well above the marginal cost of all generators in the market[91], and all generators would receive these same infra-marginal rents. Capacity markets replace or offset infra-marginal rents earned during scarcity events with a steady revenue stream. Just as there is no discrimination against specific resources that participate in the wholesale markets, there should be no discrimination in the capacity market.

Capacity markets can fill a revenue gap for energy resources, but should not be seen as a tool to ensure profitability. Instead, capacity markets can be seen as a safety net and can complement energy market scarcity rents.

A properly designed capacity market has three key components: a pre-determined level of demand, based on the system operator's assessment of resource adequacy needs; a mechanism for price discovery, preferably in the form of an auction; and a well-defined capacity product, which takes into account the contribution of the capacity resource to meet adequacy needs, but is, to the greatest extent possible, technology neutral.

[91] *Leading to windfall profits that can constitute a system inefficiency, while at the same time not being enough to incentivise the required investment.*

All these considerations about capacity markets should also be taken into account when considering the energy markets restructuring for being aligned with the RES-based transition power system. Indeed, energy markets themselves, based on marginal prices and operated by energy mixes with very low marginal price, could not be enough to guarantee the required return on investment to incentivize this RES deployment without regulatory support. In this context price volatility due to scarcity prices could also be very high, and capacity markets could contribute to stabilize it.

7.5.2 Demand response

Electricity consumers can react to variations in electricity prices according to different mechanisms:

- Through dynamic pricing, where the final consumer is actively adjusting its consumption to prices.
- Through explicit contracts in which the consumer purchases a fixed quantity of electricity and re-sells its surplus (not consumed).
- Through "imputed demand response", where an individual's consumption is estimated on a baseline and the demand response calculated on that basis participates in markets as a source of generation.

The first two forms correspond to a response to electricity prices (Figure **31**, left-hand column) where consumers agree to pay the marginal pricing for their consumption. While these approaches are straightforward, they have proven to be slow to develop in restructured electricity markets and have had mixed results.

To date, revenues from participation in the wholesale energy markets are rarely sufficiently abundant or predictable to cover the (fixed) cost of investing in the equipment needed to develop DR.

This has led market designers to consider the third option: treating demand response as a generation resource (Figure **31**, right-hand column). This might be necessary in particular where short-term market prices are not properly pricing in scarcity and real-time constraints, or where the physical and market infrastructure to implement dynamic pricing are not in place or are under development. In this case, the market design has to be updated in order to accommodate the different energy resources available, including the requirements of DR.

For treating DR as generation, and "dispatch it" on wholesale electricity markets, the direct participation of DR aggregators in capacity markets has been effective in kick-starting DR in several markets, such as the US regional transmission organisation, PJM.

This approach – treating DR as a generation source– has already been implemented in several markets to accelerate the development of DR, but it does, however, lead to a considerable increase in the complexity of the overall market design. Treating DR as generation requires complex market rules, with the need to define a baseline of consumption against which demand response can be assessed. Defining the correct level of remuneration is difficult and can be controversial.

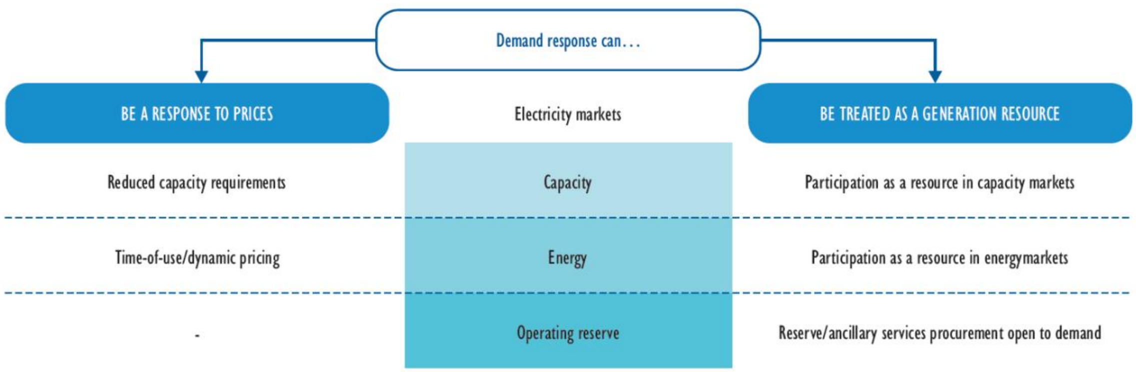


Figure 31: Approaches to demand response (Baritaud M., 2016)

Wholesale market prices might not represent sufficient compensation for the consumer to reduce its load, because market prices are rarely high enough to justify buying a unit of energy not consumed. Consequently, revenues from participation in wholesale energy markets have not been sufficient to date to cover the (fixed) cost of investing in metering and other smart devices and/or self-generation units needed to develop DR.

Capacity markets have been more effective at developing DR than energy markets[92]. Capacity mechanisms have been developed to ensure sufficient resources are available to meet peak demand at least cost. In capacity markets, the only relevant role of DR is its contribution to meeting system adequacy through load shaving.

DR is also a solution to imbalances that electricity markets face in the very short term, and which are usually dealt with in the balancing and ancillary services markets. DR relies on equipment that can react in an interval ranging from under a second to a couple of minutes. This is where the main difference lies between traditional DR and DR for the ancillary services market: the reduction in notification time, the speed and the accuracy of measurements.

DR can participate in all ancillary services markets that rely on four main types of product:

- Regulation: control of system frequency though instantaneous balance of supply and demand through automatic generation control, via a signal sent by the system

[92] That's another argument to take into account when considering the transition suitability of capacity markets.

operator's energy management system. For instance, industrial hydrolisers already provide such services.

- Spinning reserves: portion of remaining capacity (unloaded) from capacity units connected to the system and that can be delivered within 10 minutes.
- Non-spinning reserves: capacity that can be activated and can deliver within 10 minutes.
- Supplemental reserves: capacity that can be activated and can deliver within 30 minutes.

Nevertheless, not all forms of DR are capable of providing reliable ancillary services. This will depend on the requirements set for the response timing, duration and whether the demand is expected to increase.

The only practical solution to providing value to DR for its participation in the ancillary services market is to be able to dispatch and treat this resource as a generation asset.

Market prices have to be high enough to justify new entrants' consideration of offering DR as an ancillary service for balancing purposes. In this regard, it has been observed that where market rules allow aggregation (which is not always the case) for participation in balancing and ancillary services markets, this can help to increase the scale of DR such that it can compete meaningfully with other sources. On the same note, certain requirements for real-time metering (to allow the SO to assess online DR potential) might represent an additional and not inconsiderable expense for demand response operators, which could undermine their business case for entering ancillary services market with a large number of small customers.

8 Business models

The current business structure of the interface between customers and the power system is dominated by utilities and lately, as liberalized markets progress, third-party energy retailers.

DERs are putting pressure on the traditional utility BM. Current business challenges focus on the long-term viability of the current utility business model that is built broadly around increasing capital deployment (counting on a regulated rate of return on capital investment) and rising energy sales, which when set against a backdrop of rising DER deployment and flat to declining load growth[93], means that taking a BAU approach would

---

[93] *We should however note that the declining demand growth is the one that has been experienced without fully embracing the transition. In a transition context within the available time frames, in spite of a significant increase in EE deployment, the electricity demand would increase due to energy system integration, to reach a mid-transition peak (Garcia-Casals X., 2017b).*

lead to unsustainable rate increases for customers (Blansfield J., et al., 2017). Moreover, the current utility's BM does not address many of the current customer needs, and in fact it can even be felt as going in the opposite direction, which could ultimately lead to customer's grid defection.

Yet, DER technologies are creating value and form the basis for a range of new services to customers: the expectations of what the grid can deliver are changing.

SEC BMs need to focus on the future, going beyond current barriers. We are now, and will keep on being in the near future, navigating times of fast contextual and regulatory changes, with the very SEC concept forming part of these changes. Structuring a pretended SECs BM exclusively around current contexts and barriers is a recipe for business disaster and even stranded assets, since in the short term would become outdated. Moreover, BMs are part of the tools to advance the transition, and in this sense they need to explore uncharted territory in order to align the economic system with the transition, contributing to facilitate the participation from other stakeholders. However, this very particular contextual situation (sitting amidst of a transition) needs also to be factored in the BM itself, searching for a balance that allows it to take off within the current context and then swiftly incorporate the transition options (which it even helped to stimulate) as they become available.

8.1 Basic vs value-added services

Facilitating the successful development of new BM requires having a clear distinction between the different services potentially offered by utilities or third-party providers (distribution grid services, electricity supply services, value-added services), as well as their associated regulations and costs allocation and recovering mechanisms (Blansfield J., et al., 2017).

Although VAS constitute an important part of the BM's evolution within a transition context, we should not loose of sight the fact that full system smartness deployment requires extending the reach of citizens' participation and governance beyond the scope of these 'new' VAS to reach the very core of grid and supply services.

VAS are defined as energy services beyond electricity supply and energy grid services, and include private or community level: RES, DG, DS, DR, EE, integrated energy management solutions, microgrids, EV charging,…

VAS can be services primarily meeting customer needs (lowering energy bills, optimizing energy use, being a prosumer, choosing a specific energy mix,…), or services primarily meeting energy grid needs (articulating DER that provide energy, capacity, regulation, and/or other services to the power system).

VAS are often considered as optional, enhanced services, but since articulating consumers' active participation into the energy system is a significant enhancement (in fact a structural one) the line that separates VAS and basic services becomes blurry and should be expected to evolve as the transition unfolds.

Both utilities and third-party providers can in principle deliver VAS. Typical examples in the current context would be:

- VAS by a utility:
  - enhanced analysis of meter data to customers or third parties
  - DER scheduling and dispatch, enabled by the utility's unique role as the operator of the distribution system/platform
- VAS by third-party providers:
  - sale, financing, installation and operation of onsite DG or DS
  - manage customer participation in wholesale-market DR programs

Basic services could include services provided by the utility as it implements programs mandated by policy, such as EE programs. Indeed, since EE is often a least-cost resource for meeting electricity needs, it is reasonable to treat cost recovery for EE programs similarly to cost recovery for other (supply side) resources. However, we should be aware of the limited impact up till now of this approach to effectively deploy EE[94], especially in Iberia, and therefore it could be appropriate to explore other ways to deploy EE that provide more relevance to citizens as an active element of the energy system.

DER technologies can be used to provide basic services, tough we can appreciate here how the line between basic services and VAS becomes blurry, especially when the customer or community become actively involved as main actors of the energy system:

- By the utility: Energy storage deployed at a substation to relieve a distribution constraint.
- By third party and then used to sell services to the utility: Energy storage deployed behind a customer meter or as part of a community-shared solar project and used to sell demand reductions to a utility demand response program to address that same distribution constraint.

Consumer's advocates point out relevant concerns when considering the adoption of specific VAS (Blansfield J., et al., 2017):

- avoiding prematurely locking captive ratepayers into certain technological paths

[94] Some of the reasons of why this approach has not been very successful up until now could be on the one hand the implicit conflict of interests (current utilities main BM is to sell energy, and EE deployment, self-consumption of DG, DS and in general most of the DER, reduce the amount of energy they sell and its value) which limits their effective EE deployment to what benefits the utility (shaving peak load or having enough valley volume) and not to what benefits consumers and the whole of society, and on the other hand it can have something to do with the limited trust and confidence that consumers have on the utilities.

- avoiding the stranding of costs and assets for technologies that are on the verge of obsolescence.
- avoiding risks of consumer marketing abuses or privacy violations.

They also point to the need of well-designed performance metrics for VAS, which could help to measure whether the VAS has effectively resulted in an outcome favorable to the public good. Regulators should only approve the provision of VAS if they are truly capable of providing system wide benefits or if the costs of the VAS in question are borne by only the consumers who benefit from the service.

8.2 Utilities vs third-party providers

VAS can be provided by both utilities and third-party providers, with pros and cons associated to any of these options (Blansfield J., et al., 2017), and both having their role to play in different contexts. In any case, unlocking the full transition potential requires putting the citizen at the center of BMs, enabling and facilitating its participative involvement in all VAS and basic services.

Having utilities providing DER as a service in exchange for a fixed monthly fee could make it more affordable to all customers (not just high standing) and facilitate geographical optimization of RES deployment through the grid. However, appropriate regulation needs to be on place to guarantee the appropriate flow of information to underpin smartness, in such a way that where third-party providers address these services the same social goals and techno-economic optimization can be reached.

Third-party providers' view (Blansfield J., et al., 2017) often sees the utility role evolving to that of a platform provider and operator, where the platform is comprised of the physical grid and an increasingly transactive marketplace, with the main utility's role being that of a market facilitator and operator.

Utilities should be able to deploy DERs on the utility side of the meter, subject to applicable generation ownership restrictions, in order to provide basic services to customers: Indeed, DG and DS at a substation can provide grid services and capacity that can defer or avoid expensive transmission or distribution system upgrades.

From a consumer advocates' point of view, up till now there have been varying experiences with third-party providers in deregulated states, where third-party retail energy suppliers sell electricity to the end-use utility consumer. While there have been consumers who have achieved savings or have enjoyed choices, other consumers have faced variable rates changing significantly without notice, uncertainties as to how their rate is calculated or the index utilized, exploitation of vulnerable populations, and high contract cancellation fees. The incorporation of new stakeholders meant to articulate the transition potential should take care of these issues so that evolution is towards an increase of smartness instead of backwards.

8.3 Sharing economy

The principles of the sharing economy, where benefits from the economic activity are fairly shared between all the stakeholders and resources are optimally used to maximize social benefit, should underpin BMs for SECs. Indeed, on the one hand that is the only way to fully mobilize all available resources and contributions, which is a must to meet the requirements from the tight transition we need to articulate. And on the other hand this is an essential component of the credibility and trustworthiness that utilities, retailers and third-party providers need to build with citizens in order to overcome their disappointing social track record and build the bridges that allow reaping the full benefits from network-based smartness deployment, and therefore avoiding the grid defection pathway. Moreover, sharing economy is a two way pathway, and can also break some of the barriers introduced by current energy system stakeholders because of feeling their BMs threatened by transition processes[95].

By increasing the efficiency of the overall system, optimizing capital allocation and creating new services for customers, grid edge technologies can unlock significant economic value for the industry, customers and society. Analysis by the World Economic Forum has pointed to more than $2.4 trillion of value from the transformation of electricity over the next 10 years. Society will benefit from a cleaner generation mix, net creation of new jobs related to the deployment of these technologies and a larger choice for consumers. Grid edge technologies can also improve social equity by creating value for low-income segments of population: Under the right regulatory model and targeted innovative business models, low-income households could participate and benefit from the value created by grid edge technologies (WEF, 2017).

Emerging social concepts like the sharing economy, coupled with the rise of distributed technologies, foster the development of customer-centered services such as community solar or energy trading virtual marketplaces.

One such example of sharing economy, fully centered on prosumers empowerment and a bottom-up transformation of the energy system is peer to peer energy services transactions within the SEC, typically supported by blockchain technology.

The ability to complete secure transactions and create a business based on energy sharing would allow participants to bypass the electric company energy supply and ultimately build a microgrid with energy generation and storage components that could

[95] *For instance, a utility can lose income from energy sales because of EE or behind the meter DG, but new revenue streams can be generated by sharing the overall value the transition provides.*

function on their own, even during broad power failures. One example of such an ongoing project is the Brooklyn microgrid (Cardwell D., 2017), (Deaton J., 2017). This Brooklyn microgrod project is but one example of how rapidly spreading technologies like rooftop solar and blockchain are upending the traditional relationships between electric companies and consumers, putting ever more control in the hands of customers. These initiatives showcase the deployment of digital networks that offer the promise of user-driven, decentralized energy systems that can work in tandem with the traditional large-scale grid or, especially in emerging economies, avoid the need for a grid at all.

These peer to peer BMs are also being applied in places where grid electricity supply is still not available, like in Bangladesh, peer-to-peer trading networks of rural households with and without rooftop solar systems are being deployed whereby prosumers can sell excess power into the network, where neighboring homes and businesses can buy it in small increments with a cellphone[96].

8.4 Revenue streams

Combining several of these revenue streams can lead to more resilient BMs and facilitate its navigation through the transition process.

Building these BMs from the sharing economy principles will enable materializing its full potential, building the required trust bridges between all the stakeholders, and very particularly with the prosumers.

8.4.1 Energy Management

This revenue stream would capture the different levels of EM services: consumer, building, public services and community level.

At community level, the articulation of local micro grid services transactions (DG, DS, DR) provides the means to access a shared economy structure where the benefits from the community's behind-the-meter EM can be shared within the community with high citizens' involvement and governance.

8.4.2 EE as capacity expansion

[96] https://www.me-solshare.com/

EE could be traded in capacity markets together with other DER resources like DG and DR.

In general terms EE allows saving both energy and peak load.

EE often brings about other benefits like improved comfort conditions within buildings, which by internalizing a hidden or unmet services' demand could attenuate its energy and peak load savings effects.

EE has often been deployed by utilities following regulatory planned goals, and been funded through surcharges paid by all customers, including those that do not participate in these programs, since they still benefit from them.

Indeed, beyond the direct benefits to customers that deploy EE measures in their premises, overall system benefits allow other user's to enjoy indirect benefits from EE deployment:

- Avoiding the cost of producing or procuring additional electricity could bring about reductions in overall energy generation costs.
- Avoiding or deferring the need to build new power plants and upgrade substations, therefore reducing fixed system costs.
- Reduction of local pollution and the associated improved air quality
- Reduction of GHG emissions and mitigation of climate change

8.4.3 DR as flexibility service

An aggregator can offer flexibility services directly to the SO through the different markets available (frequency regulation, reserves and other ancillary services).

Another option is for the aggregator to offer its flexibility services to an electricity retailer, so that this can balance its portfolio and therefore avoid deviation penalties[97]. This offers a transition pathway for aggregators until fully operational markets for DR are deployed.

8.4.4 DS as flexibility service

DS through building's battery storage systems facilitate better integration and management of VRES, providing grid-edge visibility and resilience benefits, while allowing customers to better manage their energy use.

---

[97] *In Spain this BM is more limited because deviations have a cost penalty only if they oppose the electricity system, which makes retribution for the flexibility service more uncertain.*

DS can minimize the impact of DG onto the distribution grid by managing grid exports, and therefore allow for a higher DG penetration with a given grid infrastructure.

8.4.5 DG as generation and integration service

Both at buildings' scale and at community level (public spaces, smart mobility premises,…), on-site distributed generation plays a significant role in SEC energy supply, as well as in optimizing the operation and planning of distribution networks and infrastructure.

Both the direct DG service, as well as associated regulation and ancillary services (like voltage stabilization), and the RES integration services provided by the community through its EF mechanisms would constitute BM revenue streams.

8.4.6 Offsite community RES generation

Community owned off-site RES generation, going beyond the possibilities of on-site generation, also plays an important role for the materialization of SEC.

Indeed, cities imply a very high concentration of demand, and when a significant portion of the whole community's energy and GHG emissions footprints wants to be addressed, going beyond the NZEB concept towards the NZEC and the PEC concepts, which already capture fair transition considerations (see §8.4.11), onsite resources will likely be constrained or evidence of better economic performance by deploying off-site RES will arise, also contributing to optimize the existing transport infrastructure and overall transition. This involves accessing to economies of scale in technological development, accessing technologies better suited to complement the overall energy system (like community based CSP with integrated storage), of more appropriate sitting of energy infrastructure (like RES for hydrogen generation and storage).

Community empowerment and energy system governance require community involvement in energy system beyond the physical community boundaries, and articulating and facilitating this involvement opens up BM revenue streams.

8.4.7 Energy services provider

Evolving from trading energy to trading the final services pursued with the energy use, opens up a whole space for smartness deployment by properly aligning the economic and energy systems, since it facilitates and enables several transition elements:

- EE deployment. Introduces clear incentives for EE effective deployment, since business models evolve from making benefit by selling energy to making benefit by selling services while minimizing energy consumption. Indeed, energy evolves from the main product sold to a production input, completely changing the economic drivers.
- Optimum use of infrastructures and equipment, as well as potentiation of sharing economy.
- Sharp reduction in material requirements to manufacture products meant for users to inefficiently self-procure the service they require.

Energy services providers can deal with a whole portfolio of services in order to exploit the potential synergies, or concentrate on a specific service.

For instance, in (Lajgaard Pedersen M., Karentius Freund M.S., 2017) the HP operator and its associated BM are explored. The HP operator is a commercial market player that owns and operates the HPs installed in a building. They are responsible for the installation and maintenance of the HP, pay for the electricity used for the HP and sell the generated heat to the building owner, providing him the SH and DHW service.

8.4.8 Mobility services and its energy integration

8.4.8.1 Smart mobility services provider

This represents the evolution from the public/private structure to the individual/collective ownership structure, and offers a huge transition potential for all EE deployment, integration, DR and improving urban conditions by reducing traffic congestion and space requirements for cars.

In essence, a smart mobility services provider allows the transition from the current context of huge amounts of individually-owned and inefficiently-operated individually-owned vehicles, to small amounts of smartly and system-integrated, collectively-owned and efficiently-operated[98] EVs, that by deploying an organic network bringing together users and other public transport infrastructure allow a more satisfactory coverage of the mobility services demand while simultaneously getting rid from all the burdens associated to individually-owned vehicles, and very significantly reducing the energy requirements and emission implications associated to the manufacture of all these individually-owned vehicles. For more details see (Garcia-Casals X., 2011) and (Garcia-Casals X., 2017b)

Autonomous driving technology may be one of the biggest accelerators of EV adoption, along with declining battery costs, and smart mobility services BMs. In this context,

[98] *Because of its electrification, higher capacity factor and autonomous driving.*

individual customers buy fewer cars and companies own large fleets of electric, autonomous vehicles.

8.4.8.2 V2G integration and management

This revenue stream would consist on managing and properly integrating into the system all the DR potential associated to V2G and V2X interactions.

8.4.9 Local social welfare

A BM revenue stream addressed to valorize, articulate and enable all the transition co-benefits, energy poverty, and other local social impacts. Smartly addressing energy poverty issues in a transition context could involve empowering these consumers by valorizing the services they can provide to the rest of the energy system, which go much beyond DG to encompass DR services.

8.4.10 Transition responsibility articulation

Articulating a transition with chances to comply with the global climate boundary condition within the available time window requires implementing structural changes that empower the population and allow the successful and in-time fulfillment of individual and collective responsibilities (Garcia-Casals X., 2017b).

Although without full access to the details, community members are often aware of these challenges, and at some level reinforced by witnessing the meagre institutional progress along the last decades, they are also getting aware that without their direct involvement there won't be chances of success.

However, community individual and collective frustration often truncates any progress on assuming community members' responsibilities. This frustration originates by the perceived unsurmountable impact of existing barriers (institutional and corporate), the impression of not having available meaningful action lines where individual or community action can make a difference, the lack of governance to tackle these barriers and support effective action, the lack of traceability of individual and community action, and the perceived dilution of individual and community action in the mainstream. All of this often leads to the impression that it does not matter what one does at individual or community level, because it won't significantly affect the course of overall evolution.

The fact that effective community involvement is of paramount importance for an effective transition, and that in the current context all these multiple barriers block its effective articulation, opens the door for several value-added services with the potential to very significantly increase the trust and collaboration of citizens with utilities or third party providers:

- Facilitating the means for an effective fulfillment of community member's transition responsibilities. Contributing to articulate effective community participation and empowerment through the articulation of meaningful and traceable action items. These can be associated to other business lines like EM, EE, DR, DS, DG, off-site RES community based generation, and fair transition contributions.
- Facilitating or contributing to the creation of a social credit accounting system that properly and quantitatively captures all the individual contributions to the transition, providing visibility to its impact and the associated aggregated community contribution, in such a way that avoids the frustration of the small contributions being lost in the ocean of non-sense, provides a compelling evidence and visibility that big changes are articulated by the aggregation of small contributions, and facilitates an appropriate monitoring of transition progress.

8.4.11 Fair transition management

Aligning our socio-economic system with the global climate boundary conditions in order to limit global warming to 1.5ºC requires a very tight transition (Garcia-Casals, X., 2017b). A successful articulation of fairness considerations is a must in order to underpin such a transition.

The global North in general and Iberia in particular, fall under the 'high historic emitters' country or regional classification in Figure **32**, which means that their population already overshoot, with their current cumulative emissions (light brown bar in Figure **32**), their available fair share of the global carbon budget (green bar in Figure **32**), and they still did not complete the transition, so they will still incur in additional cumulative emissions (dark brown bar in Figure **32**). Therefore, fairness considerations lead to a per capita compensatory mitigation (red bar in Figure **32**) that needs to be effectively articulated and transferred to 'low historic emitter' countries in order for the world to stay within the available carbon budget.

Effective articulation and transfer of this compensatory mitigation opens up an important added-value service to be captured by SEC BMs.

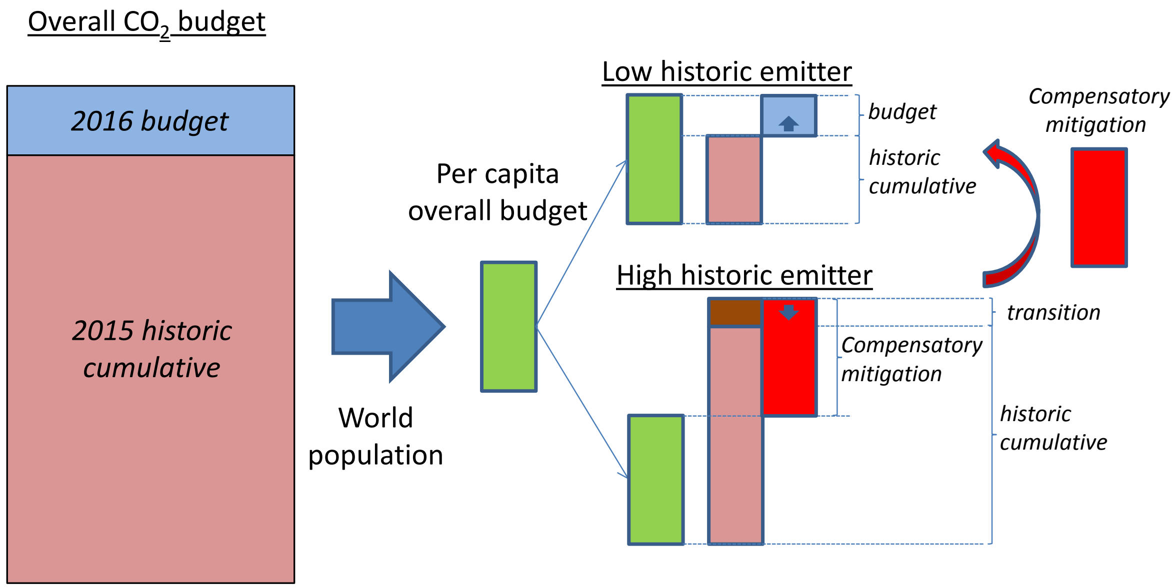


Figure 32: Basic approach for determination of fair shares of the available carbon budget, as well as the required equity compensatory mitigation (Garcia-Casals, X., 2017b)

8.5 Case example: Flexibility from HPs

Smartness when weaving BMs in a SEC context probably requires the parallel development of several of the revenue streams commented above, looking to exploit the full synergies between the different activities, and producing a resilient web of sustainable economic activity. In spite of this, early developments often try to concentrate on a single revenue line, tough one could expect them to organically mature into more holistic approaches as long as they are really rooted into the full (beyond technical gadgets) smartness deployment. That is the case of the ongoing EU-funded SABINA[99] project, from which IREC is one of the 9 project partners.

The generic high level SABINA goal is to develop new technology and financial models to connect, control and actively manage generation and storage assets to exploit synergies between electrical flexibility and the thermal inertia of buildings, responding to the flexibility requirement by targeting the cheapest possible source of flexibility: the existing thermal inertia in buildings and the coupling between heat and electricity networks it enables. However, in the practical project implementation the focus is put on a limited flexibility component from all the options available in the smart interaction between the built environment and the energy system: Articulating the flexibility from HPs, with the whole project gravitating around developing a technical aggregator tool for HP flexibility articulation and stimulating a market for it.

[99] http://sabina-project.eu/

In (Lajgaard Pedersen M., Karentius Freund M.S., 2017) a SABINA project deliverable (D 7.13) dealing with the analysis of aggregator BMs is provided. In spite of being a rather preliminary analysis of aggregator BMs, expected to be refined in D 7.14 due for September 2020, this reference already provides some interesting elements showcasing the waters that SEC BMs are currently navigating.

This reference investigates business opportunities concerning the aggregation of electrical flexibility within Europe, focusing on the development of a commercial aggregator that would utilize available flexibility provided by the control of HPs. The three most suitable counties within Europe for implementing these BMs are identified (France, United Kingdom and Denmark), and the potential market for commercial aggregation within each of these countries is analyzed. The proposed BMs developed for each of these three countries are based on research regarding energy politics, market mechanisms and current market landscapes. The analysis generically concludes that there are opportunities for aggregation of flexibility in Europe if certain barriers within the market can be overcome and the demands of prosumers are more thoroughly understood, and that the entry for these BMs can be made easier through cooperation with existing actors that have competences within the market mechanism and have responsibility for price settlement and balancing the system.

The BMs analyzed in (Lajgaard Pedersen M., Karentius Freund M.S., 2017) focus on developing a commercial aggregator in Europe, aimed to utilize the available flexibility provided by the control of HPs. Two ways of utilizing HPs are considered:

- As a product: the building owner owns its own HP and is therefore responsible for investment and maintenance. The building owner is a prosumer, who can provide flexibility through the control of the installed HPs.
- As a service: the building owner buys the heat from a HP operator who owns and maintains the HP. The HP operator can provide flexibility through the control of the installed HPs.

The flexibility provided by HPs control can be both down-regulation (switch HP on) and up-regulation (switch HP off).

The concept of a HP-operator is not a new one: In Denmark, several energy actors have developed a service-based BM for improving the implementation of HPs by reducing the complexity of the control of HPs for heat prosumers. The BM has focused on selling heat from HPs to building owners following the DH principle (with the obvious difference being that the HP is physically installed in the prosumer’s building). The HP operator owns the HP, and thus controls and maintains the installed HP during the contract period. The HP operator is responsible for securing comfort for the customer by its communication system and online monitoring of the indoor climate. The building-owner pays for the heat and the related service. The HP operator pays for the electricity the heat pump consumes, and has the responsibility for associated risks, costs and investments comprising installation, controlling, service and optimization (from a control point of view) of the HP.

The HP-operator BM opens the opportunity for a HP operator to collaborate with an aggregator to unlock flexibility. Since the HP-operator can operate several HPs, the aggregation can become more efficient than multiple links between aggregator and individual building owners.

When scanning the different countries for selecting the best options to start off these BMs, the following criteria have been used:

- Demand response development.
- Level of independent aggregation.
- The national level of barriers and legislation.
- The level of Smart Grid technology development.
- The number of EV's and heat pumps that are already installed/implemented and (potentially) available for demand response.

The considered countries have been the ones represented in SABINA (Denmark, UK, Switzerland, Spain, Greece, Belgium and Czech Republic) plus France. France has been chosen due to the advances[100] being made in market areas compatible with the BM trying to be implemented. After a quantitative and qualitative evaluation process, the three selected countries for further analysis of BM have been: France, UK and Denmark.

The SABINA Task 7.13 document, presents a preliminary Multi Agent System analysis developed to provide a framework for the actors, their roles and relationships within the frame of the pursued BM, with an associated Value Flow[101].

In the Value Flow analysis four values have been identified which are shared, delivered, received and captured among the BM actors: Physical, Data, Service and Money. Qualitative estimates and high level description from these Value Flows are provided, and these Value Flows have been applied for the development of the BM analysis.

It is worthwhile noting that among the SABINA identified monetary Value Flows, the one associated to an explicit recognition of the flexibility provided by prosumers is missing. Indeed, the proposed SABINA BMs all rely on an implicit and indirect recognition of the prosumer participation into the energy system:

- If the prosumer provides flexibility through its own HP, it is implicitly expected that it will benefit from an electricity bill reduction through its retailer.

---

[100] France is the only EU member state, which has opened both the ancillary services markets and wholesale market to demand response and independent aggregators.

[101] Value Flows associated to four different BMs are presented (tough with a preliminary character): BM based on a commercial or an independent aggregator; BM based on the BRP as the aggregator; BM based on the HP operator as the aggregator; BM based on the retailer as the aggregator.

- If there is a HP-operator, this will be the one to get the explicit benefits of the flexibility service provided, and the prosumer is implicitly expected to get a kind of rebate from the HP-operator or its retailer.

This lack of acknowledgment of the primary EF source, i.e. the prosumer, and its associated limitations on the deployment of the shared economy (properly sharing economic and social benefits), introduces significant barriers for the prosumer's empowerment within the energy system, and can easily lead to hampering the full EF potential deployment.

Different BMs[102] are proposed for each of the three countries based on the opportunities identified for potential aggregators[103]:

- France[104]:
    - BM based on a Commercial/Independent aggregator, capable to deliver larger amount of flexibility to all energy markets.
    - Partners: The primary partner is the BRP, who handles balancing of flexibility. The secondary partners would be prosumers or the HP-operator (flexibility providers).
    - Value Propositions:
        - Flexibility service to DSO/TSO (flexibility for electricity generation).
    - Customers:
        - The primary customers would be the TSO (large I&C customers) and the DSO.
    - Revenue Streams:
        - Revenue would be mainly based on payment from the TSO or DSOs for flexibility and possibly incentives given by the government or local municipality.
- UK:
    - In the UK the most suitable BM choice is a so-called "supplier-led aggregator" related to the model for flexibility opportunity for existing market actors, which is an approach to exploit the flexibility opportunities with current market actors. Here, the electricity retailer would take over the role of aggregator.

---

[102] The common key activities for all these BMs are: Flexibility services, Data collection, Counselling to customers (how to benefit the most from the flexibility service), Software development and optimization. When the BM is based on the HP-operator the original comfort energy service is included among the main activities.

[103] It is worth noting that none of these BMs includes within its costs the explicit reward to prosumers for using their EF…

[104] Historically, the primary customers for commercial aggregators in France have been TSOs as it has mostly been large I&C customers who have delivered flexibility to the grid. The implementation of this BM would allow the commercial aggregator to include DSOs as primary customers which could help to facilitate the large-scale integration of RES into the grid.

- The required building's data is likely to be more accessible for the supplier-led aggregator than other aggregators, as the electricity supplier already corresponds with their customers and has access to some of the data. The supplier led aggregator may also use fewer resources when searching for customers, as it would be easy for them to find prosumers through their existing portfolio.
- Any reduction in the prosumers' electricity bill may reduce the revenue[105] stream of the retailer from its supply contracts. However, it is possible that an overall increase in the revenue stream of the supplier could be stimulated through payments received for flexibility from primary customers (TSO and DSO).
- Partners:
  - The primary partner for the retailer acting as aggregator in this BM is the BRP, with whom they would need to collaborate in order to use the technical aggregator tool. In this 'supplier-led' scenario the BRP would balance the available flexibility in the action periods.
  - The secondary partners are prosumers or HP-operators.
- Customers:
  - The primary customers are the TSO (large I&C customers) and DSO.
- Value Propositions:
  - Flexibility service to DSO/TSO: flexibility for electricity generation.
  - Flexibility service to building: Control of electricity consumption for load shifting.
  - Flexibility service to HP operator: Control of electricity delivered to of heat pump for load shifting.
- Revenue Streams:
  - Flexibility payment from TSO/DSO.
  - Incentives (Political).
  - Electricity payment from flexible prosumers or HP-operator.

- Denmark:
  - In Denmark, a HP-operator is the most suitable to take the role of aggregator delivering both heat and flexibility as a service.
  - The needed building's data is likely to be more accessible for the HP-operator-aggregator than for other aggregators, as the HP- operator would already have access to some data from their customers.
  - Both the HP-operator and its electrical supplier will have customer portfolios, which could potentially be combined.
  - Partners:
    - The primary partners are the BRP and the electricity supplier.
    - The secondary partner is the prosumer.
  - Value Propositions:

[105] *This kind of conflict interest is what makes the independent aggregator the preferred choice.*

        - Heat from HPs (or even better comfort service) for prosumers.
        - Flexibility service to DSO/TSO: Offers flexibility to the electricity production.
        - Flexibility service to building: Control of electricity consumption for load shifting.
    - Customers:
        - Prosumers, TSO & DSO.
    - Revenue streams:
        - Flexibility payment from TSO/DSO.
        - Incentives (Political).
        - Subscription payment from prosumers (for both comfort and flexibility services supply).

From this BMs preliminary analysis, (Lajgaard Pedersen M., Karentius Freund M.S., 2017) conclude:

- A commercial aggregator using these BMs could offer value to their primary customers, the TSO & DSO, and their secondary customers, the prosumer. The TSO and DSO will purchase the flexibility unlocked by the aggregator according to the requirements of the grid. The prosumer with HPs will experience a lower energy bill, which is desirable, but the question is[106]: Will the prosumer be interested in participating as a flexible unit in the flexibility system?.
- In order for these BMs to work the energy market must develop to a point where the power threshold for trading flexibility is low enough to enable involvement of small scale commercial and domestic prosumers. The current threshold of around 10 MW in wholesale markets (1MW for certain incentives in the UK or for regulation and ancillary services markets) is too high and therefore this must be adjusted.
- Customers must experience a well-functioning technology, the pricing for flexibility must be profitable enough, and there has to be enough flexibility to make a difference to the grid.

9 Roadmaps

Roadmaps become particularly relevant for SECs BM because of the particular context under which they have to be developed:

- Fast changing contextual and regulatory environments, enabling business options never seen up till now. It is important to be aware that our socio-economic system

[106] Indeed, that's the crucial question, and in our opinion, the lack of explicit acknowledgment of prosumers as an active part of the energy system in the SABINA BMs can be a significant barrier.

has never before faced a global challenge like the one imposed by the need to mitigate and adapt to climate change, and therefore we can anticipate rates of change significantly higher than those where energy business activity has been living up till now.

- BMs themselves become an important transition tool, agents of change, facilitating and enabling the participation and new roles from other stakeholders, and specifically for those sitting at the transition's cornerstone: citizens.

Communities site on the very center of this transition process, and therefore SEC MBs need to internalize this context from the very onset.

Failing to grasp the implications from this very particular context would lead to either implementing BMs that get completely obsolete in very short periods (even generating stranded assets), or to situations where BMs cannot take off through the current barriers losing momentum so that once the barriers are out they do not have the capability to react.

Therefore roadmaps should facilitate BMs to navigate this context, by clearly and ambitiously pointing to the post-transition context, but simultaneously offering transition paths for gradually but swiftly incorporating the new options that become available as barriers crumble down spurred by the own activity from these BMs.

A typical example is the evolution of DER independent aggregators as regulation progresses. Until a market for flexibility services becomes fully operative, aggregators can build their BMs through bilateral contracts with retailers or the BRP.

Significant regulatory changes are needed for SEC BMs to get fully operative. The gap until these regulatory changes are implemented, besides being navigated with a progressive deployment of final BMs by private actors, has to be closed with transition regulation where the administration temporally takes up facilitation tasks.

The public and private sectors will need to contribute to successfully accelerate adoption of grid edge technologies, as neither can do it alone.

Public-private partnerships will help build enabling infrastructure, even if it is not yet commercially viable and thus requires initial public intervention.

Integrated roadmaps are required, to foster the synergies between the different transition dimensions by addressing, under a common framework, all the SEC system blocks. Integrated plans are most beneficial when combining technologies and data from diverse industries – for example between the automotive and electricity sectors, to support EVs. The EV test bed on South Korea's Jeju Island is a good example of an attempt to create an integrated roadmap, and a new industrial ecosystem. It combines technologies and players of the broad electricity system (technologies including microgrids, renewable energy sources, EVs and batteries, and several industries such as utilities, technology manufacturers, telecommunications and automotive). Synergies from these plans are leading to a faster expansion of technologies and more innovative BMs than if they had been introduced individually.

Still, the main priority actions for the principal grid edge technologies underpinning a SEC would be (WEF, 2017):

- EVs:
  - Invest in deploying public charging stations rather than vehicles, since vehicles will be economical without subsidies in the near future.
  - Encourage flexible charging of electric vehicles through differential pricing of electricity.
  - Develop innovative BMs to incent electrification of private sector fleets (such as Uber, Lyft and Google).
  - Update regulations on insurance and liability to enable autonomous vehicles.
- DG:
  - Invest in distributed generation where it makes economic sense – for example, where there are constraints on land use due to congestion, infrastructure or other factors.
  - Consider planned distributed generation as electricity system plans are developed – and not just for building or replacing the grid, but for capacity planning as well.
  - Incentivize innovation through outcome-based schemes, as opposed to subsidizing specific technologies.
- DS:
  - Modernize system planning to include planned DS and other options for a smart grid.
  - Connect storage to wholesale markets through focused and transparent price signals that reflect true cost/benefit of resource.
- EE:
  - Set efficiency standards and invest in other upstream initiatives[107].
  - Encourage opt-out schemes to make energy efficient products the default option.
  - Segment customers and tailor offers to target energy conscious customers.
- DR:
  - Create a seamless customer experience that is automated and self-learning (e.g. more flexible, automated and convenient “shallow” demand-response products).
  - Ensure interoperability between devices for integrated demand response (e.g. single technology standards).
  - Allow independent aggregation.

[107] *Beyond that, exploring the valorization of EE through for instance capacity markets could facilitate its deployment.*

- Set price signals (e.g. time of use).

- Digitalization:
    - Develop data laws to ensure data sharing across market actors.
    - Develop innovative business models for the use of data.
    - Encourage time-of-use or dynamic pricing.
    - Set codes and standards for smart devices.
    - Set interoperability standards.

In (Sanmartí M., et al, 2017) a roadmap for V2X[108] developed by IREC is presented, with the main goal to identify the current barriers for V2X effective deployment and propose strategies to overcome them. Actionable points are identified along the market and regulation dimension (define BMs, enable market access), technological dimension (standardization, harmonization of EVSE and battery incremental degradation because of V2X), and social dimension (engagement and promotion, involvement facilitation, sharing economic benefits, unlocking synergies with DG).

In (Den Ouden E., Valkenburg R., 2016) the results from the Roadmaps for Energy (R4E) project are presented. The R4E is an EU funded project under the Horizon 2020 programme that aims to develop a new type of energy strategy through visions for year 2050[109] and roadmaps for 8 cities[110] towards their ambition of becoming Smart Cities, focusing on three areas within the domain of sustainable energy that are closely linked to the municipalities main responsibilities: smart buildings, smart mobility and smart urban spaces.

The R4E roadmaps include interesting elements. They have been developed through a rather participative process, tough limited to few stakeholders, with expert inputs feeding the discussion, and with the opportunity to share the results coming out from the optics of cities that have rather different contexts. Therefore, the R4E allows to somehow gauging the transition thinking currently being articulated by some stakeholders.

It is worth commenting how some elements from the R4E roadmaps and visions still seem to be anchored far from current transition requirements, although they coexist with other elements that are well transition-aligned and that even contradict the first ones, which illustrates the conflicting interests still dwelling into the different stakeholder minds:

---

[108] V2G, V2H, V2L, V2V

[109] Focusing to year 2050 with sometimes rather generic goals, is in view of the current context not that much transition sensitive, since the transition should unfold faster in order to align with the climate boundary condition, and cities seem to be called to become forerunners in the transition path.

[110] Eindhoven (Netherlands), Forli (Italy), Istambul (Turkey), Murcia (Spain), Newcastle (United Kingdom), Palermo (Italy), Sant Cugat (Spain), Tallinn (Estonia).

- Quite too often there are generic empty goals centered on the differential city identity (like 'becoming a sustainability reference') that fail to capture the global dimension of the required transition.
- The R4E roadmaps often still focus on the improvement of specific components (a building) without widening the focus to improve the whole, missing the smartness potential associated to the aggregation and integration elements. Indeed, one finds many references to 'CO_2-neutal buildings', 'energy-producing buildings', 'buildings with zero energy usage from the grid', 'self-sufficient buildings', 'make buildings self-sufficient or even energy positive', which in the best case start to look to the district level aggregation to consider 'energy-neutral district' , 'self-sufficient district', 'food self-sufficiency at city level' , but that still miss the wider smartness concept that looks to optimize the whole by articulating all the synergies between the different system components. Indeed, there is too often the prevalence of an isolated view that misses the synergic interaction with its surroundings (even with the rural environment) and therefore fails to capture a big deal of the smartness potential: 'In 2050 Sant Cugat is an eco-strategic city, where all needs (e.g. local food, water and energy) are available within a 0-kilometer range'.
- With regard to mobility, some of the R4E visions fail to capture the implicit responsibility in changing behaviors and the underlying socio-economic organization in order to limit our mobility requirements. In fact, some of the R4E visions still project that image of limitless resources and magical technology that allow us to get even the fanciest wishes without stepping outside of the sustainability boundaries. And smartness is not only associated to find out the optimum way to cover demand, but also to discern what demand makes sense and to find ways to minimize the demand itself. This is very well illustrated by the 'experience, experience, experience' driver for change for the future of sustainable and livable cities in 2050, which includes the following element: 'The whole planet can be reached within a few hours. Even space travel could be an option!'.
- The R4E visions from time to time still project an image of abundance in (cheap) RES resources, which will allow us not only to maintain our consumerist socio-economic structure, but even to project it to ever increasing quotas ('Self-sufficiency based on an abundance of renewable sources and storage solutions'). That is certainly not the case, and missing the global constraints, the extremely tight global transition requirements and the co-responsibilities in the overall transition process, fails to capture a significant part of what smartness deployment should provide.

Still it is interesting to see how from the very onset, the R4E process beyond the 'smart buildings' and 'smart mobility' dimensions included the 'smart urban spaces' more overarching dimension providing some level of integration.

Few interesting elements of the ambition underpinning the R4E roadmaps:

- Smart mobility:
    - Multimodal transport with personalized advice based on actual data.
    - Integration of seamless transport.
    - Vehicle-sharing solutions for public transport.
- Smart urban spaces:
    - Solutions beyond the scope of single buildings, such as solutions for neighborhoods or city districts.
    - Create livable (social and environmental) urban spaces by engaged citizens and involvement of all stakeholders (business, university, citizens, administration).

The R4E project identified the following interesting main drivers of change:

- Smart cities:
    - Local, social businesses create community value:
        - Self-organizing, self-managing communities are the new social and market paradigm – all enabled by the new city governance models.
        - These drive the transition to empowered citizens who demand a range of sustainable solutions.
        - Municipalities facilitate this transition by creating the required economic and legal frameworks, and by constantly focusing on the public interests.
        - Fostering local business for social value.
        - New economic models taking into account social and environmental value explicitly.
        - Democratizing power: power to the citizens.
    - Enabling human development.
    - Redefining ‘smart’.
    - Regenerating resources in a circular economy:
        - Regenerative cities with circular systems for all relevant resources
        - Securing supply of food, water & clean air.
    - Democratized energy systems based on open data:
        - Entrepreneurs develop business models that provide value for them, for their users and for society at large
    - Applying new technologies.
- Smart buildings:
    - Technology with a human focus.
    - Policies aim at improving the quality of neighborhoods and strengthening the sense of community, and not only at reducing energy consumption.
    - Flexible ‘re-purposing’ of buildings.
    - Building business for social living: Affordable solutions fostering the local economy.
- Smart mobility:
    - Experience, experience, experience:

        - There's a range of convenient, clean mobility options, making use of abundant renewable energy.
        - Travel has never been easier – it provides seamless connections from where you are to where you want to go.
    - Personal mobility as a service:
        - Autonomous vehicles take affordable personal mobility to a whole new level.
        - Technology makes sharing easy, so everyone has access to a vehicle whenever they need it.
    - Small-scale production through city logistics:
        - Local and decentralized production, citizens as prosumers.
        - Most production is by small-scale services and in the home, rather than by large, centralized corporations.
        - Communities create sufficient social and functional diversity to make them self-sustaining.
- Smart urban spaces:
    - Attractive cities with unique qualities.
    - Better living at a human scale:
        - Everyday activities are within walking or cycling distance.
        - Communal spaces strengthen social cohesion.
    - Connecting to 'green' and 'nature':
        - Urban farming increases regeneration of resources, creating fresh, healthy foods, reconnecting with nature and mobilizing local communities.
    - Self-sufficient communities:
        - Socially inclusive communities are self-sufficient in foods, fresh water, renewable energy and production of tools and systems.
        - People take responsibility for their own well-being, as well as that of the community, and co-design the physical environment and services.

The specific roadmaps developed within the R4E project for each of the cities and areas can be found in (Den Ouden E., Valkenburg R., 2016). The common visions associated to these roadmaps are the following ones:

- Smart buildings:
    - Energy-efficiency and sustainability.
    - Renovation to secure cultural heritage.
    - Versatile, flexible and proactive buildings.
    - Future smart grid.
    - Community sharing.
    - High quality, easily accessible systems.
    - Sustainable behavior.

- Smart mobility:
  - Sustainable solutions.
  - Healthy lifestyles.
  - Reducing the need for travel.
  - Seamlessly connected networks.
  - Mobility à la carte.
  - Accessible, affordable and convenient mobility.
  - Personalized advice.
  - Smart management.
- Smart Urban Spaces:
  - Flexible and attractive living environment.
  - Social interaction and healthy behavior.
  - Climate resilience.
  - Synergy between urban and rural areas:
    - The city footprint is reduced and the agricultural function of the countryside is restored.
  - Smart systems.
  - New business and financing models.
  - Citizen taking the lead in co-creation.

10 References

Al-Jassim Z., Christoffersen M., Wu Q., Huang S., del Rosario G., Corchero C., Moreno M.A., 'Optimal approach for the interaction between DSOs and aggregators to activate DER flexibility in the distribution grid', 24th International Conference & Exhibition on Electricity Distribution (CIRED), 12-15 June, 2017

Asthana A., Taylor M., 'Britain to ban sale of all diesel and petrol cars and vans from 2040', The Guardian, https://www.theguardian.com/politics/2017/jul/25/britain-to-ban-sale-of-all-diesel-and-petrol-cars-and-vans-from-2040, 25 July, 2017

Barbero M., Corchero García C., Del Rosario G., Igualada L., 'Estado del arte de los agregadores en Europa', REFER Project, IREC, (Draft Version), 2017

Baritaud M., Spruck S., Verstraeten C., Wittenstein M., Müller S., Miza Razali N., Scott J., Vailles C., 'Re-powering markets. Market design and regulation during the transition to low-carbon power systems', IEA, 2016

Beddington J., Berry S., Caldeira K., Cramer W., Creutzig F., Kammen D., Lambin E., Levin S., Lucht W., Mace G., Moomaw W., Raven P., Searchinger T., Christian Stenseth N., van Ypersele J.P., 'EU must not burn the world's forests for 'renewable' energy', The Guardian, https://www.theguardian.com/environment/2017/dec/14/eu-must-not-burn-the-worlds-forests-for-renewable-energy, 14 December, 2017

Bhavnagri K., 'Australia's shift to base-cost renewables', BNEF, Australian Clean Energy Summit, 2017

Blansfield J., Wood L., Katofsky R., Stafford B., Waggoner D., NASUCA, 'Value-added electricity services: new roles for utilities and third-party providers', Future Electric utility Regulation, Report No.9, 2017

Bringault A., Eisermann M., Lacassagne S. 'Cities heading towards 100% renewable energy', CLER, Energy Cities, Réseau Action Climat, November, 2016

CarbonBrief, 'Analysis: Just four years left of the 1.5C carbon budget', https://www.carbonbrief.org/analysis-four-years-left-one-point-five-carbon-budget, April, 2017

Cardwell D., 'Solar Experiment Lets Neighbors Trade Energy Among Themselves', The New York Times, https://www.nytimes.com/2017/03/13/business/energy-environment/brooklyn-solar-grid-energy-trading.html, 13 march, 2017

Chiantore P.V., Sviluppo K., Gordon I., Hoffmann W., Perezagua E., Philipps S., Roman E., Sandre E., Sinke W., Simonot E., Martínez A., 'Future renewable energy costs: solar photovoltaics. How technology innovation is anticipated to reduce the cost of energy from European photovoltaic installations', KIC Innoenergy, 2015

Chrisafis A., Vaughan A., ‘France to ban sales of petrol and diesel cars by 2040’, The Guardian, https://www.theguardian.com/business/2017/jul/06/france-ban-petrol-diesel-cars-2040-emmanuel-macron-volvo, 6 July, 2017

Deaton J., ‘In Brooklyn, you can now sell solar power to your neighbors’, Grist, http://grist.org/article/in-brooklyn-you-can-now-sell-solar-power-to-your-neighbors/, 23 May, 2017

De Groote M., Volt J., Bean F., ‘Is Europe ready for the smart buildings revolution?’, Buildings Performance Institute Europe (BPIE), February, 2017

Deign J., ‘Updated: Mexico’s Energy Auction Just Logged the Lowest Solar Power Price on the Planet’, gtm, https://www.greentechmedia.com/articles/read/mexico-auction-bids-lowest-solar-wind-price-on-the-planet#gs.W2XNk8I, 21 November, 2017

Den Ouden E., Valkenburg R., ‘R4E: Roadmaps for Energy’, http://roadmapsforenergy.eu/, 2016

Dipaola A., ‘Saudi Arabia Gets Cheapest Bids for Solar Power in Auction’, Bloomberg Markets, https://www.bloomberg.com/news/articles/2017-10-03/saudi-arabia-gets-cheapest-ever-bids-for-solar-power-in-auction, 3 October, 2017

Domínguez J.L., Perez A., ‘Energia Solar Fotovoltaica. Prospectiva energètica de catalunya a l’horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya’, IREC, October, 2017

Domínguez J.L., ‘Smart Grids. Prospectiva energètica de catalunya a l’horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya’, IREC, October, 2017

Domínguez J.L., ‘Energia Eòlica. Prospectiva energètica de catalunya a l’horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya’, IREC, October, 2017b

Ferroukhi R.; Sawin J., Sverisson F., Wuester H., Kieffer G., Nagpal D., Hawila D., Khalid A., Saygin D., Vinci S., ‘Rethinking Energy 2017: Accelerating the global energy transformation’, IRENA, 2017

Garcia-Casals X., ‘Renewables 100%’, Greenpeace, http://archivo-es.greenpeace.org/espana/es/Trabajamos-en/Frenar-el-cambio-climatico/Revolucion-Energetica/Renovables-100/, 2006

Garcia-Casals X., ‘Energy 3.0’, Greenpeace, (http://www.revolucionenergetica.es/), 2011

Garcia-Casals X., ‘Neighborhood energy footprint from sustainable urban planning in Denmark’, personal communication, 2017a

Garcia-Casals X., ‘A transition analysis for a 1.5C Climate Vision’, http://xavigarciacasals.blogspot.com.es/2017/08/a-transition-analysis-for-15c-climate.html, 2017b

Garcia-Casals X.,' Renewable Energy deployment versus Fossil Fuel phase-out in the power sector: Where to focus?', https://xavigarciacasals.blogspot.com.es/2017/09/renewable-energy-deployment-versus.html, 2017c

Go 100% Renewable Energy, http://www.go100percent.org/, January, 2018

Götz M. , Lefebvre J., Mörs F., Koch A.M., Graf F., Bajohr S., Reimert R., Kolb T. ,'Renewable Power-to-Gas: A technological and economic review', Renewable Energy, Volume 85, January 2016, Pages 1371-1390. doi:10.1016/j.renene.2015.07.066, 2016

Hausfather Z., 'Why Natural Gas Is Not a Bridge Fuel', EcoWatch, https://www.ecowatch.com/natural-gas-bridge-fuel-1983761881.html, 23 August, 2016

ICLEI, '100% Renewable Energy Cities & Regions Network', http://www.iclei.org/activities/agendas/low-carbon-city/iclei-100re-cities-regions-network.html, January, 2018

Igualada L., Corchero C., 'Análisis comparativo de sistemas de gestión energético de autoconsumo para el sector residencial', IREC, SG4, 2017

IREC, 'Aggregator functions and communication channels in REFER', 2017

IRENA, 'Renewable Power Generation Costs in 2017', IRENA, Abu Dhabi, 2018

Klein N., 'As New York city declares war on the oil industry, the politically impossible suddenly seems possible', The Intercept, https://theintercept.com/2018/01/11/new-york-city-big-oil-fossil-fuels-climate-change/, 11 January, 2018

Lajgaard Pedersen M., Karentius Freund M.S., 'Business canvas model: Deliverable D7.13', SABINA (SmArt BI-directional multi eNergy gAteway) project, under EU H2020-LCE-01-2016-2017 (Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network), August, 2017

Lipari G., Del Rosario G., Corchero C., Ponci F., Monti A., 'A real-time commercial aggregator for distributed energy resources flexibility management', Sustainable Energy, Grids and Networks, Article in Press, 2017

McConnell D., 'A month in, Tesla's SA battery is surpassing expectations', RenewEconomy, http://reneweconomy.com.au/month-teslas-sa-battery-surpassing-expectations-41248/, 16 January, 2018

Mahapatra S., 'India Considers 100% Electric Vehicles By 2030', Clean Technica, https://cleantechnica.com/2017/04/21/india-considers-100-electric-vehicles-2030/, 21 April, 2017

Manyes, L. Sisó, J. Salom, Block level study and simulation for residentialretrofitting, in: BS2013: 13th Conference of the International BuildingPerformance Simulation Association, Chambery, France, 2013

McDonald J., 'China to ban petrol and diesel cars, state media reports', Independent, http://www.independent.co.uk/news/world/asia/china-petrol-diesel-car-ban-gasoline-production-sales-electric-cabinet-official-state-media-a7938726.html, 10 September, 2017

Muttitt G., McKinnon H., Stockman L., Kretzmann S., Scott A., Turnbull D., 'The Sky's Limit. Why the Paris climate goals require a managed decline of fossil fuel production', Oil Change International, 2016

New Energy Update, 'ACWA Power scales up tower-trough design to set record-low CSP price', http://analysis.newenergyupdate.com/csp-today/acwa-power-scales-tower-trough-design-set-record-low-csp-price, September 2017

Oró E., Flox C., 'Emmagatzematge d'energia. Prospectiva energètica de catalunya a l'horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya', IREC, October, 2017

Oró E., 'Energia Solar Tèrmica. Prospectiva energètica de catalunya a l'horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya', IREC, October, 2017

Oró E., 'Energia Solar Termoelèctrica. Prospectiva energètica de catalunya a l'horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya', IREC, October, 2017b

Ortiz J., Guarino F., Salom J., Corchero C., Cellura M. 'Stochastic model for electrical loads in Mediterranean residentialbuildings: Validation and applications', Energy and Buildings 80, pp 23–36, 2014

Ortiz J., Fonseca A., Salom J., Garrido N., Fonseca P., Russo V., 'Comfort and economic criteria for selecting passive measures for the energy refurbishment of residential buildings in Catalonia', Energy and Buildings 110, pp. 195–210, 2016

Ortiz J., Fonseca i Casas A., Salom J., Garrido Soriano N., Fonseca i Casas P., 'Cost-effective analysis for selecting energy efficiency measures forrefurbishment of residential buildings in Catalonia', Energy and Buildings 128, pp. 442–457, 2016b

Ortiz J., Salom J., 'Estimación del efecto de la rehabilitación energética en la salud de las personas. Enfoque económico', IREC publication, 2016

Ortiz J., Torrent M. , 'Sistemes Eficients de Gestió i Transformació de la Energia. Prospectiva energètica de catalunya a l'horitzó 2050 (PROENCAT 2050) i la transició energètica de Catalunya', IREC, October, 2017

Parkinson G., ‘The first Australian utility to embrace era of “base-cost renewables”’, RenewEconomy, http://reneweconomy.com.au/the-first-australian-utility-to-embrace-era-of-base-cost-renewables-93569/, 2017a

Parkinson G., ‘Biggest game-changer on network spending approved – a decade late’, RenewEconomy, http://reneweconomy.com.au/biggest-game-changer-on-network-spending-approved-a-decade-late-25198/, 2017

Parkinson G., ’Tesla big battery officially switched on in South Australia’, RenewEconomy, http://reneweconomy.com.au/tesla-big-battery-officially-switched-on-in-south-australia-55285/, , 1 December, 2017b

Parkinson G., ‘Tesla big battery outsmarts lumbering coal units after Loy Yang trips’, RenewEconomy, http://reneweconomy.com.au/tesla-big-battery-outsmarts-lumbering-coal-units-after-loy-yang-trips-70003/, 19 December, 2017c

Parkinson G., ‘Speed of Tesla big battery leaves rule-makers struggling to catch up’, RenewEconomy, http://reneweconomy.com.au/speed-of-tesla-big-battery-leaves-rule-makers-struggling-to-catch-up-36135/, 21 December, 2017d

Parkinson G., ‘Base-cost renewables: When wind and solar finally kill coal’, RenewEconomy, http://reneweconomy.com.au/base-cost-renewables-when-wind-and-solar-finally-kill-coal-72324/, 19 July, 2017e

Parkinson G., ‘Why the Tesla truck will turn freight industry upside down’, RenewEconomy, http://reneweconomy.com.au/why-the-tesla-truck-will-turn-freight-industry-upside-down-13500/, 26 Septembre, 2017f

Parkinson G., ‘Death spiral for cars. By 2030, you probably won’t own one’, RenewEconomy, http://reneweconomy.com.au/death-spiral-for-cars-by-2030-you-probably-wont-own-one-93626/, 9 May, 2017g

Patteeuw D., Reynders G., Brunix K., Protopapadaki C., Delarue D., D’haeseleer W., Saelens D., Helsen L., ‘CO2-abatement cost of residential heat pumps with active demand response: demand- and supply-side effects’, Applied Energy, 156, pp490-501, 2015

Péan T.Q., Ortiz J. and Salom J., ‘Impact of Demand-Side Management on Thermal Comfort and Energy Costs in a Residential nZEB’, Buildings 2017, 7, 37

Pérez-Arriaga I., Gómez T., Batlle C., Rodilla P., Cossent R., Herrero I., Usera I., Mastropietro P., Vinci S., Chaves J.P., Koirala B.P., Boschi F.; Parajuli B., ‘Adapting market design to high shares of variable renewable energy’, IRENA, 2017

Pernetti R., Reynders G., Knotzer A. (Eds.), ‘Energy flexibility as a key asset in a smart building future’, Contribution of IEA Annex 67 to the European Smart Building Initiatives, Position paper of the IEA Energy in Buildings and Communities program (EBC) Annex 67 ‘Energy Flexible Buildings’, November 2017

Ralon P., Taylor M., Ilas A., Diaz-Bone H., Kairies K-P, ‘Electricity storage and renewables: costs and markets to 2030’, IRENA, 2017

REN21, ‘Renewables 2017 Global Status Report’, Renewable energy Policy Network for the 21st century, 2017

Reynolds P., Phillips J., Jones F., Mura T., ‘Batteries: Beyond the spin. The dawning era of digital inertia on the Island of Ireland’, Everoze, October 2017

Salom J., Joanna Marszal A., Widén J., Candanedo J., Byskov Lindberg K., 'Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data', Applied Energy 136,pp 119–131, 2014

Sanmartí M., Corchero C., González-Villafranca S., Carroll B., Perez Y., Bach P., Vidal N., Francis J., Thompson A., Ribberink H.,'V2X Roadmap', IEA IA-HEV, IREC, (Draft version), 2017

Schmidt P., Weindorf W. , Roth A., Batteiger V., Riegel F., ‘Power-to-Liquids: Potentials and Perspectives for the Future Supply of Renewable Aviation Fuel’, German Environment Agency, Umwelt Bundesamt, September, 2016

SEDC, ‘Explicit Demand Response in Europe: Mapping the Markets’, Smart Energy Demand Coalition, http://www.smarten.eu/wp-content/uploads/2017/04/SEDC-Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf, 2017

Sierra Club, ‘100% Commitments in Cities, Counties, & States’, https://www.sierraclub.org/ready-for-100/commitments, January, 2018

Spector J., ‘Brooklyn's social housing microgrid rewrites relationships with utility companies’, The Guardian, 17 August, 2017

Spratt D., ‘Displacing coal with wood for power generation will worsen climate change, say researchers’, http://reneweconomy.com.au/displacing-coal-wood-power-generation-will-worsen-climate-change-say-researchers-41759/, 19 January, 2018

Staufenberg J., ‘Norway to 'completely ban petrol powered cars by 2025', Independent, http://www.independent.co.uk/environment/climate-change/norway-to-ban-the-sale-of-all-fossil-fuel-based-cars-by-2025-and-replace-with-electric-vehicles-a7065616.html, 4 June, 2016

UNDP, ‘The Emissions Gap Report 2017. A UN Environment Synthesis Report’, United Nations Environment Programme, November, 2017

Valpy B., English P., ‘Future renewable energy costs: onshore wind. How technology innovation is anticipated to reduce the cost of energy from European onshore wind farms’, KIC Innoenergy, 2014

Valpy B., Hundleby G., Freeman K., Roberts A., Logan A., ‘Future renewable energy costs: Offshore wind. 57 technology innovations that will have greater impact on reducing the cost of electricity from European offshore wind farms’, KIC Innoenergy, 2017

van der Burg L., Whitley S., ‘Rethinking power markets: capacity mechanisms and decarburization’, Overseas Development Institute (ODI), May, 2016

Vorrath S., ‘Another mini-grid breakthrough for AusNet in suburban Melbourne trial’, RenewEconomy, https://onestepoffthegrid.com.au/another-mini-grid-breakthrough-ausnet-suburban-melbourne-trial/, 19 December, 2017

Vorrath S., ‘Canberra switches on its own Big Battery – 1MW of household variety demand response’, https://onestepoffthegrid.com.au/canberra-switches-big-battery-1mw-household-variety-demand-response/, 30 November, 2017b

Vorrath S.,’AGL kills idea of gas as transition fuel: wind, solar + storage cheaper’, RenewEconomy, http://reneweconomy.com.au/agl-kills-idea-of-gas-as-transition-fuel-wind-solar-storage-cheaper-63013/, 2 May, 2017c

WEF, ‘The Future of Electricity. New Technologies Transforming the Grid Edge’, World Economic Forum, 2017

Zarza E., Simonot E., Martínez A., Winkler T., Pérez-Segarra C-D., Crespo L., Sánchez M., Pitz-Paal R., ‘Future renewable energy costs: solar-thermal electricity. How technology innovation is anticipated to reduce the cost of energy from European solar-thermal electricity plants’, KIC Innoenergy, 2015

11 Annexes

11.1 RES for SEC: technologies and costs

RES technologies have been progressing very significantly along their learning curves during the last years, reaching a level of costs that for those RES technologies that have experienced the highest deployment up to date has already reached (or is very close to reach) parity of costs with conventional electricity generation technologies, even without including the externalities from conventional technologies. Progress is expected to keep on going to with the prospect of RES electricity generating costs to still be significantly reduced.

RES power generating capacity saw its largest annual increase ever in 2016 (data from 2017 not yet available), with an estimated 161 GW of capacity added. Total global capacity was up nearly 9% compared to 2015, to almost 2017 GW at year's end. The world continued to add more renewable power capacity annually than it added (net) capacity from all fossil fuels combined. In 2016, renewables accounted for an estimated nearly 62% of net additions to global power generating capacity. Solar PV saw record additions and, for the first time, accounted for more additional capacity, net of decommissioning, than did any other power generating technology. Solar PV represented about 47% of newly installed renewable power capacity in 2016, and wind and hydropower accounted for most of the remainder, contributing 34% and 15.5%, respectively (REN21, 2017).

PV and wind have achieved high and maintained growth rates along the last decade, reaching worldwide cumulate installed capacities of 303 GW for PV and 487 GW for wind in 2016 (Figure 33 and Figure 34). LCOEs from these technologies are steadily reducing, reaching in 2017 already very low values in specific projects and regions, making them economically competitive with conventional generation[111]. However, as we may see in Figure 35 presenting ranges and averages for onshore wind and PV in 2016 in different regions, there is still a significant spread of LCOEs both regionally and from project to project.

[111] *In many regions of the world, VRE is now the lowest-cost source of newly constructed power generation available, thanks to rapidly declining capital costs and zero fuel costs.*

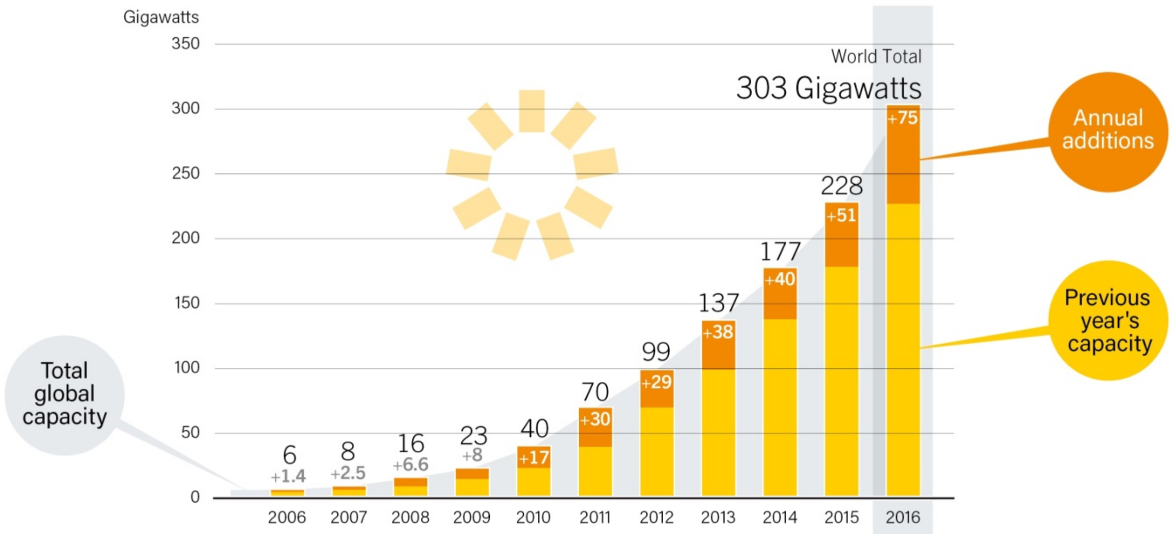


Figure 33: Solar PV Global Capacity and Annual Additions, 2006-2016 (REN21, 2017)

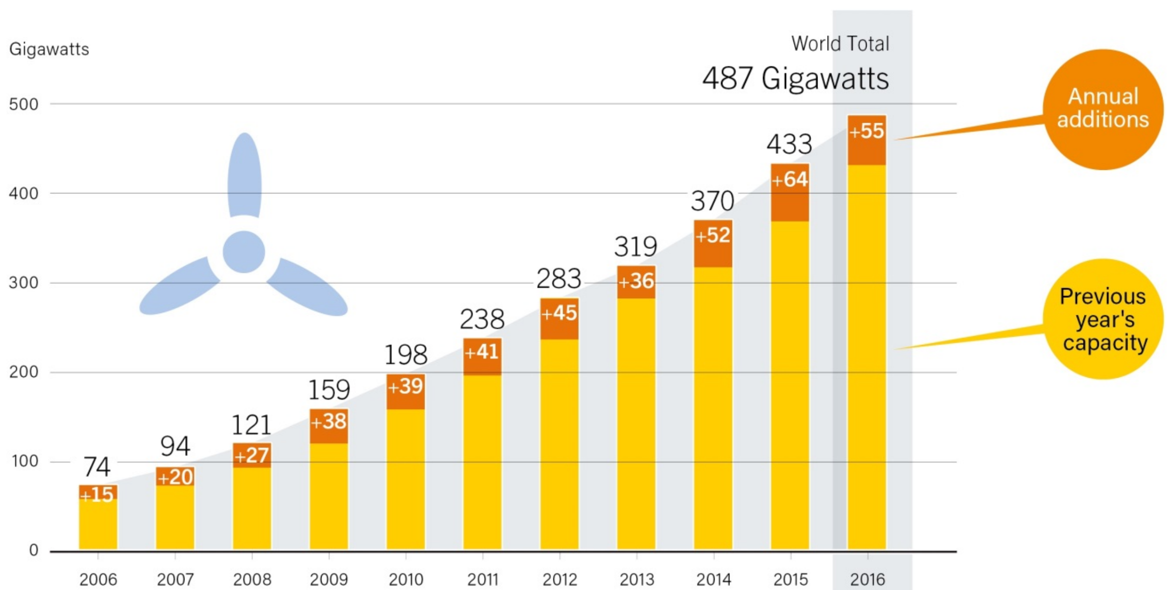


Figure 34: Wind Power Global Capacity and Annual Additions, 2006-2016 (REN21, 2017)

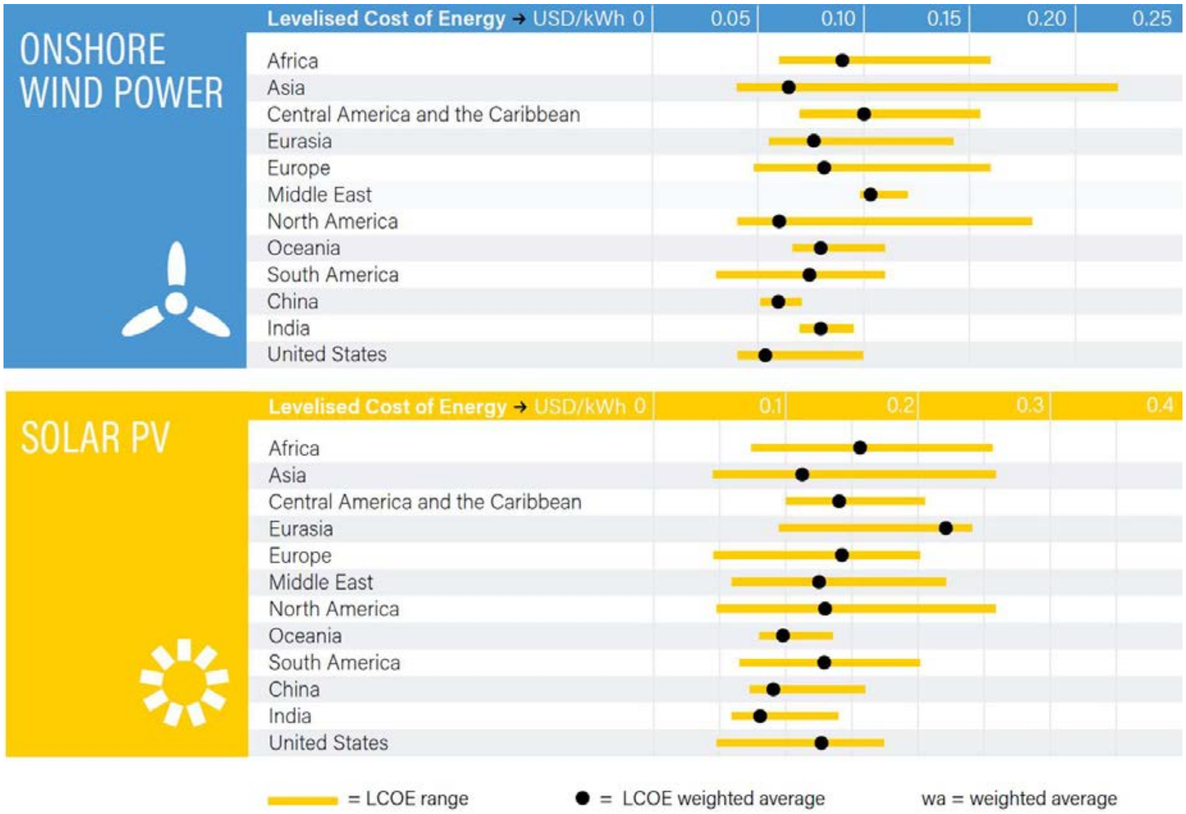


Figure 35: Onshore wind and PV LCOE in 2016: Ranges and average values in different geographic regions (REN21, 2017)

Global new investment in renewable power and fuels (not including hydropower projects larger than 50 MW) was USD 241.6 billion in 2016. Although this represents a decrease of 23% compared to the previous year, the decline accompanied a record installation of renewable power capacity worldwide in 2016[112]. Investment in renewable power and fuels has exceeded USD 200 billion per year for the past seven years. Including investments in hydropower projects larger than 50 MW, total new investment in renewable power and fuels was at least USD 264.8 billion in 2016. These estimates do not include investment in renewable heating and cooling technologies. For the fifth consecutive year, investment in new renewable power capacity (including all hydropower) was roughly double that in fossil fuel generating capacity (REN21, 2017).

[112] *There were two main reasons for the decline in global investment in renewable energy during 2016. One was the slowdown in investments in Japan, China and some other emerging countries. The other was the significant cost reductions in solar PV and onshore and offshore wind power, which also improved the cost-competitiveness of those technologies. The result was that in 2016 investors were able to acquire more renewable energy capacity for less money.*

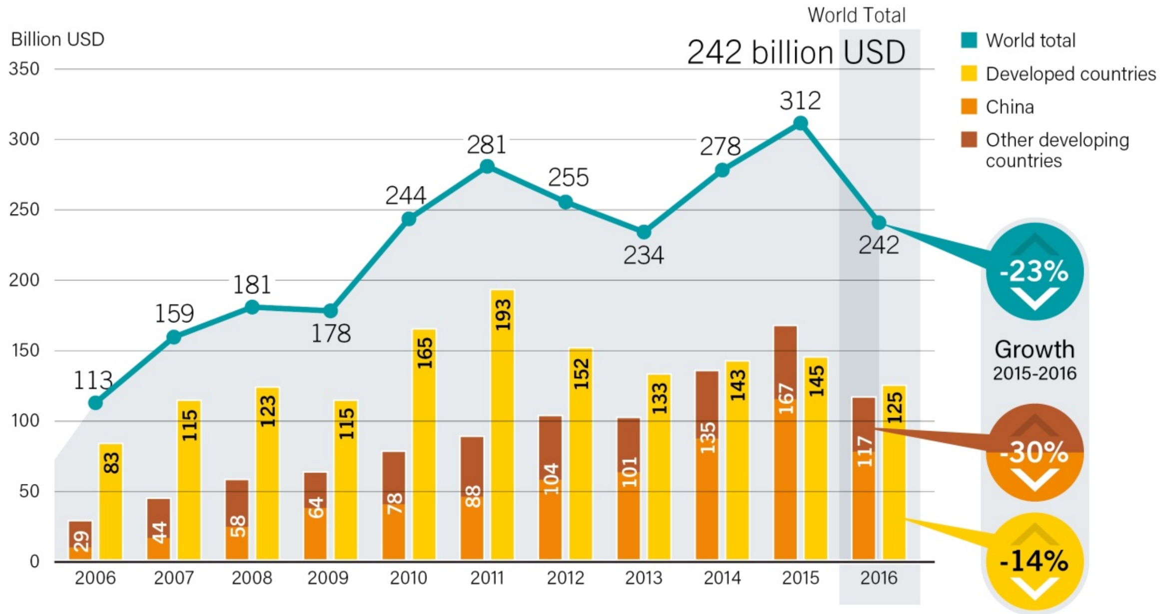


Figure 36: Global New Investment in Renewable Power and Fuels, Developed, Emerging and Developing Countries, 2006-2016. Figure does not include investment in hydropower projects larger than 50 MW. Source BNEF. (REN21, 2017)

RES contribution to the current global electricity production has already reached a 24.5% share, still dominated by hydropower production (Figure 37).

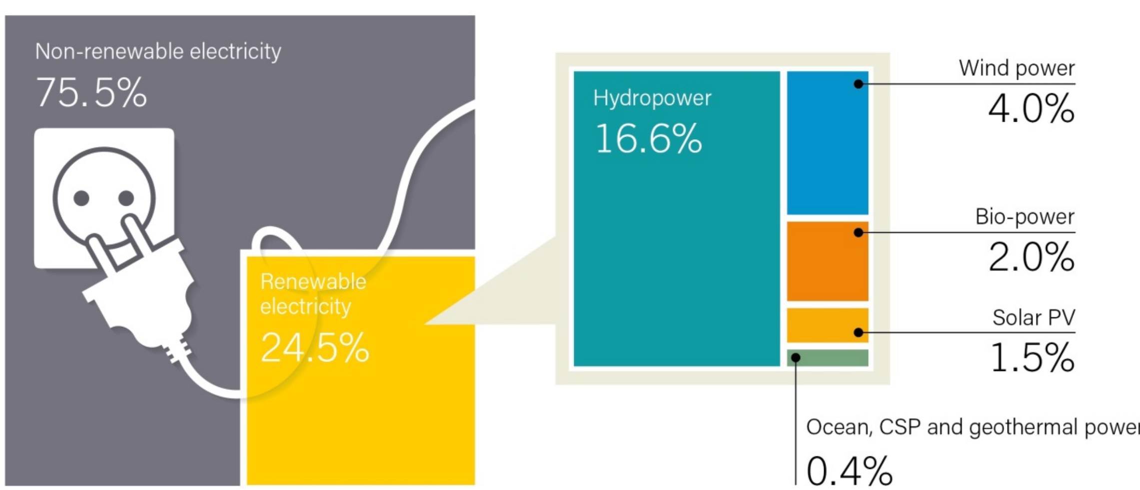


Figure 37: Estimated Renewable Energy Share of Global Electricity Production, End-2016 (REN21, 2017)

In spite of the significant growth of RES power generation in the recent years, overall RES contribution to total final energy consumption is still small (Figure 38), especially for those 'modern' RES that underpin the perception of high RES deployment: The total contribution of wind, solar, biomass and geothermal power to the total final energy consumption was barely 1.6% in 2015. This clearly indicates that there is still a long way to fully materialize the transition, and a lot of room for improved energy system integration.

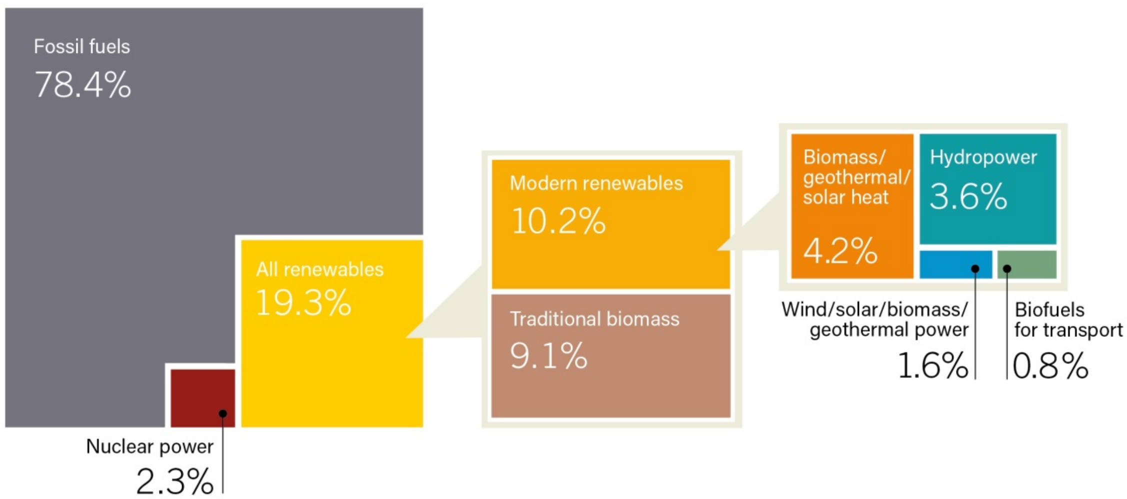


Figure 38: Estimated Renewable Energy Share of Total Final Energy Consumption, 2015 (REN21, 2017)

The KIC Innoenergy has produced prospective analysis of how technology innovation is anticipated to further reduce the cost of energy from European RES plants, based on cost models developed to explore and track the impact of innovations on the LCOE:

- In (Valpy B., English P., 2014) the analysis for onshore wind energy is presented, anticipating a 5.5% LCOE reduction due to technological innovation in year 2025 with respect too year 2014.
- In (Valpy B., et al, 2017) the analysis for offshore wind energy is presented, forecasting a 36% LCOE reduction due to technological innovation in year 2030 with respect too year 2017.
- In (Chiantore P.V., et al, 2015) the analysis for PV is presented, forecasting a LCOE reduction due to technological innovation in year 2030 with respect too year 2015 of 30%, 28% and 22% for thin film technology, high efficiency c-Si technology and conventional c-Si technology respectively.
- In (Zarza E., et al, 2015) the analysis for CSP is presented, forecasting a LCOE reduction due to technological innovation in year 2025 with respect too year 2014 of 29%, 27% and 24% for parabolic trough technology, central receiver technology and linear Fresnel technology respectively.

The IREC has developed an energy and transition prospective for Catalonia with the horizon of year 2050 (PROENCAT 2050), where several[113] technologies are analyzed:

- PV (Domínguez J.L., Pérez A., 2017):
    - Technology: Discusses current technology and its expected evolution, covering all the system components from modules to inverters and rest of BoS.
    - Deployment: PV has experienced a high CAGR (40% between 2010 and 2016) along the last years, leading to a 1.3% fraction of total worldwide electricity generation in 2016 (3.4% in Europe). Following a 2015 Fraunhofer IES scenario for 2050, in spite of decreasing CAGR PV is expected to become a dominant part of the generation park, with total cumulative PV installed power is expected to be between 5.6 TW and 16.7 TW, contributing to total worldwide electricity generation between 13% and 44%.
    - LCOE: Following the IEA 2014 projections up to 2050, LCOE is expected to reduce to around one third of its current value by 2050. For rooftop installations the 2013 LCOE (average = 180.9 €/MWh; minimum = 121.5 €/MWh; maximum = 485.1 €/MWh) are therefore expected to be reduced by 2050 to (average = 70.2 €/MWh; minimum = 40.5 €/MWh; maximum = 143.1 €/MWh). For utility scale installations the 2013 LCOE (average = 159.3 €/MWh; minimum = 107.1 €/MWh; maximum = 286.2 €/MWh) are therefore expected to be reduced by 2050 to (average = 50.4 €/MWh; minimum = 36.0 €/MWh; maximum = 87.3 €/MWh). However, we should highlight that these IEA projections for PV LCOE evolution are significantly underestimating the cost reduction potential for PV installations, with some cost levels seen in 2017 already falling below the minimum costs predicted by IEA for year 2050 (36 €/MWh)
- CSP (Oró E., 2017b):
    - LCOE: Presents results from scenarios developed by different references with LCOE in year 2025 ranging between 90 and 130 $/MWh, and in year 2050 ranging from 75 and 110 $/MWh, depending on the site. However, no mention is made to the fact that in 2017 lower PPAs than those LCOEs predicted for year 2050 have already been witnessed, like the 73 $/kWh from the 700 MW project awarded to ACWA in Dubai in September 2017 (New Energy Update, 2017).
- Wind (Domínguez J.L., 2017b):
    - Technology: Discusses some technology trends for both onshore and offshore wind, which are expected to lead towards increased CF and lifetime and reduced investment and operational costs, and significantly

[113] *The technologies and items covered by PROENCAT 2050 are: solar PV, solar thermal, CSP, wind, storage, energy management, smart grids, CO_2-economy, mobility and EVs.*

increase the available sites for wing generation (lower speed onshore sites and deep water offshore).

- Deployment: Cumulative worldwide wind capacity has increased very fast along the last decades from 6.1 GW in 1996 up to 487 GW at the end of 2016, with Asia[114] dominating the world market. In Europe, cumulative installed capacity has grown significantly along the last decade, from the 41 GW in 2005 up to 154 GW at the end of 2016, with Germany (50 GW) and Spain (23 GW) leading the absolute European installed capacity, with Denmark, Ireland and Portugal leading the wind penetration in electricity generation in Europe with 37% , 27% and 25% shares respectively.
- LCOE: Significant LCOE cost reductions are expected for wind power in spite of being the RES technology with a longer track record (besides hydro power). Based on Lazard's scenarios, average LCOE in 2016 (40 €/MWh) is expected to reduce to 35 €/MWh in 2020, 26 €/MWh in 2030 and 18.6 €/MWh (53% reduction) in 2050, with minimum values in 2050 around 10 €/MWh (75% reduction). Other scenarios presented in this report have median scenarios indicating a reduction of LCOE from 2014 to 2050 of 35% for onshore, 41% for fixed-bottom offshore and 38% for floating offshore, with the low costs scenarios forecasting a 52% LCOE reduction for year 2050. The main drivers for LCOE reduction are increases of CF and plant lifetime, reductions of CAPEX & OPEX, and improved financing conditions for offshore wind (reduced WACC).
- SCOE: But it is a fact that the LCOE, in spite of being the most used techno-economic indicator to evaluate and compare different generation technologies, does not capture all the costs and benefits for society, and when planning for a transition or tracing its roadmap overall societal costs should be the performance indicator to be used. In order to overcome this shortcoming from the LCOE, the SCOE is introduced. Beyond the techno-economic elements included in the LCOE (CAPEX, OPEX and energy yield), the SCOE incorporates an evaluation of the environmental impact and other external costs, geopolitical risks, employment effects, transmission needs and variability costs. The results of SCOE evaluations made by Siemens are presented, showing how in terms of SCOE wind energy significantly increases its advantage with regard to conventional FF or nuclear generation.

• Solar Thermal (Oró E., 2017):
    - Technology: Different ST technologies for operating at different temperature levels, from low temperature (< 65ºC) to mid temperature (<250ºC), in applications that go from DHW to space heating & cooling and industry, are available and with a significant track record. However, in spite of being one of the first forms of RES that started its commercial

[114] *Led by China and India.*

deployment, its penetration up till now is rather limited[115]. Some of the few barriers that still persist are the need for back-up and storage, and the still high costs.

- Deployment: Worldwide ST cumulative capacity was around 196 GW_{th} by 2010, dominated by China with 118 GW_{th}. In Europe cumulative deployed capacity reached 33 GW_{th} by 2015. The IEA roadmap foresees for 2050 a ST cumulative deployment for industrial processes (< 120 ºC) of 3200 GW_{th}. Industrial processes represent a promising market in Spain and Catalonia, with total thermal demand of 289 GWh/y for Spain and 66 GWh/y for Catalonia, and the 41% of it being below 250 ºC.
- LCOE: For DHW and space heating applications the LCOE of ST significantly depends on system size, ranging[116] from 140-180 €/MWh for DHW applications in single family home, to 40-50 €/MWh in DH systems. For medium temperature industrial applications LCOE ranges from 30 - 170 €/MWh depending on the temperature level and solar technology.

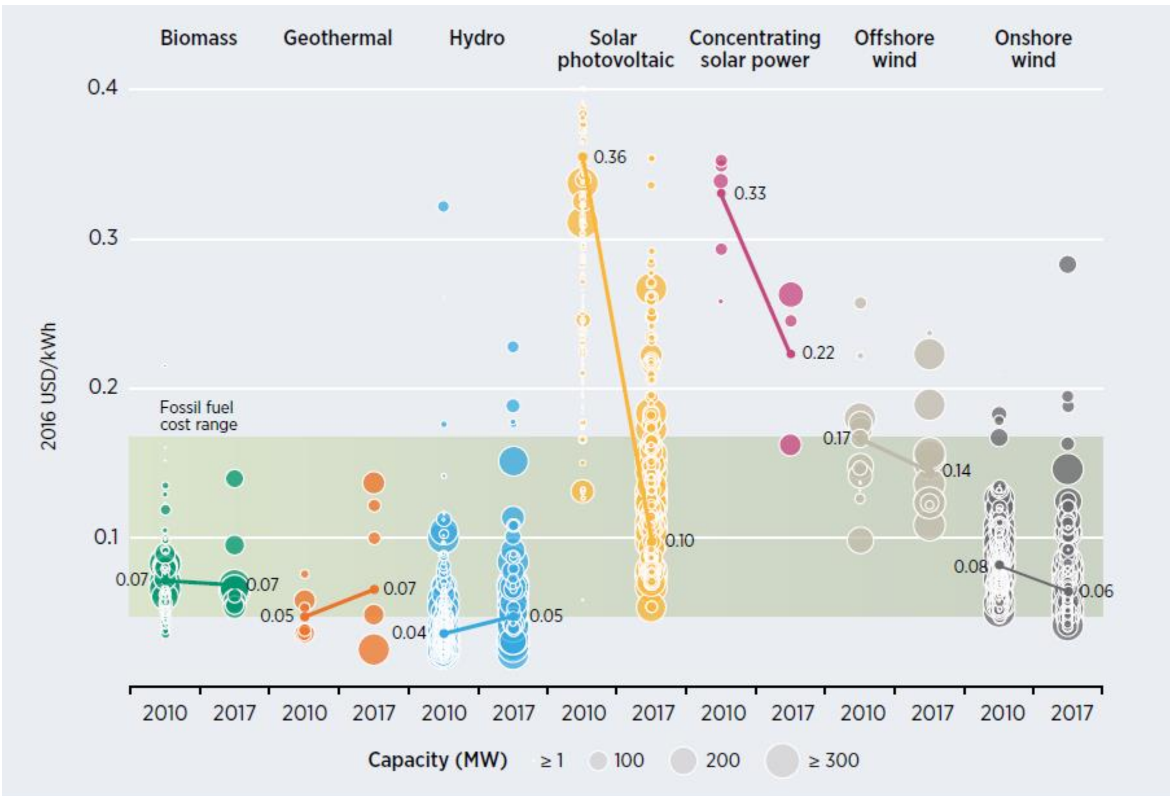
- Smart grids (Domínguez J.L., 2017):
  - Presents an approximation to the Smart grid concept, specifically from the corporate stakeholder point of view, and therefore failing to capture the full potential associated to smartness deployment, missing most of its distributed and empowerment elements.
  - Deployment: With regards to SMs, in UE electricity markets an 80% penetration is expected for year 2020.
  - GHG mitigation: Smart grids deployment leads to direct (energy savings from peak load management, reduced line losses, direct feedback on energy usage, EE improvement, generation and demand management,...) and enabled GHG reductions (RES integration, EV deployment facilitation,…).
  - Costs and benefits:
    - Smart grids deployment provides direct (increased distribution efficiency -for instance through improved voltage-reactive power control, enable consumer behavioural changes as response to appropriate price signals, reduced OPEX like remote meter reading and grid operation, improved measurements and preventing fraudulent electricity use,…) and indirect (RES integration, fault prevention and management,…) benefits.
    - Benefit-cost ratios (where benefits include reduced grid poles & wires upgrading investment, productivity, personal security, environment, quality of service, quality of life, operational security,

[115] In a transition context, where system integration plays a major role, and where efficient electrical options based on HPs and RES electricity generation are available for efficiently covering most of the thermal energy demand targeted by ST, the technological niche for ST could be significantly reduced.

[116] At these LCOE levels it is difficult for ST to compete with efficient HPs operating on RES-based electricity, which beyond cost considerations also offer an improved system integration.

reliability, ...) around 3 to 6 have been evaluated for smart grid deployment.

Figure 39 presents the evolution from 2010 to 2017 of the global weighted average LCOE from different RES, as well as the LCOE values for different projects together with an indication of the associated project size. We can appreciate still a high LCOE dispersion between different projects, but a clear trend for all VRES to reduce LCOE reaching already in 2017 the lower boundary of the FF cost range.

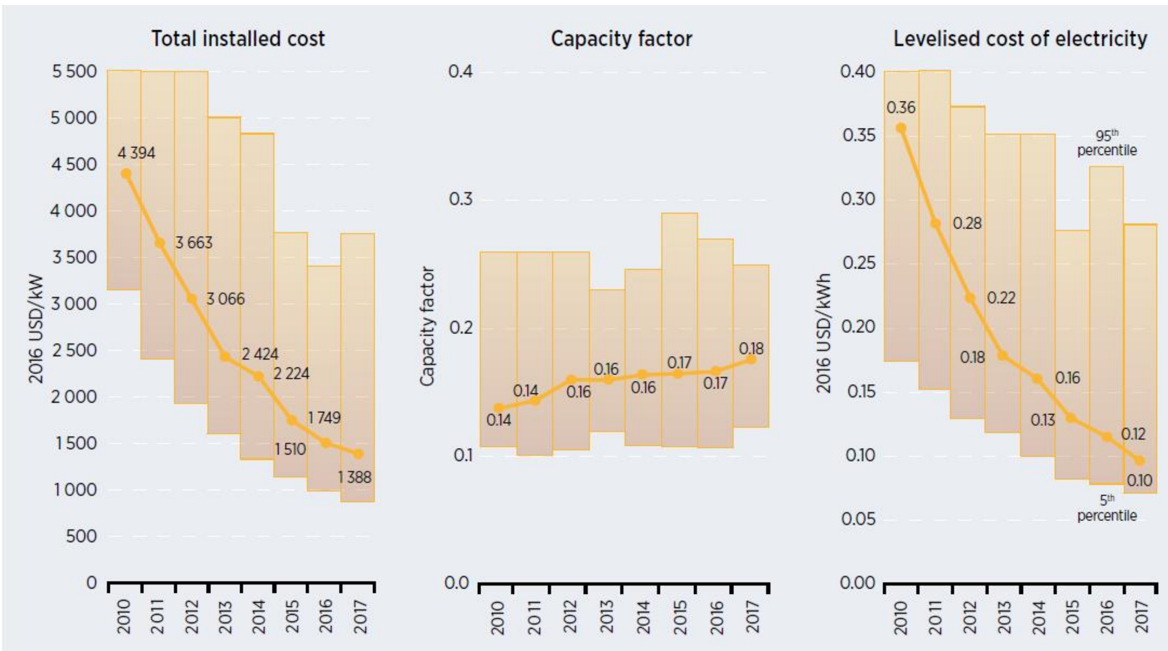


Source: IRENA Renewable Cost Database.

Note: The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average LCOE value for plants commissioned in each year. Real weighted average cost of capital is 7.5% for OECD countries and China and 10% for the rest of the world. The band represents the fossil fuel-fired power generation cost range.

Figure 39: Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017 (IRENA, 2018)

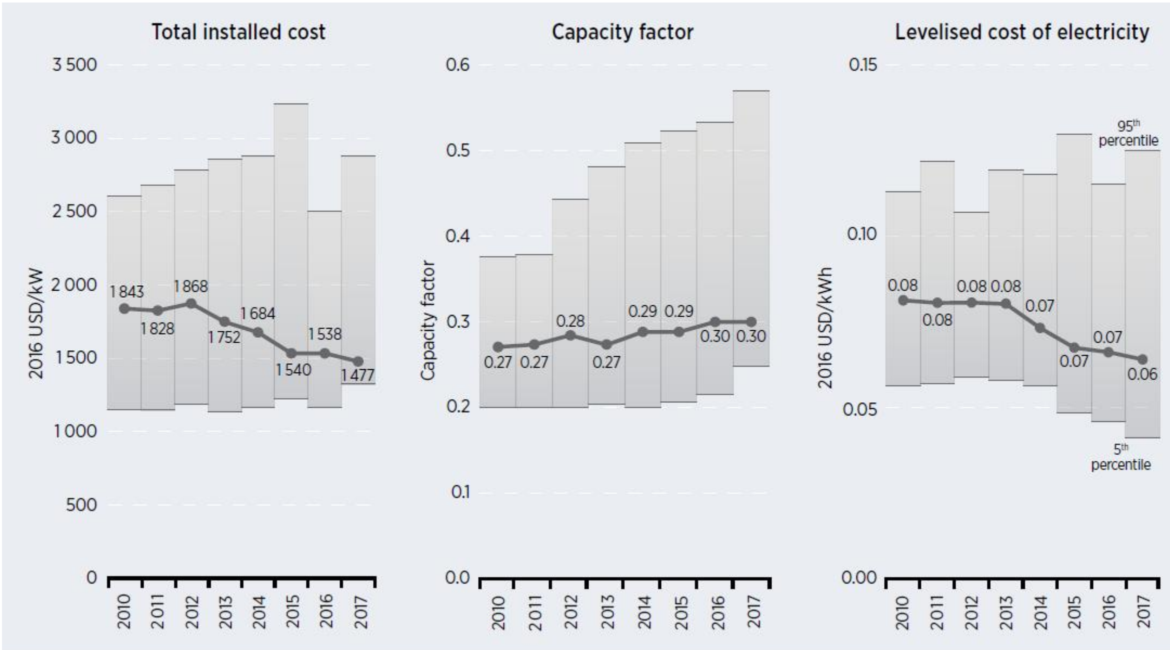
In Figure 40, Figure 41, Figure 42 and Figure 43 we find the evolution from 2010 to 2017 of total installed cost, capacity factor and LCOE, both in terms of global weighted averages and projects range, for PV, onshore wind, offshore wind, and CSP respectively. In all four VRES cases we can appreciate the same trend of decreasing investment costs, increasing CF and decreasing LCOE, although these trends are clearer for PV and onshore wind. In the case of offshore wind the lower technology maturity each time advancing towards deeper waters still produces a significant oscillation in techno-economic performance parameters, tough in the last couple of years the trend seems to have stabilized towards a steady cost reduction. In the case of CSP, its lower maturity, lowest number of projects developed, and the high impact on the techno-economic performance parameters of the amount of TES incorporated in each project also produces still a significant oscillation of techno-economic performance parameters, but in terms of LCOE it seems to finally have come back to the decreasing cost trend[117].



Source: IRENA Renewable Cost Database.

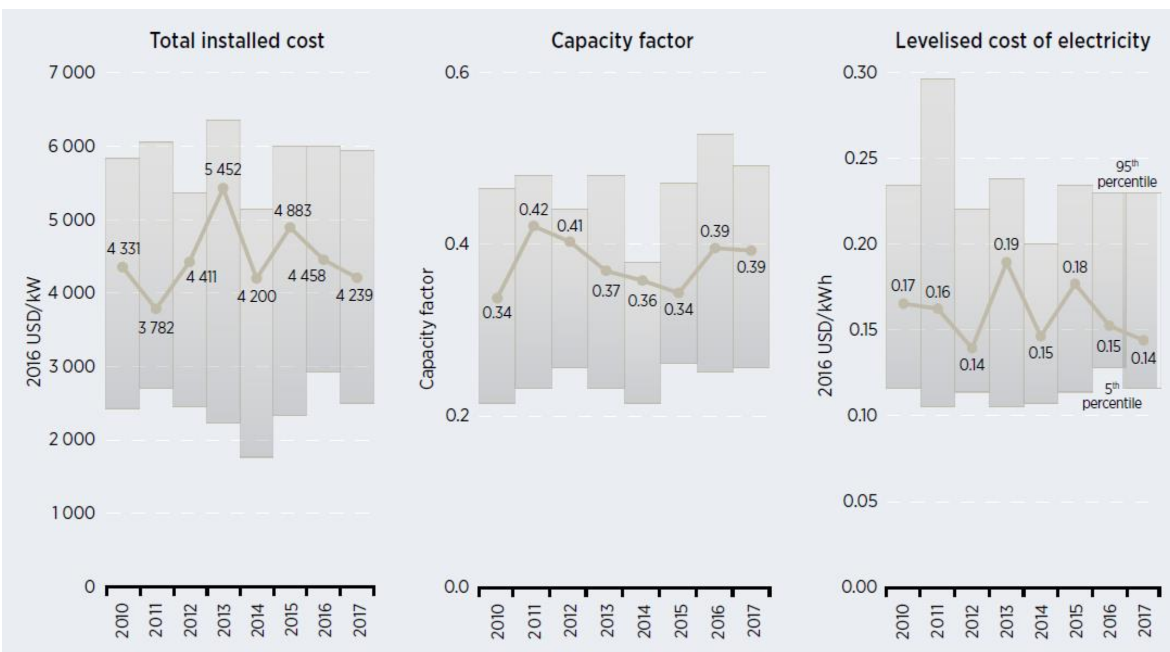
Figure 40: Global weighted average total installed costs, capacity factors and LCOE for solar PV, 2010-2017 (IRENA, 2018)

[117] *Tough a higher number of projects is required to confirm this trend.*



Source: IRENA Renewable Cost Database.

Figure 41: Global weighted average total installed costs, capacity factors and LCOE for onshore wind, 2010-2017 (IRENA, 2018)



Source: IRENA Renewable Cost Database.

Figure 42: Global weighted average total installed costs, capacity factors and LCOE for offshore wind, 2010-2017 (IRENA, 2018)

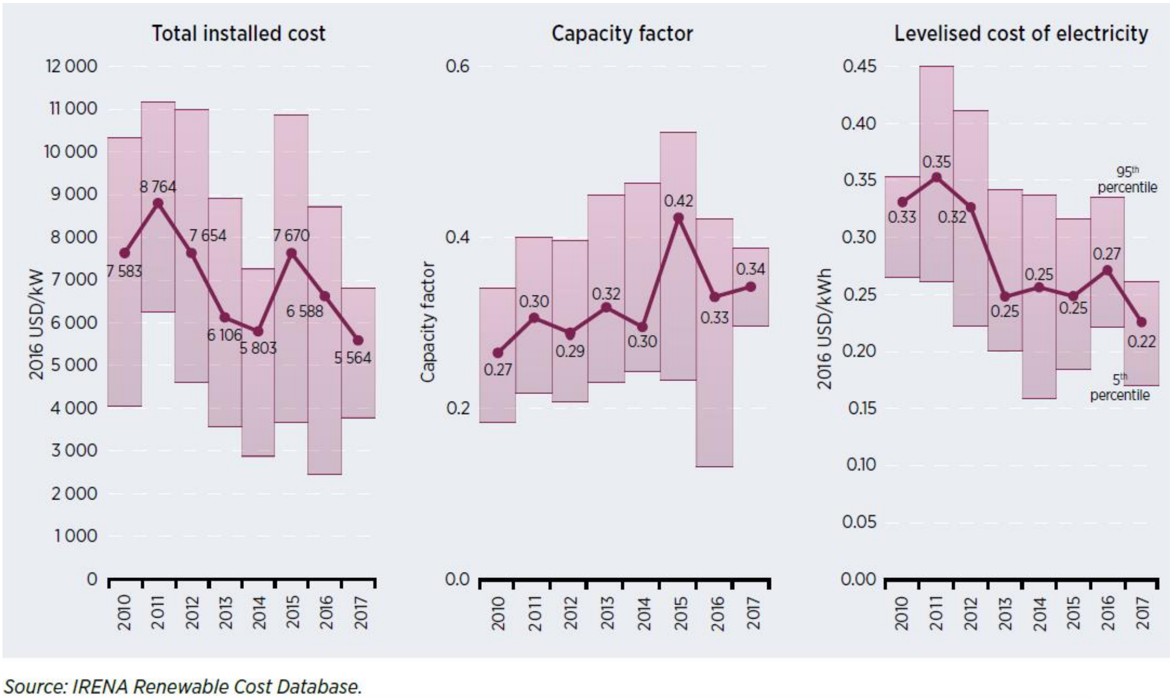


Figure 43: Global weighted average total installed costs, capacity factors and LCOE for CSP, 2010-2017 (IRENA, 2018)

RES deployment and transition requirements are disrupting the baseload paradigm embedded in the power sector since its origins, and shifting it towards what is being called 'base-cost renewables' (Parkinson G., 2017e). Indeed, in many regions of the world, VRE is now the lowest-cost source of newly constructed power generation available, thanks to rapidly declining capital costs and zero fuel costs. Subsequent to the growth of VRE in many locations, traditional baseload generators are beginning to lose their economic advantage and may no longer be the first to dispatch energy.

With VRE providing increasing amounts of generation, several key aspects of power system operation and planning will change (REN21, 2017):

- As the lowest marginal-cost form of energy on the system, VRE generation in most circumstances will be used when it is available, even if the next cheapest (in terms of marginal cost) generator must reduce its output.
- In established power systems, the market share for traditional baseload generators as providers of bulk energy will decline as operators opt instead for least-cost VRE generation. This, in turn, will make near-constant operation less viable if all VRE is to be effectively utilized, further reducing the cost competitiveness of baseload generation relative to VRE. Under certain circumstances, traditional baseload generators may begin to operate in a fashion

similar to intermediate providers by ramping their output more frequently, to the extent that plant-specific economics and technical constraints allow, raising their average cost per unit of output.

- The remaining energy demand beyond that met by VRE (i.e., residual load) will be more variable, due to the impacts of variable wind and solar generation. Generators that must serve this more variable residual load will be required to operate more flexibly than under the old paradigm.

Many technologies and approaches exist to increase flexibility on both the demand and supply sides of power generation:

- improved VRE forecasting
- use of shorter system dispatch intervals
- grid reinforcements and strengthened interconnections
- improved information and control technologies for grid operations
- co-ordination and trade of electricity supply across larger balancing areas
- electricity storage
- demand response
- energy system integration (coupling of electricity, H&C and transport sectors)

Variable renewable energy systems themselves also can provide flexibility, and operators and regulators are increasingly requiring the use of VRE technology features that provide services to the grid.

Different power systems can employ a combination of flexibility options that are most appropriate and cost-effective under their different institutional, technological and economic contexts.

As the penetration of higher shares of VRE increases, a different type of planning paradigm is required – one that takes into consideration the various costs and benefits derived from RES generation as well as the operational demands of VRE on system flexibility.

Countries in which high shares (20-40%) of VRE have been integrated (e.g., Denmark, Germany, Portugal, Uruguay and Cabo Verde) have demonstrated the shift away from the traditional baseload paradigm[118].

Another relevant aspect with regards to RES in a transition context is how much RES and at which rate need to be developed in order for the resulting transition to be aligned with

[118] *In Denmark and Germany, interconnection with other European grids has helped to support peaks of 140% and 86.3%, respectively, of electricity generation from renewable energy. Cabo Verde, which supplies 25% of electricity with wind energy, plans to build an additional 20 MW of pumped storage capacity to help manage expanding renewable energy capacity on the island.*

the environmental boundary condition (1.5ºC global warming). In (García-Casals X., 2017b) a transition analysis aimed at checking the feasibility to deploy a climate consistent transition is presented, and among other results the required RES penetration and deployment rate are obtained. Figure **44** presents the results in terms of the per capita required cumulative worldwide RES capacity. Results for four transition paths (A, B, C and D) are presented. All these transition paths articulate the maximum energy system component transition rates, the difference being when the transition starts (year 2017 for A and C, and year 2020 for B and D), and how the maximum component transition rates are deployed (from the onset in A and B, and linearly growing along a 10-years time window for C and D). The figure also shows the BAU RES deployment and the RES deployment associated to the Greenpeace advanced energy revolution scenario (ER+). From all these transition paths, only the more aggressive (transition-A) manages to keep its cumulative CO_2 emissions within the available carbon budget.

Besides the cumulative RES capacity, the required rates for RES deployment (the slopes from Figure **44**) are very relevant from a transition point of view. Current (and maximum) world average per capita RES deployment rates are around 20 W/p-y, tough some countries have punctually reached RES deployment rates of around 180 W/p-y. Articulating the transitions from Figure **44** requires reaching world average RES deployment rates up to 300 W/p-y or higher, which is more than one order of magnitude higher than current values. This result gives a clear picture of how far we are still from the transition requirements, and how important it is the bottom-up contribution from SECs to contribute articulating these transition rates both within the SEC boundaries and beyond through its fair transition contributions[119].

[119] Note that the 300 W/p-y is a World average, and therefore is almost of no use that the SEC focuses only to reach this figure within its physical boundaries, because then we can be sure that the world average will be significantly below, and consequently the transition won't be successful.

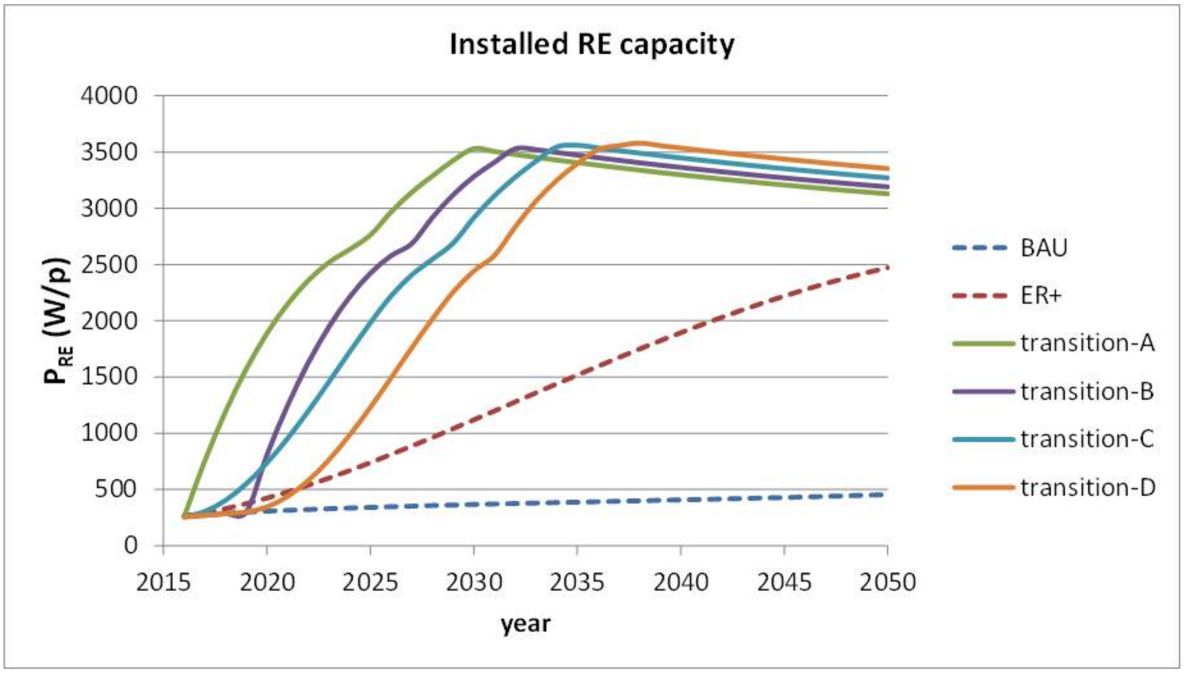


Figure 44: Required cumulative worldwide per capita RES capacity in four climate consistent transition paths (A, B, C and D). ER+ designates the advanced energy revolution scenario from Greenpeace. (García-Casals X., 2017b)

11.2 Storage for SEC: technologies and costs

Battery storage provides the kind of fast, flexible and smart response needed by RES-based energy systems. From a technical point of view the astonishing capabilities of battery storage for contributing to power system regulation, by far surpassing those from the conventional technological regulation approaches used up till now, has for a long time been known. However, it is just recently when battery costs became low enough to enable real projects to be developed in order to provide proof of reality to sceptics and stake holders anchored in the past.

And this is happening even at centralized grid level, with facilities like the Australian big battery (the world's biggest lithium-ion battery storage installation to date: 100 MW / 129 MWh) switched on in the South Australia network at the beginning of December 2017. The main goal of this battery is to facilitate RES integration by providing the flexibility required to match wind and solar resources with the load, which the installation has demonstrated even from the day before official switching on (Parkinson G., 2017b). But in its short live time the installation has already displayed its astonishing capabilities to contribute to grid frequency control and other ancillary services, outsmarting conventional grid regulation facilities and preventing grid black outs caused by conventional unit trips (Parkinson G., 2017c).

But the big-big thing about battery storage is that its huge potential can be better unlocked through distributed small battery storage units sited in the very spot where consumption takes place, and if needed aggregated to produce a big-big battery, a virtual big battery, with improved techno-economic performance by increasing the diversity of services that it provides and therefore the revenue streams for making up its BC, while simultaneously empowering citizens to play their role in the energy system transition within a sharing economy context, which is the SEC's approach. And this is also already happening right now also in Australia (Vorrath S., 2017b), with 1 MW virtual battery getting online.

And as transport becomes integrated in the electricity system, V2G enables a dramatic increase of the potential for DS and the capability to configure virtual storage facilities nearly in each urban environment.

Smart management of DS is what allows getting the maximum value out of it. Aggregation of DS to configure a VPP increases the potential benefit from smart management by enabling many different revenue streams. But even at individual household level there is room for improvement. For instance, in (Igualada L., Corchero C., 2017) an analysis is presented comparing the performance of a Spanish household (4.5 kW peak demand) equipped with PV and battery storage with conventional commercially available energy management systems for self-consumption, and with an energy management system with optimization capabilities developed by IREC. The results from this analysis show that although there is room for improvement through additional smartness in the management system (allowing the storage to participate also in energy arbitrage), the lack of smartness in the rest of the electricity system (inappropriate price signals) leads to a relatively small decrease in overall electricity costs for the household.

One of the issues often argued to limit the penetration of RES (and specifically VRES) into power systems is the system's loss of inertial response to provide very fast frequency regulation (sub-second). Indeed, up till now, synchronous generators in power systems such as those from CCGTs provide instant frequency stabilization called inertial response, but the number of such plants connected to the grid is dropping as RES is being deployed, which leads to the requirement of operating these thermal power plants at part load (less efficiency and more specific emissions) and limiting the RES share in the power system. Therefore, to take electricity system decarburization to the next level, we must address the challenge of providing clean inertial response.

Following a fault event in the grid, if RoCoF exceeds 1Hz/s, additional power stations could be tripped offline and / or damaged in the first few fractions of a second following the fault event. Therefore, very fast response is required to provide grid reliability.

Up till now this regulation service has been provided solely by analogue inertia (sync. generators) through the kinetic energy stored in the spinning turbomachinery and generators from thermal power plants, up to the point of the service itself being called by its inertial characteristics as SIR (Ireland). Indeed, the grid connected synchronous spinning machinery responds automatically to any grid fault event and immediately slows down, releasing energy stored by the large rotating masses contained in these plants, each unit providing a power increase of 7-14% of their rated total capacity within 0.05 seconds for a typical large event, subsequently tailing off after a few seconds and then being replaced by a governor response that tries to push the frequency back up. However, in order to respond, synchronous generators must be running, with each unit only being able to increase output by a small proportion of its rated capacity, which means that a large number of conventional thermal units have to be running on the system, in case there is a fault, displacing variable renewables.

But batteries can also provide fast and effective synthetic inertial response without displacing RES. This is what is called digital inertia (Reynolds P., et al., 2017). Indeed, batteries can respond as quickly as the fault can be measured, with reaction times approaching 0.1 seconds, and respond dynamically with high ramp rates, with the capability to deliver full output in less than 0.2 seconds, an output that can be sustained for minutes to hours depending on the size of the battery. Therefore, in fact batteries can provide a significantly better regulation service[120] than what synchronous generators do. By responding more aggressively to faults, and at full power output, batteries reduce RES curtailment – allowing renewable generation to replace more conventional generation, while reducing[121] the cost of SIR services[122].

Global grid-connected and stationary energy storage capacity in 2016 totaled an estimated 156 GW[123], with pumped storage hydropower accounting for the vast majority (Figure **45**). Grid connected batteries are seeing very high growth rates along the last years (Figure **46**).

---

[120] And in fact, in the context of a SEC this kind of frequency regulation services can be provided by many other flexible technological options, like those associated to DR, or by the active contribution of VRES to regulation, or by the use of other RES technologies with inertial characteristics (CSP, biomass, geothermal).

[121] Batteries will require some remuneration for this service, but additional costs should be low when stacked with other services provided by batteries such as FFR.

[122] A product costing consumers up to €19M/yr in 2019/2020 in Ireland (Reynolds P. et al., 2017)

[123] This total aims to include all storage with the exception of off-grid storage or batteries in EVs, but it may exclude some thermal storage in district heating systems.

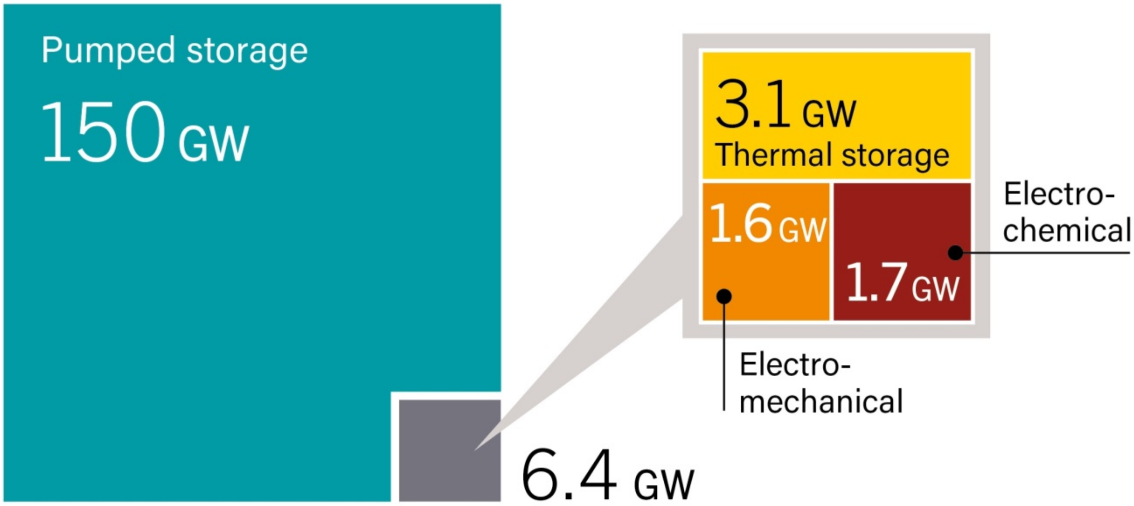


Figure 45: Global Grid-Connected Energy Storage Capacity, by Technology, 2016. Electrochemical storage are batteries, and electromechanical storage includes both flywheels and compressed air. (REN21, 2017)

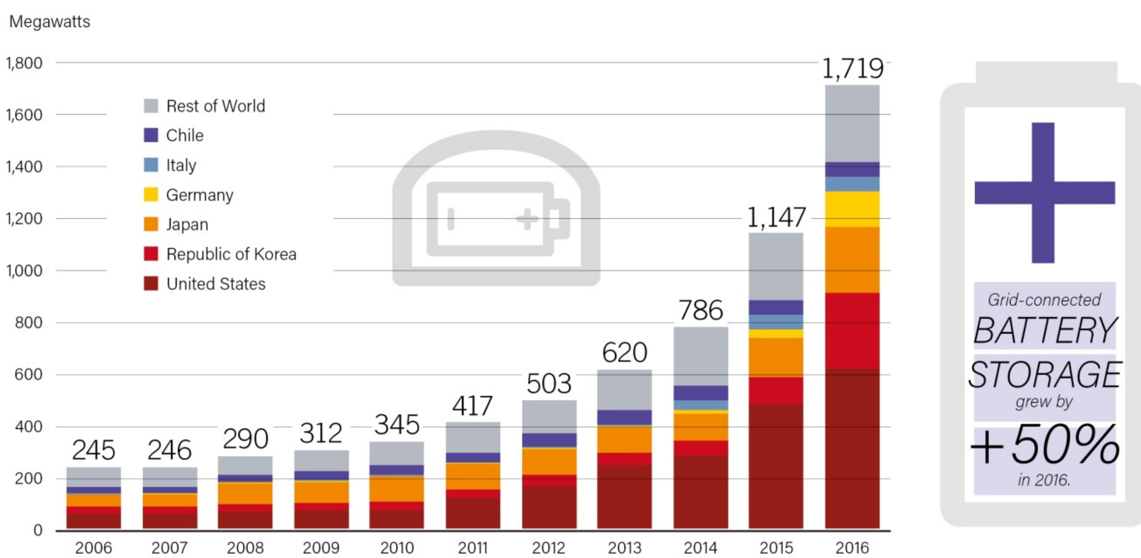


Figure 46: Global Grid-Connected Stationary Battery Storage Capacity, by Country, 2006-2016

The IREC has developed an energy and transition prospective for Catalonia with the horizon of year 2050 (PROENCAT 2050), where different[124] transition technologies are analyzed, with storage being one of them (Oró E., Flox C., 2017), dealing with all the available storage technologies (chemical, electrochemical, electrical, mechanical and

[124] The technologies and items covered by PROENCAT 2050 are: solar PV, solar thermal, CSP, wind, storage, energy management, smart grids, CO_2-economy, mobility and EVs.

thermal)[125], analyzing their status and technical characteristics, their potential contribution to the transition, and presenting their current and forecasted cost levels:

- Electrochemical storage (batteries):
  - In 2016 there were around 1.6 GW of battery storage installed, dominated by Li-ion batteries (1.1 GW), followed by sodium batteries (0.2 GW), lead batteries (0.1 GW), flux batteries (0.07 GW) and nickel batteries (0.03 GW).
  - Many different kinds of battery technology are already known, tough only few have up to date reached a significant commercial development. Therefore we have plenty of technology alternatives to support battery deployment.
  - The general UE development goals for batteries in year 2030 are costs below 150 €/kWh, efficiencies above 90% and lifetimes of thousands of cycles.
  - Many available battery technologies with different degree of development:
    - lead-acid batteries:
      - TRL 9.
      - currently dominating the batteries' market.
      - performance ratios:
        - Energy density: 35-50 Wh/kg.
        - Efficiency: 75-85%.
        - CAPEX: 50-150 €/kWh.
    - Nickel-based alkaline batteries (Ni-Cd, Ni-Zn, Ni-Fe, Ni-MH):
      - TRL 9 (Ni-Cd & Ni-MH).
      - Used where specific power and energy ratios are important.
      - Ni-Cd batteries have become popular for solar storage, thanks to the capability to withstand high temperatures.
      - Good and stablished recycling circuits.
      - However, no further development from the Ni-Cd technology is foreseen due to the fact that Li-Ion and even Ni-MH technologies are occupying its niches.
      - Performance ratios:
        - Energy density: 30-80 Wh/kg.
        - Efficiency: 60-70%.
        - Cycles: 1000-5000.
        - CAPEX: 400-700 €/kWh ; 500-1500 €/kW.
    - High temperature sodium batteries (Na-S; $Na\text{-}NiCl_2$ (ZEBRA)):
      - TRL 8.
      - Since the early 90s are being manufactured in Japan.
      - Currently around 350 MW with 6-7 h storage capacity have been installed[126].

[125] *Worldwide installed storage by 2016 was 171 GW, with many different storage technologies offering a potential far beyond their currently installed capacity.*

- The $Na-NiCl_2$ technology has been introduced along the last decade for EV applications, thanks to its scalability, and capability to maintain performance ratios even at high temperatures, tough they are also used in other applications (buildings and power grid).
- Performance ratios:
  - Energy density: 100-120 Wh/kg.
  - Efficiency: 75-85% (Na-S); 85-95% ($Na-NiCl_2$).
  - Cycles: 2000-5000.
  - CAPEX Na-S: 400-600 €/kWh; 3000-4000 €/kW.
  - CAPEX $Na-NiCl_2$: 550-750 €/kWh; 150-1000 €/kW.

▪ Li-Ion batteries:
- Thanks to its high scalability and flexibility in power and energy, Li-Ion batteries are used in many different applications: EVs, buildings, power grid…
- Recycling processes and facilities are already being deployed, reaching recycling efficiencies well above 50%.
- Market currently dominated by Asian manufacturers (Japan, Korea, China) because of its extended use in mobile phones and PCs. Because of the increasing use of these batteries for EVs and power grid applications, Europe should develop its own manufacturing capacity.
- These batteries are succeeding thanks to its flexibility and weight with quickly reducing CAPEX. Many other battery chemistries are available and proposed as future substitutes of Li-Ion batteries, but the fast evolution through the learning curve is making from Li-Ion batteries a hard to beat technology option.
- Performance ratios (EVs):
  - Energy density: 120-180 Wh/kg.
  - Efficiency: 90-98%.
  - Cycles: 2000-10000.
  - CAPEX 700-1300 €/kWh; 150-1000 €/kW.

▪ Na-Ion batteries
- TRL 2-3 (in development).
- Identified as a priority development option for power grid storage by both CE and DOE in 2010, due to its potential for lower costs[127] than Li-Ion batteries. By 2030 it is expected that its costs have reduced 40%.

---

[126] The biggest Na-S installation up to date is a 34 MW and 245 MWh facility used to regulate wind generation in northern Japan.

[127] Down to LCOSE < 10 c$/kWh, which requires CAPEX below 300 $/kWh and more than 5000 cycles.

- RFB (Redox Flux Batteries):
  - Have been developed since 1970. Systems with up to 200 kW and 800 kWh have been built and operated[128].
  - For Vanadium the technology has TRL 7, for Zn-Br TRL 5-6 and other chemistries are in TRL 3-4.
  - Power and capacity are independent in this battery, which makes RFB unique because their design can be tailored for each individual application.
  - Due to its relatively low energy density and thanks to their long lifetime its use is focused on big stationary power grid applications (peak shaving, time shifting…).
  - Performance ratios:
    - Cycles > 12000.
    - Efficiency: 70-75%.
    - CAPEX goal for 2030: 120 €/kWh ; 300 €/kW.
    - CAPEX goal for 2050: 70 €/kWh ; 200 €/kW.
- Li-S batteries:
  - TRL 4-5.
  - Development goals for these batteries mainly focused on EVs are doubling energy and power densities[129] with regard to Li-Ion batteries, while maintaining low costs (150 €/kWh).
- Metal-Air batteries (M-Air):
  - TRL <= 4-5.
  - Provide the highest potential for energy density
  - Some of them, like Zn-Air has been already commertially available for decades.
  - Currently these batteries already have a 75% efficiency and 160 $/kWh CAPEX, and for 2050 they are expected to reach 500-1000 Wh/kg energy density, 10000 cycles and 100 €/kWh CAPEX.

- Electrical storage:
  - supercapacitors:
    - Storing electrons into an electrostatic field.
    - Technological maturity of TRL 8-9 for EDLC and TRL 4-5 for hybrids.
    - Supercapacitors have already been in commercial use for decades, both in transport and grid security applications, showing that they are a low cost and reliable technological option for high power-low energy and fast cycle applications. Since the mid-eighties small EDLCs have been used as power back up in consumption

---

[128] IREC participates in several RFB development projects.
[129] Currently Li-S batteries already provide 350 Wh/kg,and development goals are to reach 500 Wh/kg with 3000 cycles in 2030 and 600 Wh/kg with 10000 cycles in 2050.

electronics. During the nineties bigger cells were developed for their use in industrial electronics. Since then EDLCs are present in industrial electronics, providing service in many diverse applications like windmill power stabilization. More recently they are being applied for ICE start-stop cycles.

- Their high life cycle (1 million cycles) and lifetime (10-25 years), together with their wide temperature operating range (from -40ºC to 70 ºC), makes them fit for grid applications.
- The deployment of supercapacitors as grid storage technology is growing fast, both in isolation or hybridized with battery systems.
- Charging and discharging processes are highly reversible, providing supercapacitors with a very high number of operative cycles.
- Supercapacitors are a very interesting option because of their capacity to provide very high power during short time periods. Regulation requirements of RES-based systems is more power-based than energy-based (Garcia-Casals X., 2006).
- Performance ratios:
    - Cycles: 1000000.
    - Lifetime: 10-25 years.
    - Response time: 5 ms.
    - Efficiency: 90%.
    - Density: 4-7 Wh/kg ; 5-8 kW/kg.
    - CAPEX: 10000 – 20000 €/kWh ; 100-500 €/kW.
- 2050 goals:
    - Density: 50 Wh/kg.
    - CAPEX: 50 €/kW.

- SMES:
    - Storing electrons into a magnetic field. Energy is stored as a magnetic field created by the circulation of a current through a superconducting coil maintained below its critical temperature.
    - Since the only energy conversion process associated to SMES is from AC to DC, its overall efficiency is very high, since they are not subject to the thermodynamic losses associated to the conversion between different kinds of energy.
    - SMES offer very fast energy discharge, and very high number of operating cycles, which makes them interesting for many applications.
    - Performance ratios:
        - Lifetime: 20-30 years.
        - Response time: 1-10 ms.
        - CAPEX: 400 – 4000 €/kW.
    - 2050 goals:
        - CAPEX: 200 €/kWh ; 100 €/kW.

- Mechanical storage:
    - Systems with capacity to store different kinds of mechanical energy: water gravitational potential energy, compressed air internal energy or rotational kinetic energy.
    - PHS:
        - TRL 9.
        - Storage of water gravitational potential energy.
        - Has been extensively used[130] to provide energy regulation capacity between peak to valley, and other ancillary services (frequency and voltage regulation).
        - Worldwide there are around 170 GW of PHS operative, with 57 GW in Europe.
        - IEA scenarios forecast for 2050 a PHS capacity in Europe between 91 GW and 188 GW, which would mean a significant growth ratio[131].
        - PHS has a relatively fast response time (minutes), and therefore is appropriate for the following grid services:
            - Contingency reserve, with typical response time of around 10 min.
            - Regulation reserve, providing both upwards and downwards regulation.
            - Load following.
            - Load shifting (energy arbitrage).
            - Black start.
            - Voltage regulation.
        - Currently, the main PHS limitation is the requirement for an adequate orography. However, currently its underground application using old mines is being explored.
        - Performance ratios:
            - Discharge time: min – 10h.
            - Lifetime: 80 years.
            - Efficiency: 70 – 85%.
            - Density: 0.3 – 3 Wh/kg.
            - CAPEX: 40 – 150 €/kWh; 400 – 1500 €/kW.
    - CAES
        - Storage of air internal energy by increasing its pressure.
        - Two options are being explored, depending on whether compression thermal energy is recovered or not (A-CAES, D-CAES)

---

[130] However, under a RES-based power system operation scenario, CFs from PHS plants increase significantly with regard to their operation in a conventional FF-based power system (Garcia-Casals X., 2006) in order to exploit their full flexibility potential.

[131] We should however note that IEA scenarios traditionally underestimate the growth of DER, which could alleviate the PHS deployment requirements to operate a RES-based power system.

- D-CAES:
  - TRL 9 (in spite of its very limited deployment[132], but involves well stablished technologies).
  - Compressed air is stored in underground cavities, at hundreds of meters depth (500 – 800 m) and around 100 bars.
  - Storage discharge involves heating up the stored compressed air (typically by combustion of a fuel[133]) and its expansion through a gas turbine.
  - Storage efficiency is relatively low (around 53%).
  - Performance ratios:
    - Discharge time: 1-10 h.
    - Response time: min.
    - Storage efficiency: 53%.
    - CAPEX: 50-150 €/kWh; 1200 – 2000 €/kW.
- A-CAES:
  - Air is compressed and stored in underground cavities at hundreds of meters depth and at around 100 bar. The heat produced during the compression process is stored in a TES. During the discharge process, the compressed air is first heated up by unloading the TES and recovering the thermal energy, and then expanded through a gas turbine to recover the mechanical energy.
  - A-CAES are currently under demonstration and not commertially available.
  - Performance ratios:
    - Discharge time: 2 – 24 h.
    - Response time: 5 min.
    - Efficiency: 50 – 90 %.
    - CAPEX: 60 – 600 €/kWh ; 500 – 3500 €/kW.
- LAES:
  - Cryogenic storage of liquid air. The storage process involves using electricity to cool down air until it is liquefied[134]. Liquid

---

[132] Currently there are only two D-CAES plants operating in the world: Germany (since 1978) and USA (since 1991)

[133] Therefore, unless biomass is used (which is not the case up till now, where FF are used) this storage technology cannot be considered as appropriate for a RES-based energy system. In fact D-CAES is not a storage technology itself, but a hybrid between storage and an open gas turbine generation cycle.

[134] Note that this is a similar process of mechanical energy storage as the one from A-CAES. Indeed, in A-CAES a compressor is used to increase the air pressure and store in form of internal air energy this mechanical energy. In LAES, a compressor is used to operate a refrigeration cycle that extracts thermal energy from the air, and therefore the mechanical compression energy is stored in the form of the differential air internal energy with regard to the surrounding thermal

air is stored in an insulated tank at low pressure. Storage discharge involves pumping the liquid air at high pressure, allowing it to evaporate by absorbing ambient thermal energy[135], and expanding the gaseous and pressurized air through a turbine or volumetric engine.

- This technology promises to offer low LCOSE.
- Performance ratios:
  - Discharge time: 1 – 10 h.
  - Response time: min.
  - Storage efficiency: 70%.
  - CAPEX: 1200 – 2000 €/kW.

- Flywheel:
  - Rotational kinetic energy is accumulated in a spinning mass[136]which is kept rotating in a vacuum environment that minimizes energy losses.
  - Storage efficiencies are high (80 – 90 %), response time very fast, and number of cycles very high.
  - Used in conjunction with other storage technologies (batteries) can lead to optimized hybrid storage that maximizes lifetime by combining the time response from the different technologies.

- Thermal storage (TES):
  - Three different ways to store thermal energy: sensible heat, latent heat (PCM), thermochemical (TSM). Sensible heat TES can be considered as a mature technology. PCM is finding it difficult to get commercial due to its high costs. TSM are still under development.
  - TES is already used in many applications: buildings (space H&C, refrigeration,...), transport (cabin H&C, battery electronic protection,...), thermal protection (electronic devices, data centers, food, biomedical,...), Industry (ST, CSP,...).
  - TES application in CSP plants, providing the capability of solar dispatchable generation through the incorporation of 10 to 15 h (or even more) of storage, is one of the flexibility components from RES-based energy systems, and allows a system operation very similar to that used up till now in conventionalpower systems where FF thermal power plants are used for regulation and ancillary services.

---

environment. Since phase change is also involved, this could be considered a TES, but because of the fact that mechanical energy is used as primary input and output, and because of its similarities with A-CAES, we include it under the mechanical storage cathegory.

[135] Note that in the LAES the thermal energy recovery from A-CAES is accomplished by using the ambient (atmosphere) as TES.

[136] Note that the concept is exactly the same that is involved in the primary frequency regulation services provided by synchronous machines (analogic inertia), upon which all the fast frequency response regulation of nowadays power systems is based.

- Thermal energy forms a very significant part of the energy system, and therefore its smart integration into the energy system could significantly facilitate the transition.
    - About 50% of Europe's energy demand is for thermal processes.
    - Besides industrial processes, most of this thermal energy is stored and used in water systems (sensible heat) for its application in the distributed building stock.
    - The DS capacity from existing thermal systems is higher than existing PHS capacity.
- TES advantages:
    - Allows the recovery of residual heat, therefore leading to efficiency increases.
    - Absorbs consumption peaks, therefore allowing for a lower generation equipment rating.
    - Enables the use of RES, like ST, HPs, biomass and geothermal.
    - Increase the flexibility that the building stock can offer to operate the power system.
- TES barriers:
    - Missing regulation to incorporate TES to energy markets.
    - PCM still have short lifetimes, high costs and many are under development to improve their thermos-physical properties, lacking commercial experiences of their incorporation to the built environment.
    - TSM still under development.
    - Limited amount of experiences involving seasonal storage.
    - Missing the power system smartness to take advantage of the potential from TES DS.
- Performance ratios:
    - Sensible:
        - Density: 10 – 80 Wh/kg.
        - Efficiency: 50 – 90 %.
    - PCM:
        - Density: 50 – 150 Wh/kg.
        - Efficiency: 75 – 90 %.
    - TSM:
        - Density: 120 – 350 Wh/kg.
        - Efficiency: 75 – 100 %.

- Chemical storage (P2X):
    - Storage of electricity into chemical products (gas and liquids) with very high energy density[137].
    - P2X is bound to play a very important role[138] in a RES-based and smart energy system, providing huge flexibility potential for the energy system

[137] *Energy density is as high as that from FF (10000 Wh/kg)*

operation, and allowing for the smooth introduction of RES[139] in some energy subsectors that cannot benefit from direct electrification (air transport, industry, sea transport, freight road transport,…).

- P2G:
  - The first step in P2G is the electrolysis of water to obtain hydrogen (conversion of electricity into the chemical energy stored in hydrogen).
  - Though the direct energy vector obtained in P2G is hydrogen, through its combination with CO_2, synthetic methane (natural gas) can be obtained.
  - P2G technology is mature and ready for its use.
  - Another less mature technology option is co-electrolysis, where H_2O and CO_2 are simultaneously reduced in a single electrolyzer to produce syngas (H_2 & CO),which can then directly be used as a fuel or as a precursor of other synthetic fuels.
  - Since 2010 activity in P2G projects has intensified significantly, with around 30 different projects already in operation[140]. Just in Germany there are already 14 pilot operational plants and another additional 17 plants under development.
  - One of the P2G advantages is that the storage capacity is already available. Indeed, currently, worldwide, there is a natural gas storage infrastructure capable of storing around 4000 TWh, while current RES electricity generation capacity is well below that. The existing natural gas storage infrastructure could be seamlessly used to store P2G products.
  - Hydrogen from P2G can be directly injected[141] into the natural gas distribution grid to increase the heating value.
  - P2G provides a direct means for distributed and integrated storage, tough it can also be operated centrally to supply fuel for other energy subsectors (like air transport).
  - The main current barriers from P2G options are low efficiencies and high costs. New technologies like SOEC and alternative methanization processes are expected to improve P2G performance.
  - P2G offers huge amounts of flexibility[142] to operate a RES-based energy system.

---

[138] P2X is a very powerful energy system integration element, providing what we could consider indirect RES-based electrification to complement the direct electrification used to integrate the energy system.
[139] The fact that the energy storage product (a gaseous or liquid fuel) is very similar to FF facilitates enormously its integration into the current energy system structures and organization.
[140] In Catalonia, IREC participates in the COSIN project that started at the end of 2016 and plans to built and operate a P2G installation in Sabadell.
[141] Current regulations limit the amount of hydrogen to be injected to below around 12%.

- P2G can use different types of electrolyzers:
  - AEC:
    - TRL 9.
    - The cheapest and most mature electrolyzer technology. More than 20 years with available commercial electrolyzers.
    - Temperature operation range: 60 – 80 ºC.
    - Efficiency (HHV): 60 – 78 %.
    - CAPEX: 1000 €/kW, which could be reduced to 900 €/kW through manufacturing industrialization.
    - The electrolyte is corrosive and toxic.
  - PEM:
    - TRL 7 – 8.
    - Temperature operation range: 60 – 80 ºC.
    - Efficiency (HHV): 60 – 80 %.
    - CAPEX: 1000 €/kW, which could be reduced to 400 €/kW by 2050.
    - Currently significantly lower lifetime than other electrolyzers.
    - Potential for higher efficiencies and lower costs than AEC.
    - Easy to operate and non-toxic materials.
  - SOEC:
    - TRL 4 – 5.
    - High efficiencies, co-electrolysis option, capability to use residual heat.
    - Temperature operation range: 700 – 950 ºC.
    - Efficiency: 80 – 90%.
    - CAPEX: 5000 – 8000 €/kW, expected to be reduced to 500 €/kW by 2030.
- Hydrogen use:
  - Supply industrial hydrogen markets. Currently, worldwide, around 50 MtH_2/y are used as feedstock for different industrial processes. Due to the modular and distributed

---

[142] In (Garcia-Casals X., 2006) and (Garcia-Casals X., 2011) whole country-based energy system simulations from RES-based energy systems are performed to analyse the viability and implications of operating the whole energy system with different mixes of 100% RES generation. In these simulations, P2X was shown to be a very powerful flexibility and integration mechanism to allow the cost-efficient operation of virtually any 100% RES-based generation mix, providing full regulation capacity, and eliminating the need of very significant RES curtailment from the installed capacity.

character of RES-based hydrogen, both in situ hydrogen generation in those sites far away from central hydrogen production facilities[143], or centralized hydrogen generation could be targeted[144].

- Distributed CHP. Mainly based on reversible SOEC/SOFC systems, where grid RES-based electricity is used when most convenient[145] to produce hydrogen with an electrolyzer, which then is stored locally conveniently decoupling generation and consumption, until local demand requires its conversion to heat and power through a fuel cell. This locally produced hydrogen could also be sold to the local gas distribution network directly or after methanating it.
- Generation of electricity in isolated sites, already competing in costs with diesel generators[146].
- Power grid centralized balancing services. Contributing with its flexibility to integrate RES generation. The hydrogen produced could be used on the same site to generate electricity with a FC when needed, therefore increasing the grid balancing services, or deviated to other parts of the energy sector (road freight, air or marine transport).
- Synfuels production. The advantage of further processing the hydrogen into a synfuel is that these synfuels are compatible with the existing FF infrastructure which reduces the costs associated to fuel storage, fuel transport, and even investment in end-use equipment. With oil prices of around 100 $/barrel, synfuels based on SOEC could already be competitive, requiring SOEC.

▪ Methanation:

- Is the synthesis of methane through the hydrogenation of CO_2 or CO, processes that have already been used during decades.
- Catalytic methanation is the more mature option, with 400-1500 €/kW CAPEX and 80% efficiency, leading to global electricity2methane efficiencies of 55 – 60 %.

---

[143] In Europe, currently siting mainly in Germany and the Netherlands.

[144] However, in terms of cost, RES-based hydrogen production could compete earlier in isolated sites where current hydrogen cost is 10-30 €/kg than in central hydrogen manufacturing facilities where hydrogen cost of production is currently around 2 €/kg.

[145] Low prices associated to excess RES generation capacity, and often linked to income generation by providing regulation and ancillary services to the grid.

[146] Indeed, stand-alone diesel electricity could cost currently around 65 c€/kWh or more (depending on distance to serve the diesel fuel), while hydrogen based SOEC/SOFC electricity fed by local wind electricity could have around halve this cost.

- Biologic methanation uses methanogenic microorganisms as bio-catalyzers to produce methane from hydrogen and CO_2, with the potential for a drastic cost reduction, but still not commercially available.

- P2L
  - Production of synthetic liquid fuels[147] from RES-based electricity, water and CO_2.
  - Three main phases in the P2L process:
    - Hydrogen production from water by electrolysis and RES-based electricity.
      - High temperature electrolyzers (SOEC with TRL 5) provide higher efficiency.
      - CO_2 procurement and storage.
        - Extracting CO_2 from the atmospheric air has a TRL 6.
      - Synthesis of the liquid fuel. There are two main routes for this process, both of them with TRL 8-9 and fully implemented in the chemical industry:
        - Fischer-Tropsch synthesis. Catalytic process to obtain hydrocarbons from hydrogen and CO, working at high temperatures (150 – 300 ºC) and pressures (200 bar). The required CO is obtained from CO_2 by the reverse water gas shift reaction.
        - Methanol synthesis, where the reverse water gas shift reaction can be avoided.
  - Global P2L efficiencies:
    - Similar for both synthesis processes.
    - Much dependent on the source for CO_2:
      - CO_2 from air:

---

[147] The CO_2 origin is fundamental for the sustainability and climate alignment of P2X synthetic fuels. Only if CO_2 is extracted from the atmospheric air (or captured from synthetic fuel emissions) the integration of P2X fuels in the energy system is neutral in GHG emissions, without affecting GHG atmospheric concentrations (once the synthetic fuel is burned, CO_2 goes back to the atmosphere), and transition aligned. If the CO_2 comes from FF combustion or industrial processes, the synthetic fuel produced with it will ultimately release to the atmosphere this GHG emissions, and the original processes themselves should be changed by non-GHG emission processes in order to be transition aligned. If the CO_2 comes from biomass, although globally neutral in the long term, unless simultaneously compensated by directly linked energy crops, the process would produce a step increase in atmospheric GHG concentrations by displacing carbon from the biosphere to the atmosphere (Garcia-Casals X., 2011), and could have sustainability issues associated to the biomass production. However, the use of biomass for P2L significantly reduces the required amount of required biomass compared with the option of producing biofuels, since for an equivalent total heating value, the addiction of RES-based hydrogen significantly increases the HHV of the synthetic fuel for a given carbon content.

- Hydrogen from AEC: 42%.
- Hydrogen from SOEC: 47%.

- CO_2 from concentrated source (for instance exhaust from industrial process):
  - Hydrogen from AEC: 54%.
  - Hydrogen from SOEC: 64%.

In Figure **47** we see the foreseen P2L jet fuel prices for year 2050 according to (Schmidt P., et al, 2016). Jet fuel price in August 2016 was 422 €/t, around one third of projected P2L costs for 2050, but jet fuel cost could double for year 2040, and externalities are not captured[148] by current FF jet fuel costs, which all together bring P2L closer to or within economic viability.

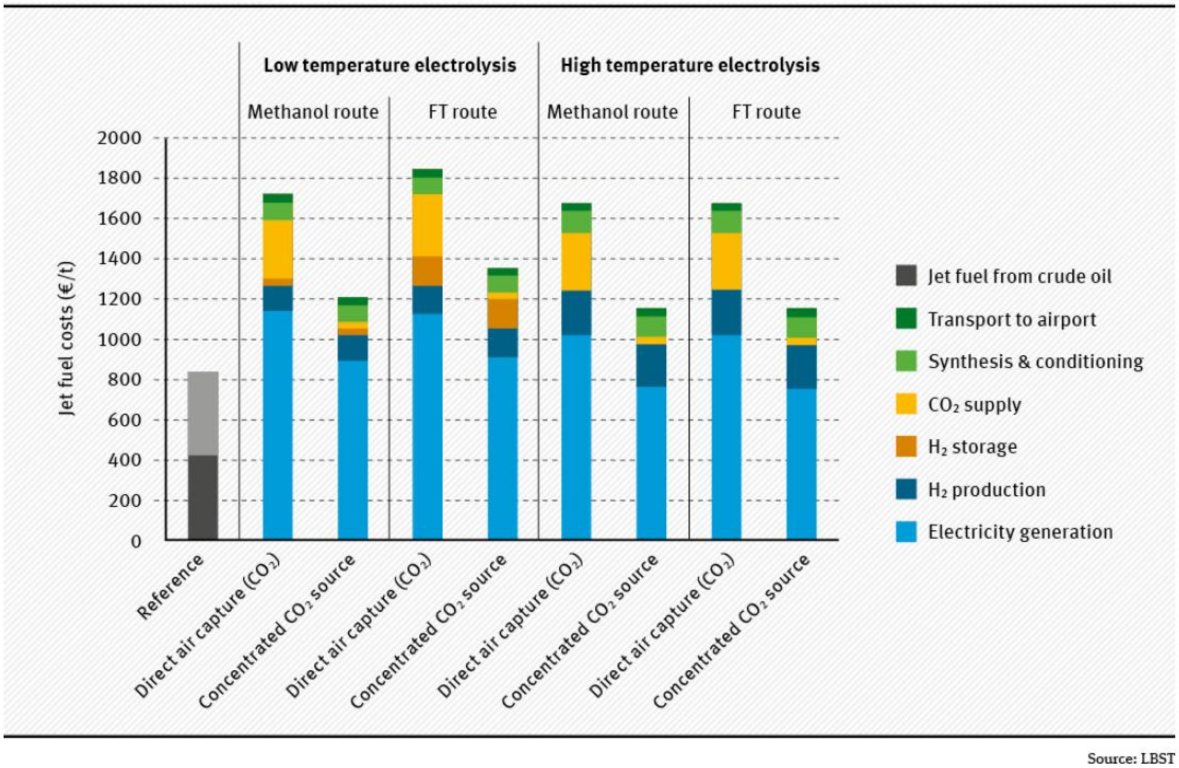
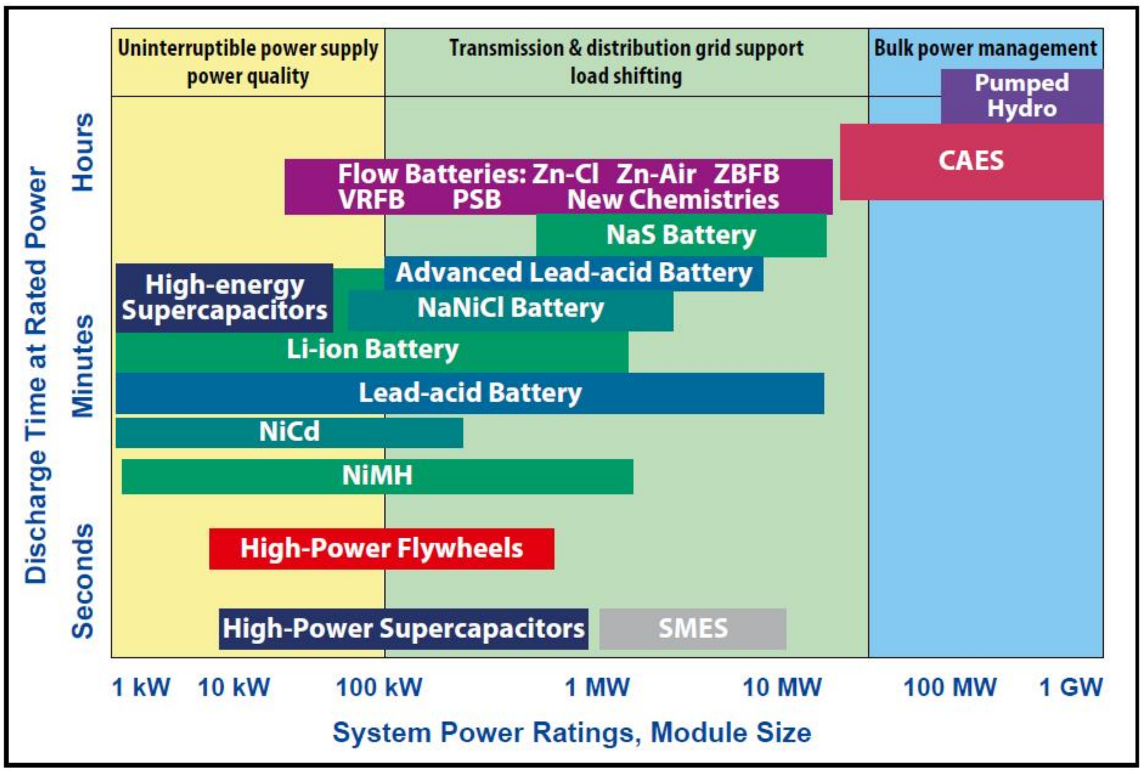


Figure 47: Jet fuel costs projected for P2L plant in 2050, assuming RES costs of 40 €/MWh and a plant CF of 43% (Schmidt P., et al, 2016)

[148] Externalities of air transport are huge, and they will increase as time goes by and we approach the limits of the available carbon budget to maintain climate change below acceptable global warming limits. In (Garcia-Casals X., 2017b) BAU GHG emission scenarios from the air transport sector are developed, showing how if this sector continues to evolve unattended and without social limits on its externalities, it will eat up a huge portion of the remaining carbon budget, and therefore unlock climate change beyond the accepted limits even if an appropriate transition is undertaken in the rest of the energy sector, which would have huge social external costs.

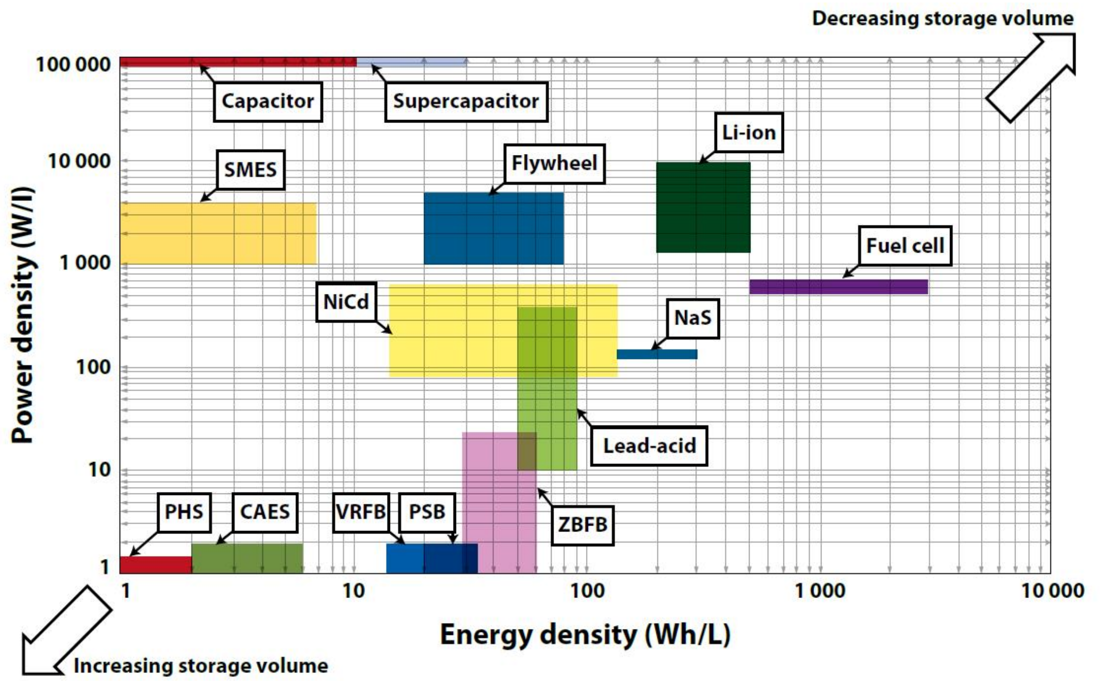
Hence, we have many storage options available to support the transition by introducing very high flexibility into integrated energy systems, facilitating RES introduction into the power sector and the efficient and reliable operation of a RES-based energy system.

The different available storage options are to a great degree complimentary in terms of the services they can provide to the power system. Figure 48 shows the positioning of diverse energy storage technologies per their power rating and discharge times at rated power, while Figure 49 presents a comparison of different storage technologies in terms of power density and energy density.



Source: US DOE/EPRI, 2015.
Note: Zn-Cl = zinc chlorine flow battery; Zn-Air = zinc air flow battery; ZBFB = zinc bromine flow battery; VRFB = vanadium redox flow battery; PSB= polysulfide bromine flow battery; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; NiCd = nickel cadmium; NiMH = nickel-metal hydride; SMES = superconducting magnetic energy storage.

Figure 48: Positioning of diverse energy storage technologies per their power rating and discharge times at rated power (Ralon P., et al, 2017)



Source: Luo *et al.*, 2015.
Note: SMES = superconducting magnetic energy storage; NiCd = nickel cadmium; NaS = sodium sulphur; PHS = pumped hydro storage; CAES = compressed air energy storage; VRFB = vanadium redox flow battery; PSB= polysulfide bromine flow battery; ZBFB = zinc bromine flow battery.

Figure 49: Comparison of power density and energy density for selected energy storage technologies (Ralon P., et al, 2017)

Current use of global storage capacity is already rather diverse, providing a good platform and track record from where to intensify the storage usages demanded by the transition. Figure **50** shows global energy storage power capacity shares by main-use case and technology group, at mid-2017. Uses of storage are expected to evolve as transition progresses:

- PHS is currently mainly used to shift the electricity supply from times of low demand to times of high demand to reduce generation costs, while in a transition context regulation and RES integration would gain a dominant role.
- Electro-chemical storage (batteries) is currently mainly used for frequency regulation. This use is expected to keep on being important while advancing the transition, since batteries' synthetic inertia should pick up a significant part of the very fast primary frequency regulation currently provided by the analogic inertia from thermal power plants. However, the share of batteries use to support RES integration is expected to increase.
- Electro-mechanical storage use is currently dominated by on-site power, but its regulation contribution is expected to increase as the transition progresses.
- The world's thermal energy storage deployment is currently dominated by the molten salt storage in CSP plants and, therefore, 72% of the capacity in today's main-use case is categorized as renewable capacity firming. This is somewhat

open to debate, however, as it could also be classified as electricity time shift. It also does not take into account that the flexibility this gives to a CSP plant could result in it providing a range of other services. As the transition progresses, we could expect an increased share of TES contribution to RES integration and power system regulation through the mobilization of the distributed TES in the building stock.

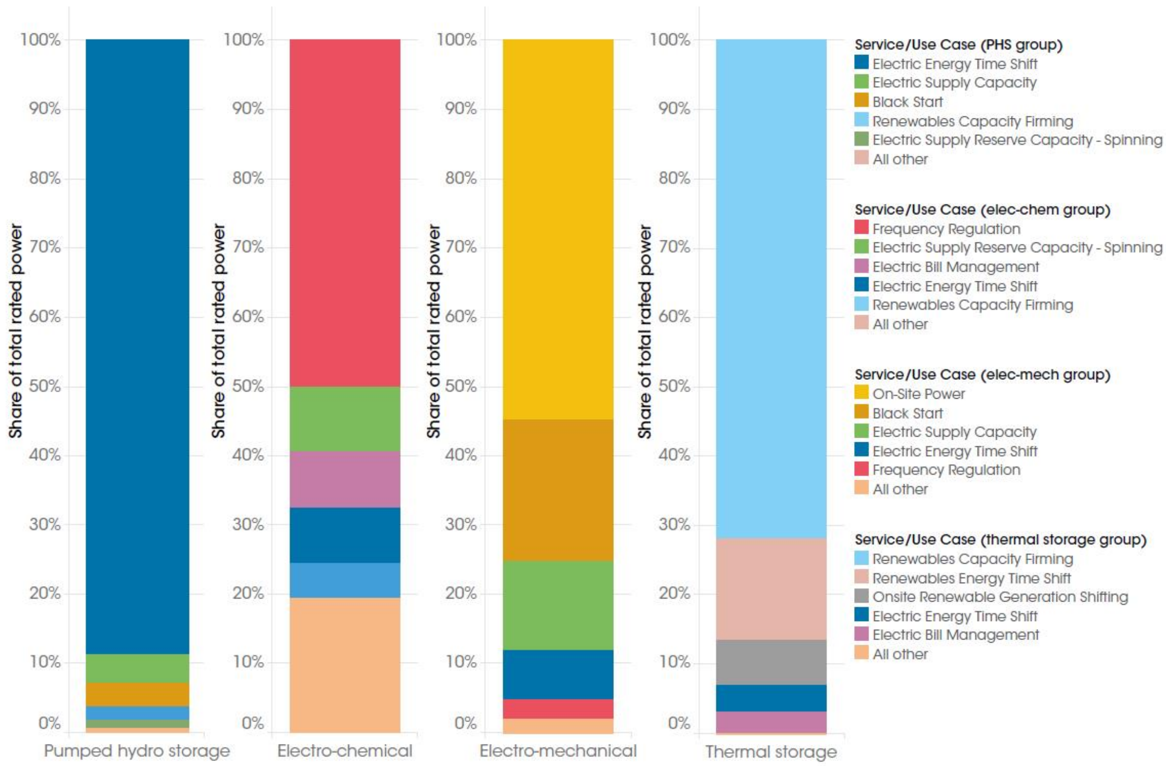


Figure 50: Global energy storage power capacity shares by main-use case and technology group, mid-2017 (Ralon P., et al, 2017)

But except for PHS, the absolute deployment from the other storage technologies is still very limited (Figure **51**), with TES applications dominated by the molten salt thermal storage deployed with commercial CSP plants in the last years, and electro-chemical storage dominated by Litium-ion batteries spurred by EVs deployment and with already few relevant grid applications.

Indeed, the growth electro-chemical storage has followed a strong exponential path along the last decade (Figure **52**) spurred by the decreasing costs of Li-ion batteries.

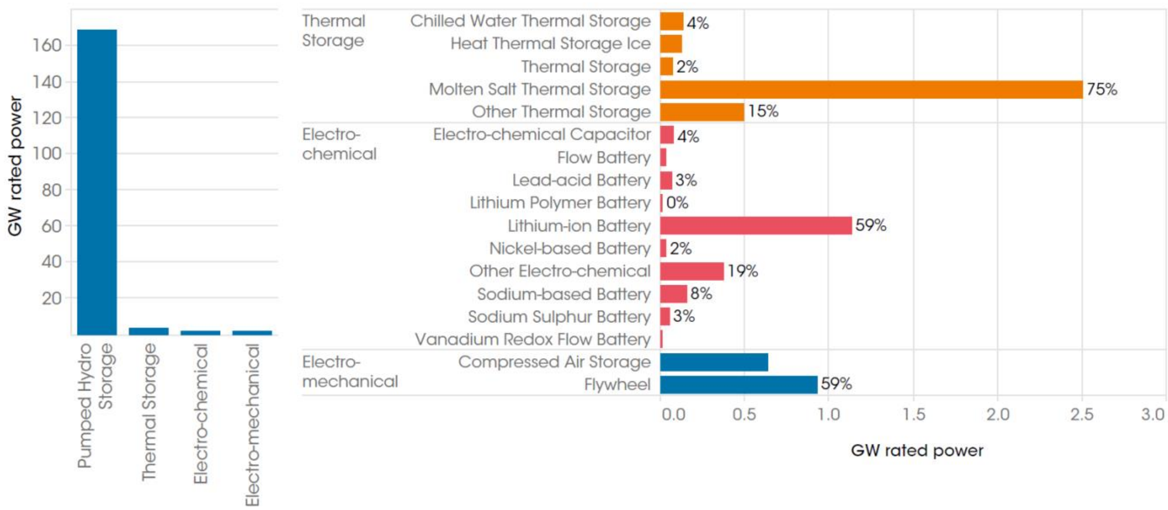
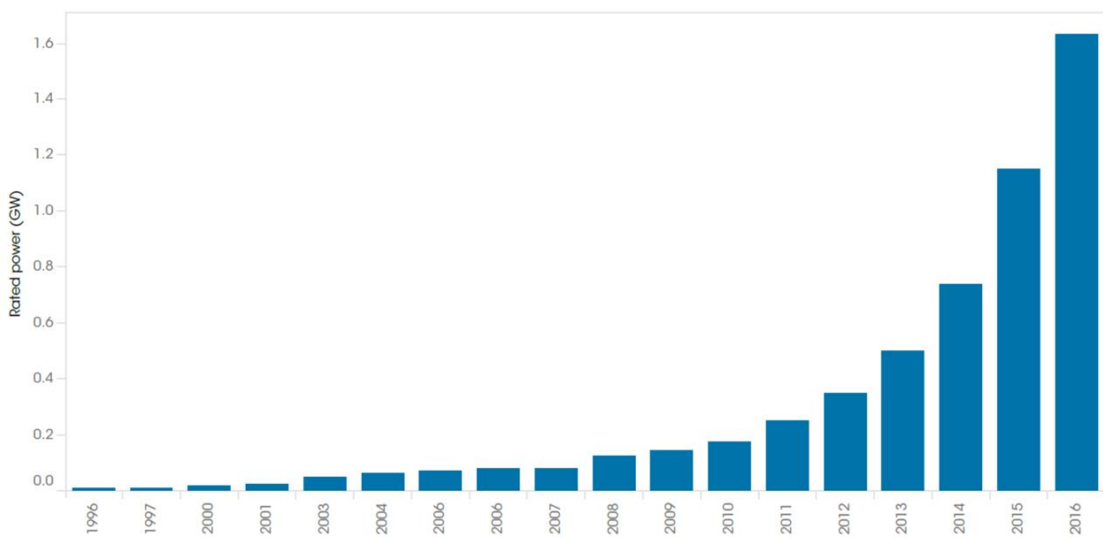


Figure 51: Global operational electricity storage power capacity by technology, mid-2017 (Ralon P., et al, 2017)

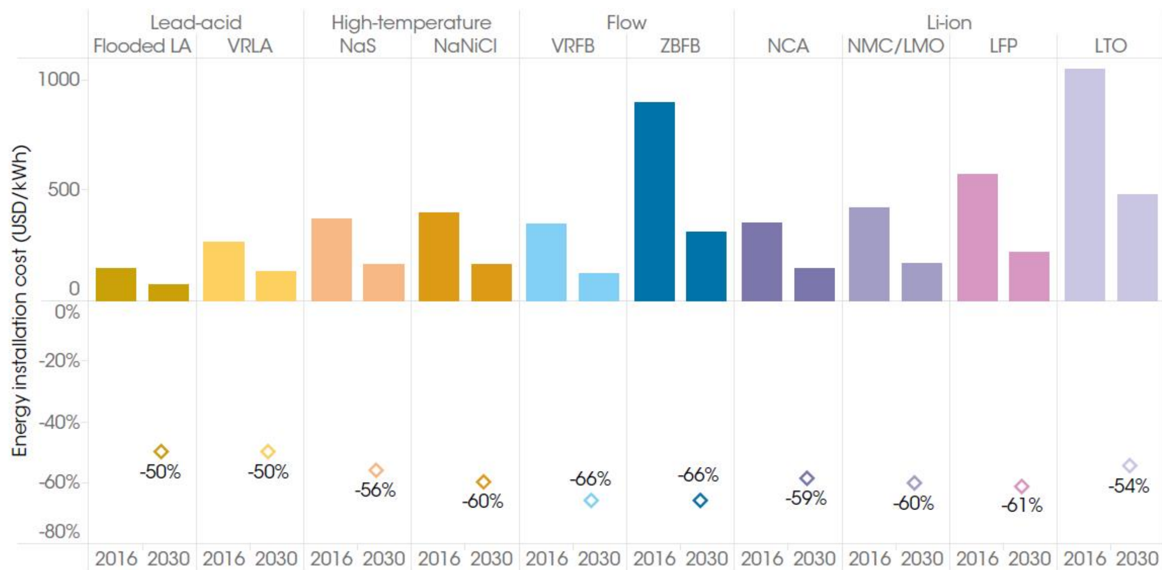


Source: US DOE, 2017.

Figure 52: Global electro-chemical storage capacity, 1996-2016 (Ralon P., et al, 2017)

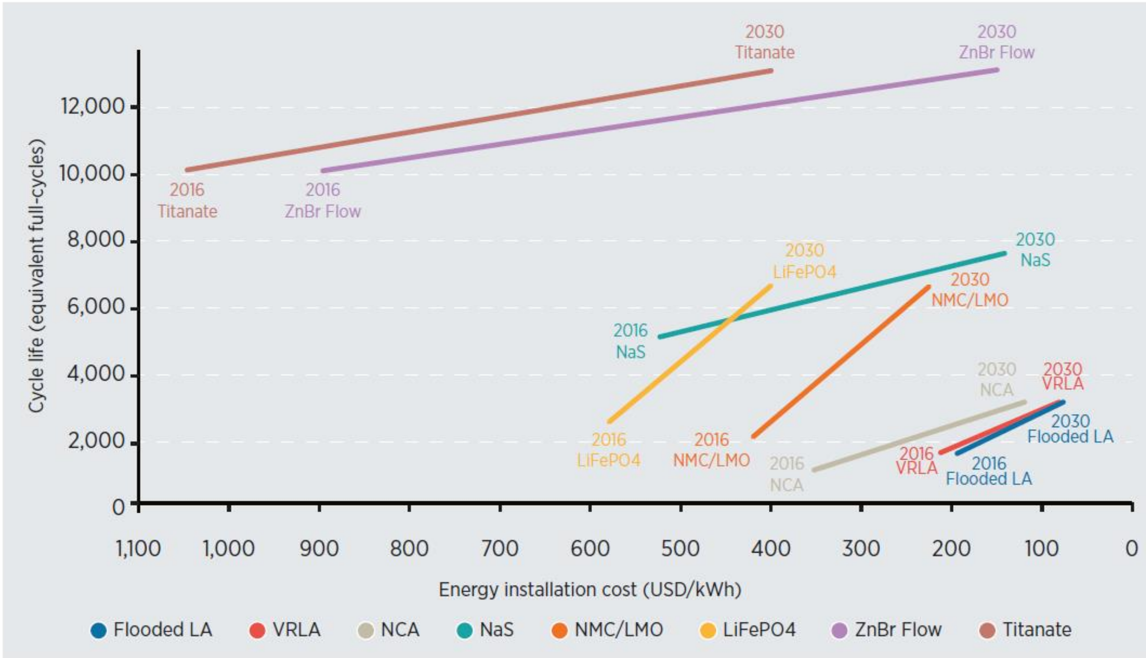
In spite of the dominance of Lithium-ion batteries up to date, we have seen that many other battery technologies are available or under development, with the capability to increase the diversity on deployed technologies because of their better matches with different applications, and pushing away any concerns about supply chain constraints on a single technology. Figure **53** presents the foreseen CAPEX reduction potential for year 2030 and the different battery technologies. While Li-ion batteries will keep on being very competitive, other battery technologies are expected to reach similar and even lower CAPEX.

Figure **54** complements this vision on the evolution of different battery technologies CAPEX with the associated evolution of battery life cycles, with both parameters simultaneously driving towards lower LCOES.



Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

Figure 53: Battery electricity storage system installed energy cost reduction potential, 2016-2030 (Ralon P., et al, 2017)



Note: Titanate: Lithium Titanate; ZnBr Flow: Zinc-Bromine; NaS: Sodium Sulphur; NMC/LMO - Nickel Manganese Cobalt Oxide (NMC) / Lithium Manganese Oxide (LMO); LiFePO4: Lithium Iron Phosphate; NCA: Lithium Nickel Cobalt Aluminium; VRLA: Valve regulated lead-acid; Flooded LA: Flooded lead-acid

Source: IRENA, 2017b

Figure 54: Energy installation costs and cycle life of battery storage technologies, 2016 and 2030 (Pérez-Arriaga I., et al, 2017)

11.3 EVs & charging infrastructure

EVs are a transition enabling technology that facilitates energy system integration.

Beyond offering the prospect to reduce FF use in the transport sector, EVs can help integrate growing quantities of variable renewable energy by using “smart” EV charging strategies that communicate with grid operators and energy markets to promote flexibility, allowing for the use of generation that otherwise might be curtailed. Also, EVs have the potential to send electricity back to the grid during periods of high demand and to substitute for stand-alone customer-sited electric energy storage.

Electrification of the transport sector expanded during 2016, enabling greater integration of renewable energy in the form of electricity for trains, light rail, trams as well as two- and four wheeled EVs.

Global deployment of EVs for road transport, and particularly passenger vehicles, has grown rapidly in recent years. In 2016, global sales reached an estimated 775,000 units, and more than 2 million passenger EVs were on the world’s roads by 2016 year’s end (Figure 55).

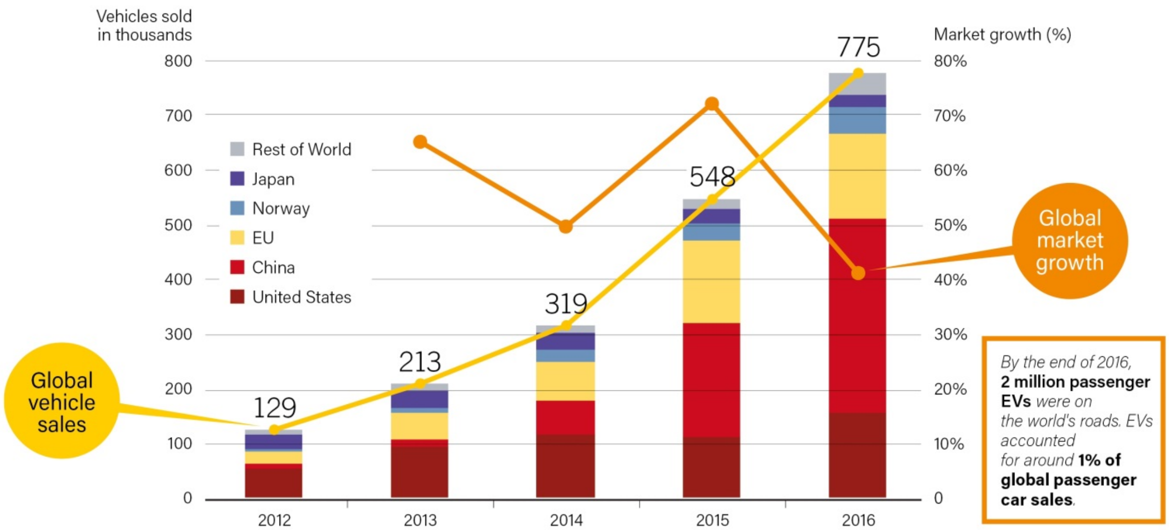


Figure 55: Global Passenger Electric Vehicle Market (Including PHEVs), 2012-2016 (REN21, 2017)

In broadly cited estimates, in which EV adoption relies on individual customer purchases, EVs will represent a growing and significant portion of new car sales globally: 25% by 2030 and 35% by 2040. Sales at this level would mean that EVs could make up 5% to 10% of total vehicle stock by 2030, in line with IEA estimates to reach the UNFCCC Paris Agreement targets of deploying 100 million electric cars by 2030 (WEF, 2017). However, under a SEC context, EVs deployment could be significantly faster, driven by mobility service BMs.

EV technology has evolved rapidly over the past five years. Range has improved from less than 160 km up to 480 km for some models, addressing a prime convenience issue compared to traditional vehicles with ICEs. The cost of batteries has declined from about $1,000/kWh in 2010 to below $300/kWh in 2015, dramatically lowering the cost of EVs and enabling lower-cost models such as the Nissan Leaf or the Tesla Model 3. As a result, 2015 was the year where over one million EVs globally were on the road. Battery costs are expected to decrease to below $200/kWh by 2020, making EVs economical without subsidies in many countries, reaching three to five-year breakeven periods compared to an investment in a traditional car or truck (WEF, 2017).

Today, slow charging stations cost about $1,200 for a residential charger, $4,000 for a commercial garage charger and $6,000 for a curbside charger.

11.4 DR and aggregation

An assessment of the development of the regulatory environment for DR in the different Member States is presented in (SEDC, 2017) along the following dimensions:

- DR access to markets: Whether regulation allows and facilitates DR to participate in electricity markets.
- Service providers access to markets: Whether regulation allows and facilitates that aggregators can properly participate in electricity markets.
- Product Requirements: Whether the participation requirements in the electricity markets enable access of a range of resources, including demand-side resources. Many different product/programme participation requirements were historically designed around what generators could conveniently deliver. Today these narrow criteria are no longer justifiable because they block low-cost demand-side resources, and hence artificially inflate procurement costs[149].
- Measurement and verification standards[150], and payments and penalties requirements.

Pooling the results from the four DR and aggregation dimensions above, Figure **56** presents the overall results from this analysis, with countries grouped in four categories (green, yellow, orange and red):

- Green countries are those where enabling regulation is already in place to the extent of providing commercially active participation of DR through aggregators in

[149] For example, a system's physical need for reserves typically requires the resource to be available for between ½-2 hours. However, the market participation requirements for some reserve markets may state that load must be available up to 12 hours and up to 60 hours over the weekend. This suits coal-fired generation, which can operate for extended periods of time at minimal incremental cost once the start-up costs have been incurred, but it does not reflect the actual system need. This may not have been a problem in the past, but it is now, as it blocks consumer participation, since most consumers are unable to adjust their consumption for 16 consecutive hours.

[150] Volumes of demand-side flexibility are calculated as the difference between what the consumers normally consume (the baseline) and their actual measured consumption during the dispatch, measured using appropriate metering. The baseline cannot be measured directly, so it must be calculated based on other available measured data, using an agreed, robust methodology. Transparency is a must to enable DR, therefore it is essential that the methodologies in place are made available to consumers and DR service providers.

the energy markets[151], tough there are still market design and regulatory issues that exist in these well-performing countries[152].

- Countries marked yellow are those where regulatory barriers remain an issue and hinder market growth[153]. Although several markets in these countries are open to DR in principle, programme requirements continue to exist which are not adjusted to enable demand-side participation. Furthermore, a lack of clarity remains around roles and responsibilities of the different actors and their ability to participate in the markets.
- Countries marked in orange are those that have taken the first steps to articulate DR and aggregation tough still did not reach a condition where they can be incorporated into markets[154].
- Countries are marked in red when aggregated demand-side flexibility is either not accepted as a resource in any of the markets or it is not yet viable due to regulation, showing a critical disconnect between political promises and regulatory reality. Unfortunately Iberia currently sits under this category with the lowest mark[155].

---

[151] Finland stands out amongst the Nordic countries primarily as it allows independent aggregation in at least one of the programmes in the ancillary services, and due to its advanced provisions for measurement and verification.

[152] New legislation addressing the role of the aggregator and independent aggregation will soon be put in place in Belgium, which will help to provide an equal footing for all market actors; a strong sign for the uptake of DR. However, there are still some issues regarding measurement and verification that inhibit the growth of DR.

[153] Germany has moved from orange status in 2015 to yellow in 2017. This is primarily due to the fact that product definitions have been updated or are about to be updated, and balancing reserve markets are about to be opened for independent aggregation.

[154] Italy has slowly started to take the regulatory steps needed for a solid framework for DR. However, despite the gradual opening of markets, significant barriers still hinder customer participation. For example, major sections of the market are still closed off and they lack a viable regulatory framework for DR overall.

[155] Indeed, Spain and Portugal have a grading of 1, while France gets a grading of 18.

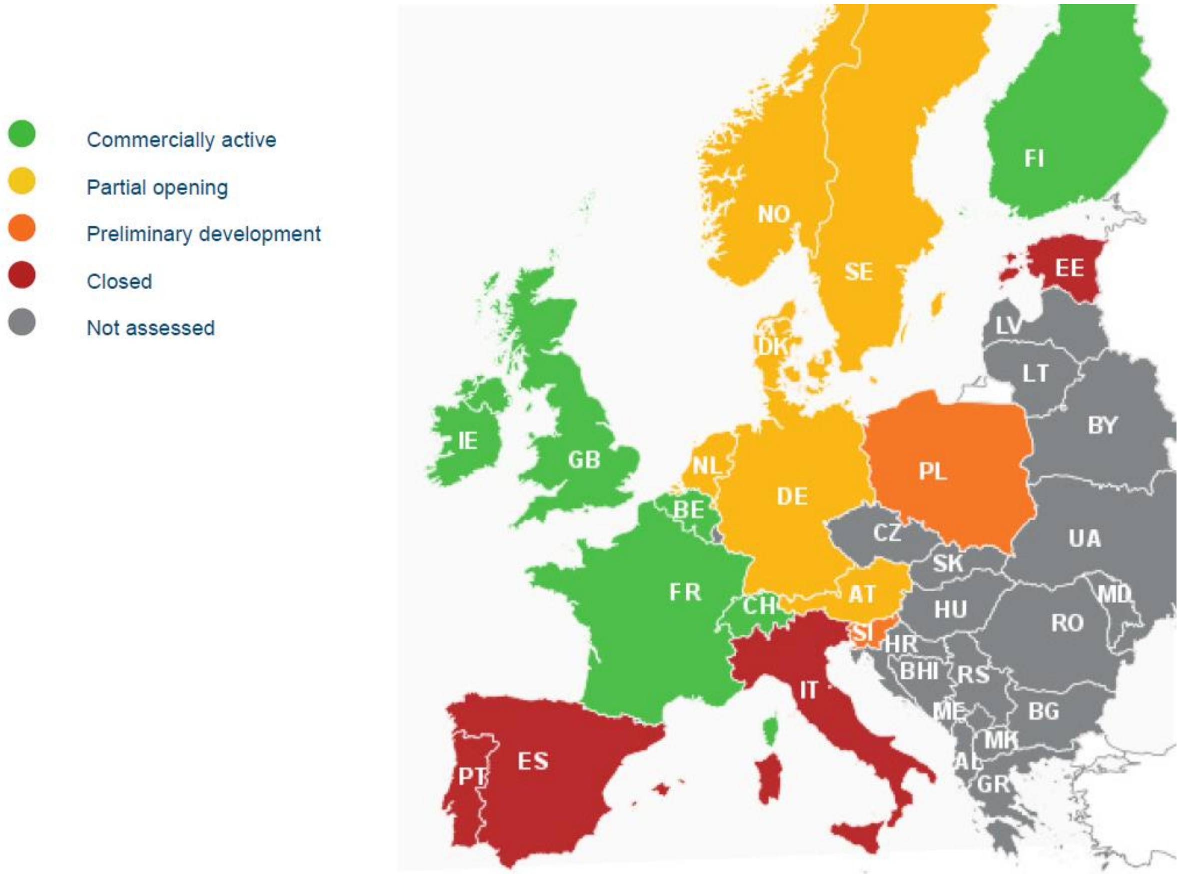


Figure 56: Map of Explicit DR development in Europe (SEDC, 2017)

With regards to the first criteria evaluated, ie demand response access to markets, Figure 57 provides the results obtained in the (SEDC, 2017) evaluation. In several national markets, DR is either not accepted as a resource in the balancing, capacity or wholesale markets or is still limited to a couple of specific areas within the ancillary services. Moreover, in the majority of the countries, the only way for DR or DG to participate in the markets is by being sold directly through the retailer/BRP. Iberia is lagging in Europe with regard to the DR access to markets. In Spain, participation in different markets is still almost non-existent (in fact, DR activity is restricted to industrial consumers in interruptible contracts).

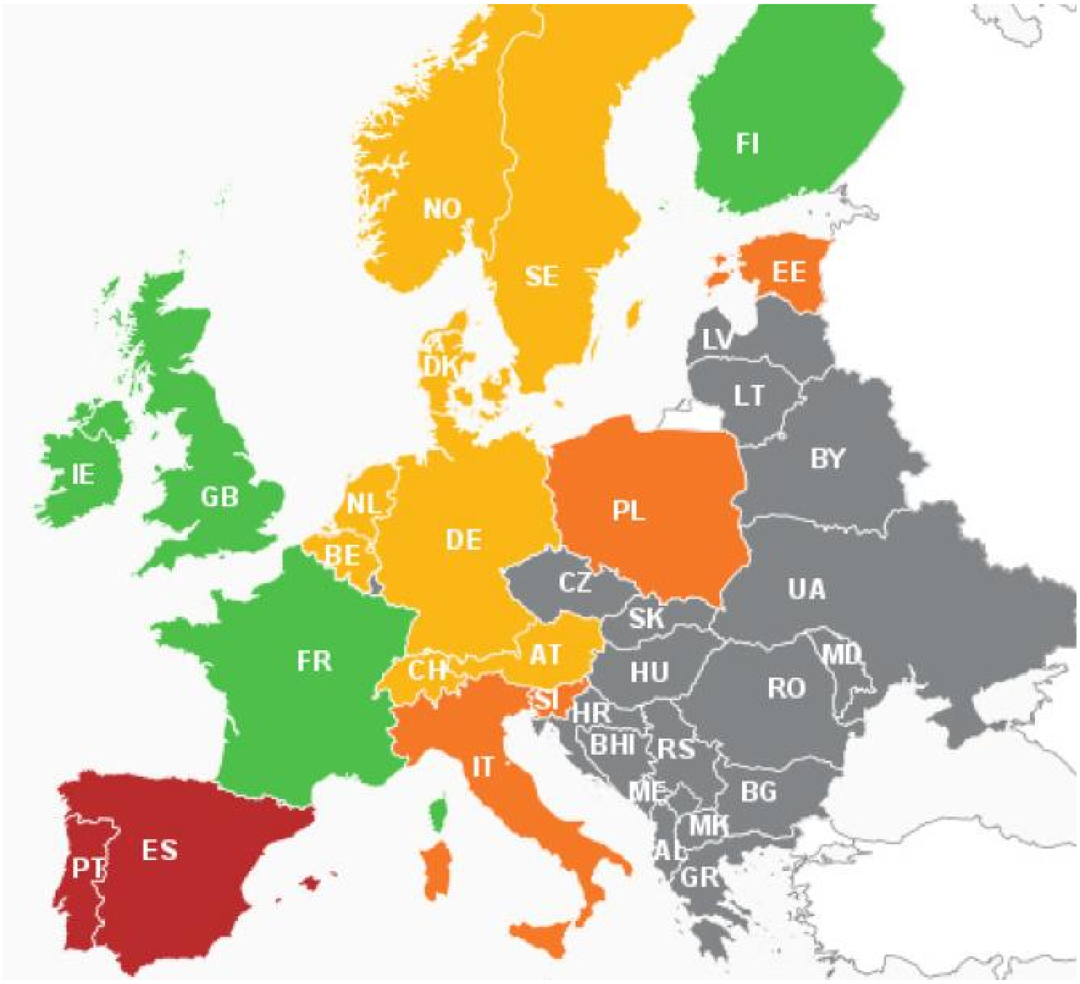


Figure 57: Demand response access to markets in Europe (SEDC, 2017)

With regards to the second criteria evaluated, ie service providers access to markets, Figure 58 provides the results obtained in the (SEDC, 2017) evaluation. Consumer Access still appears to be one of the most problematic areas, directly contradicting existing EU legislation[156]. The European Commission's legislative proposal for the revision of the Electricity Directive – when adopted and properly implemented – should overcome this problem, stating that "Member States shall ensure that their regulatory framework encourages the participation of aggregators in the retail market and that it contains at least the following elements: (a) the right for each aggregator to enter the market without consent from other market participants…".

In the majority of European countries, market rules do not provide specific details on how independent DR aggregators should engage with consumers, nor do they make it viable for them to access the market. They may allow these new service providers to participate in the markets, but they lack fair competition. In these Member States, independent

[156] *Electricity Directive*

aggregators must negotiate bilaterally with BRP/retailers to sell consumers' flexibility on the markets. This is a major disincentive for new market actors from attempting to enter the market, as the rules create a barrier to entry and result in retailers/BRPs being essentially the only actors providing aggregation services. The lack of a framework, in addition to the non-defined roles and responsibilities, increases the risk for all parties, and enables the abuse of consumer rights (including contractual arrangements and price stability).

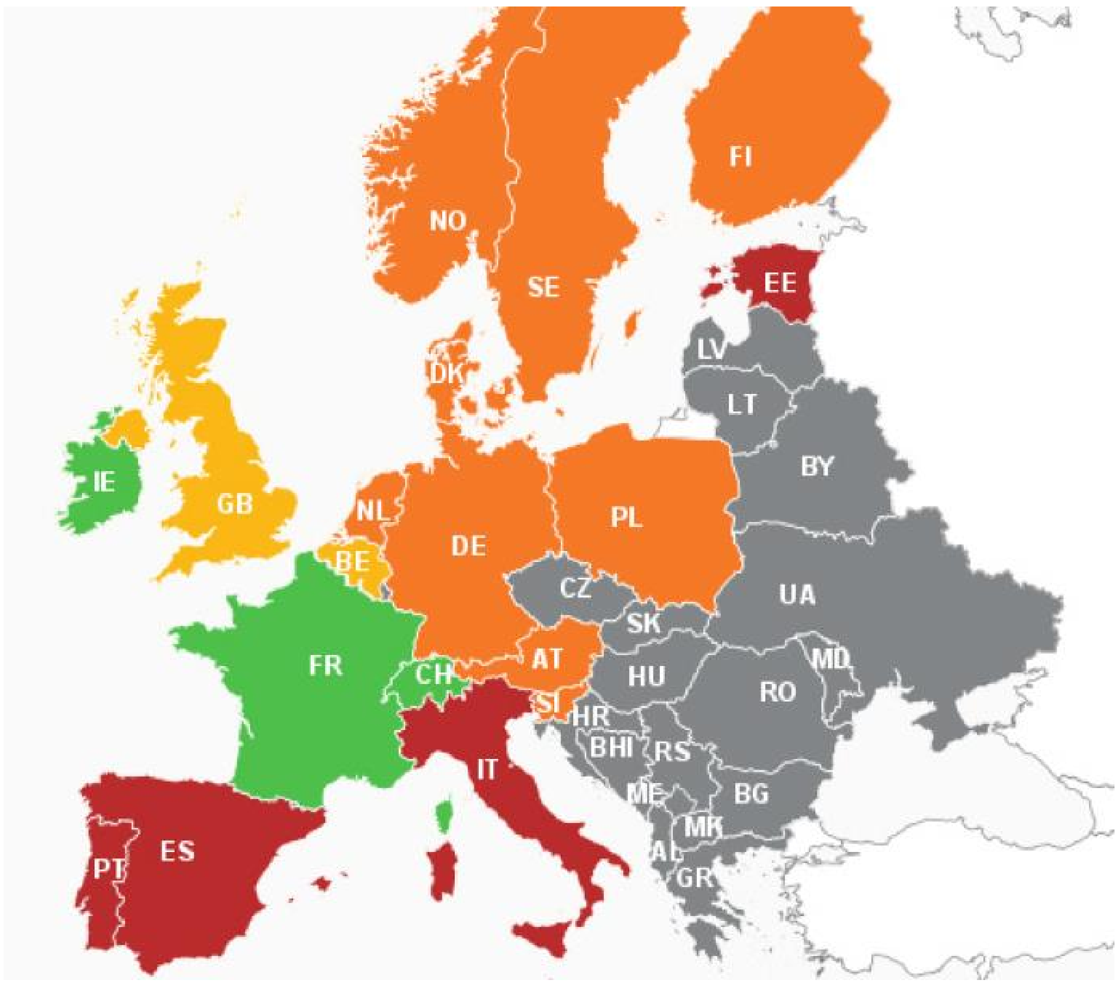


Figure 58: Service providers access to markets in Europe (SEDC, 2017)

With regards to the third criteria evaluated, ie product requirements, Figure **59** provides the results obtained in the (SEDC, 2017) evaluation. Few Member States have started to address the issue of product requirements, especially on balancing markets. Narrow product requirements continue block low-cost demand-side resources and artificially inflate the cost of balancing in several countries. Although demand-side resources are more flexible and can react faster than most generators, large minimum bid sizes (over 5 MW), long event durations, high frequency of events, and short resting periods between events prevent larger consumer participation. For example, while consumers can participate quickly and provide a secure resource, they have difficulty providing availability 24/7.

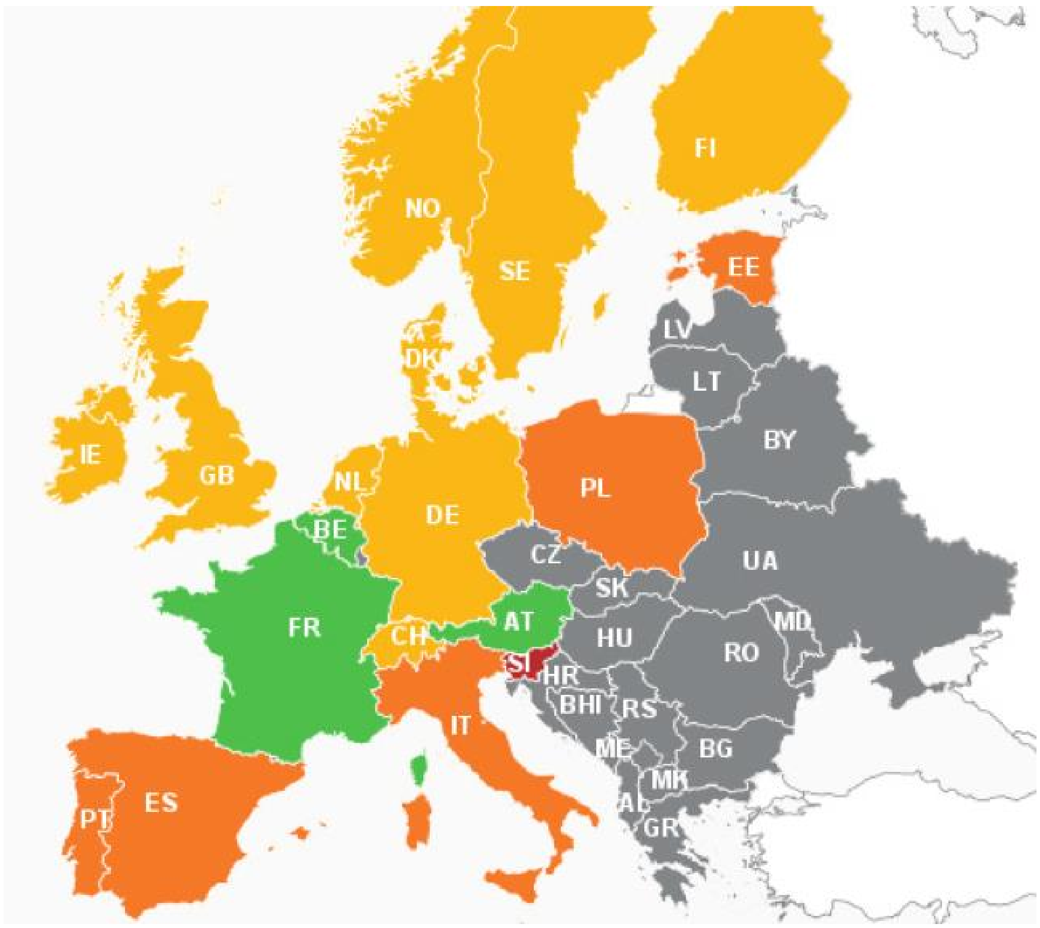


Figure 59: Product requirements in Europe (SEDC, 2017)

With regards to the fourth criteria evaluated, ie Measurement and Verification, Payments and Penalties, Figure **59** provides the results obtained in the (SEDC, 2017) evaluation. The regulation concerning measurement and baseline methodologies is still progressing across the analysed countries. There has been some momentum towards establishing standardised prequalification rules and baseline methodologies. However, issues remain such as transparency, multiple baseline methodologies, and in some scenarios, there being no requirements for how energy consumption reduction is to be measured. These are major barriers to the uptake of DR, and for new market actors accessing the markets.

Penalties for non-performance are generally acceptable, but fair and adequate payment for Demand Response is more problematic.

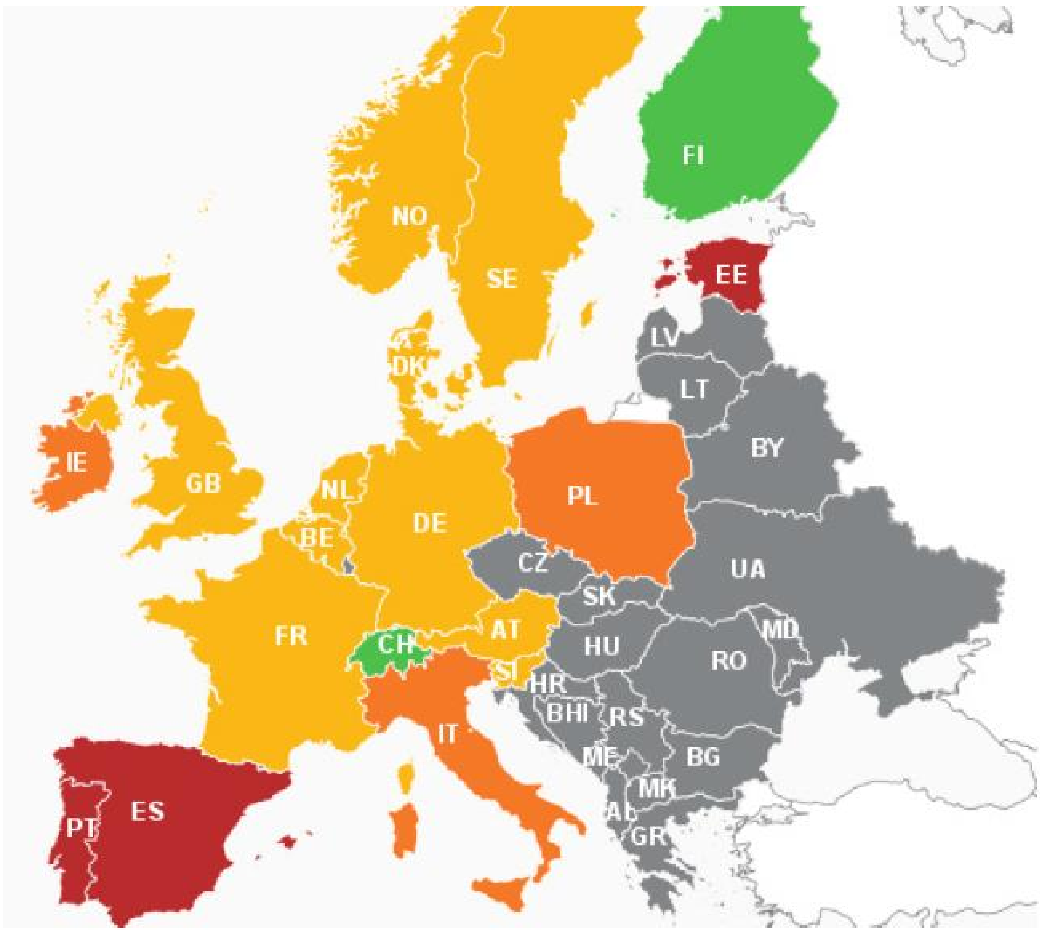


Figure 60: Measurement and Verification, Payments and Penalties in Europe (SEDC, 2017)

Buildings are an important source of EF. Indeed, since they represent around 40% of the annual energy use worldwide, they should also contribute to the required energy system flexibility. The concept of smart buildings, and their EF implications, has gained explicit interest in Europe since the introduction of the Winter Package (11/2016). However, a common terminology and methodology for characterization and labelling of EF in buildings is still missing, both at building level and at clusters of buildings level. In (Pernetti R. et. al., 2017), the contribution from the IEA Energy in Buildings and

Community program[157] (IEA-Annex67) to cover this gap is presented, focusing on exploiting EF in buildings to optimize EE and CO_2-reductions at an aggregated or community level, and acknowledging that EF is not only the result of the available technologies in a building[158], but depends significantly on the way these technologies are used - i.e. controlled - and their interaction with the surrounding energy network, the occupants and other boundary conditions, such as local climate. The IEA-Annex67 proposed methodology represents EF by quantifying the amount of energy a building or cluster of buildings can shift according to external forcing factors, without compromising the occupant comfort conditions and taking into account the technical constraints of the building and of its HVAC system. In order to standardize indicators, the proposed approach form IEA-Annex67 quantifies the EF potential according to the buildings' response to a step change in the external control signal[159], where the response is characterized by a set of parameters defining it and that can be used to integrate this EF capability in the energy system operation: time from when the signal is submitted to when an action stats (time delay in response); period from start of response to maximum response (ramp-up time); maximum response (power); duration of the response; shifted amount of energy during the response period; rebound effect for returning the situation back to reference.

Since this EF characterization is rather technical, the IEA-Annex67 is also working on a EF labelling that can be communicated to a broader audience, where the EF potential is rated according to the building's share of reduction on price/consumption/CO_2-emissions (depending on the target of labelling) when using an external signal-aware control instead of an external signal ignorant control.

The IREC has developed an energy and transition prospective for Catalonia with the horizon of year 2050 (PROENCAT 2050), where among other[160] technologies, different building sector DR components[161] capable to provide EF are analyzed (Ortiz J., Torrent M. , 2017):

- HP:
    - HPs have become the best transition option to supply the buildings and industry with its thermal energy requirements. Indeed, they mobilize environmental distributed RES (solar energy stored in the air, water or ground) and provide system integration through efficient electrification, which provides additional flexibility through DR. Together with thermal

[157] *Through its 'Energy Flexible Buildings' Annex 67, where IREC participates.*
[158] *Which is the approach followed by the Smart Readiness Indicator (SRI) based on the rating of different smart services integrated in buildings.*
[159] *The external signal, in a market context would be a price signal. But it could be a GHG emissions intensity signal, or a RES integration requirements signal.*
[160] *The technologies and items covered by PROENCAT 2050 are: solar PV, solar thermal, CSP, wind, storage, energy management, smart grids, CO_2-economy, mobility and EVs.*
[161] *Beyond other flexibility components associated to the building and community scales like DS, DG and V2G.*

storage systems, HPs can contribute to provide flexibility to integrate vRES.

- HPs have already reached a significant deployment (in Spain 34% of the buildings are already using HPs), but there are still barriers hindering their further deployment:
  - In the buildings sector, these barriers are mainly the lack of awareness of their environmental and transition benefits, and their relatively high investment costs[162], especially for existing buildings currently covering their thermal demand with FF boilers.
  - In the industry sector the use of HPs for medium temperature ranges and big scales is still very limited, and needs further technology[163], control and system integration improvements, as well as a better demand characterization and reducing its paybacks from its current 3 to 5 years.
- The roadmaps to enable the full HPs contribution to the transition require:
  - Reducing CAPEX about 40%
  - Simplify and improve its installation and operation requirements as well as its building integration
  - Develop products optimized for different buildings (nZEB, commercial buildings with simultaneous H&C loads,...)
  - Increase operating temperatures to widen potential aplications in industrial processes. Today's maximum temperatures are around 80-100 ºC in the condenser. Working temperatures would need to be increased till up to 150-200 ºC in the condenser and 100 ºC in the evaporator[164].
  - Improve HP integration into industrial processes.

- Smart control and management:
  - The access and management to an ever increasing amount of detailed information about the status of infrastructures and demand has a big potential for improving the efficiency, both of services supply and the network itself. The currently centralized and vertical communication and control architecture will evolve towards a distributed and bidirectional architecture that allows the automatic and smart interaction between huge individual components to optimize the interactions at building level, between buildings and with the energy networks. This evolution will require a restructuring of the control layers currently used, in order to achieve a global and flexible control system capable of a smart coordination between the different system components (DR, DS, DG, V2G,…)

[162] For the building sector, cost reductions up to 40% and COP improvements up to 60% are expected for 2050.
[163] Most HPs operate below 65 ºC, however new developments allow going beyond 100 ºC.
[164] For heat recovery applications.

- Unlocking the flexibility potential is often associated to articulating the appropriate control algorithms. This is for instance the case of the flexibility potential associated to buildings and EVs.
- Control strategies can be RBC or MPC. RBC are simple heuristic pre-defined methods based on logic if-statements applied to certain conditions acting as a gate to specific actions. On the other hand MPC are more complex control strategies based on a model able to project the future behaviour from the controlled component (i.e. building) and implementing optimization routines to find the best control solution to operate the system under real conditions and restrictions fulfilling the goal of optimizing specific performance parameters.
- Different control strategy goals can be pursued depending on the local and global context, and control systems should be flexible in order to adapt to different requirements: demand shedding, peaks shaving, minimize consumption, minimize energy costs, facilitate RES integration, provide ancillary services to the grid,…
- Current technological challenges to implement these smart control and management systems:
    - Missing appropriate price signals properly reflecting network and energy system contexts and needs, as well as a lack of systems to react properly to these signals. For instance, traditional BMS are design to offer different services (thermal comfort, air quality, lighting,…), but are unable to adjust their operation in response to a price signal or a forecast of RES generation.
    - Lack of commercially available low cost control and optimization systems that facilitate an active involvement of final users and that respond through DR to the overall energy system needs without compromising the final service (i.e. thermal comfort, internal air quality, illumination, …)
    - Lack of appropriate M&V technologies and protocols that allow properly quantifying and verifying the provided DR.
    - Introduce BMS in residential buildings and upgrade existing commertial building's BMS so that they can smartly interact with the energy networks and markets.
    - Reduce costs, so that the required equipment (sensors, controls, actuators, enhanced ICT,…) have paybacks below 3 years.
    - For a building or cluster of buildings the following elements should be included in BMS:
        - Meteorological forecasting availability and access
        - Demand forecasting (H&C, DHW, electricity…) based on predictive and matching learning models. At least 80% reliability for a one hour time horizon would be required.
        - New algorithms capable to optimize the overall system operation maintaining an adequate comfort level while

responding to the energy system needs (RES integration, regulation requirements,…)

- mCHP FC:
  - mCHP based on FC and using RES-based hydrogen or synfuels as input could provide an adequate distributed flexibility, especially when coupled with upstream (hydrogen or synfuel) and downstream (thermal storage, batteries) storage. Indeed, FC provide very high electric conversion efficiencies (50-60% compared with 30% from micro turbines), are easy to integrate into the building environment (silent operation), allow for CHP, and when combined with an electrolyser could provide very significant flexibility to the energy system.
  - Main current barriers for mCHP FC are its high costs and the complexity to adapt to the different regulations, together with the fact that other technologies are available and capable to provide similar services at lower cost. Indeed, mCHP has a very limited deployment up to date, and its current CAPEX makes them non-competitive. CAPEX reduction, as of today, seems to be mainly associated to increasing the production volume, with the potential for a 50% CAPEX reduction when reaching production levels of around 50000 units/year[165].

According to the IEA, DR potential typically amounts to around 15% of peak demand. The IEA assessed that the potential could exceed 150 GW by 2050 in the European Union (Figure **61**).

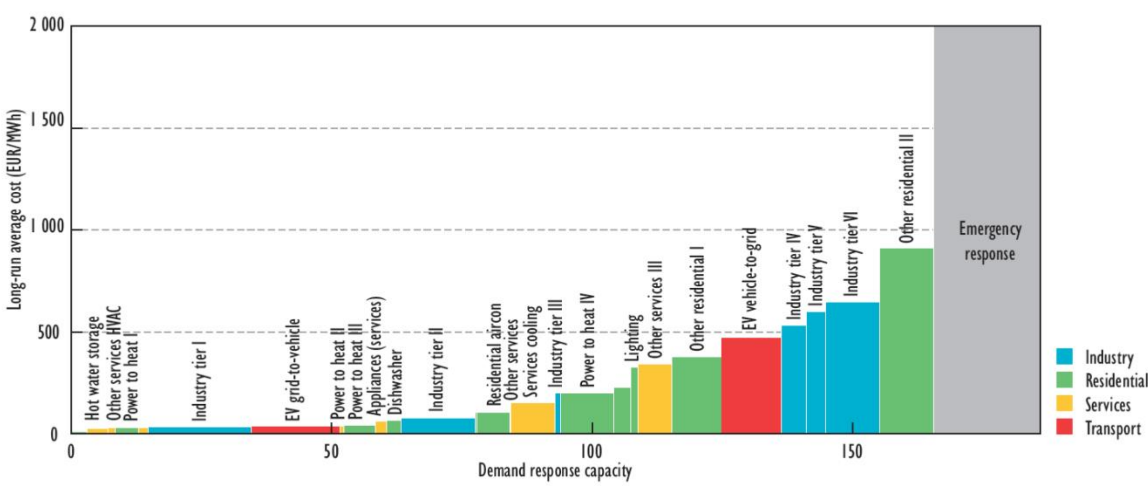


Figure 61: Modelled demand response and supply curve in the European Union in 2050 (Baritaud M., et al, 2016)

[165] In 2015 worldwide FC shipment was just over 60000 units (around 300 MW), which represents an still very small market.

11.4.1 Iberia (Spain & Portugal)

Herewith we include the main specific results for Iberia obtained in (SEDC, 2017).

11.4.1.1 Portugal

The electricity market in Portugal is characterised by a high generation capacity margin. Beyond that, telemetering of customers with a contracted power above 41.4 kW and the existence of the interruptibility service for consumers with contracted power above 4 MW, makes DR participation in the ancillary services market less appealing to market actors. However, the regulator is currently carrying out a review of the regulatory context that among other goals will aim to give greater visibility to the possibility of DR participation in the ancillary services market.

DR has not been defined in Portuguese law[166]. Hence, currently DR does not have access to either the balancing market or the ancillary services.

The interruptible contracts programme does not allow aggregation and is limited to large industrial consumers, connected to the HV grid. It represents an available capacity of 2.000 MW of demand reduction in peak hours. Industrial energy consumers involved in this scheme are construction industries (steel, concrete, glass, etc.), or other material factories (paper, chemistry, etc.).

Only generators with a production unit of at least 50 MW, can participate as a seller in the wholesale market. Flexibility resources can participate in the spot market, through demand bids with indication of price.

The capacity mechanism allows for the participation of generation units only, providing both availability and utilisation payments.

In Portugal there are no DSO driven DR programs.

The role of independent Demand Response aggregators is not defined in Portugal and there is no regulatory framework describing roles and responsibilities, access rights and all other technical modalities required for creating a clear path for consumer participation. A BRP/retailer may include consumers within their portfolio; however, there seems to be little interest from the retailers present in the market. This may partially be due to a large amount of capacity and the capped electricity prices, which slow market development.

No rules are in place regarding baselining, measurement, pre-qualification and payment of Demand Response.

---

[166] *As a first step, Portugal is incorporating storage from pumped hydro plants in the balancing market, which might pave the way for DR.*

11.4.1.2 Spain

Today, Spain relies mostly on hydro and gas for its flexibility needs.

While Spain is the first country in the world where the default price for households is based hourly spot prices and could thus drive important progress for Implicit Demand Response, and even though some smart grid pilot projects are in place, the development of Explicit Demand Response is limited to industrial consumers.

Aggregation is still not legal in the Spanish electricity system and currently there is only one scheme allowing Explicit Demand Response: The Interruptible Load programme. The scheme, which is reserved only for large consumers, is managed by the TSO. The programme acts as an emergency action, in case the system is lacking generation and there are insufficient balancing resources. Although annual tests are conducted, this programme has not been called on for several years.

Even though aggregators are not recognised in Spain, the role of “representatives” exists, which sell energy in the name of their “representees” and build balancing perimeters, thus minimising deviations from programme and resulting penalties. It is believed that the TSO and relevant stakeholders have started conversations for the future opening of these services to flexible demand.

While some of the markets are open for DR in principle (Tertiary Control, Technical Constraints, Real-Time Constraints, Capacity Mechanism), in practice this applies only for large industrial consumers. Aggregated Demand Response is allowed only for Tertiary Control.

Currently, aggregated Demand Response does not have access to the balancing market, nor to ancillary services. However, in 2015 a new regulation allowing the participation of generation based renewables in balancing markets was approved. As such, since 2016, decentralised and renewable energy resources (in particular wind generators) have been able to prequalify and participate in the tertiary reserve which is an important development in paving the way for aggregated Demand Response to participate in this market.

In 2015 and 2016 around 3 GW of interruptible load contracts were assigned through auctions. Depending on the notification time (from zero to two hours) and duration of the interruption (from one to twelve hours), there are five different types of contract. Interruptions can take place for up to 240 hours a year, with a maximum of one interruption per day and five per week.

Only generators, with a production unit of at least 50 MW, can participate as a seller in the wholesale market. Flexibility resources can participate in the spot market, through demand bids with indication of price.

The capacity mechanism allows for the participation of generation units only, providing both availability and utilisation payments.

Demand-side flexibility could represent an important tool for local congestion management. If needed, DSOs have the possibility to request from the TSO to call the use of the interruptibility service or as for redispatching and curtailment of generators. Furthermore, at DSO level, some pilot projects are on-going at city level, such as “Smart City Project” in Malaga, and the “Barcelona Smart City”.

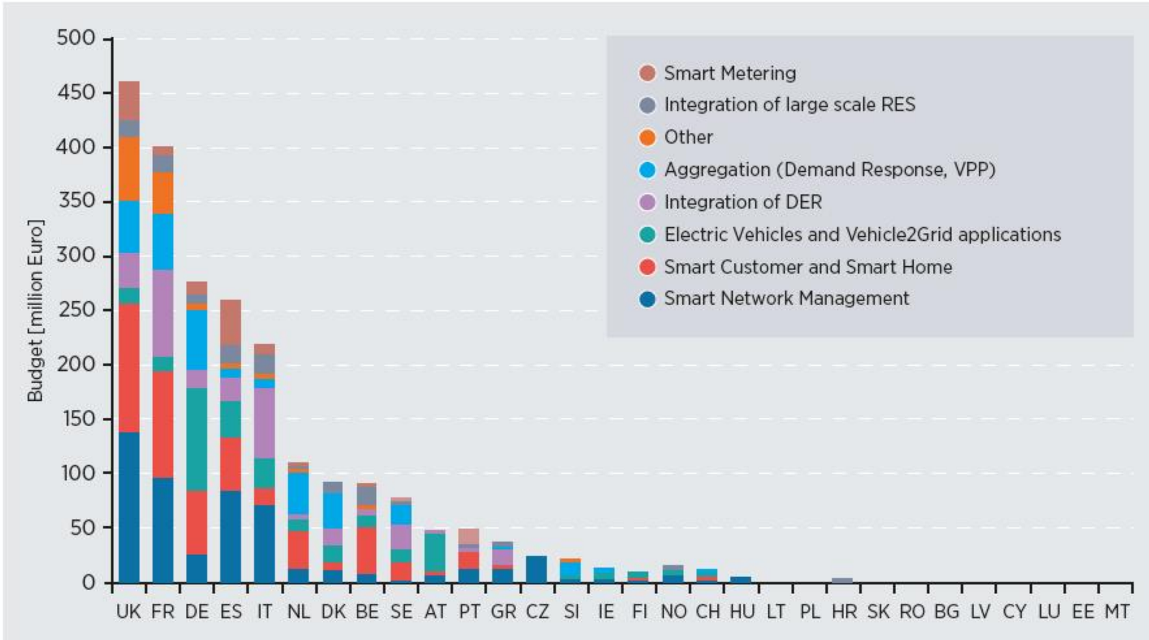
The current regulatory regime poses limited opportunities for Explicit Demand Response offerings in congestion management.

Overall, there is no possibility for aggregated demand-side resources to take part in the Spanish electricity market. There are no standards at the moment defining their relationship with the BRP and the TSO.

Aggregated DR does not have access to the balancing markets. Only consumers with contracted power above 5 MW have access to interruptible demand service managed by the TSO. There is no involvement of aggregation in the interruptible contracts programme, it is limited to large industrial consumers, connected to the HV grid.

11.5 Smart Grid & smartness

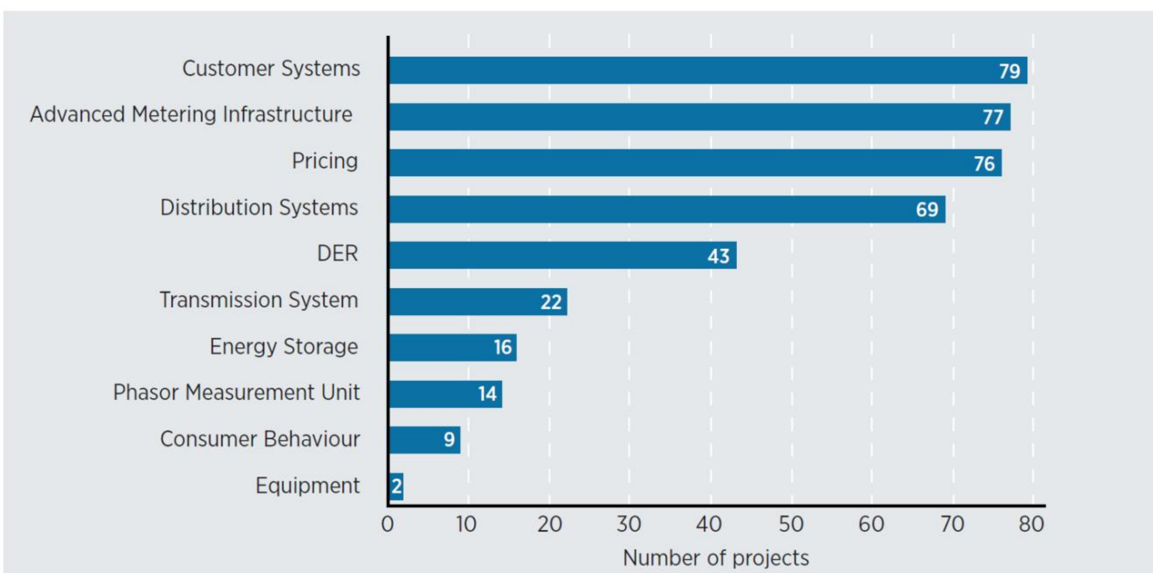
As the conventional centralised power grid transitions towards a decentralised smart grid, the physical infrastructure will be replaced with a digital (or ‘virtual’) infrastructure. The smart grid will use two-way flows of electricity and information to create an automated and advanced distributed energy infrastructure. One of the main purposes of the smart grid will be to allow real time information to be received and sent to and from various parts of the grid to make the control as efficient as possible. The aim of smart grids is to improve energy efficiency, demand profile, utility, and reduce costs and emissions (Lajgaard Pedersen M., Karentius Freund M.S., 2017).



Source: Adapted from JRC, 2014

5. http://ec.europa.eu/energy/en/topics/markets-and-consumers/smart-grids-and-meters/smart-grids-task-force.
6. http://www.gridwise.org/index.asp.
7. http://indiasmartgrid.org/.
8. http://iea-isgan.org/.

Figure 62: Distribution of budget per country and smart grid application in Europe, considering only demonstration and deployment projects (Pérez-Arriaga I., et al, 2017)



Source: Based on Smartgrid, 2017

Figure 63: Categorisation of US smart grid demonstration projects per type (Pérez-Arriaga I., et al, 2017)

But system smartness goes well beyond the grid itself.

Buildings have a pivotal role in the articulation of SECs. Smart buildings can play a leading role in transforming the energy market, by transforming it into a more decentralised, RES-based, interconnected and variable system that maximises efficiency and ensures that all resources are used in an optimal way, while at the same time enabling a better living and working environment for the occupants.

The building stock and energy system are at the initial stages of a journey towards becoming smart: moving from a centralised, FF-based and highly-energy-consuming system towards one that is more efficient, decentralised, consumer-focused and powered by RES. For the building stock to effectively contribute to the global climate target, the built environment must undergo a deep transformation and become both smart and efficient, which requires a change of mind-set to recognise buildings as an integral part of the energy infrastructure and make the full use of their wide-ranging abilities. In the European context (De Groote M., et. al, 2017) assesses the extent to which Member States across Europe are ready for the transition to a highly efficient and smart building stock by assessing how smart-ready the wider built environment is, understanding by a smart-ready built environment one that incentivises the building stock to become smarter and where citizens and businesses are empowered by the control of their own energy system, producing, storing, managing and consuming energy – whether passively or actively. For this purpose, twelve characteristics (Figure **64**) from the building stock are evaluated through fifteen[167] indicators and combined into a single smart built environment indicator. Figure **65** shows the result of this evaluation, with a clear NO as an answer to the question of whether European countries are ready for smart buildings. The aggregated smart built environment indicator result ranges from 1.13 (Cyprus) to 2.92 (Sweden) out of 5: No country is fully ready to take advantage of the benefits the smart revolution will entail, including greener, healthier and more flexible energy use.

[167] Three of the 12 characteristics are evaluated trough two different indicators: Building energy performance (Building envelope performance & Final energy consumption); Efficient heating & cooling capacity (HPs & DH); Dynamic energy market (Dynamic pricing & Flexible market).

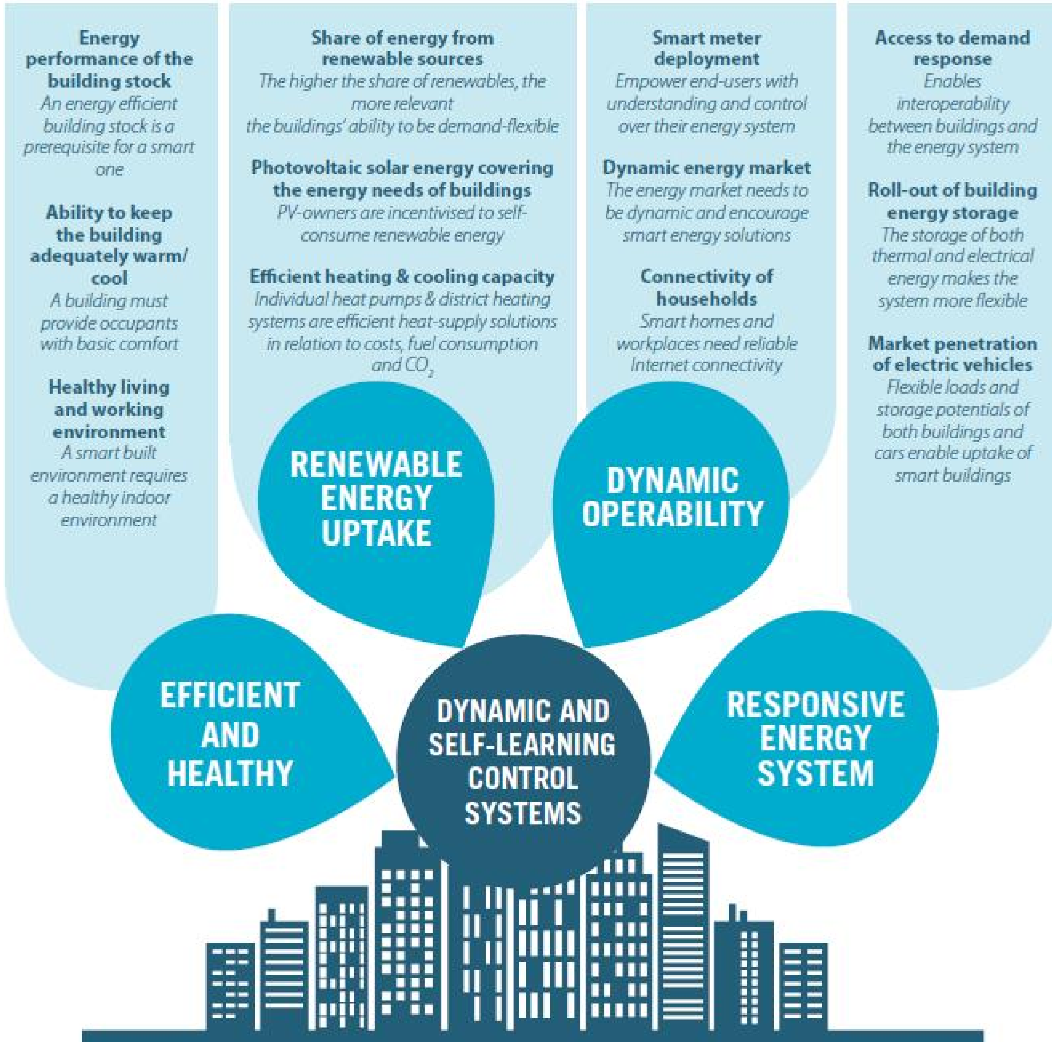


Figure 64: Characteristics of a smart built environment used by BPIE to evaluate the smart-readiness level of the building stock (De Groote M., et. al, 2017).

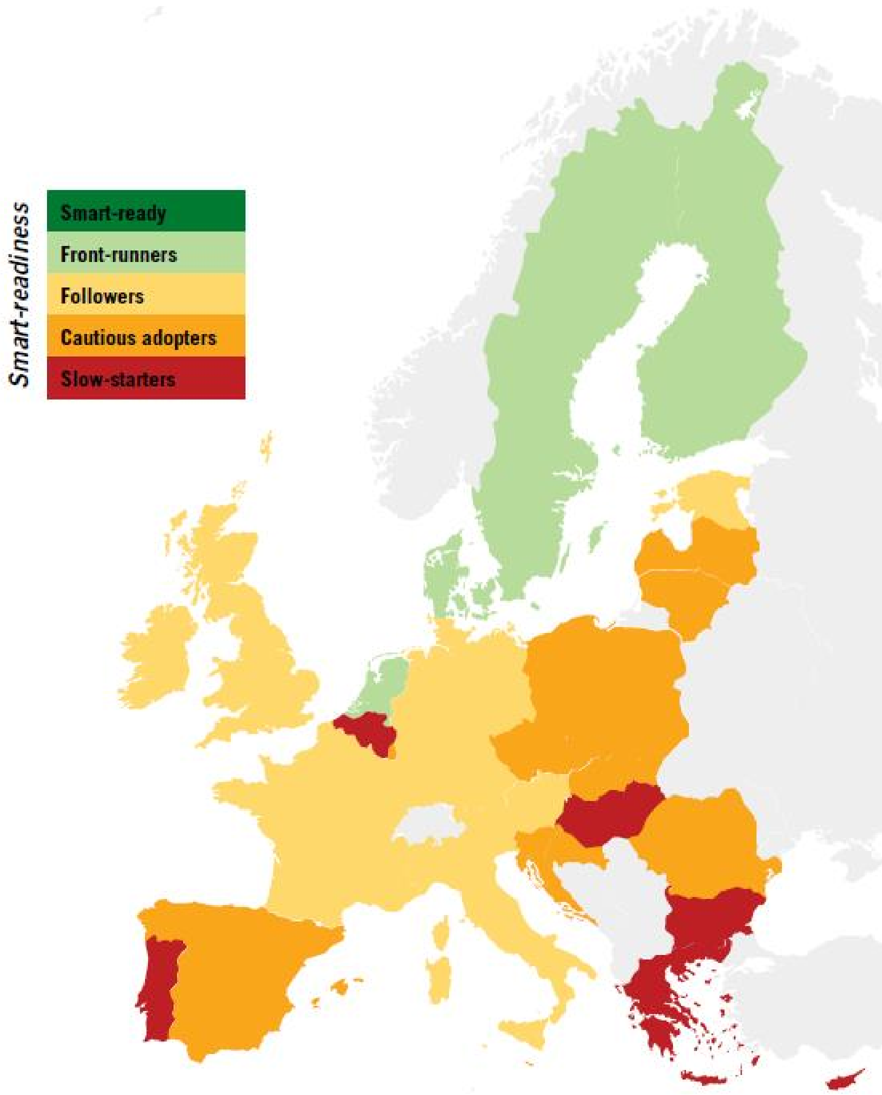


Figure 65: Smart-readiness of buildings across Europe (De Groote M., et. al, 2017).

11.6 Services for SECs

11.6.1 SEC audit

In the SEC context there is room to offer different kinds of audits, to the overall community or to individual elements from this community (residential and tertiary buildings, businesses operating within the community,…). Some of these audits are more conventional, like the ones addressed to evaluate the EE potential or power invoice optimization, but other are more novel services directly associated to the SEC concept. Several of the fields where audits could be offered are:

- EE potential and deployment.
- Reducing electricity costs by adapting consumption to electricity tariff.
- Developing local roadmaps for a gradual transition of the community towards a SEC.
- Evaluating flexibility potential and depending on its characteristics articulating it through the different available market options to generate income (primary, secondary or tertiary frequency control, operating reserves, other ancillary services).