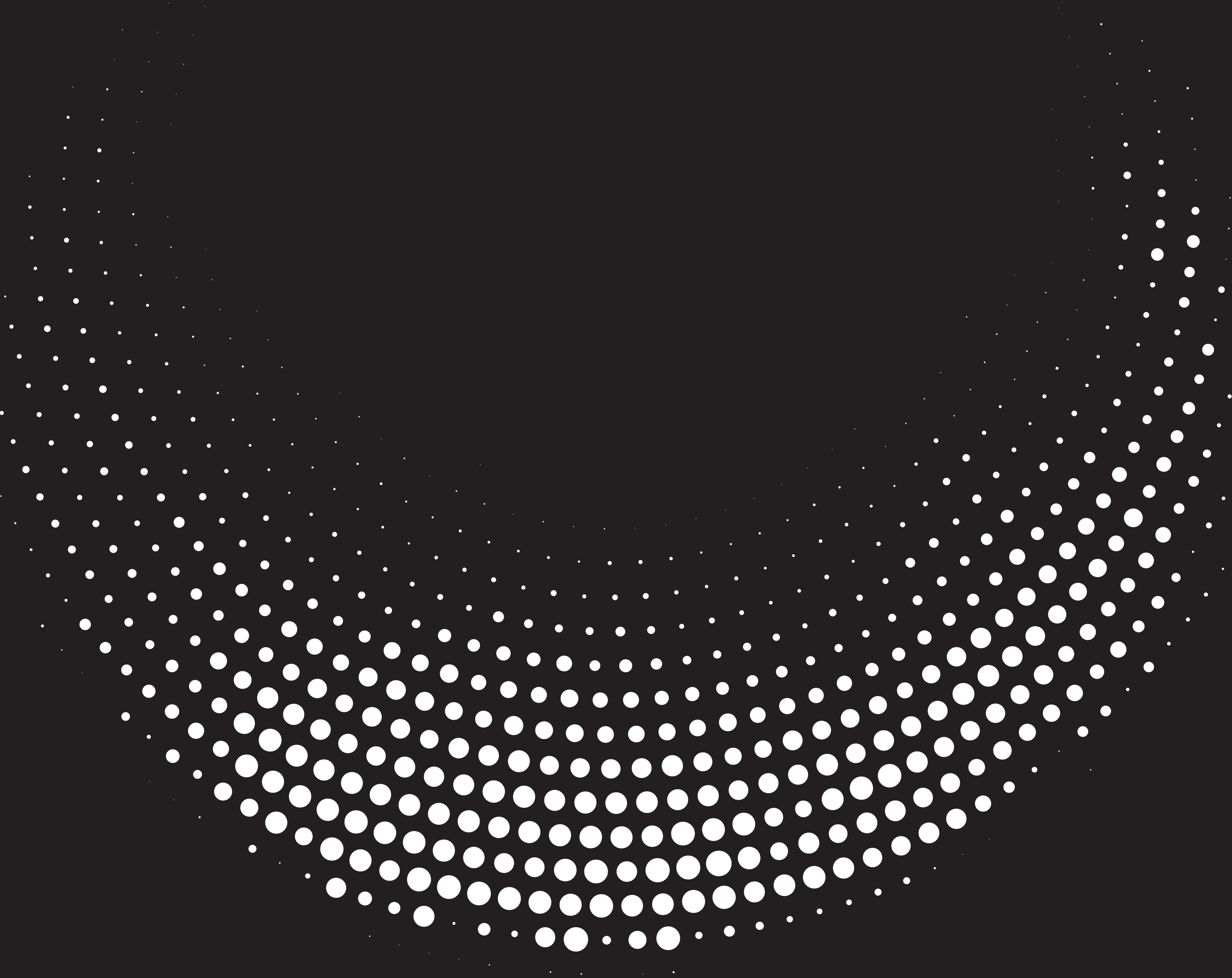


ENVIEW

How collective mobilization, supported
by AIoT technologies, can ensure that:

“GREEN FUELS GROWTH”

EDITION 1: Flexible grids for a Net Zero Carbon future

Envision
digital

Table of CONTENT

TOPIC BOXES

Table of FIGURES

WHAT IS ENVIEW?

EnView reflects the point of view of Envision Digital on strategic questions related to our area of expertise: decarbonization and full efficiency (“no-human-touch” “machine-to-machine” optimization).

Envision’s mission focuses on solving the sustainability challenge for mankind. We are convinced that this challenge is vital and urgent but that it can be addressed by the right aligned efforts of all parties (top-down and bottom-up, public and private, corporations and individuals) and by technological innovation, both urgently implemented, with no further ado. With the right technology-enabled set of aligned actions, not only can we reconcile “green” and “growth” but we can indeed enable “green” to feed “growth”.

This edition of EnView is dedicated to Smart Grids and electricity transmission and distribution challenges in an era of growing renewable electricity and electrification of usages.

EXECUTIVE SUMMARY

The sanitary and economic crisis triggered by Covid-19 pandemic rightly-so attracted all attention of governments, corporations and citizens over the last months. However, the sustainability challenge has not gone away.

The extreme slowdown of economic activities during Covid-19 deepest crisis only bended down emissions by less than 20%, demonstrating that Malthusianism would not be the way out.

But Covid-19 also came with its load of valuable learnings: only general aligned mobilization of Public Powers, Economic Players and Individuals, combined with technology innovation, could address a problem of this magnitude.

Coming back to Global Warming, containing expected temperature increase below 1.5 to 2° Celsius below pre-industrial levels, as per the targets of Paris Agreement, requires a similar urgent and general mobilization.

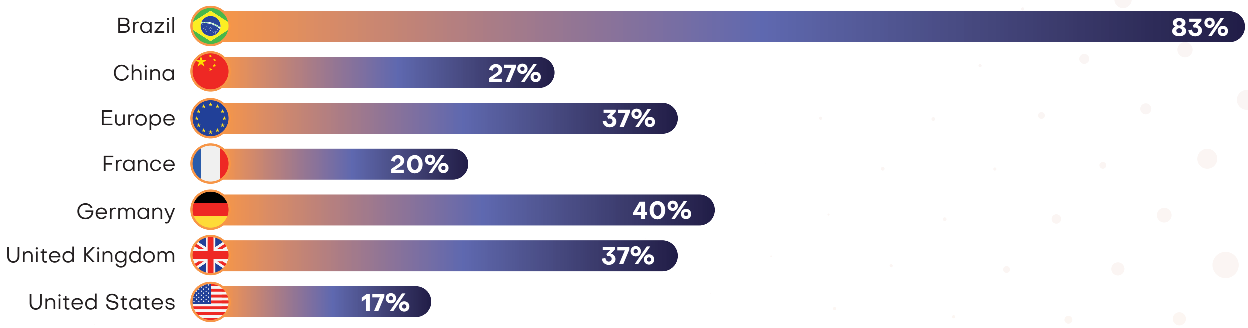
> **Envision's mission, at the heart of all activities of the Group, is to solve *sustainability challenge for mankind*. We deeply believe in three core principles: all parties must get into actions in a concerted and converging way, sustainability is a systemic issue requiring systemic resolution and technology innovation has a central role to play.**

EnView expresses the point of view of Envision Digital's Global Center of Excellence for "Smart Grids and Vehicle-to-Grid" (located in Paris, France) on critical challenges and opportunities of our century. This first edition is dedicated to the flexibility challenge and the ways to address it.

Electrification is a major step towards a more sustainable economy and significant measures have been taken to enable and foster electro-mobility or electric heating. However, this only makes sense if electricity itself is not only decarbonized but renewable. Renewable electricity is not only eco-friendly: its cost also follows the "Moore's Law" of technology, unlike fossil fuels' cost. Oil and gas' costs are following market laws and subjects to exploration and production decisions of majors, diplomatic negotiations between petroleum exporting countries as well as other forms of speculation. To the contrary, the cost of wind and solar energy constantly goes down, year after year (8% per year and 18% per year for the respective Levelized Costs of Energy for Wind and Solar between 2010 and 2019). It means renewables are on a journey to provide more and more affordable electricity to the many, critically enabling global sustainable development.

Significant investment programs and stimuli are already identified to commission more wind and solar capacities. However, most of renewables are intermittent as they depend on natural forces and meteorological goodwill. It means an unprogrammable quantity of renewables electricity will be injected into the power grids, in the same time as an undocumented consumption pattern materializes from new usages such as electro-mobility. In addition, generation, which used to be centralized, is now increasingly distributed: companies and individuals produce electricity via local solar panels or small wind turbines, meeting their needs as well as injecting into the power grids.

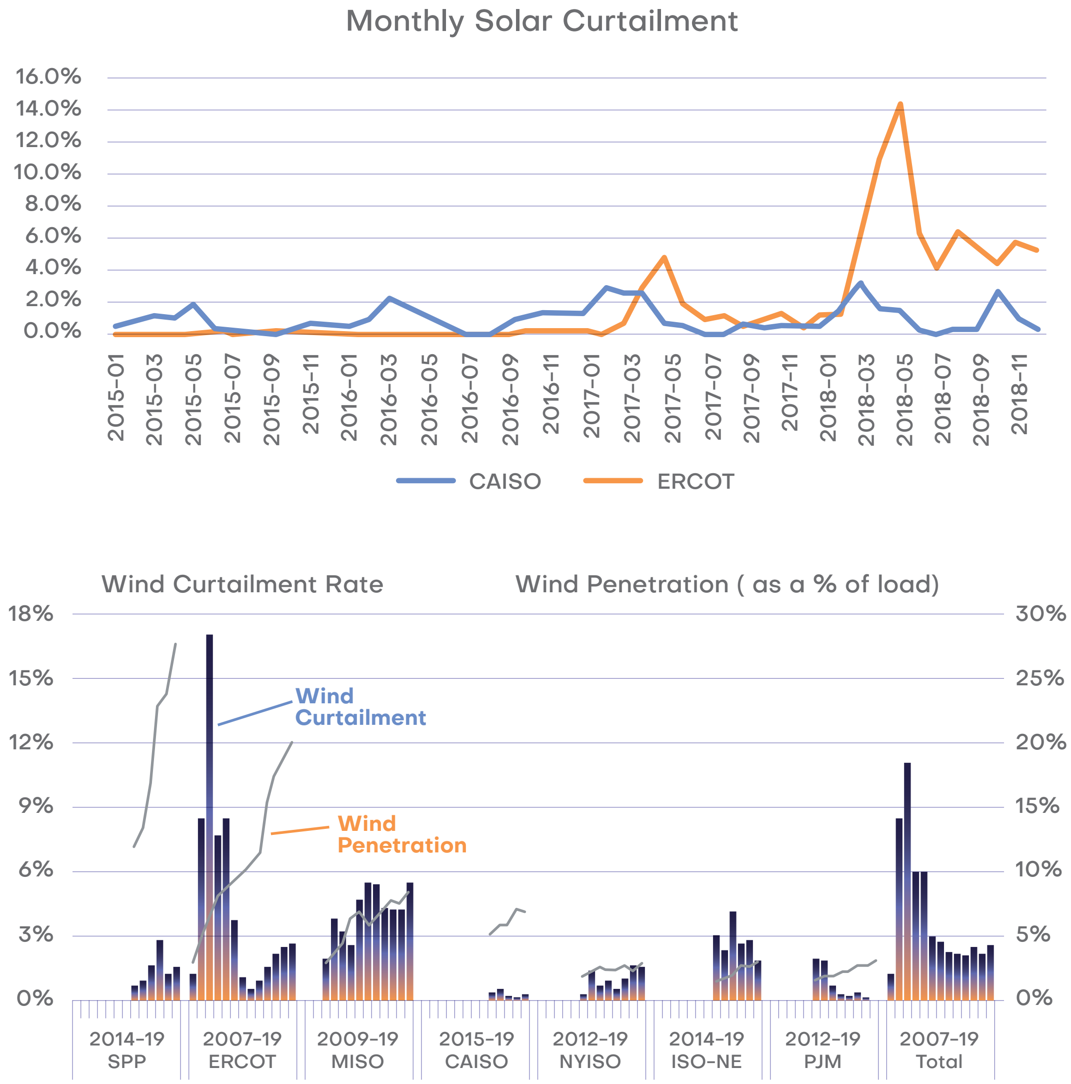
Share of renewable energy generation by country



Source: ourworldindata.org – 2019 generation

In the absence of evolution of both the transmission and distribution grids, we will face a situation by which renewables generation, renewables' share in the overall electricity mix and adoption of electric vehicles will be heavily constrained and limited. Countries which most broadly adopted renewables already faced some of those challenges during Covid-19 crisis, when demand plummeted, controllable traditional electricity generation sources were consequently shutdown, leading to a challengingly high proportion of renewables in the overall mix. Electricity prices turned negative certain days (producers were penalized for injecting electricity into the grid) and situations of "quasi blackout" were witnessed. Similar issues occur at local level. The increasing adoption of electric vehicle or the local production of solar energy by personal or corporate solar roof-tops reach the limits of the local grids or the local substations. Bottlenecks appear, here and there, at macro and micro levels.

Fig 1: **Wind and solar curtailment value for the US Market**

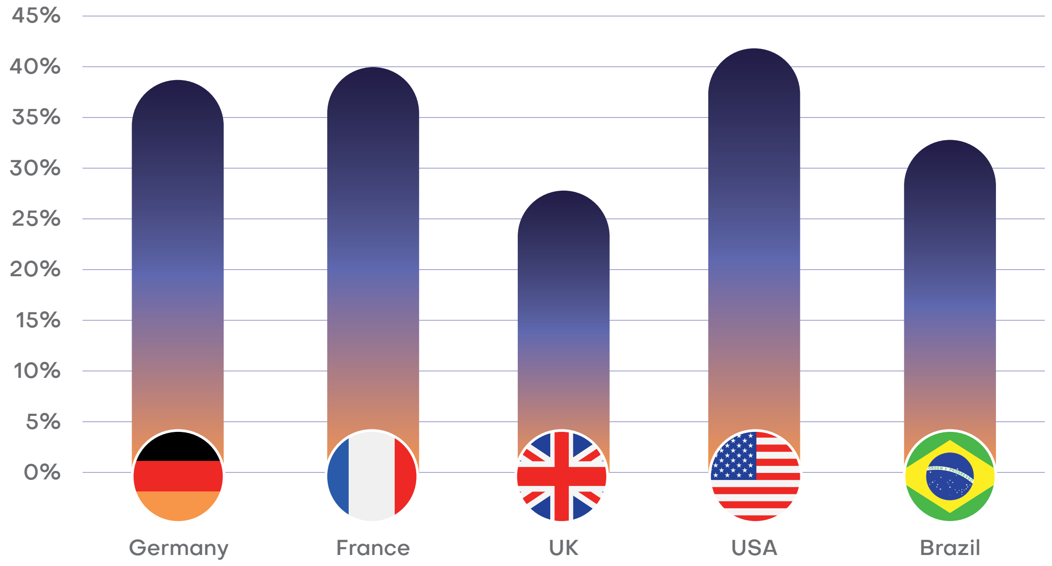


Note: In US, RE have a merit order inferior to traditional electricity production methods that induce frequent curtailment of both wind and solar energy plant. This curtailment represents a consequent loss of revenue. In continental Europe, on the contrary, DRE comes first in merit order, generating high disturbances in case of high production day as other production sources as not as responsive (e.g. nuclear). Those two different problems still advocate for the same solution which is to increase drastically electrical storage availability on the network in order to balance out production and retrieve revenue loss.

Source: US regional TSOs

If “old recipes” are applied, new high tension and low tension lines should be invested which represents not only billions of investments (TenneT alone plans to inject €35 billion over the next 10 years to increase the capacity of its German and Dutch networks), but also environmental impacts (be it buried or air lines) and, last but not least, significant implementation cycle times due to social and technical complexity to structure such capacity expansions. Moreover, the overall economic model of “pumped-up” grid is questionable. Today, grid costs represent up to 40% of consumers’ electricity bill in many countries.

Fig 2: Transmission and Distribution costs* components in selected countries – % over final households bill



**Refers to direct costs of transmission and distribution as well as taxes related to renewable subsidies*

Note: In US, France and Germany, T&D costs represent on average 40%* of household electricity bills, this is inflated by taxes related to renewable subsidies. If no smart solution is implemented to support grid balancing, traditional network maintenance and expansion costs could even increase this percentage, pushing electricity prices higher.

Source: Florence School of Regulation, Trinomics, ENTSO-E

The regions which are experiencing the highest percentage of self-consumption of decentral-produced electricity struggle to collect the grid remuneration. Grids can end up being comparable to huge highways, over-sized to cope with rush hours, and that less and less people use, leading to inflationist tolls for the fewer remaining drivers.

Electricity storage solutions (lithium-ion batteries, which cost is also falling according to a “Moore‘s Law” effect, or hydrogen, not mature yet when it comes to economically avoid curtailing the production of renewable electricity) can create “buffers” between generation and injection of wind and solar electricity into the grid, creating some degree of “controllability”.

However, the only convincing way out of these challenges is to introduce proper financial incentives and suitable market mechanisms to foster “virtual grids” and “virtual power plants” ie to ensure some adaptation of demand, storage and supply will be triggered to avoid shocks on the grid and to find more ecological and economical balancing solutions.

For example, the ‘substation of the future’, digitally enabled and eco-friendly, for advanced control and automation of power systems, will be key to balance regional and decentralized power supply, storage and demand. The share of Artificial Intelligence and Internet of Thing (AIoT) and operational control systems, run by highly skilled operations teams (all associated costs mostly sitting in the OPEX category) will be much higher than in the traditional CAPEX-heavy solutions (ie investments in transmission and transformers physical assets). However, what most grid regulatory environments cope with, to date, is physical CAPEX, excluding “smart” mechanisms supported by AIoT optimization.

We would summarize our recommended way out by: “more fiber, less coper”. This would mean a pervasive use of “smart” technologies to create and unlock new sources of flexibility. The combination of Artificial Intelligence and Internet of Thing allows to gather information about demand and supply but also weather and historical patterns, to better model and predict future balance challenges and, finally, to anticipate, schedule and execute smoothing actions. Such action can consist in differing peak loads (e.g. smartly scheduling the time of charging of an electric car, knowing cars sit idle 95% of the time) or orchestrating smart storage to retain and reinject electricity timely. Grids have been smart for many years already, but they were designed to handle different configurations (top-down centralized and controllable generation, no decentralized generation and no prosuming, no massive electro-mobility). So, in order to address the “new normal”, full use of available devices and data (in respect with GDPR[1] and other data privacy expectations) is needed, combined with relevant incentives and rewards and supported by multi-dimensional investment programs. In the lack of proper coordination of all those dimensions by the Public Powers and the regulators, we may end up with a “zero paper” effect : we stopped printing pages to create the next challenge in congesting massive data centers with stored emails!

With the right systemic design and implementation, technology can reconcile “green” and “growth” and our core belief is even that, thanks to ongoing innovation’s adoption, “**green can feed growth**”.

SYLVIE OUZIEL
International President
Envision Digital

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[1] GDPR: General Data Protection Regulation

INTRODUCTION

The Paris Agreement adopted in 2015 has set the goal to reduce Greenhouse Gas (GHG) emissions in order to contain global average temperature increase, in 2050, below 2°C above pre-industrial levels.

To reach this goal, all sectors must limit GHG emissions to the minimum in production, consumption and transportation segments of their value chain. To that extend, decarbonization of electricity becomes critical.

The growth of renewable electricity generation into the overall electricity mix has been spectacular in the past 20 years. More specifically, the share of intermittent renewable electricity (i.e. excluding hydro power) in global electricity generation increased from 1% in 2000 to 11% in 2019. In the IEA Sustainable Development Scenario[2], intermittent electricity share should reach 30% in 2030[3].

The cost of electricity generation from wind (onshore and offshore) and solar (photovoltaics) has significantly decreased over the past years:

1 **The LCOE[4] of onshore wind has fallen by 8% per year since 2010 to be within a range of $38 to$107/MWh worldwide in 2019;**

2 **The LCOE of offshore wind reached a range $88 to $157/MWh worldwide in 2019;**

3 **Even more impressively, the LCOE of solar decreased by 18% per year to reach a range of $52 to $190/MWh[5] worldwide in 2019. In certain very sunny regions and with improved technologies (bifacial cells) it could be as low as $13,5/MWh[6].**

As the share of those intermittent energy sources grows, it becomes critical to be able to store produced electricity as it may not be immediately needed at the time of production, when the sun shines or the wind blows! Similarly to the observed trend in electricity generation, the cost of battery storage also fell by 87% over the last 10 years to reach an average of $156/kwh[7].

Overall, if one does not consider the additional costs incurred by the grid[8], onshore wind and solar are already quite competitive with other sources of electricity generation such as the existing nuclear reactors[9] and one can expect that the “Moore’s Law” effect will push further down the costs of generation and storage in the coming years thanks to scale effects, learning effect and continuous technology innovation.

The fundamentals of renewables’ economics are of intrinsic interest. The price of fossil fuels reflects market dynamic and the sharp drop in oil price in early 2020 was mainly driven by the fall in demand due to the Covid-19 combined with the standoff between Saudi Arabia and Russia with the latter refusing to cut its production. To the contrary, the price of wind, solar and storage decreases in a predictable and continuous manner following the “Moore’s Law” effect, with no impact from major geopolitical shocks. The various subsidy systems can distort the price curve, particularly as States seek to support early stage of renewables’ entry into a particular market, but the underlying trends are clear and supported by abundant technological and economic evidence. When coal, oil and gas are natural resources which prices fluctuate depending on demand and supply, wind and sun are infinite resources, transformed into electricity via a fundamentally technological process. Wind and

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[2] The Sustainable Development Scenario is an approach developed by the International Energy Agency that allows to meet the Paris Agreement

[3] https://www.iea.org/reports/renewable-power

[4] LCOE: Levelized Cost Of Electricity is the total cost of building and operating a facility over its lifetime

[5] Renewable power generation costs 2019, IRENA

[6] https://www.pv-tech.org/news/ewec-confirms-edf-jinkopower-masdar-among-winners-in-abu-dhabis-world-record

[7] https://www.greencarreports.com/news/1126308_electric-car-battery-prices-dropped-13-in-2019-will-reach-100-kwh-in-2023#:~:text=2019%20 84%20 Comment

[8] These additional costs are highly dependent on the design of the networks and the share of renewables; the average cost is 30%

[9] The LCOE of nuclear in France is around €60/MWh

solar energies follow similar laws to electronic chips rather than the natural resources market laws influenced by OPEC decision together with shocks on demand.

A total of 125 countries signed the Paris Agreement, committing to reduce their GHG emissions.

The European Union preceded this movement and, as early as 2007, pledged to reduce its GHG emissions by 20% (target to be reached by 2020) and by 40% in 2030. Its Member States have launched energy transition plans to decommission their fossil fuel power plants, especially coal power plants. Germany will shut down all its coal-fired power plants (around 40 GW) by 2038, with a capacity shutdown of 12.5 GW in 2022 and an additional 17 GW before 2030.

Without clear alignment between the two approaches, these plans also demand to limit the share of nuclear energy in the total energy production mix, even if the latter is a schedulable and carbon-free source electricity source.

Other countries like Germany have decided to shut down prematurely their nuclear reactors[10].

From the grid balancing point of view, shutting down nuclear reactors to the benefit of solar and wind means shifting from schedulable electricity generation sources to intermittent sources. This increases the complexity to always keep production and consumption in real-time balance into and out of the power grid. New and less well statistically documented usages such as electro-mobility are adding to this real-time balance complexity that transportation and distribution grids need to cope with. Failing to maintain this real-time balance would result in power outages and blackouts which are obviously unacceptable. The ability to actually expand renewables in the mix and develop electro-mobility is therefore heavily dependent on the grid capacity to efficiently deal with the implied challenges.

In more details, several structural elements have significant impacts on the grid.

Electric Vehicles (EVs) batteries charging is creating a significant demand shock into the system for three reasons. First, EV batteries are more “power greedy” than classic household or office appliances. They require strong power call (e.g. 10 or 20 kVAs even for slow charging) when the most “greedy” appliances of the home only require around 3kVA for an electrical oven, or 4 to 8 kVA for a medium size flat heating or cooling. Second challenge sits with EVs fast charging which can go as high as 60 kVA. Third and not least, EVs tend to charge simultaneously: on a high way station on the way for the weekends or the holidays, at 7 p.m. when everyone comes back at home and also turns on the house’s appliances or at 9 a.m. when everyone arrives at the office, creating simultaneous significant shocks. Simply increasing the capacity of the transportation and distribution grids would not be ecological: it would be neither good for the environment nor economically viable. One could compare it to building a massive highway to only cope with very limited “rush hours” traffic peaks. Grid operators (Transmission and Distribution Operators, i.e. TSOs and DSOs) and all involved stakeholders (utilities, public and private charging providers, battery manufacturers, etc.) must cooperate to develop technical solutions and offer financial incentives to smooth charging patterns and make them “digestible”.

This technological transition is also unprecedented when it comes to its dynamics. Yes, the transition is firmly driven by governments and large utilities in a top-down manner, but it does require and indeed is meeting a complementary bottom-up transition, coming "from the field" (consumers and private corporations). More and more companies and individuals are taking advantage of their roofs and lands to install green generation capacities serving their own needs, taking them partly off the grid thanks to locally balanced “microgrids”, and partly exporting surplus electricity into the shared grid. Self-consumption and micro-grids that are managed autonomously (or quasi-autonomously)

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[10] All nuclear reactors will be shut down in 2022

in a district or a region are even more prominent in places which were, until now, challenging to reach and, thus, poorly supplied with electricity (such as islands). However, they are expanding more broadly with smart campuses and compounds around the world. DSOs usually end up bearing the task of managing the additional uncertainties created by sometimes very granular energy sources that they have little historical understanding and modelling of, and even less control upon.

The electricity network was historically designed for transmitting and distributing electricity from concentrated large generation centers to decentralized consumers. Traditionally, the transmission network (high voltage) feeds the distribution network. With the development of renewable energies, often connected to distribution network, the amount of reverse electricity flowing up from distribution network to transmission network is increasing, adding uncertainties to TSOs grid balancing management.

Moreover, 50 years ago, the electrical networks were national. International connections have been more recently developed in order to increase trade flows, thereby increasing the security of electricity supply. European Union's plans continue to encourage and finance these interconnections which are costly and often complex to carry out (such as the France-Spain link).

Continental European countries are reasonably well interconnected and so is the Nordic region with Nordpool. However, one cannot consider that the present network as truly one single European network: even if common management rules have been adopted by the TSOs for many years now, every network is, in reality, still managed at a national (or regional) level.

> **More recently, the crisis caused by Covid-19 has accelerated the digitalization of business operations, individual relationships and, more generally, of economies, highlighting the importance of telecommunications, information systems and data virtualization in the Cloud enabling the already emerging "anywhere trend"** (i.e. the ability to work and interact "from anywhere").

The electrical system as an essential enabler of economy's virtualization and decarbonization must provide reliable and quality electricity.

The recent Covid-19-triggered situation showed how critical electricity supply was and, in the same time, brought additional challenges to the electricity "value chain". It revealed the limits of networks' flexibility, notably in Europe, when abnormal demand patterns and notably record low demand in some places were combined with a high proportion of intermittent renewables, leading to quasi blackout situations (see Topic Box 'Covid-19 pandemic has demonstrated the insufficient level of grid flexibility'). As such trends and phenomena are here to last, it becomes urgent to take every possible measure to increase the flexibility of electrical networks.

In this "Point of View", we will review:

1. The current status and forecasted evolutions of electricity networks (mainly in Europe) and of electric vehicle adoption;
2. The current grid balancing approach and necessary changes in investments ("more fiber, less copper"), companies' and consumer's data sharing, grid services pricing as well as grid tariffs calculation methodology;
3. The changes in electricity consumption patterns as well as ways to incentivize end customers for them to participate in grid balancing activities.

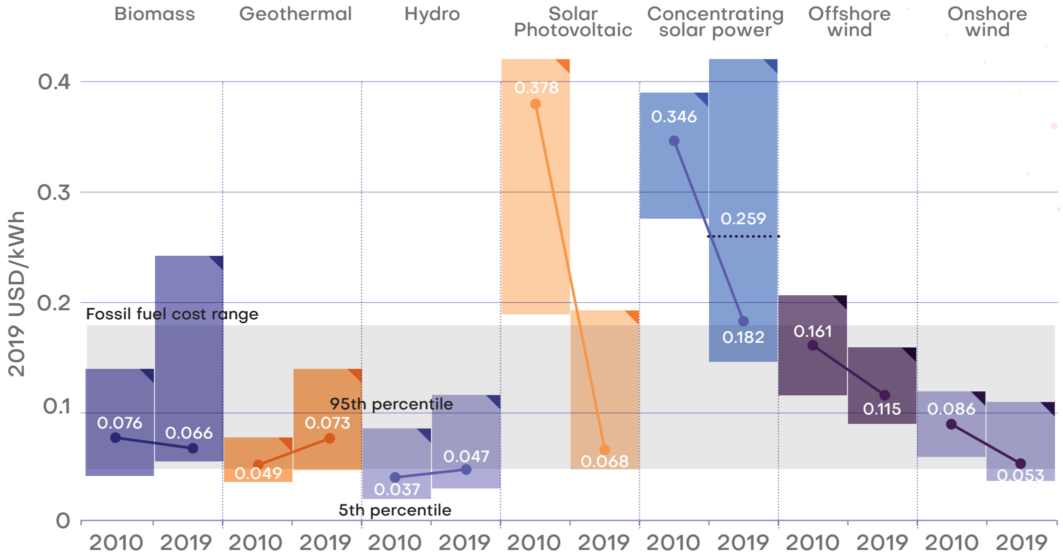
1. ENERGY TRANSITION PLANS ARE BEING IMPLEMENTED

The objective of a carbon-free economy is central to the Energy Transition laws voted in many countries or regions of European Union (EU) and is included in the post Covid-19 stimulus plans. The main components of those transition plans are: increasing solar and wind energy generation, developing storage (electrical batteries mainly), fostering clean transportation (electric vehicles for the time being complemented, in the future, by hydrogen / fuel-cell-powered transportation). These trends and the needed investments are hereafter analyzed.

1.1. Renewables generation and batteries cost decrease

Over the past decade, renewable energies costs have plummeted, driven by technological improvement, manufacturing scale and supply chain optimization. Levelized costs of electricity (LCOE) for utility-scale solar photovoltaic (PV) dropped by 82% between 2000 and 2019 and by 39% for onshore wind.

Fig 3: Global weighted average levelized cost of electricity from utility-scale renewable power generation technologies, 2010 and 2019



Note: For CSP, the dashed bar in 2019 shows the weighted average value including projects in Israel.

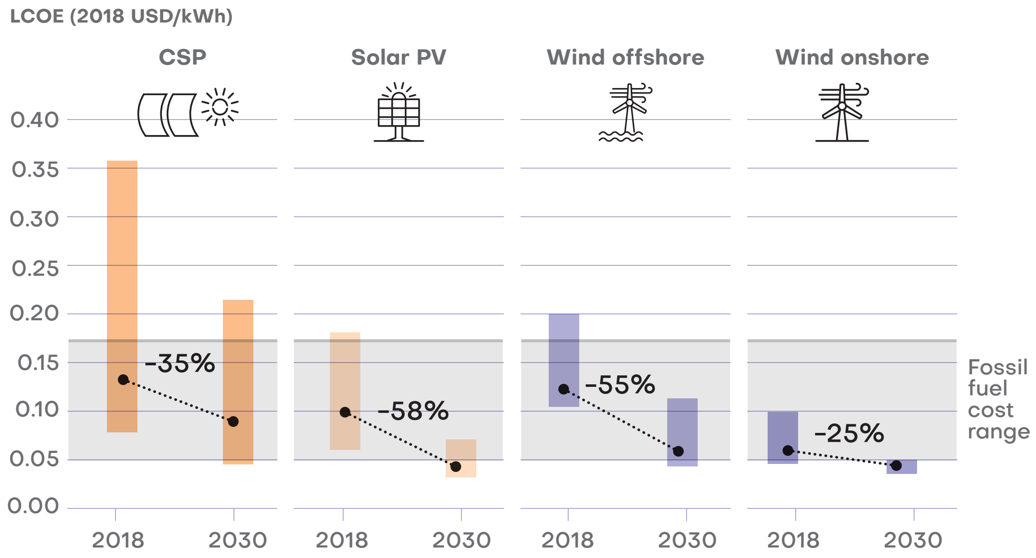
Note: This data is for the year of commissioning. The thick lines are the global weighted-average LCOE value derived from the individual plants commissioned in each year. The project-level LCOE is calculated with a real weighted average cost of capital (WACC) is 7.5% for OECD countried and China and 10% for the rest of the world. This single band represents the fossil fuel-fired power generation cost range, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

Source: Renewable power generation costs in 2019, IRENA

According to the Energy Information Administration, as a result of these impressive cost decreases wind and solar should dominate new added generation capacities in 2020 in the US. Despite the phasing out of deferral tax incentives for renewables, 42 GW of these types of capacities will be added during the year while coal and natural gas will represent the main retirements (up to 85% of plants' closures). It now makes more economic sense to build clean generation capacities than to run coal plants, and even more if one takes into account the decreasing investments in fossil fuel dependent systems.

Looking forward, it is estimated that by 2030, variable renewables energies' LCOE will continue to significantly decrease: by as much as 58% between 2018 and 2030 for solar PV (which is the technology that already saw the largest drop over the past decade) and by 55% for offshore wind (a technology that is less mature than onshore wind which LCOE is still expected to further decrease by 25% by 2030).

Fig 4: **Solar and wind power: Expected cost reductions until 2030 (LCOE development of CSP, solar PV, onshore and offshore wind technologies (G20 country averages), 2018-2030**



With a share of variable renewables energies attaining high levels and even exceeding permanently 50% of the total installed generation base – levels that have been observed in certain European countries during the Covid-19 lockdown – grid operators must adapt. Even if, during this short demanding period (March to May 2020), TSOs adapted and managed to ensure the security of supply, certain countries already almost encountered blackouts (see Topic Box 'Covid-19 pandemic has demonstrated the insufficient level of grid flexibility').

COVID-19 PANDEMIC

HAS DEMONSTRATED THE INSUFFICIENT LEVEL OF GRID FLEXIBILITY

In order to maintain the stability of the electricity grid, supply and demand must be balanced in real time. In general, maintaining such balance is difficult during the time of high demand (for example a working day during an extremely cold winter) when the means of electricity generation are insufficient in the country. The network operators will, if possible, call for the import of electricity. If the supply remains insufficient after mobilizing foreign resources, the grid operator will cut, in a targeted way, the supply to the least well-connected, and thus most challenged and fragile area in order to avoid a massive blackout.

The Covid-19 pandemic created an unprecedented situation, also from an energy point of view. The suspension of many socio-economic activities led to a sharp landing of power consumption.

In EU-28 countries, electricity demand quickly reached all-time low levels. For the period of 10 March to 10 April 2020[11], compared to the same period in 2019, the crisis translated into a 10% drop in electricity demand.

As intermittent renewable energies (wind, solar) come first in the merit order (which is, in many countries, based on variable marginal generation cost), when demand decreases, the share of electricity generated from these sources increases in the electricity mix while schedulable more traditional generation sources have to "leave the floor".

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[11] During the lock-down period

In Europe, March and April were particularly windy and sunny with high renewable electricity production from those sources. In some countries, electricity generation mix turned mainly green: 46% share of renewable generation in the mix with a simultaneous 29% drop in coal-based generation.

For example, Germany broke its renewables electricity generation records on 21 April 2020, with wind, solar and hydro accounting for 70% share of generation.

This explains why, during some weekends when consumption was very low, several fossil fuel or nuclear power plants have been shut down in Europe, generating long period of negative prices. Electricity producers who then injected energy in the network were penalized and ended up paying for injecting (via a negative price mechanism) instead of being financially rewarded for their production!

Germany, who has substantial wind and solar capacities, experienced several "quasi-blackout" in June 2019. Thanks to their central geographic location in Europe, German networks can export their surplus electricity (and import electricity during times of little wind and little sunshine). Without such interconnections, Germany would have most likely experienced blackouts.

Another case of "quasi-blackout" occurred on March 23 in the UK, which unlike Germany, has little interconnection with the rest of Europe. With a fall in electricity demand of around 20% and high generation from wind and solar, the share of renewables in electricity generation[12] increased up to 60.5%. Facing such a share of intermittent generation in its mix, British electricity network is challenged to maintain proper balance as it was designed to remain stable for a share of renewables at or below 50%.

To deal with such exceptional situation, the UK National Grid signed an agreement with the French EDF to half the electricity production of Sizewell B nuclear plant for at least six weeks.

National Grid also asked smaller wind and solar electricity producers be ready to stop their generation in exchange for compensation, and even asked to OFGEM[13] exceptional rights to unilaterally proactively disconnect these installations from the network in case such an extreme recourse would become necessary to avoid a blackout.

These "quasi-blackout" cases show that the European electricity system was not designed for and, thus, is not ready for a majority share of renewable energy such as wind and solar.

By 2030, renewables (including hydropower) should represent 55% of the total installed capacity in Europe[14]. The share of renewables will be around 50% to 60% in the UK and over 60% in Germany. These two countries, who have little hydropower resources, will mainly rely on intermittent energy (i.e. wind and solar).

The "quasi-blackout" situations during the Covid-19 crisis, as described above, prefigure what would happen in 10 years if the network adaptation measures were not taken.

Outside Europe, Mexico[15] has taken radical measures to preserve its national energy security during the Covid-19 crisis. In May and June 2020, the Mexican government rose very significantly grid connections fees for renewable power plants (up to nine-fold) and introduced restrictions on grid connections for new wind and solar power projects. The grid inflexibility has thus led to depriving the country of a carbon-free domestic electricity source and could durably imped further development of renewable capacity.

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[12] According to National Grid

[13] OFGEM is the British energy regulator

[14] Wood Mackenzie European Power & Renewables Service https://www.greentechmedia.com/articles/read/woodmac-renewables-to-supply-53-of-europes-power-by-2030

[15] Enerdata June 16, 2020

1.2. Renewables generation share increase in electricity mix

In its latest Global Renewables Outlook, IRENA develops different scenarios amongst which the "Planned Energy Scenario (PES)" based on current governments' energy plans and the "Transforming Energy Scenario (TES)", an energy transformation pathway complying with the 2015 Paris Agreement.

The share of renewables in the EU reaches 50% (including hydropower) in 2040 in the PES scenario (from a 31% share in 2017) and 55% as soon as 2030 in the TES scenario. These are levels that have been observed in several countries during the Covid-19 crisis. In a way, the crisis served as a stress test for these electricity market stakeholders who had to manage a large share of intermittent renewable energies.

Fig 5: Projected share of renewable energy in EU, in IRENA's Planned Energy Scenario and Transforming Energy Scenario

● European Union		Where we are heading			Where we need to be		
	2017	2030 (PES)	2040 (PES)	2050 (PES)	2030 (TES)	2040 (TES)	2050 (TES)
Renewables shares (modern)							
Supply (TPES)	15%	23%	28%	33%	39%	50%	71%
Consumption (TFEC)	17%	24%	30%	34%	36%	48%	70%
Power generation	31%	44%	50%	58%	55%	73%	86%

Note: TPES: Total Primary Energy Supply and TFEC: Total Final Energy Consumption

Source: IRENA

These new additional capacities will not only come from decreasing costs and continuous technology improvements (for example, bifacial solar panels or floating offshore wind getting mature, and battery storage further industrializing) but also from new corporate players taking proactive initiatives. Over 200 companies are now part of RE100, a global initiative committing companies who join it to supply 100% renewable electricity by 2050 or before. It is worth noting that in 2019, more than 50 companies joined the initiative, which marked a record.

These long-term scenarios may be revised to take into account the impact of the Covid-19 crisis. Indeed, many projects have been delayed or stopped: China, which is the main global producer of solar panels, wind turbines and batteries may not be in the position to meet all delivery deadlines and India is facing delays on 3 GW of solar and wind projects. In its 2020 Global Outlook report, the IEA estimates that new solar PV installations will decrease worldwide by 18% compared to 2019. The decrease would be 12% for wind.

In the PES scenario, investment projections indicate that, for $1 invested in renewables, $1 investment is required in power grids and systemic flexibility. The ratio differs in the TES scenario: for $1 invested in renewables ($78 billion per year in average over the 2016-2050 period), $0.72 investment is required in power grids and system flexibility ($56 billion per year in average over the 2016-2050 period).

Fig 6: **Energy system investments (average annual, 2016-50) USD billion/year**

● European Union	Where we are heading	Where we need to be
	Planned Energy Scenario 2016 - 2050 (PES)	Transforming Energy Scenario 2016 - 2050 (TES)
Energy system investments (average annual, 2016 – 50) USD billion/year		
Power	98	145
– Renewable	38	78
– Non-renewable	22	12
– Power grids and system flexibility	38	56
Industry (RE + EE)	6	8
Transport (electrification + EE)	18	32
Buildings (RE + EE)	89	130
Biofuel supply	2	5
Renewable hydrogren – electrolysers	0	0.7

Note: RE = renewable energy; EE = energy efficiency

The findings in this report consider targets and developments as of April 2019. The wind and solar PV capacities in the Transforming Energy Scenario in 2030 in this report are slightly higher than the estimates presented in IRENA's reports (IRENA, 2019b; 2019c) which consider developments as of the third quarter of 2019.

Source: IRENA

1.3. Innovative hybrid farms help to mitigate intermittency disturbance on the grid balancing

To cope with the intermittency issues of variable renewable energies such as wind or solar and to mitigate the disturbance on the grid arising from this kind of energy sources (details in part 2.2), hybrid farms combining different generation types (wind, solar, hydro) together with storage capacities have emerged.

These projects aim at benefiting from the complementary generation profiles of solar PV that produces only during the day and wind that are generally most productive during the night. For project developers, when conditions are favorable (sunny and windy location with available grid capacity), it is a way to maximize the revenue from a given amount of land and grid connection.

By maximizing revenue and reducing the burden on electrical networks, such approaches are, de facto, lowering permitting, siting, equipment, interconnection, transmission, and transaction costs per generated kWh.

> **The first hybrid farm was built in 2012 in China (100 MW of wind power, 40 MW of solar power and 36 MW of lithium-ion battery). Since then, various projects emerged around the world notably in India. Still, triggered by significant grid penalties in case of deviation between actual power generated and forecaster generation, China is expected to remain the most dynamic market for such projects over the next decades.**

In Europe, similar projects exist in Germany, the UK, Spain and the Netherlands. For example, Vattenfall commissioned a €35 million hybrid farm (22 MW wind, 38 MW solar and 12 MWh battery) in the Netherlands in September 2020.

In the US, in February 2019, utility Portland General Electric announced a hybrid plant combining 300 MW wind, 50 MW solar PV and 30 MW/120 MWh battery storage.

In theory, such projects could allow renewables to participate in capacity markets and be used during peak demand periods that would otherwise require tradition peak generation, such as gas-fired plants, to be triggered.

The global hybrid solar-wind market is expected to grow from more than $0.89 billion in 2018 to over $1.5 billion by 2025[16] (a nearly 8.5% CAGR over the seven-year period).

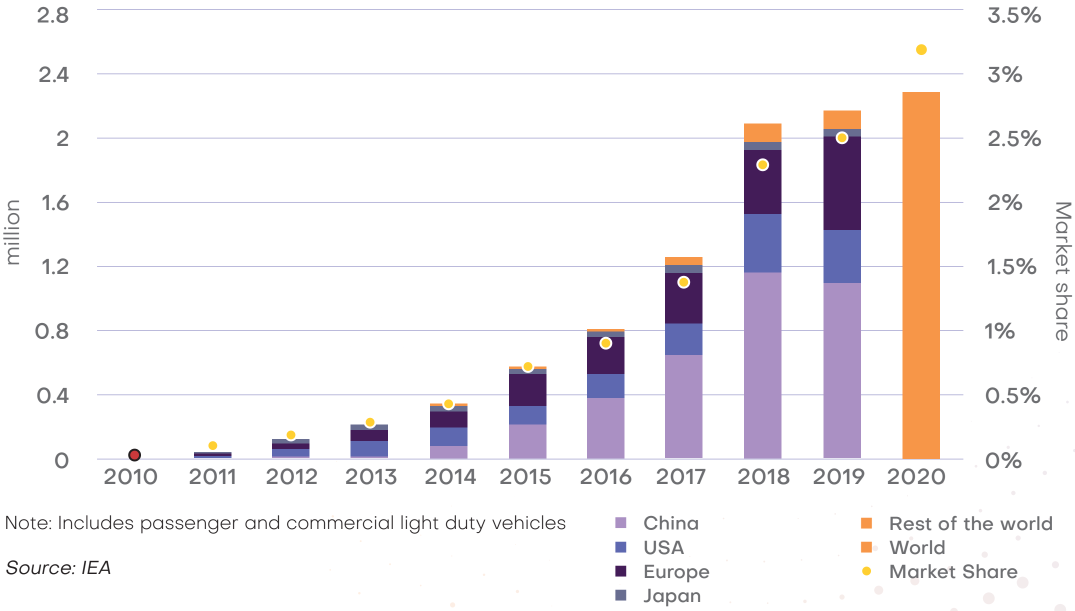
1.4. Low carbon transportation: electric vehicles are boosted by subsidies and penalties

Over the past decade, electric cars[17] developed rapidly with more than 60% global sales growth every year, thanks to incentive policies and technology progress.

While Chinese electric vehicles market is by far the largest (in 2018, Chinese EV sales amounted to 1,182,000 compared to 409,000 in Europe and 358,000 in the US), EU Regulation has set mandatory emission reduction targets for new cars. Those European targets are associated with heavy penalties for car manufacturers who would not meet them. By 2021, and phased in from 2020, the European Union demanded that all new cars must meet 95 grams of CO2 per kilometer which is 24.7 g/km less than the recorded average for the 11 manufacturers selling more than 300,000 units in 2018. From 2021, European manufacturers selling cars in Europe could have to pay an excess emissions premium around €30 billion (calculated before the Covid-19 crisis). As a direct consequence of this European penalties scheme as well as to address evolving (corporate and individual) customers' expectations, car manufacturers have already significantly electrified their new vehicle ranges and put forward attractive sales programs and incentives to decarbonize their yearly new car sales mix.

2019 was an exception in electric car development since the global electrical market contracted by 6% due to regulatory change in China and overall passenger car sales contracted in major markets. End of 2019, 7.2 million electric cars were on the roads worldwide, which represents a 2.6% market share in overall car fleet.

Fig 7: Global electric car sales by key markets, 2010-2020



Note: Includes passenger and commercial light duty vehicles

Source: IEA

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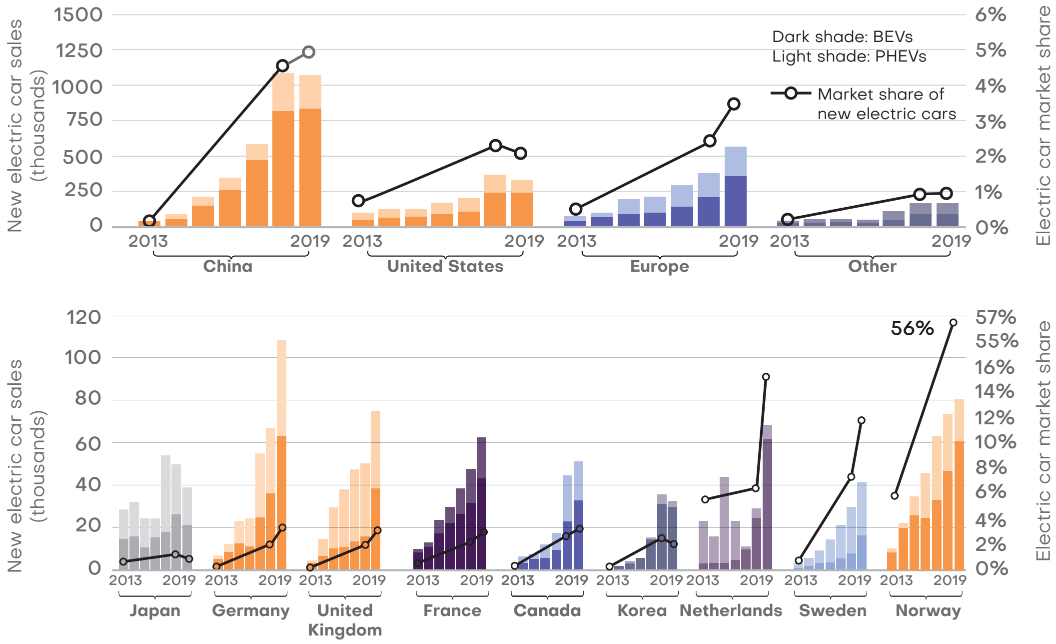
[16] Zion Market Research, 2019

[17] Electric car refers to battery electric vehicles or a plug-in hybrid electric vehicles

Fig 8: Passenger electric car sales and market share in selected countries and regions, 2013-2019

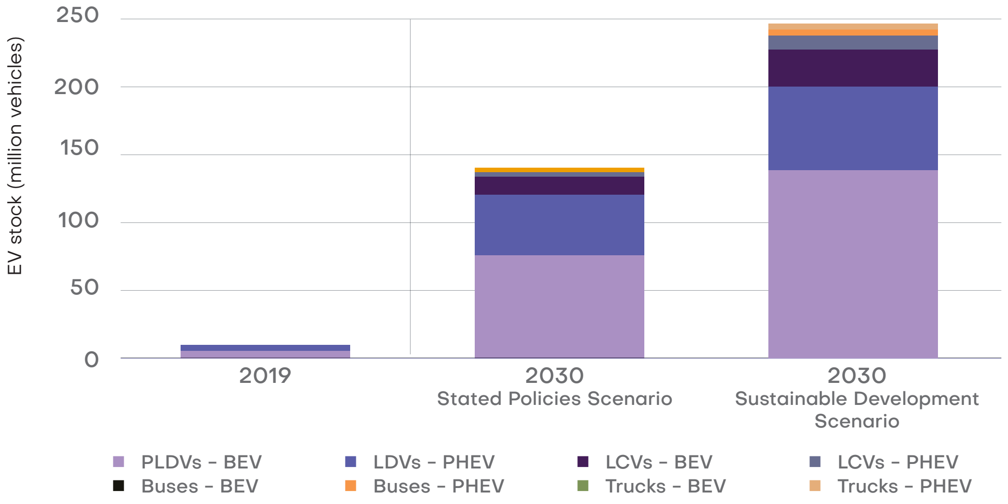


Note: Regions and countries in this figure represent the largest electric vehicle markets and are ordered by size of their conventional car market

Source: IEA

While global car (ICE[18]cars plus EVs) sales projections are pessimistic in the very short term (-17% in 2020 vs. 2019), estimations for electric cars remain on an upward trend (+9.5% in 2020 vs. 2019) in this deflating market; this would bring EVs' market share at more than 3%. In Europe, in the first quarter of 2020, registrations of electric cars jumped to 57.4% of total new cars registrations.

Fig 9: Global electric vehicle stock by scenario, 2019 and 2030



Note: PLDVs = Passenger light-duty vehicles; LCVs = light commerical vehicles; BEV = battery electric vehicles; PHEV = Plug-in hybrid electric vehicle.
Source: IEA

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[18] ICE: Internal Combustion Engine

Very voluntary policies have been adopted by 17 EU countries, which announced targets of 100% zero-emission vehicle or the phasing-out of internal combustion engine vehicles by 2050. Late 2019, France was the first country to adopt a law banning petrol and diesel by 2040.

Today, several factors encourage the purchase of electric vehicles by consumers and businesses:

1. **Technological improvements enabling longer autonomy ranges in the same time as shorter charging times;**
2. **Diversifying offerings now proposed by car manufacturers with more and more variety of models;**
3. **Policy measures such as tax reduction, fiscal incentives or subsidy schemas for installing charging infrastructures.**

In response to the huge impact of the Covid-19 crisis on the automotive sector, several governments decided to support financially their national industry, putting an emphasis on electric and hybrid cars. France, for example, unveiled a €8 billion stimulus plan for its car industry, a part of which is dedicated to boosting local manufacturing of electric and hybrid cars and incentivizing consumers towards clean models through increased government subsidies. Germany also set up measures in favor of electric cars: the country doubled the government incentive to 6,000 euros and included a temporary 3 percentage point cut to VAT for the purchase of an EV. Contrary to France who maintained a 3,000 euros government contribution for the purchase of new diesel or petrol cars providing they are cleaner that consumers' previous one, Germany refused to keep such a stimulus despite leading carmakers pleas in the hope to sell remaining combustion engine cars stocks.

While the development of cleaner vehicles is great news for a more sustainable energy system, the associated battery charging represents a new and unknown / unexperienced demand pattern that grid operators need to handle. Additional good news: EVs indeed create a new demand problem for grid operators but they can also constitute a solution by themselves. Obviously, more EVs will exacerbate the stress on the distribution grid and increase peak loads due to simultaneous charging of electric cars (in the mornings, at lunch time or the evenings) calling for the need to make investments to reinforce grids locally. However, cars are parked 95% or 96% of their lifetime and when these cars are electric ones, their batteries can provide an attractive controllable flexible load for the power system. EV batteries, when connected with smart chargers to the grid, can constitute a massive electricity storage reserve providing a broad range of services to the system such as primary and secondary power reserves, fast-frequency reserves, arbitrage, voltage control and congestion management through load shifting and peak-shaving.

Smart charging systems are essential since they could adapt charging cycles thanks to digital technologies, ensuring the best outcome for the environment, the power grid, the economic cost of charging and the EV battery life expectancy.

DSOs should align with developers of public EV charging infrastructures to build their charging stations in the most appropriate locations in order to avoid grid congestions.

Together with regulators, DSOs should launch or further strengthen existing network tariffs for smart public, corporate and domestic charging infrastructures in order to avoid grid reinforcement which would be made necessary to handle a few peak charging hours in the absence of such digitally optimized solutions.

In summary, EVs can shift from being a burden to being a symbiotic virtual power plant (shaving demand or pulling electricity from the grid at the most appropriate time to smooth the overall demand-supply profile) provided the right smart orchestrated charging solutions are deployed and the economic incentives for flexibility are in place.

TECHNICAL BREAKTHROUGH:
HYDROGEN

GREEN HYDROGEN COMPETITIVENESS:

The most common way to produce hydrogen is from fossil fuel ("grey" hydrogen) using processes releasing significant quantities of GHG. Those gases can be partially captured and retained ("blue" hydrogen). Finally, hydrogen can be produced out of electrolysis fed by renewable decarbonized electricity: this is "green" hydrogen.

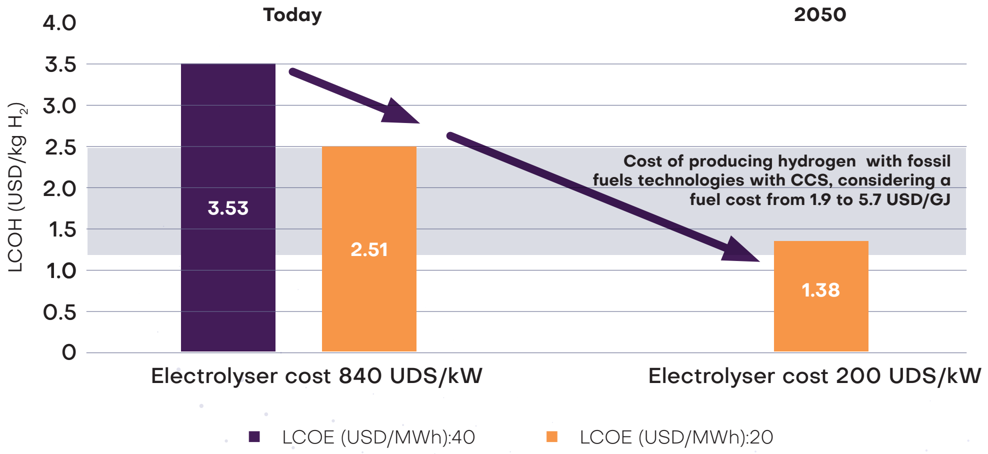
Hydrogen can be used in transportation sectors as well as an energy storage solution to provide flexibility services on the grid.

For competitiveness reasons with "grey" hydrogen, "green" hydrogen must be generally produced at less than $2.5 per kilogram (kg), but this value also depends on whether production is centralized or decentralized[19].

In 2019, "green" hydrogen produced from electricity was around three times more expensive than the one produced with natural gas, but the costs of solar and wind electricity have decreased in recent years. As they continue to further decrease, "green" hydrogen production and usages will develop.

In a similar way to renewable electricity costs, electrolyzers' costs (CAPEX and OPEX) are decreasing. Simulations show that with an electrolysis cost at $200/MW[20](which are already achieved in some projects in China) and low renewable origin electricity cost at $20/MWh, LCOH[21] are lowered to around $1.4/kg H2 compared with cost of producing "grey" hydrogen with fossil fuels technologies with CCS[22], at $1.3/kg H2 to $2.5/kg H2.

Fig 10: Hydrogen costs at different electricity prices and electrolyzer CAPEX*



*Load factor=48%

Source: IRENA

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19 Hydrogen a renewable energy perspective, September 2019 - IRENA
20 Compared to $840/MW on average in 2020
21 LCOH: Levelized Cost Of Hydrogen
22 CCS: Carbon Capture and Storage

HYDROGEN USAGES:

There are many industrial usages of hydrogen in chemical industry and refineries. More innovative usages are focused on electricity produced with fuel cells fed with hydrogen:

- **The transportation sector:**

  In 2019, more than 200 projects were under way[23] relying heavily on public funding. More recently within the post Covid-19 economic stimulus plans, national governments pledged to allocate more funds to ambitious projects.

  For example, the German "strategy for hydrogen" plan adopted early June 2020, will allocate €7 billion to develop research, infrastructure and the framework conditions needed to produce 5 GW of hydrogen from renewable energy sources by 2030.

  - **Hydrogen train:** On 4 June 2020, the French Alstom, and the Italian SNAM signed a five-year agreement to develop hydrogen fueled trains in Italy.

  - **Hydrogen ship:** Shipping is responsible for 2.5% of global GHG emissions. In April 2018, the shipping industry committed to a GHG target of reducing emissions by 'at least' 50% by 2050. Hydrogen boats are required to achieve this ambitious goal.

  - **Hydrogen cars:** The German plan allocates €3.6 billion of subsidies for the purchase of hydrogen cars and for building the needed fueling stations infrastructure. European car manufacturers see hydrogen as an opportunity to master the green vehicles supply chain by a “leapfrog” attempts whereas China currently leads the electric battery industrialization as an early adopter and front runner.

  - In parallel, **China** is also aggressively driving hydrogen and fuel cell developments and is on track to outpace development in the EU and US with a focus on hydrogen busses and trucks.

    In the first seven months of 2019, installed capacity of hydrogen fuel cells has increased six-fold.

  - **Infrastructure**: large infrastructures are to be built for hydrogen transportation usages. While some dedicated hydrogen pipelines have been in operation for decades, refurbishing existing natural gas pipeline constitutes an attractive option currently explored even if further analysis and experiments are required before concluding. In all cases, those infrastructure investments and operations will have to be factored in hydrogen’s cost.

- **The electrical grids:**

  Hydrogen can provide additional flexibility to a constrained power system and enable increase of intermittent generation:

  - **Demand response:** Modern electrolyzers can ramp their production up and down on a time scale of minutes or even seconds, and further improvements are foreseen. They can thus absorb the extra electricity produced by renewables (when there is a lot of wind or sun) that otherwise would be curtailed.

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[23] IEA 2019 report

- ➜ **Electricity storage:** Hydraulic storage and hydrogen are the main inter-seasonal storage solutions as stationary electrical batteries can only provide short-term storage. In western countries nearly all suitable sites are already equipped with dams.

  With increasing share of renewables (thus a decreasing share of schedulable electricity), green competitive hydrogen will enable to store large amounts of electricity needed to stabilize the grid.

- ➜ **Locating hydrogen production near wind or solar farms has two main advantages:** avoiding hydrogen transportation costs and optimizing the balance of plant[24] of the combined installation (renewables and hydrogen electrolyzers and fuel cells) thus decreasing the overall costs.

However, producing hydrogen out of otherwise curtailed electricity (versus producing full time hydrogen out of dedicated renewable farms) still has to be done at a competitive cost. Even if otherwise curtailed electricity can be considered as “free” (zero marginal cost, zero opportunity cost) and even if PEM[25] electrolyzers are suited for fast turning “on” and “off”, the CAPEX and OPEX of an electrolyzer cannot be justified only for very part-time utilization during curtailment periods, at least with current electrolyzing costs.

In a near future, hydrogen could become an important source of grid flexibility provided the economic equation is solved by technological improvement and cost decreases.

After setting the stage of current energy transition dynamics, we will, in the following section, analyze the impacts to the electricity systems and explore the potential sources of flexibility.

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[24] The balance of plant refers to all the supporting components and auxiliary systems of a power plant needed to deliver the energy, other than the generating unit itself

[25] PEM: Polymer electrolyte membrane

2. GRID BALANCING IN THE NEW ELECTRICITY SYSTEM

Grid operators continuously balance supply and demand. Until the latest development of renewables, supply was coming from a limited number of schedulable, controllable, highly visible large centralized power plants while demand always fluctuated by nature, following more or less well-known seasonal and daily patterns. With increasing number of intermittent electricity assets connected to the grid and producing electricity only when the sun is shining or the wind is blowing, the supply side of the balance equation starts to also show significant and uncontrollable fluctuations. Additionally, apart from utility-scale renewables able to generate several hundreds of megawatts (MW) of electricity injected in the networks, small individual solar installations can sometimes generate a surplus of electricity that DSOs also need to reinject in the transmission network. From a one-way transmission-distribution system, networks have become a bi-directional system.

A larger share of variable renewable energies in the total electricity capacity has many impacts on grid operations: new infrastructures development including power lines and control systems, grid instability, voltage drops, congestion or curtailment leading TSOs and DSOs to adapt. Grids must master several additional capabilities that will translate in costly investments:

- Weather forecast was always a critical capability to anticipate demand but it becomes even more important to also forecast supply, at geographic and temporal high resolution scale;
- The uncontrollable nature of solar and wind electricity production requires grid operators to be highly flexible and able to react promptly to fast-changing production patterns;
- In order to keep a continuous balance between supply and demand, and respect energy transition goals (fossil fuel plants that are often used as back-up flexible production are being phased out), electricity storage deployment and smart control are a must to introduce new flexible control points in the system, at least for the short-term horizon;
- Last, unless fully dedicated to “green” hydrogen production, new large renewables farms that may be built in areas with no or few transmission lines would require significant new grid investment.

According to Eurelectric study[26], achieving the Paris agreement objectives in Europe is feasible if electrification share increases to around 60% with a decarbonized power system. According to this professional organization, with the technical progress and cost decrease of renewables (wind and solar PV) electricity could be nearly carbon-free by 2045 with 85% of renewables (including hydropower) and 12% of nuclear.

Simultaneously, it is estimated[27] that annual investments of €95 to €145 billion would be needed in the power sector in 2021-2050. These investment needs consist of:

- Electricity generation: €54 to €80 billion per year;
- Electricity transmission and distribution grids: €40 to €62 billion per year;
- Compared to those physical infrastructure ticket items, investments in storage and demand response are still rather low. They should significantly increase to provide the needed flexibility and avoid some physical investments in transmission and distribution;
- Investments in electrical lines and overall infrastructure were anticipated and estimated (e.g. TenneT announced they would inject €35 billion in their transmission networks in Germany and the Netherlands over the upcoming 10 years) but such infrastructure investment would, alone, not constitute the smartest and above all not the most sustainable solution to the flexibility challenge. It is fast becoming essential to increase flexibility via smart control of generation injection and/or consumption demand to maintain indispensable balance without having to engage massive, costly multi-year physical network deployment. Smart control allows to postpone controllable demand loads to future more adequate timing or trigger storage of not immediately needed electricity which otherwise would be curtailed. Smart forecast and smart control can also integrate additional actions such as planning maintenance activities as well as additional input variables / optimization functions beyond balancing such as minimizing carbon footprint and maximizing profit in reaction to an external price signal or ancillary revenue signal form the grid.

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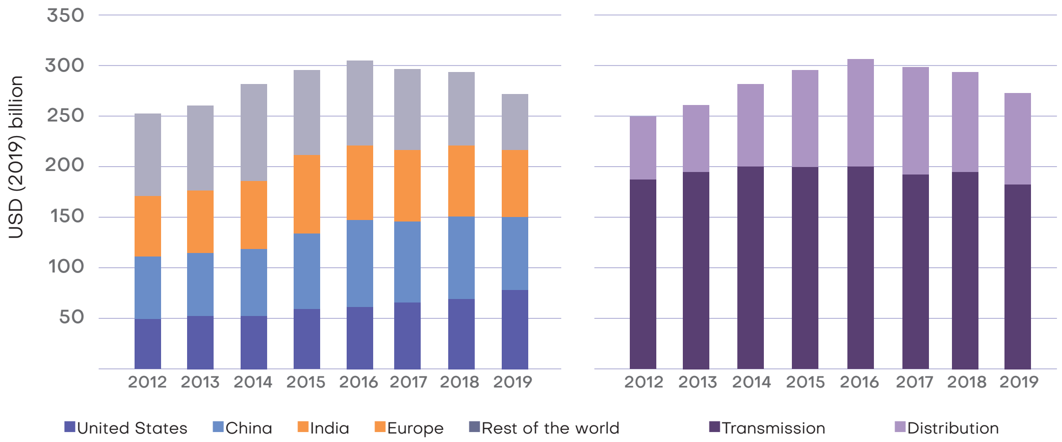
[26] https://www.eurelectric.org/decarbonisation-pathways/
[27] https://www.eesc.europa.eu/sites/default/files/files/energy_investment.pdf

2.1. The “traditional “approach

According to IEA 2019 report, global investment in electricity networks has stalled in 2017 and 2018 even if investment in digital grid continues to raise.

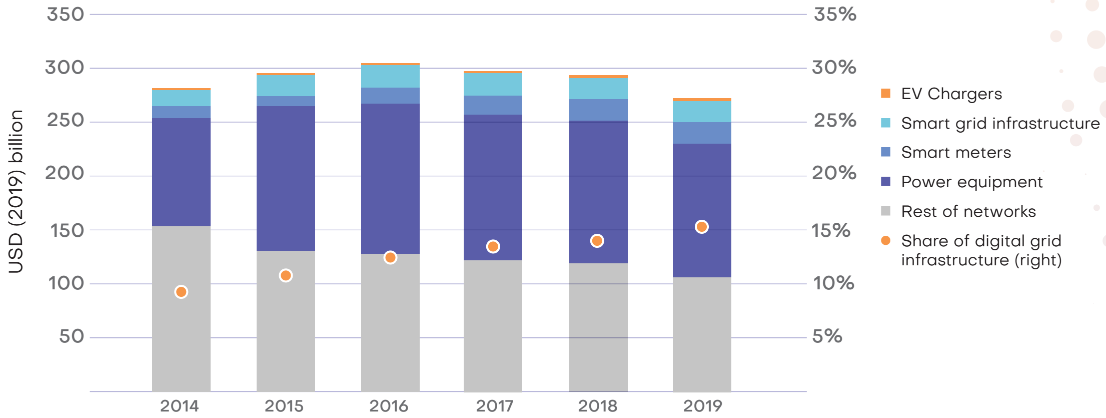
Fig 11: Investment in electricity networks



Note: Investment in electricity networks is calculated as capital spending for installed lines, associated equipment and refurbishments

Source: IEA World Energy Investment 2020

Fig 12: Investment in electricity networks by equipment type



Note: Two- and three-wheeler EV charging stations are excluded from the analysis. Smart grid infrastructure comprises utility automation equipment at substation level. Power equipment corresponds to transformers, switchgear, power systems and substations

Source: IEA World Energy Investment 2020

In Europe, the electric networks are relatively old, the electrification of the continent having taken place in majority during the first 60 years of the 20th century with slight difference between countries. As an example, France underwent an important investment plan into electricity networks during the 1985-1995 decade. Modernization of EU networks is now needed, both continuously to replace outdated cables and transformers, as well as more strategically, introducing disruptive technologies, mainly related to smart grids.

In such a context, investments in the European Union increased by 8% in 2018, with €30 billion invested in EU's distribution networks (i.e. 85.7% of the total EU grid spending) and €3.5 billion in transmission networks. However, these investments, especially in the distribution grid, still need to grow further and even at least double in the next decade. Presently, the share of smart grid investments remains quite (and we think too) limited.

Let's now take a closer look at transmission, distribution, and interconnections investments.

TRANSMISSION GRIDS:
renewable expansion triggers significant investments in transmission lines which typically takes between five to 10 years to build. These long lead times are slowing down renewables' expansion.

For example, the wind offshore development in German North Sea is slowed down by the opposition to build North-South lines. However, in the lack of other means of transportation for electricity, such lines are indispensable to "move" this renewable electricity from "where the wind blows" to "where electricity is needed", meaning from North Sea to the large industrial players located in the South part of Germany. Overhead lines being rejected by the community for environmental reasons, the German TSOs (Tennet, Transnet, 50 Hz and Amprion) have launched in 2020 the "German Link" project consisting in building HVDC (High Voltage Direct Current) underground cables in three 700 km corridors. The completion of these corridors' projects will take until 2026 and will cost at least €10 billion.

Fig 13: Map of electricity transmission projects of common interest

Source: European Commission

DISTRIBUTION GRIDS:

Investments are needed in new lines and in equipment to make distribution grids robust, resilient and intelligent enough notably to accommodate the increase in renewable energy and other DER[28], EV charging infrastructure and the development of data centers.

Increasing flexibility in the power system is another key success factor for energy transition. Investments in digital AIoT and storage technologies are needed to accelerate digitalization of the grid and facilitate the interactions of network customers, flexibility providers and prosumers. These AIoT investment come across as marginal, in amount, compared to the massive generation, transmission and distribution investments we previously covered in the study. However, these AIoT and storage technologies constitute the critical enabler of a successful green electrification as well as a powerful alternative to further physical assets investments. Beyond generation asset building and grid expansion, a more fundamental model shift is required, impacting in a systemic way business processes, data sharing and utilization, investment decision making process, generation operation principles, but also, as key incentivizing context elements: electricity pricing (and notably as green electricity specific pricing) as well as tariff-setting for network services. Such a systemic shift also requires significant adaptations of the regulatory frameworks.

Another challenge DSOs have to address is the development of Electric Vehicles (EV). EVs are becoming increasingly competitive for the light-duty vehicles and passenger cars segments, reaching cost parity between EVs and ICE alternatives in many European countries no later than the mid-2020s.

EVs have an ambivalent impact on the electric grid. On the one hand, they will increase significantly peak time challenges, based on natural car owners' behaviors. In the absence of smart charging solutions, drivers will "plug" their car into the grid when arriving at home and when arriving at the office, generating peaks of demand which will coincide with other peaks of demand such as turning on computers, TVs or cooking appliances! On the other hand, most cars sit idle 95 to 96% of the time in average, which means that with the proper smart charging AIoT system, cars' batteries can represent short-term storage and grid services opportunities and can be "used" as allies to the grid providers, potentially minimizing grid reinforcement needs.

A EUROPEAN UNIFIED GRID:

Presently there is no European electricity grid as each network is managed as a separate entity. However, cross border interconnections and increasingly common technical and trading rules are increasing interoperability of the national grids over time. The Internal Electricity Market was integrated as an objective of the EU Commission in order to further secure electricity supply in Europe by having fluid electricity flows between European countries. As of today, this vision of a seamless European electricity grid has not come to reality yet. For example, some key milestones, previously set by the Commission (i.e. interconnexions enabling 15% of national electricity generation, cross border flow in 2030) will probably not be met by many European countries.

The harmonization of all cross-border market rules is a necessary key enabler of this European integration by ensuring that electricity freely flows in response to price signals. Market integration will increase system security by allowing balancing energy to be drawn from more sources (by the principle of "global optimum" versus "the sum of local optima"), reducing the need for back-up generation and facilitating the integration of renewable energy sources.

Last but not least, electricity balancing exigence is multi-horizons: it must be ensured every second but this target can only be met if proper day-ahead, week-ahead and even years-ahead scheduling, planning as well as decisions and actions take place. It means reporting systems, forecasting systems (integrating weather, demand and supply signals), as well as actual control systems (actioning decisions towards physical assets and grids) must display critical availability, accuracy, resilience as well as speed of processing and real-time reactivity.

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[28] DER: Distributed Energy Resource

The single market achievement is a combination of physical interconnections increase, common network rules, market coupling enabling prices to converge and AIoT solutions able to inform decisions and implement actions with the required real-time reliability and speed.

- Physical interconnections: Let's note that because of communities' opposition against overhead electrical lines, some interconnections (as France-Spain) can take more than a decade to be built.

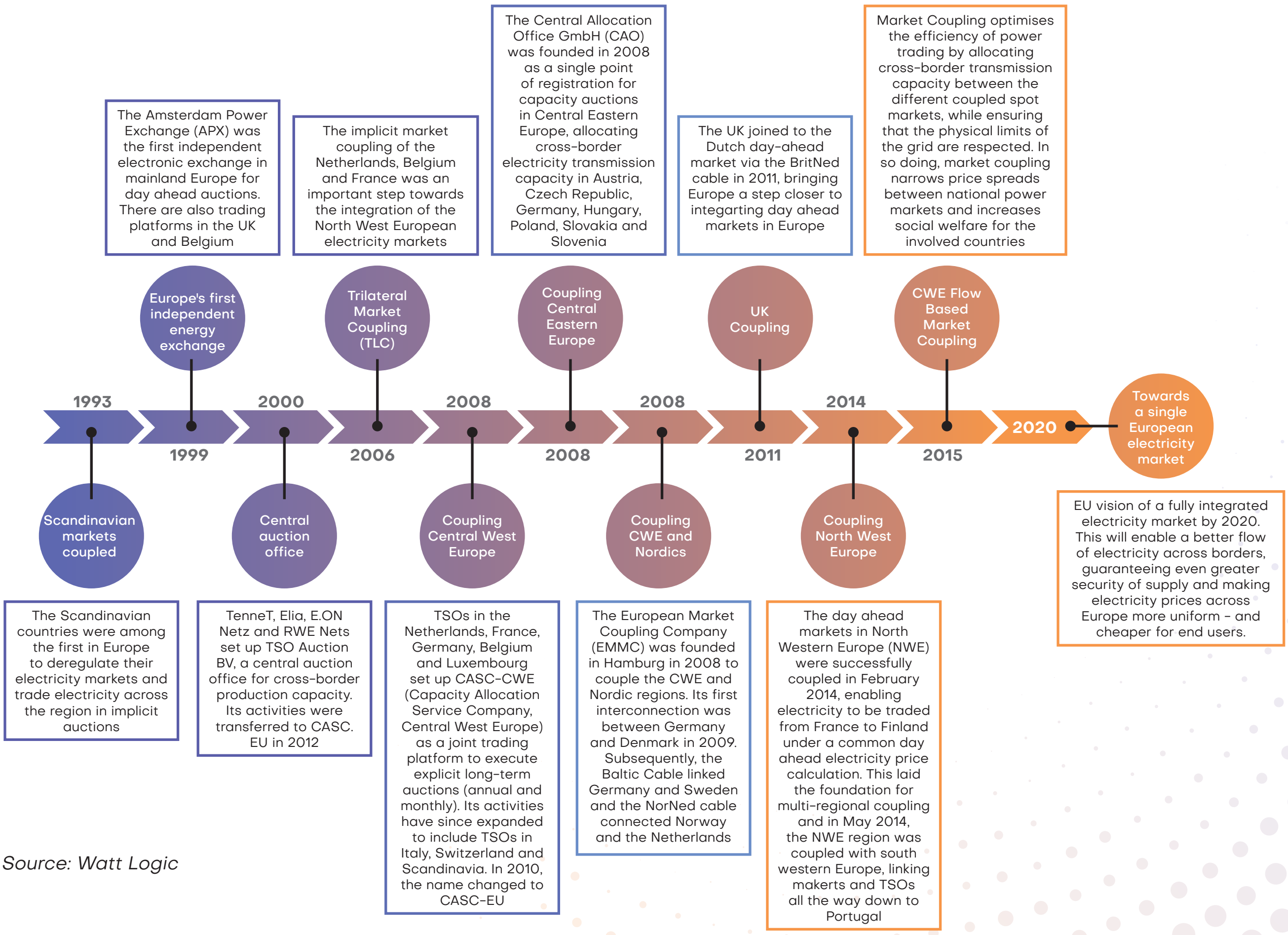
  Using underground or submarine cables helps to decrease public opposition but is between three and eight times more costly in construction and maintenance;

- Market coupling between European countries started in 2010 on "day ahead" markets for the Central Western Europe. It has since expanded to nearly all EU-28 countries as well as countries like Greece, Serbia, Bulgaria.

  The intraday market coupling was launched in June 2018 and is expanding all over Europe. Consequently, intraday trading volumes increased very significantly (up to 100% for some markets) and spot price correlation improved;

- The grid codes were published in 2018. They are key enablers of the European Single Market however their implementation requires extensive consultations between stakeholders. The creation of RSCs (Regional Security Coordination), in charge of providing analysis and recommendations such as security analysis, capacity calculation and outage coordination on their regional areas, should accelerate their implementation.

Fig 14: Market coupling Europe, key milestones



The Scandinavian countries were among the first in Europe to deregulate their electricity markets and trade electricity across the region in implicit auctions

The Amsterdam Power Exchange (APX) was the first independent electronic exchange in mainland Europe for day ahead auctions. There are also trading platforms in the UK and Belgium

TenneT, Elia, E.ON Netz and RWE Nets set up TSO Auction BV, a central auction office for cross-border production capacity. Its activities were transferred to CASC. EU in 2012

The implicit market coupling of the Netherlands, Belgium and France was an important step towards the integration of the North West European electricity markets

TSOs in the Netherlands, France, Germany, Belgium and Luxembourg set up CASC-CWE (Capacity Allocation Service Company, Central West Europe) as a joint trading platform to execute explicit long-term auctions (annual and monthly). Its activities have since expanded to include TSOs in Italy, Switzerland and Scandinavia. In 2010, the name changed to CASC-EU

The Central Allocation Office GmbH (CAO) was founded in 2008 as a single point of registration for capacity auctions in Central Eastern Europe, allocating cross-border electricity transmission capacity in Austria, Czech Republic, Germany, Hungary, Poland, Slovakia and Slovenia

The European Market Coupling Company (EMMC) was founded in Hamburg in 2008 to couple the CWE and Nordic regions. Its first interconnection was between Germany and Denmark in 2009. Subsequently, the Baltic Cable linked Germany and Sweden and the NorNed cable connected Norway and the Netherlands

The UK joined to the Dutch day-ahead market via the BritNed cable in 2011, bringing Europe a step closer to integarting day ahead markets in Europe

The day ahead markets in North Western Europe (NWE) were successfully coupled in February 2014, enabling electricity to be traded from France to Finland under a common day ahead electricity price calculation. This laid the foundation for multi-regional coupling and in May 2014, the NWE region was coupled with south western Europe, linking makerts and TSOs all the way down to Portugal

Market Coupling optimises the efficiency of power trading by allocating cross-border transmission capacity between the different coupled spot markets, while ensuring that the physical limits of the grid are respected. In so doing, market coupling narrows price spreads between national power markets and increases social welfare for the involved countries

EU vision of a fully integrated electricity market by 2020. This will enable a better flow of electricity across borders, guaranteeing even greater security of supply and making electricity prices across Europe more uniform - and cheaper for end users.

Source: Watt Logic

The architecture of this revised electric system approach must include AIoT added-value to ensure real-time information sharing and information exploitation, more and more accurate forecasting and, above all, increasingly reactive control of critical loads.

As pointed out by the French Regulator in its answer to the consultation on the European Commission's Roadmap for the revision of the guidelines for trans-European Energy infrastructures

> **" leaving the definition of methodologies for assessing the value of projects to the TSOs alone introduces a risk of bias in favor of solutions fostering the construction of infrastructure although alternatives might be better suited".**

2.2. Increased technical constraints on network management

As already described, the intensifying efforts to reduce CO2 emissions and increase energy efficiency are bringing large number of distributed energy resources (DER), such as distributed generation (DG), energy storage systems (ESS) as well as new types of consumer devices like heat pumps (HPs) or electric vehicles (EVs) to the distribution grids. The presence of these new components is changing the way networks are operated and creates technical constraints on TSOs and DSOs:

- **Frequency volatility:** with proportionally fewer traditional generators, the frequency of the system is more volatile, moving away from target frequency more rapidly. The services which used to manage this are both expanding and evolving to be more transparent, more dynamic, and more responsive (near real-time,) which boils down to being able to more accurately forecast response capability in near real-time;

- **Voltage constraints:** Traditionally, reactive power services from large transmission-connected generation plants sufficed to manage system voltage. This is not more the case in today's increasingly complex reality. For example, the UK DSOs, traditionally modeled as loads (e.g. "consuming" electricity), now regularly export power back into the transmission system (in an unusual up-flow way);

- **Restoration:** Restoring a national electricity system from a complete or partial blackout is a complex operation, further complexified by the decentralization of generation and the decreasing system inertia;

- **System Stability (inertia):** the increasing penetration of renewables and decreasing amounts of traditional power stations result in reduced system inertia. A consequence of lower inertia is that changes in system frequency (which are increasingly common) may trigger generators' protection systems throughout the network? Those generators' protection systems were historically set conservatively to prevent asset damage but may be unsuitable for a, by-design, more volatile current and future reality. Over protective reactions of generators can result in rapidly cascading outages;

- **Congestion:** The electric power limitation of infrastructure to handle peak demands, also known as congestions, could be predicted in the classic generation models. Numerous analysis of wind generation impacts on German grid congestion shows that the suddenly of such events is unprecedented and taking by surprise historical anticipation mechanisms. At another level, decentralized solar power generation or increasing EV charging in some districts starts to put pressure on some nodes of the distribution network and new bottlenecks, such as now-undersized substations, appear is what used to be a perfectly fit-for-purpose top-down electricity distribution grid.

To face this "new normal", as discussed in previous section, investment in transmission and distribution network is expected to double in coming decades according to European Commission. Nevertheless, the share of smart grid and associated AIoT and storage flexibility investments to address those new increasing technical constraints is still limited. National public debates are taking place in some countries to decide on the most appropriate way to invest in flexible solutions.

This was recently the case in France: the French regulator (CRE), when analyzing French TSO (RTE) 2020-2030 investment plan, specifically wrote "*CRE wants the use of all flexibility solutions to be systematically considered* ***as an alternative to investment****. This requires an evolution in the design methods and the RTE decision-making process since the traditional approach consists in providing redundancies of works to deal with certain failures of the electricity network, without taking flexibilities into account. CRE will be attentive to the fact that the search for flexibility that meets the characteristics of the identified constraint is integrated into all of RTE's methods and practices.*"

Two additional topics were brought to the attention of the TSO by the French Regulator:

1 The French regulator demanded to check, at a later stage, if stationary batteries could be a lever to manage grid congestion while this solution was ruled-out by the French TSO as non-competitive;

2 **The French regulator requested to publish, in open data mode, the congestion information on the network (present and future / expected), so that flexibility service providers could better position their solutions. In 2020, the French TSO engaged into such an effort to foster transparency.**

Similar debates about the appropriate investments and how to potentially limit physical assets and physical grid CAPEX are emerging between regulators and grid operators. Multiple academic works also modeled flexibility services as an alternative to physical grid investments. Last but not least, some countries start to engage significant investments in flexibility solutions, such as:

- China starting to impose up to 20% of stationary batteries for new RENewable electricity generation (REN) capacity installed[29];
- Ireland (EirGrid) having real-time visibility of generation units' availability and issuing dispatch instructions to reduce demand, based on availability and cost[30].

2.3. Renewable energy generation could be a source of flexibility

Even if REN integration increases the need for network flexibility and, thus, overall network costs, this challenge can be addressed in two fundamental ways. The first one is to increase short-term and longer-term affordable storage capacity, as the "Moore's Law" produces its effects on storage's costs and performance. This creates a buffer between intermittent generation and the grid itself, partially absorbing with some of the supply "shocks". The second one is about controlling the renewable energy generation itself in a somehow flexible way.

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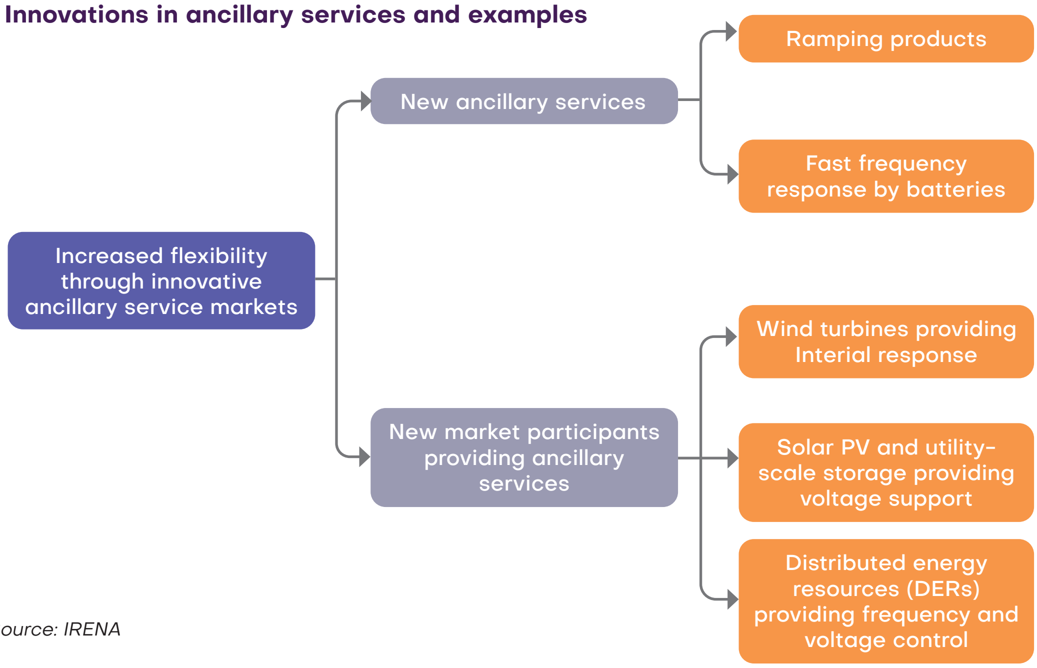
[29] Bloomberg NEF, 2020
[30] Accenture 2020

Fig 15: Innovations in ancillary services and examples



Source: IRENA

IRENA published in 2019 its view of latest ancillary services innovation showing where some REN possibilities can be activated:

- **Ramping products**
  California Independent System Operator (CAISO) in the US was among the first independent system operators in North America to implement a separate flexibility ramping product. In November 2016, CAISO implemented Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards, which are ancillary service market products to procure ramp-up and ramp-down capability for 15 minute (min) and 5 min time intervals. Any resource meeting the ramping requirement can participate. Market participants do not provide bids for this product but are instead compensated according to their lost opportunity cost of providing other services in the ancillary service market. Such innovative products faced implementation issues, according to CAISO's assessment back in April 2018, but they are still being considered and refined since then;

- **Fast frequency response provided by batteries**
  Australia's energy market operator contracted Tesla's 100 MW/129 MWh lithium-ion battery in South Australia. The battery, known as Hornsdale Power Reserve, provides accurate response to the frequency control and ancillary services market at a lower rate than conventional sources of energy. In its first four months of operation, the price of frequency ancillary services was reduced by 90 % (Gabbatiss, 2018; Vorrath & Parkinson, 2018).

  Multiple similar examples are developing around the world: Japan, UK or China;

- **Wind turbines providing inertial response**
  VRE[31] technologies have been exempted from balancing responsibilities in many countries. However, some VRE technologies can offer balancing services. Wind turbines connected to the power system through a power electronic converter can provide inertial response (also known as synthetic inertia) during frequency disturbances.

  Quebec was one of the first area to test such technology with a 2 GW wind capacity back in early 2010s;

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[31] VRE: Variable Renewable Energy

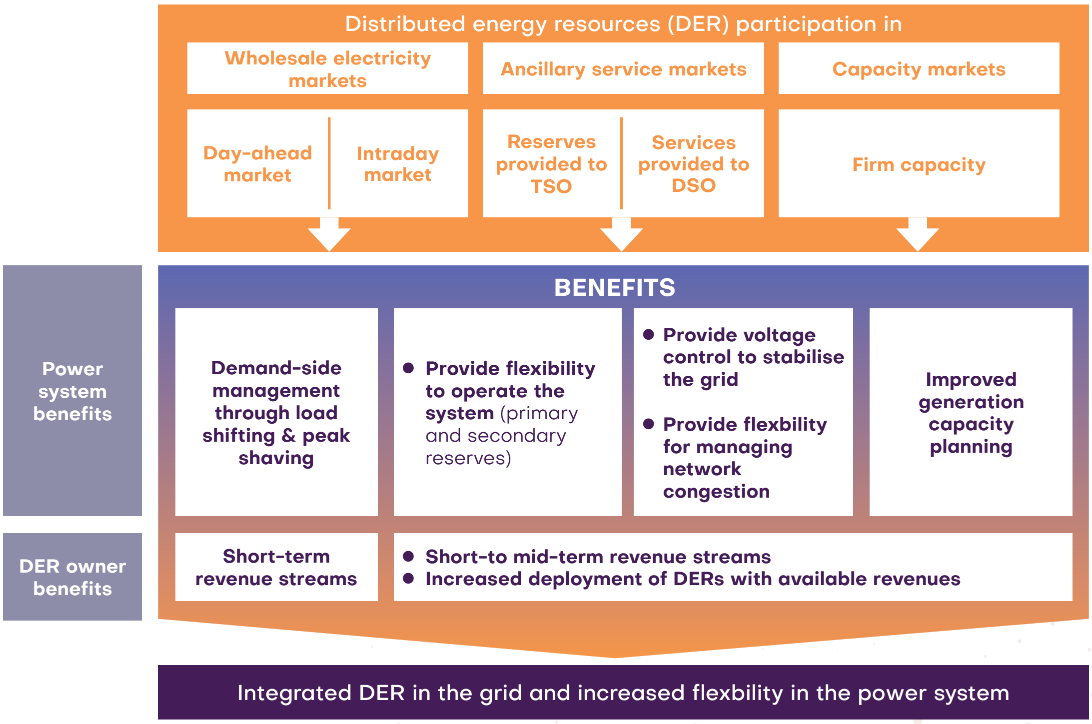
- **PV power plants and utility-scale storage providing reactive power**
  Reactive power must be supplied, when needed, from a nearby source meaning that there may be limited alternative sources of reactive power for a given location. Devices such as solar PV or battery storage, can provide reactive power support. Reactive power support from large-scale wind and solar generation connected to the grid via inverters is quite important in some jurisdictions – notably, where high-quality primary energetic resources are located in remote areas, far from main load centers, and connected via "weak" networks.

  UK National Grid, for example, in its "Power Potential Project A guide to participating" is looking for the following technical requirements: "*The DER[32] plant should be capable of moving the operating point 90% of the possible change from full lead (importing reactive power) to full lag (exporting reactive power) within two seconds.*"

  Even if renewable energy curtailment is an antieconomic solution, leading to "wasting" the spot opportunity to get electricity at "free marginal cost" from the natural elements, one has to notice the controllability and reactivity of solar and wind assets themselves when it comes to ramping generation up and down during favorable wind and solar times;

- **Distributed energy resources**
  DERs, such as rooftop solar systems, behind-the-meter battery storage systems, plug-in electric vehicles, and commercial and industrial loads, can provide ancillary services to system operators while still creating a win-win situation both for power system and DER owner. For instance, prosuming / self-consumption of a house, using its solar panels to charge its car, can alleviate the burden on the grid at a given point in time, if properly orchestrated with the "needs" for the grid. Equally, some loads can be erased or more precisely differed to more favorable times (e.g. water heating, room heating, washing machines cycles can be differed by a few minutes or hours without major impact on users' lives) provided that the right signals, transparency, reliable automation as well as an incentivizing financial mechanism are deployed.

Fig 16: Benefits of market integration of distributed energy sources



Source: *IRENA*

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[32] DER: Distributed Energy Resources

IRENA, in its recent analysis of DER integration highlighted several examples, especially on ancillary services.

Fig 17: Potential services provided by DERs to TSOs in ancillary service market

Type of market	Service traded	Capacity/ Energy trade	Response time	Duration of service provision	DERs suited for market need	Examples[3]
Ancillary service market	Primary reserves	Capacity	< 30 seconds	Up to 15 minutes (depending on the service)	**Direct control:** Aggrgated EVs, commercial and residential loads, electrical heating, storage systems	**UK:** Demand response with dynamically controlled refrigerators. **US:** EVs and stationary batteries for frequency regulation in PJM.
	Secondary reserves	Capacity	< 15 minutes	From 15 minutes up to a couple of hours	**Direct control:** Aggregated EVs, residential continuous loads, electrical heating, storage systems	
	Transmission congestion management	Energy	13 minutes – 2 hours	Several hours	Aggregated EVs, energy storage and combined heat and power (CHP) units	**France:** Volatis, an aggregator, supports the TSO when the network is congested

REN and DER costs are decreasing year-on-year leading, together with an increasing consumers and corporations' awareness, to a strong adoption ramp-up around the globe. More and more projects proved technical feasibility, but also scalability, of most of those flexibility levers. Social acceptance of such AIoT smartly controlled and optimized solutions, leveraging proper shared data, was proven excellent, when direct environment and economic impact of such optimization would be explained and demonstrated to the consumers and companies. For instance, Germany saw the multiplication of successful community green electricity initiatives at country or local scale with strong positive adoption. Eprimo, PolarStern, GreenComs networks, Sonnen, Regionah Energie, EnBW, Stadtwerke Wunsiedel, Jurenergy, Acytensys, NatürlichEnergie EMH among others exemplify community, smart and green initiatives across Germany.

Many corporations move to prosuming and Private Purchase Agreements (PPA), generating more or less directly their own green electricity to fulfil their energy needs while improving their carbon footprint.

The remaining pending question regard more financial incentives and regulatory framework than technical feasibility.

2.4. Less copper and more fiber investments

The reinforcement of transport and distribution energy networks is essential to support decarbonization both via electrification of the energy mix and via greenification of electricity mix. It is also essential to support global economic development by providing energy access to the many. Last but not least, such investments to bring green electricity, in line with always increasing expectations for high reliability of supply, to as many businesses and consumers as possible, can provide adequate stimuli in post Covid-19 challenging economic times. However, simply pulling more coper cables is not the whole solution. Community's expectations have evolved: higher accessibility, availability and quality of service but also lower prices, decarbonization of production, no impact on natural landscapes, fauna or flora. Public resistance to additional visible transmission lines imposed new constraints on infrastructures[33]. As covered in a previous section, when it comes to investment, trade-off must now be made between classical network reinforcement (increasing the "diameter of the pipes") vs. new technologies (making smarter use of existing capacities thanks to smart demand, storage and generation orchestration). We would summarize this trade off in one slogan: "less copper, more fiber".

This question becomes particularly acute for distribution networks. Distribution grids face the triple challenge of being much wider than transmission grid – requiring more upgrade investments –, being less redundant – therefore more fragile –, and, nonetheless, having to accommodate for most decentralized renewable energy production[34]. The respective innovation efforts clearly quantitatively and qualitatively reflect this reality: TSOs have, on average, spent 0.6% of their revenues on research, development and innovation activities, while DSOs have spent more than €800 million on smart grid projects[35].

These findings converge towards building combined IoT and Energy networks, supported by high-end algorithms for prediction (2.4.3) and operations that unlock optimal and automated use of the grid systems. AIoT solutions are deployed at substation levels to enhance transmission and distribution networks, stationary batteries improve grid balancing (2.4.1) and, at local level (topic box China), batteries combined with renewable installations enhance supply schedulability. In addition, at residential level (topic box French smart grids) smart meters (2.4.2) allow for a more accurate evaluation of load and smarter dispatch of resources while empowering consumer regarding electricity consumption.

2.4.1. Smarter grid equipment

ENTSO-E[36] advocates, in its recently published R&D investment roadmap[37], that a successful electrical market expansion is conditioned to a better and smarter (i.e. AIoT-enabled) coupling and integration of the TSO-DSO networks through a *"new and comprehensive TSO-DSO interface to provide grid users with the best service"*.

In particular TSOs are targeting to build a *"so-called 'substation of the future', i.e. a digitally enabled and eco-friendly substation for advanced control and automation of power systems with high level of inverter-based components coupled to some storage systems 'as a virtual transmission line'"*[38].

This characterizes a shift towards a new asset management approach combining sensors, IoT, satellites and drones coupled with big data and machine learning for predictive asset management. It should be supported by digital twins and AI-based coordination of controllable power generation, storage and consumption devices.

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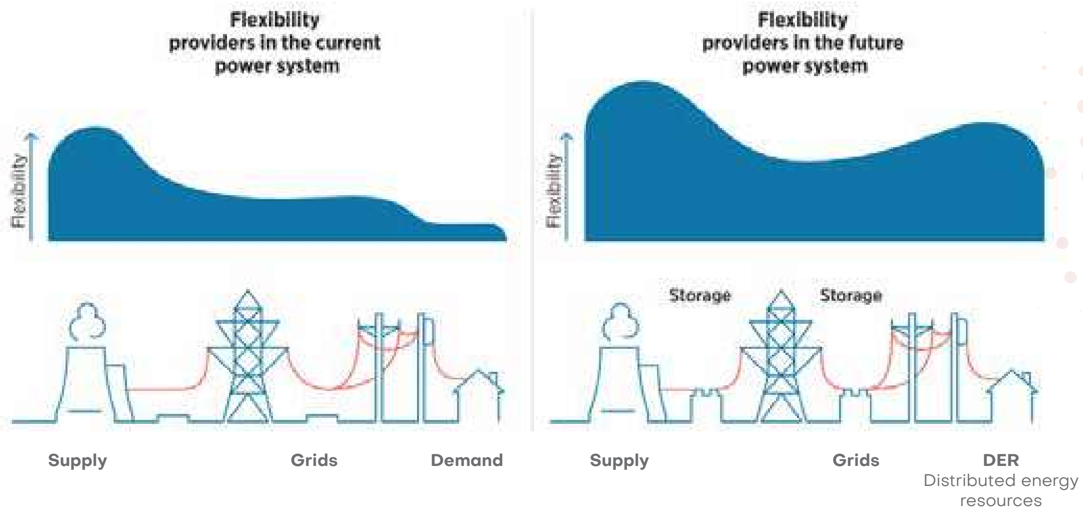
[33] http://www.smartgrids-cre.fr/media/documents/0712_CapG_SmartGridDHousemanMShargal.pdf
[34] https://www.cre.fr/Electricite/Reseaux-d-electricite/Presentation-des-reseaux-d-electricite
[35] https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/RDC%20documents/entso-e_infrastructure_reform.pdf
[36] ENTSO E: European Network of Transmission System Operator for Electricity
[37] https://eepublicdownloads.azureedge.net/clean-documents/Publications/RDC%20publications/entso-e-rdi_roadmap-2020-2030.pdf
[38] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Innovation_Landscape_preview_2019.pdf?la=en&hash=10221885865D12F47747356D9F6290283B205210

In order to fulfil the "smart grid" efficient real-time balance, advanced power system operations must evolve towards automated optimization and less manually-managed controls. Such an evolution requires that different grid actors agree to set unified standards for data, underpinning information exchange across shared and connected smart grid infrastructure.

Similar needs surfaced on the DSO side. For instance, the French TSO, RTE, and DSO, Enedis, launched an initiative to develop a "*smart substation*" (HV to MV) and a "*smart distribution substation*"[39] (MV to LV). These are equipped with numerous sensors, and are connected to other objects in the network. Sensors transmit information about the state and level of production and controllers allow remote operations.

A particularly advanced application of these infrastructures has been tested between 2011 and 2016 by Enedis and RTE. The power distribution on Medium Voltage/Low Voltage network is impacted by the weather. For instance, the wind can cool down the lines and therefore increase their ampacity (which is their maximum acceptable capacity). Coupling weather forecast and real-time measurements of physical constraints on the structures enables to estimate the remaining transit capacity on the lines over a short period of time. It is then possible to distribute the power in real time such as to remain as close as possible to the maximum capacity of the infrastructure[40].

Fig 18: Storage systems 'as a virtual transmission line' are one of the technological aspects of the transmission and distribution network smartification



Source: IRENA https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_Innovation_Landscape_preview_2019.pdf?la=en&hash=10221885865D12F47747356D9F6290283B205210)

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[39] https://www.enedis.fr/sites/default/files/Dossier_smart_grids.pdf
[40] https://www.cre.fr/Documents/Deliberations/Communication/retour-d-experience-des-demonstrateurs-smart-grids

SMART GRIDS

DEMONSTRATORS IN FRANCE

Several smart grid demonstrators have been set-up across Europe during the past decade in order to test and quantify the benefits of integrated energy and telecommunication networks. Those demonstrators focus on various aspects of intelligent network flexibility. They study both technical and economic feasibility and scalability. We hereafter introduce three demonstrators built to provide flexibility through respectively: load shedding, use of batteries and wide scale predictive managed control of the electricity grid.

The **Greenlys** demonstrator[41] aggregated 1000 residential households along with 40 tertiary sites between 2009 and 2015. It aimed at exploring different smart grid functionalities in urban areas using "Linky"[42] smart meters as an interface between the distribution power grid and customer's home. This experimentation concluded that smart meters are useful to implement demand response. Demand response was operated throughout remote site control of 140 households' heaters during winter 2012/2013. It analyzed the "rebound" effect following a demand response action consisting in turning down a heating device for a certain period. The cut was followed by a rebound of up to 50% power increase but the experiment showed that it was possible to limit such a rebound by using an ad-hoc restart procedure. It showed as well that consumption postponement was around 95% both for tertiary and residential installation. This means that, even if smart meters could avoid peaks of demand and smooth consumption profile to the benefit of the grid, and even if this potentially meant avoiding the recourse to the least clean energy generators in some high peak instances, smart meters were only allowing 5% overall energy saving as 95% of postponed consumption would finally take place later. The demand response actions generated an average decrease of temperature of 0.2°C for households and 0.5°C for tertiary building. The low rate of people deactivating temporarily the remote control (around 5%) proved that the demand response effects on consumer comfort were considered widely acceptable and sustainable[43].

Nice grid[44] demonstrator aimed at testing the economic and technical feasibility of inserting Li-Ion battery energy storage system (BESS) on the grid, both at the network nodes and inside residential households. It mobilized from 2012 to 2016 up to 300 consumers, 2,350 "Linky" smart meters, 1.5 MW of BESS and 2.5 MWp solar production.

This demonstrator showed the ability to perform sub-network "islanding" preserving voltage and frequency during periods up to 4 hours. It showed how efficient BESS can be as a source of electrical network flexibility: BESS was proven more reliable and represent more volume than residential load shedding. A 43% power peak shaving in winter's time was achieved by BESS. BESS as well proved to be helpful integrating PV electric production on the grid. Industrial BESS displayed a 90% availability rate and a 75% to 80% efficiency; residential BESS only reached a 63% average efficiency. Efficiency and battery lifetime appeared to be optimizable using real-time smart charging algorithm including weather forecast and detection input. While the integration of BESS into the grid turned out to be a technical success, the cost of batteries, at the time of the demonstrator, happened to erase dramatically the economic profit. At this point in time, BESS did not prove to be a financially sound alternative to standard network reinforcement[45].

Smart grid Vendée[46] has connected 120 tertiary buildings, 1,200 public lighting points, 7 water treatment plants, 4 wind farms, 47 solar farms, 1 electric vehicle charging station and 2

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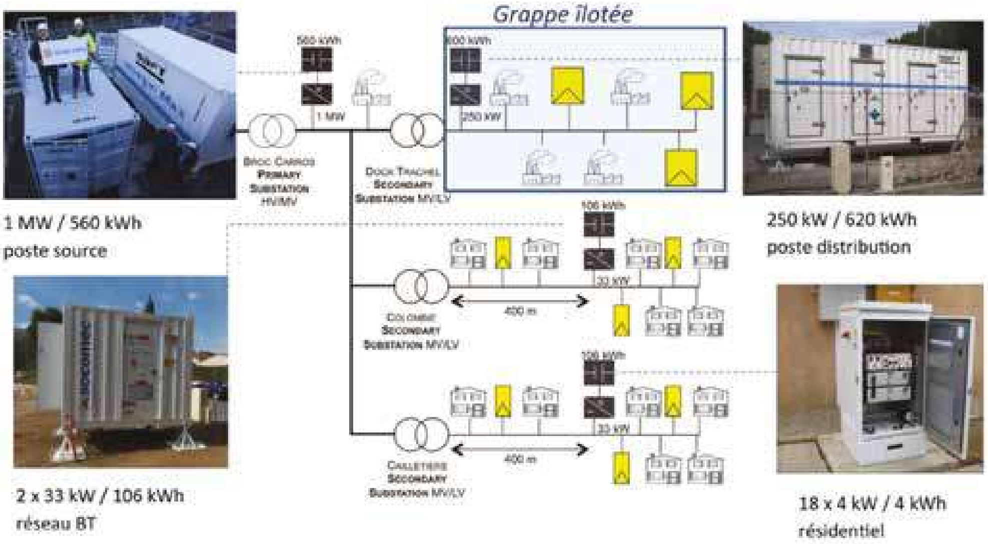
[41] https://www.enedis.fr/sites/default/files/greenlys_leaflet.pdf
[42] www.enedis.fr › linky-compteur-communicant
[43] ADEME, RAPPORT - Systèmes Electriques Intelligents | Premiers résultats des démonstrateurs
[44] http://www.nicegrid.fr/
[45] http://www.nicegrid.fr/wp-content/uploads/2016/11/FOCUS-02-le-stockage-r%C3%A9seau.pdf
[46] http://www.smartgridvendee.fr/

meteorological stations from 2013 to 2018. It offered a unique opportunity to test a wide-scale predictive management control of the electrical network, allowing for predictive renewable generation and grid maintenance operations. A real-time grid voltage management has been implemented to deal efficiently with the intermittent renewable energy injection.

This prototype showed the technological feasibility of a smart management of electrical consumption and production at a regional scale. On top of that, smart control obtained energy savings in the range of 1 to 10% of standard consumption. It estimated that it was possible to shed up to 1 kW capacity subscription per household: a significant figure compared with the average 6 to 9 kW consumer's subscriptions.

Among many other things, those three smart grids demonstrators showed the technical feasibility and interest of implementing various flexibility levers into local electricity grids: demand response, orchestrated batteries storage and predictive managed control to integrate renewable energy. Those demonstrators showed that it is possible to decrease energy consumption and improve grid flexibility by investing in communication network and AIoT solutions, complementing the electrical network's reinforcement. Some of those levers have not reached yet the price points which would make them financially attractive alternatives to classic network reinforcement however scale and learning effects will drive price points down. Temporary "ignition" subsidies may still be needed to "bridge the gap", incentivize early adopters and "prime" the productivity gains. Scale effects, industrialization, learning curves as well as technological innovation are already significantly at work: the price of Li-Ion battery collapsed from $1,100/kwh in 2010 to $156/kwh in 2019[47] (87% cut in less than 10 years) which correspondingly increased the competitiveness of BESS solutions as sources of flexibility for the grid. The growing adoption of electric vehicles equally opens new perspectives to use cars' batteries as mobile energy storage[48]. Car batteries being anyhow needed to propel the car, their marginal usage as grid stabilators is an economic "no brainer" as long as three conditions are met. First, the smart algorithms managing "vehicle-to-grid" services must protect car batteries' health (as the state of health of the battery is a key driver of the residual value of an electric vehicle) and adequately take into account driver's needs in terms of range and autonomy. Second, proper economic rewards should be proposed by the grid operators to incentivize the provision of such services. Last and probably not the simplest, overall grid systemic set-up (e.g. smart metering, local substations and various bottlenecks handled…) has to be aligned.

Different type of stationary storage solution used for the Nicegrid project



Source: ADEME, RAPPORT – Systèmes Electriques Intelligents | Premiers résultats des démonstrateurs

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[47] https://www.greencarreports.com/news/1126308_electric-car-battery-prices-dropped-13-in-2019-will-reach-100-kwh-in-2023#:~:text=From%20 2010%20to%202019%2C%20lithium,represents%20a%20cut%20of%2013%25.

[48] https://www.lesechos.fr/pme-regions/occitanie/vehicle-to-grid-le-projet-flexitanie-lance-dans-le-gard-des-cet-automne-1224000

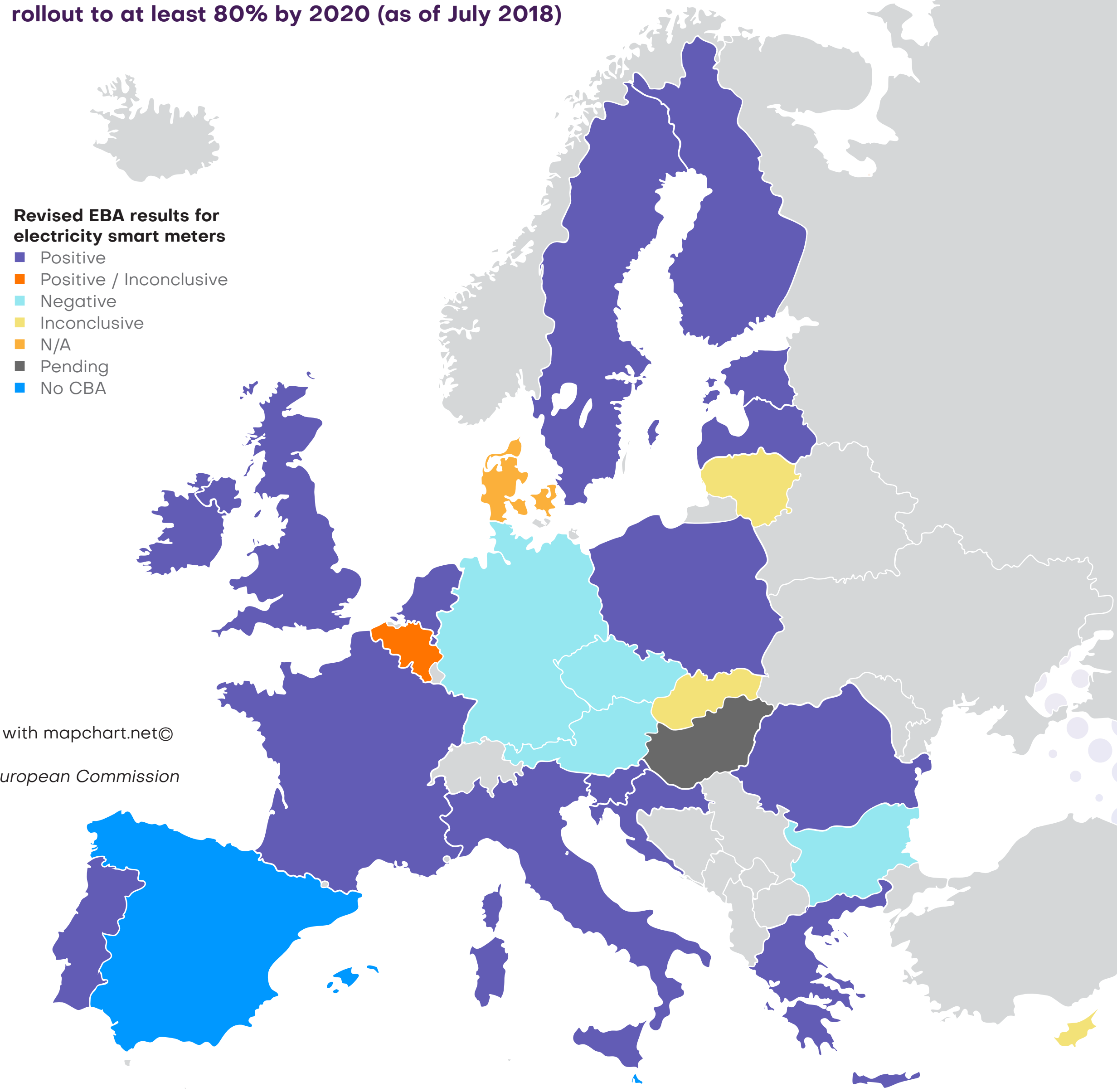
2.4.2. Smart meters have a dual role

They have a dual role: bi-directional sensors allowing better distribution grids' management as well as tools for consumers to master their energy consumption.

The European Union, through its successive Energy and Climate packages, is pushing towards the modernization and transformation of the energy sector. The implementation of smart meters is part of this effort. All countries had to conduct a cost benefit analysis, leading to a first benchmarking report in 2014. Since then, the rollout of smart meters at a large scale has been engaged by a certain number of Member States, some of them (Sweden, Italy, Finland or Spain) have finished their deployment while others (Ireland, Czech Republic) are still at the beginning of the process.

In France, the deployment of Linky smart meters, which measures consumption every half hour, started in 2015. As in most European countries, the deployment of Linky has faced some opposition from consumers, expressing concerns spanning from exposure to electromagnetic fields to respect for data privacy. Despite some resistance, Enedis will have deployed, in 2021, 35 million meters, respecting the deadlines and the initial budget (between €4 and €5 billion).

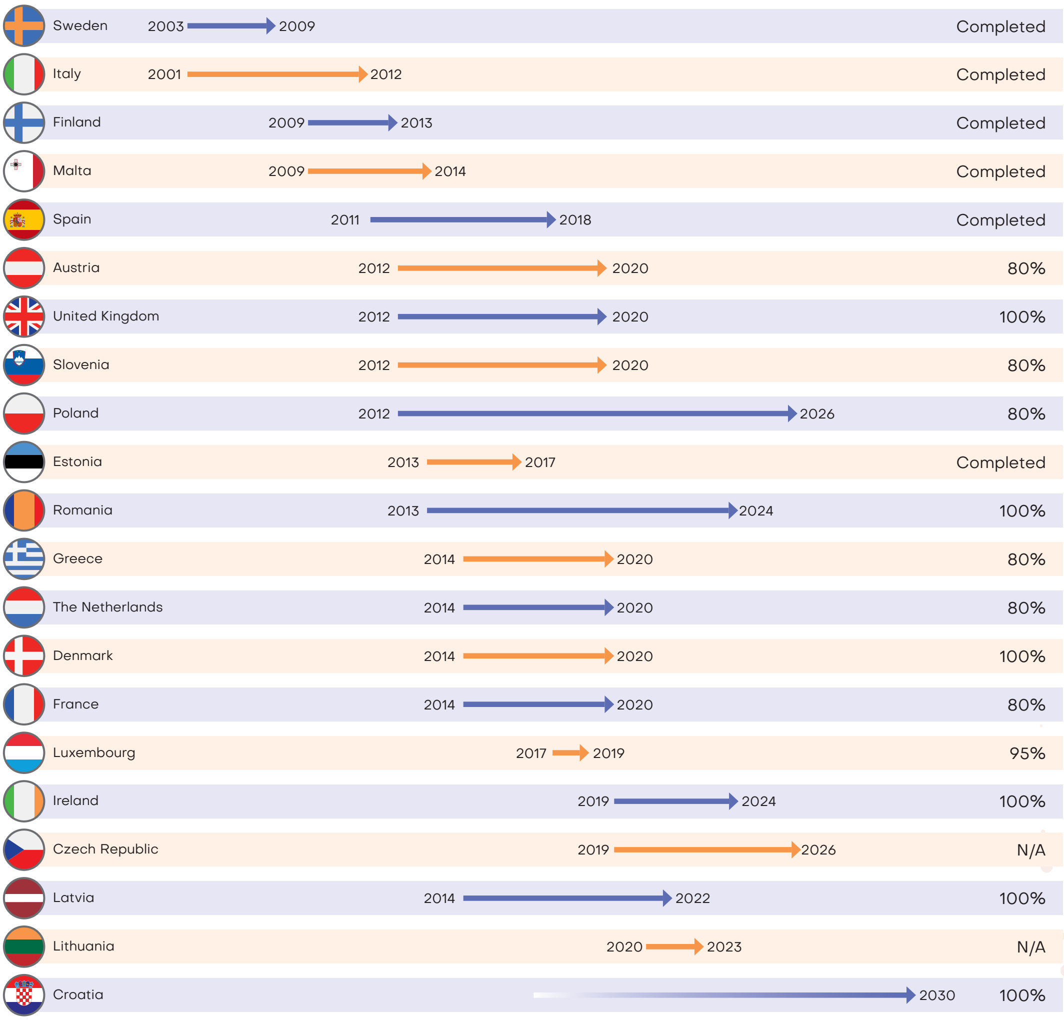
Fig 19: **Revised CBA results electricity smart meters considering a large-scale rollout to at least 80% by 2020 (as of July 2018)**



Credited with mapchart.net©

Source: European Commission

Fig 20: **Official deployment strategy per Member State on the large-scale roll-out (80% or higher coverage) of smart electricity meters**



Source: European Commission

Smart meters, as bi-directional sensors, offer new benefits for consumers: automatic meter reading, actual billing versus previous estimated bills, time-of-use flexible tariffs incentivizing consumers and corporations to adapt their consumption patterns either manually or, most likely, via automatic AIoT controllers. Last but not least, some smart meters support grid services and electricity injection into the network, opening up for an even smarter real-time use of solar panels, battery storage or electric cars as sources of flexibility. In addition, such bi-directional sensors also allow automation of grid's operation via fault detection and diagnosis, automatic reboot and overall real-time network information.

Energy suppliers implemented various services enabled by smart meters in order to materialize the added-value of such an innovation in customers' day-to-day lives. Some utilities propose applications to display electricity consumption in kWh and euros, advise on energy savings or tariff adjustments, or communicate bills. Some retailers went into gamification or offered free tablets to motivate consumers to engage in more active energy management, with the target to build customer's loyalty and increase retention / avoid consumer churn.

Fig 21: Overview of 10 smart metering functionalities including the relevance for the different actors

Consumer	a. Provide readings directly to the consumer and/or any 3rd party b. Update readings frequently enough to use energy saving schemes
Metering Operator	c. Allow remote reading by the operator d. Provide 2-way communication for maintenance and control c. Allow frequent enough readings for networking planning
Commerical Aspects of Supply	f. Support advanced tariff system g. Remote ON/OFF control supply and/or flow or power limitation
Security - Data Protection	h. Provide secure data communications i. Fraud prevention and detection
Distributed Generation	j. Provide import/export and reactive metering

Source: European Commission

A significant proportion of smart meters installed in Europe has limited data storage capacity, which prevents them from offering dynamic pricing for example. The most recent generation of smart meters provides increased efficiency of remote reading or greater data availability, unlocking more added-value use cases for final users.

The appropriate offerings now supported by such functionalities, combined with appropriate information and communication campaigns, should allow consumers and companies to better comprehend the potentialities of smart meters.

With smart meter deployment to households and an hourly frequency of consumption readings, a huge amount of data becomes available. DSOs are starting to make them public, at anonymized cluster levels, thereby sharing enriched knowledge on consumption behaviors. Data transparency opens the door to new services, provided that the frequency of data release can be increased.

2.4.3. Upgraded forecasting algorithms: from more insight to more actions

Anticipation is the key to balancing an electricity grid: forecasting power generation and consumption provides strategic input into the balancing act. While forecast models developed by the TSOs are robust and well proven to balance a grid in a “traditional” generation and consumption context, the need for accurate and reliable forecasts has further evolved and spread, with the development of intermittent renewable energy resources and new power consumption patterns notably linked to electro-mobility.

Various horizons of forecast are needed. Long-term forecasts (typically beyond one year) are used to optimize investments in the renewable energy systems and in the grid, medium-term forecasts are needed for the resources planification, including maintenance and reinforcements and finally, short-term, up to the real-time, forecasts (so-called now-casts) inform the grid for actual balancing monitoring.

At the same time, improved forecasting systems are needed at all geographical scales of the power grid. Accurate and near real-time forecasts must consider very local environmental conditions, that will directly impact the incoming power generation or power consumption. Less wind or sun very locally directly means less or no production from a panel or a turbine. Equally, a storm means a drop in temperature and thus a drop in building's cooling-related consumption. To become smart, the grid needs accurate high resolution multi-horizons weather forecast, production and consumption models and fast capacity to process, analyze and optimize based on those, for more and more automated real-time controls and AI-suggested mid and long-term maintenance and investment actions.

Local weather data availability as well as accurate generation curves, as responses to a given radiance or wind, are critical trumps to precisely assess and optimize the return on a renewable energy investment. Wind and solar farms operation and maintenance companies typically schedule maintenance and cleaning activities during anticipated low wind / low radiance periods. These are well-spread common practices.

More emerging constraints and opportunities emerge in the world of renewable energy generation.

In many countries, renewable energy is traditional secondary in the energy mix and called in the priority of sequence as its marginal generation cost is barely nil. However, as the role of renewables becomes more prominent in generation, they will progressively be faced with the same challenges as other generation sources: having to accurately forecast their production and to take all proactive actions (such as curtailing excess generation) to avoid grid penalties.

This is already the case in China where, to avoid significant grid penalties, wind power developers must deploy a state-of-the-art weather forecasting system. As renewables' share in the energy mix keeps increasing, many Chinese provinces now demand the installation of smartly orchestrated battery storage capacity together with new wind farms in order to both avoid unexpected grid "shocks", avoid curtailment, wasting potential energy generation and finally constitutes a source of controllable flexibility as battery discharge could be commanded at the most favorable time of the day… or the night.

Moving into mid-term considerations, most renewable farms today play for their maintenance and cleaning activities during expected weather conditions which would be unfavorable. No wind, no sun, meaning no production, meaning no loss of production if we take advantage of this day to clean the panels or check the rotor. However, with more and more grid pressure on renewable generation to "help with flexibility challenges" and more and more "fluctuating" prices to reflect the value of flexibility (cf. the example of negative electricity prices during recent Covid-19- crisis), this operations' optimization could expand into further end-to-end integration. Why not planning for maintenance or cleaning not only when production is more or less favored by the weather but also when prices are more or less favorable. Should one inject electricity into the grid while prices are negative even if the sun is shining and the wind is blowing full speed? It would probably be a better decision to take advantage of this day for other non-generating activities.

As a conclusion, when it comes to forecasting and acting upon forecast-based insight, four conditions must be met:

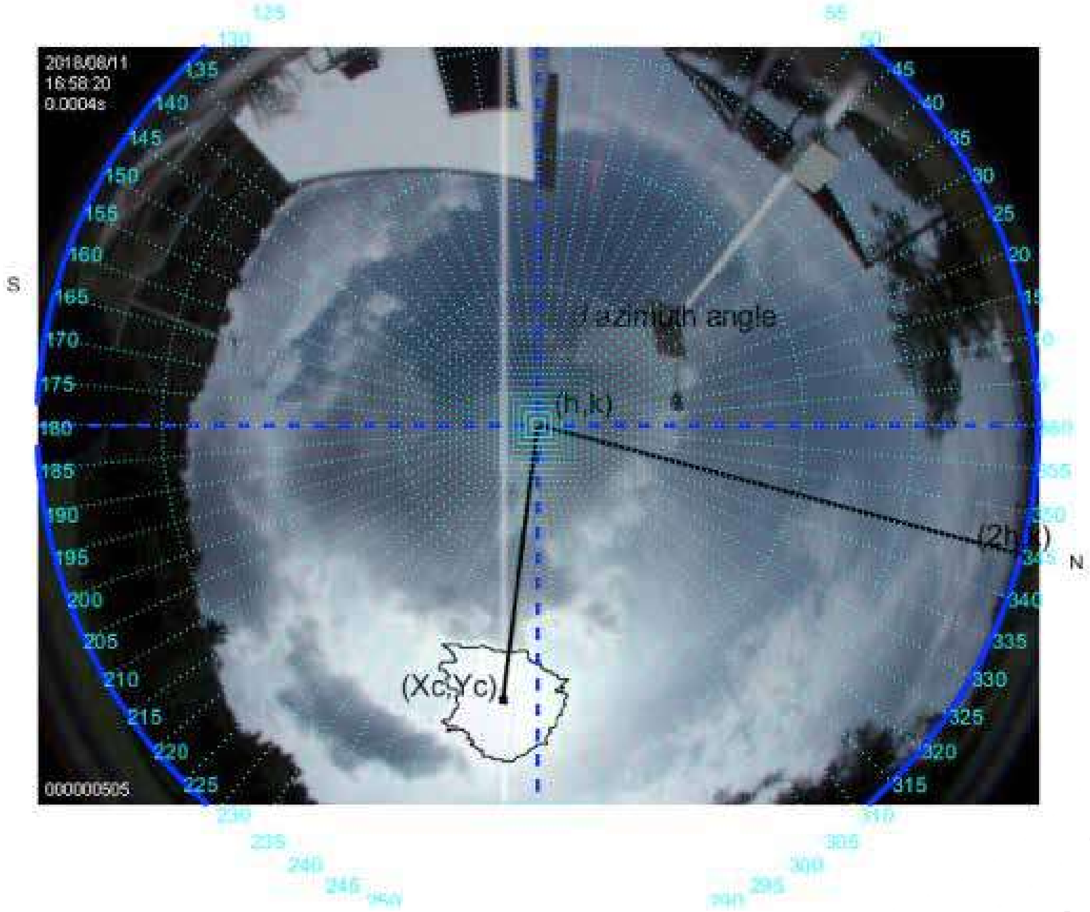
- **First, energy system must be smart by-design in terms of:**
    - Data gathering: sensors must gather state of the device, record historical production, collect super-local meteorological data,
    - Insight generation from data: evolving generation curves based on observed generation, detecting deviations from the normal sound of a rotor's rotation to initiate an alert,
    - Actionability from insight: ability to trigger, more or less real-time, optimization actions.

- **Second, local data insight and local actionability must leverage the network effect:** cross data with other asset's data to better predict overall macro-market situation or increase the precision of local algorithm based on wider machine learning insight;

- **Third, enriched insight should be coupled with enriched actionability:** better storage solutions create additional degrees of flexibility to, not only anticipate challenges and opportunities, but actually take actions to address them;

- **Fourth and last, data, insight and actions must stay nimble to accompany broader systemic evolutions:**
  - More renewables in the energy mix,
  - More price volatility,
  - Better grid services rewards,
  - Better mid-term affordable electricity storage solution with upcoming hydrogen capabilities would change the dynamics in such a way that algorithms but also optimization strategies and processes should evolve.

Fig 22: Fish eye camera monitoring sky solar activity for local PV forecast purposes



Source: https://doi.org/10.1016/j.heliyon.2019.e01398

STATIONARY BATTERIES

ELECTRICITY STORAGE IN CHINA

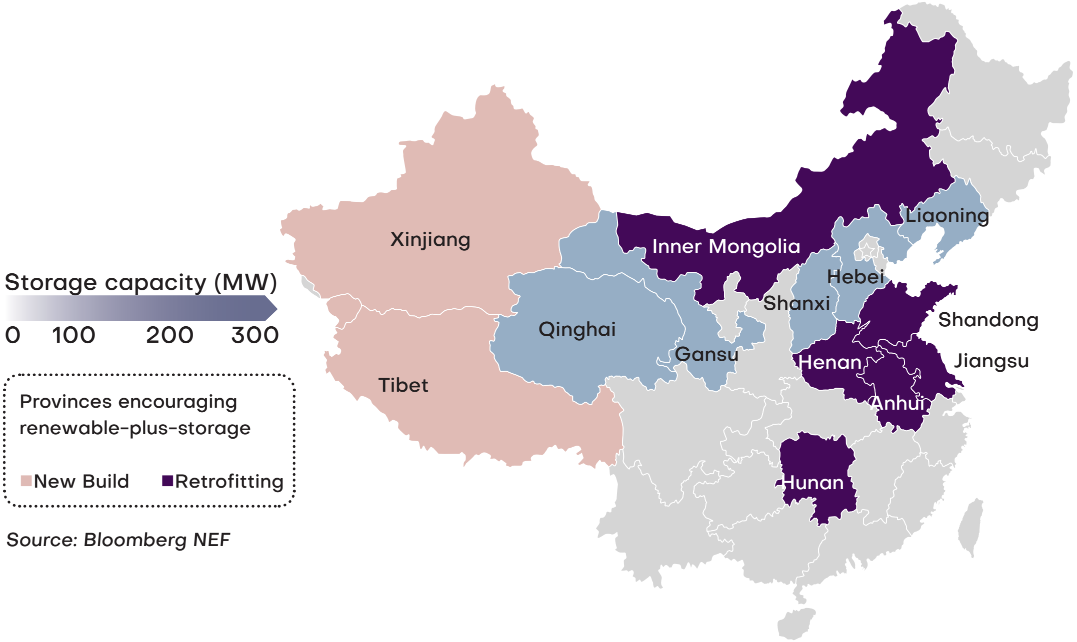
Electricity storage will be at the heart of the energy transition by providing services to the electricity network system and to the “prosumers”.

As already covered, stationary batteries storage can reduce constraints on the transmission and distribution networks thus postponing the need for infrastructure investment. They can provide ancillary grid services, such as frequency regulation, voltage support, capacity reserve and spinning reserve.

As the penetration of wind and solar renewables grows, the need for these services will increase. According to Irena study[49], total battery capacity in stationary applications could increase from a 2017 estimate of 11 GWh up to 100 GWh or even 167 GWh by 2030. This trend is presently illustrated in the Chinese market.

In 2018, grid companies began developing storage systems for Transmission and Distribution services and by the end of 2019 there were more than 300 MW stationary batteries installed[50].

Fig 23: Regional distributions of renewable-plus-storage pipeline projects in China



Source: Bloomberg NEF

While the cost of batteries keeps decreasing steadily and the technology keeps improving, while overall direction is unquestionably clear, early adoption remains economically challenging. In May 2019, China’s NDRC[51] ruled that grid companies could not include battery storage as network infrastructure and could not add those investments to their asset base which is used to calculate the network tariffs.

As a result of this incentive’s removal, grid storage projects slowed down.

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[49] Electricity storage and renewables. Irena 2017 report

[50] Bloomberg NEF report

[51] NDRC: National Development and Reform Commission

In the future, though, pairing Battery Energy Smart Storage (BESS) systems with new renewable projects could build a new momentum for those projects. By doing so, renewable developers could avoid grid penalties or secure permitting and grid connections.

In China, three business models dominate:

- ***Co-locating storage with new build renewable projects*** in order to secure grid access priority for those projects. Six Chinese provinces released policies prioritizing connections for solar or wind assets paired with storage. Pairing is the first choice of wind developers willing to commission their new assets before the end of China's onshore wind feed in-tariffs (by the end of 2020);
- ***Retrofitting storage to existing renewable assets.*** In order to reduce renewable curtailment, local Chinese governments started to incentivize retrofitting storage to solar assets in 2019. However, to be viable, the storage portion of the project needs additional revenue;
- ***Pairing stand-alone storage with renewable hubs.*** This model is implemented in Northwest and Northeast China. These projects could also secure additional revenue from existing peak-shifting markets.

Business case for BESS improves if the batteries can generate additional services such as:

- ***Renewable asset penalty reduction:*** In China, variable renewables are requested to take more responsibility for system balancing. Regions such as Northwest China are applying stringent assessment criteria for renewable generation operations among which forecast accuracy, automatic generation control and fast frequency response. Renewable plants that cannot meet these criteria are facing penalties and revenue losses. Improving renewables' flexibility and, thus, reducing penalties, generates a value stream for BESS;
- ***Securing grid connection priority:*** Earlier grid access leads to more revenue and more profit as feed-in tariffs are progressively reducing;
- ***Peak-shifting service compensation:*** The impact of BESS charging to shift peak generation is often dwarfed by thermal power generation reducing their output. If the "special compensation price" specific to storage providing peak-shifting services is approved, BESS profitability would improve.

In the future, with increased share of renewables in the electricity mix, the above-described BESS business models could apply more widely in European countries or certain US States, for instance.

2.5. Capacity markets should improve security of supply

The electricity wholesale market can be chaotic with episodes of negative prices. During these episodes, the market is oversupplied with too much volatile generation capacity (solar and wind) and not enough schedulable generation (nuclear and gas fired plants) in the overall mix.

Infrastructure investment needs, for electricity and gas, are estimated at €1,100 billion[52] for the next 10 years (out of which €500 billion in generation, €400 billion in distribution network and €200 billion in transportation grids). Obviously, present market prices give a wrong signal to investors.

Continuing gas plant closures challenges security of supply.

However, capacity markets, finally accepted by the European Commission, should improve the situation.

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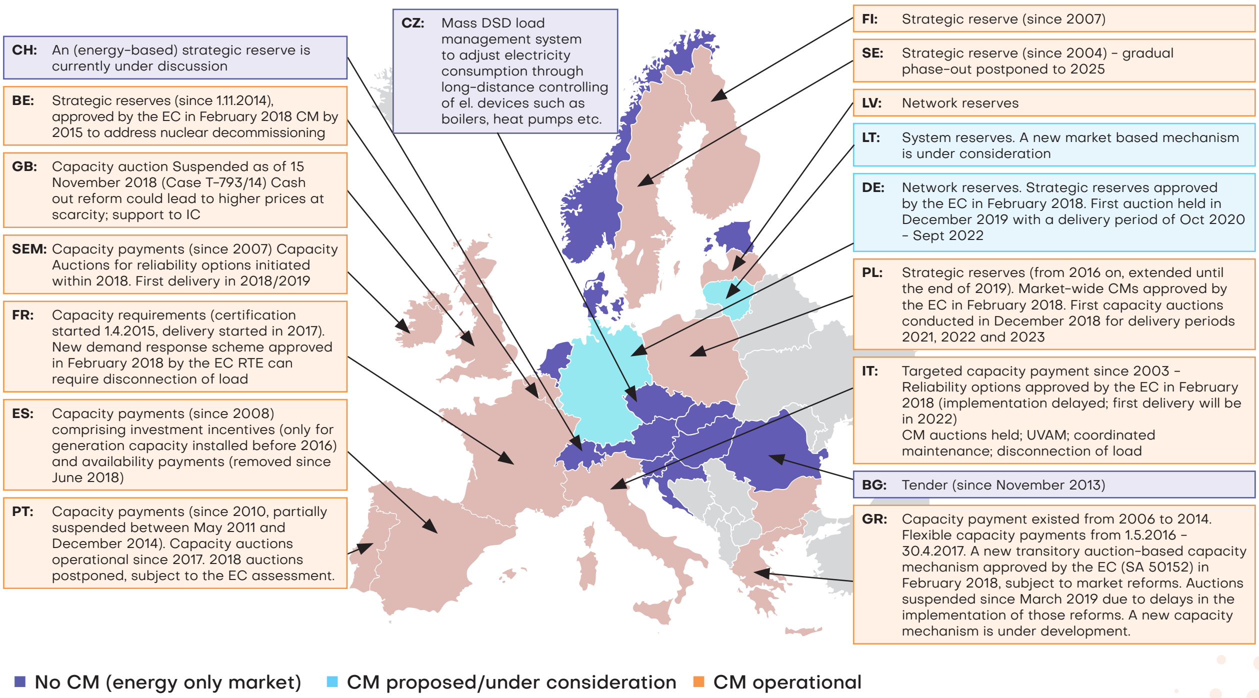
[52] Bloomberg NEF report

Fig 24: Map of capacity mechanisms in the EU



CH: An (energy-based) strategic reserve is currently under discussion

BE: Strategic reserves (since 1.11.2014), approved by the EC in February 2018 CM by 2015 to address nuclear decommissioning

GB: Capacity auction Suspended as of 15 November 2018 (Case T-793/14) Cash out reform could lead to higher prices at scarcity; support to IC

SEM: Capacity payments (since 2007) Capacity Auctions for reliability options initiated within 2018. First delivery in 2018/2019

FR: Capacity requirements (certification started 1.4.2015, delivery started in 2017). New demand response scheme approved in February 2018 by the EC RTE can require disconnection of load

ES: Capacity payments (since 2008) comprising investment incentives (only for generation capacity installed before 2016) and availability payments (removed since June 2018)

PT: Capacity payments (since 2010, partially suspended between May 2011 and December 2014). Capacity auctions operational since 2017. 2018 auctions postponed, subject to the EC assessment.

CZ: Mass DSD load management system to adjust electricity consumption through long-distance controlling of el. devices such as boilers, heat pumps etc.

FI: Strategic reserve (since 2007)

SE: Strategic reserve (since 2004) - gradual phase-out postponed to 2025

LV: Network reserves

LT: System reserves. A new market based mechanism is under consideration

DE: Network reserves. Strategic reserves approved by the EC in February 2018. First auction held in December 2019 with a delivery period of Oct 2020 - Sept 2022

PL: Strategic reserves (from 2016 on, extended until the end of 2019). Market-wide CMs approved by the EC in February 2018. First capacity auctions conducted in December 2018 for delivery periods 2021, 2022 and 2023

IT: Targeted capacity payment since 2003 - Reliability options approved by the EC in February 2018 (implementation delayed; first delivery will be in 2022)
CM auctions held; UVAM; coordinated maintenance; disconnection of load

BG: Tender (since November 2013)

GR: Capacity payment existed from 2006 to 2014. Flexible capacity payments from 1.5.2016 - 30.4.2017. A new transitory auction-based capacity mechanism approved by the EC (SA 50152) in February 2018, subject to market reforms. Auctions suspended since March 2019 due to delays in the implementation of those reforms. A new capacity mechanism is under development.

■ No CM (energy only market) ■ CM proposed/under consideration ■ CM operational

Source: ENTSO-E

If European capacity markets all share the same objective (preventively "set aside" generation capacity to handle peak hours), they resort to different models:

- **Strategic reserves:** Some capacity, designed to ensure security of supply in exceptional circumstances, is placed in reserve. These reserve plants cannot take part in the commercial electricity exchanges. This model has been adopted in Spain and Sweden;
- **Capacity obligation:** Suppliers are required to contract a certain level of capacity from generators at a price which is agreed between the parties. France has adopted this model;
- **Capacity auction:** The total required capacity is set several years in advance by the TSO or the regulator. The price is set by forward auction and paid to all participants in the auction.

The results of the first UK auction for capacity in 2018-2019 were announced in January 2015. Through this auction, the government has procured 50 GW of capacity at a high clearing price of £19.40/kW per year. The market has then be suspended in November 2018.

The first auctions since market's reinstatement took place early 2020, for delivery over winter 2022/23, and cleared at £6.44/kW per year; this is the lowest outturn since the auctions for long-term services began in 2014 for a 45 GW capacity.

Results announced end of February 2020 for the French capacity market auctions which had low-emissions requirements, saw 253 MW of energy storage awarded 7-year contracts, along with 124 MW of demand response capacity.

These capacity markets should improve security of supply. However, having been launched separately by Member States, they have different designs which, among other challenges, poses the question of cross-border participation.

More fundamentally, current market mechanisms were designed as different points in times and ended-up "piling up". A more systematic redesign is now needed to combine main market components (wholesale market, capacity market, networks regulation, energy transition policies) with the goal of improving security of supply, facilitating renewables' integration and fostering efficient transformation of transmission and distribution grids.

BALANCING FLEXIBILITY

IN THE FRENCH MARKET

As abundantly commented, demand and supply of electricity must always be kept in balance. If production is insufficient in relation to consumption, a deterioration in the supply will be observed by all consumers connected to the network, starting with a drop in frequency and possibly going as far as a blackout. If the deterioration is not too abrupt (in speed and scale), the TSO will be able to react by mobilizing means, these are the so-called “ancillary / grid services”. These services are activated by the TSO based upon previously-contracted agreements with market players, who are traditionally electricity producers. Additionally, various flexibility operators (pulling levers such as curtailment or storage) can now provide such services. Each market player has to balance consumption and generation for its customers, either directly themselves or by finding another player able to provide the required energy. Those Balance Responsible Parties (BRP) are made liable of the overall supply demand alignment.

On the French energy market, suppliers buy electricity ahead of time and generators produce as per end-customers’ need. Suppliers have the right to modify their purchases, and generators their production program, until the “gate closure”, typically one hour before real time. The TSO is the ultimate real-time demand-supply orchestrator.

Capacity markets contracts “obligated” market players, mostly suppliers must hold mobilizable capacities in proportion to the maximum consumption of their customers at peak times. For a supplier, “holding capacity” means having purchased capacity certificates from producers. RTE[53], the French TSO, issues such certificates to producers, up to the amount of their yearly production capacity.

Curtailment is the first flexibility mechanism that has been gradually integrated into the market, now followed by storage. A curtailment operator capable of shaving 100 MW on a very cold day (for a certain number of hours) obtains a 100 MW certificate, exactly as a certificate issued to an electricity producer. Curtailment aggregators can participate in the energy market as well as in the capacity market. To ensure curtailed powers are accurately balancing the needs of the electricity grid, RTE has two solutions: calling for and purchasing curtailment bids on the MA[54] mechanism or trading curtailment demands and supplies on the NEBEF mechanism[55].

Local flexibility – and the involvement of DSOs – is emerging and is already integrated in the Clean Energy Package. In fact, curtailment not only avoids producing electricity and building generation capacity but also transporting electricity and upgrading the grid itself. This mechanism will become more important as the intermittent and distributed renewable production increases.

2.6. Regulatory rules must evolve to remunerate flexibility

A liberalized competitive electricity market calls for regulation and coordination of the players. Walking away from historical production monopolies does not mean that pure market laws should apply. Such a competitive market is an ecosystem in which competitors (e.g. power generation companies, energy suppliers) interact with other, often still (regional or national) monopolistic players of the value chain (e.g. TSOs, DSOs). All these players need new legislative frameworks and market rules. The remaining “natural monopolies” rely on specific regulations which define their remuneration models to plan investments in the long term. In practical terms,

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[53] RTE : Réseau de Transport d’Electricité
[54] Mécanisme d’Ajustement
[55] https://clients.rte-france.com

regulations steering TSOs and DSOs were inherited from the past and often tend to support more traditional investments. With current and future energy transition and digital AIoT realities, there is a need to revisit regulations, market rules, pricing formulas, balancing mechanisms to make sure latest opportunities are fully harvested and virtuous incentives are created.
For market-based competitors, as the share of intermittent renewable generation progresses, the European dispatch rules and notably the merit order definition will have to include curtailment and grid penalty for excess renewable intermittent generation as it is the case in China (see Topic Box 'Stationary batteries electricity storage in China') which, in early stages of solar and wind deployment, was never imagined. To the opposite, renewable energy had the absolute undisputed priority to "feed" the grid.

Remuneration models for (regional or national) TSO monopolies should also evolve to better align with new realities. These remuneration models reward TSOs and DSOs for the utilization of infrastructure and incentivize them to invest in further expanding the physical grids. Typical grid tariffs are revised on a periodic basis by the regulators (e.g. the French TURPE[56] tariffs are revised every five years). Such tariffs ensure the independence of TSOs and DSOs from electricity markets while allowing fair access to electricity for all consumers all over the territory by imposing a single price of power grid utilization for the end-users, regardless of their location.

Fig 25: Grid component of French residential customers bills as of 1 August 2019 (TURPE 5)

Management component	€12.72/year
Metering component	For subscribed capacity from €3 to 15 kVA: €20.4/year
	For subscribed capacities equal or above 18kVA: €20.4/year
Racking component	According to utilization

Source: https://prix-elec.com/energie/comprendre/turpe

Tariffs define a remuneration rate for the utilization of the Regulated Asset Base (RAB) which is invested and managed by the TSO or DSO. The corresponding investments are usually very significant and often slow to implement both due to lack of support from public opinions fearing environmental impact and due to intrinsic large infrastructure construction complexities. Geared to ensure adequate return on investment for massive multi-year assets' constructions, those regulated tariffs do not provide nimble incentives for fast adaptation to fast changing generation, storage and consumption landscapes. Typically, software licenses, OPEX costs, digital services and other intangible assets will not be included in the RAB base, and thereby, will not be supported by the tariff formula. However, such solutions usually require more limited budgets and can be implemented faster. They constitute more reactive solutions to address the pressing real-time demand-supply balance need in a fast-changing connected world.

Regulators became aware of this pricing bias and currently investigate alternative schemes which would signal the appetite for different solutions, namely for "less coper but more fiber". The French regulator CRE organized a public consultation on 14 February 2019, about the future tariff regulation which should apply to regulated electricity infrastructure operator. That consultation identified the need for new levers to encourage open innovation data and IT-based solutions, as well as more broadly new contract mechanisms.

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[56] TURPE: Tarif d'Utilisation du Réseau Public d'Electricité

SUPERCONDUCTIVITY

BENEFITS FOR THE ELECTRICAL SYSTEM

HISTORY

Superconductivity was discovered in 1911 by physicists in the Netherlands. They observed that below a certain critical temperature Tc, the electric resistance in some materials drops to zero. The potential applications of this phenomenon mobilized massive efforts for more than a century, making a few Nobel prize winners in the process. Theoretical work (seeking better understanding of this effect) and experimental work (e.g. succeeding to increase Tc) were both conducted and rewarded over time.

Applications seemed extremely promising since no resistance means no energy loss in power systems and very short time responses in electronics. Unfortunately, for 75 years, Tc leveled around 20 K or -250°C. The materials being used were essentially various metals and metal alloys out of which electric wires could easily be made.

In 1986, two physicists discovered a new class of materials which allowed to increase Tc. This resulted in a worldwide competition which brought Tc around 100 K or -170°C.

PRESENT DEVELOPMENTS

It is very tempting to use superconducting cables to transport energy since there is no energy dissipation. As an example, the energy loss in well-maintained European grids is around 10%[57] of the total energy produced. At the scale of France this implied that around five nuclear plants only work to “heat the cables”.

Large scale experimentations have been conducted during the past years to check the feasibility of transporting power in superconducting cables. For instance, a link, long of more than 500 meters, was installed in the US by Long Island Power Authority (LIPA)[58]. In this case, the superconductor was a copper oxide, cooled around nitrogen temperature.

Superconductors are being tested in distribution power cables, where increasing density of populations requires to bring more power. In order to avoid civil engineering works, existing conducts (initially built to host classical cables) are reused. For example, superconducting cables are implemented in the distribution network of downtown Essen by RWE in Germany.

Research is now taking place to build superconducting electric generators. Nacelles of wind turbines could host more powerful generators without having to change existing masts.

Superconductivity is intensively adopted in medical devices such as MRI[59] and is one of the most promising technologies supporting quantum computers.

FUTURE DEVELOPMENTS

Research is ongoing to increase acceptable temperature and decrease costs of superconductors. The extreme of superconductivity at room temperature may not be reachable but is worthwhile pursuing to:

Save around 10% of the electricity energy transported;

Ease electricity distribution in very dense areas;

Build smaller and lighter power generators;

Perhaps equip quantum computers.

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[57] In the French electrical system, there are presently 2% losses in transportation, 6% in distribution and 2% in transformer stations

[58] https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/LIPA__5_16_08.pdf

[59] MRI: Magnetic resonance imaging

We described how grid strengthening should not only mean physical capacity expansion (which probably was fit for purpose for times of centralized energy generation and top-down distribution) but equally mean “smartification” and digitization thanks to forecasting solutions, AI-based optimizers and real-time resilient control capabilities.

Such digital solution would require more limited investments and could be deployed faster. They would also better fit the new reality of more distributed power generation and more engaged electricity customers, be they consumers or corporations.

We also covered the necessity to adapt the market rules and regulation to incentivize TSOs and DSOs towards digitization as well as to properly reward new players for the contribution they could make to the flexibility challenge.

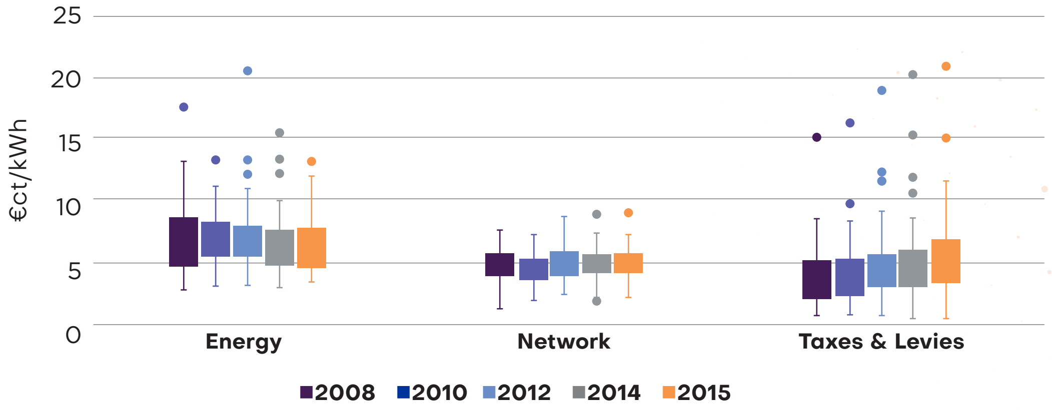
3. ELECTRICITY DEMAND IS MORE COMPLEX

After reviewing the present retail prices components and the impact of renewable generation on the total price, we will analyze customer's patterns change (consumers become more prosumers) and different economic and regulatory measures which would incentivize them to participate in load balancing.

3.1. Retail prices components vary according to customer segments and countries

Retail prices refer to the prices paid by the final customer, be they consumers / households or corporations / businesses. Retail electricity prices are typically divided into three components: energy, network and taxes & levies. The energy component reflects the generation stage, the network component relates to the transmission and distribution stages and taxes & levies finance policy support costs and other regulated activities.

Fig 26: Evolution of retail electricity price for households in Europe per invoice component (energy cost, network and operation cost, and taxes)



Source: European Commission

Fig 27: Components, subcomponents and elements of retail electricity prices

	RETAIL PRICE FOR ENERGY		
Components	Energy	Network	Taxes & Levies
Sub components		Transmission Distribution	Renewable and CHP Social Nuclear System operation Market operation Energy Efficiency Security of Supply Environmental and excise taxes Other VAT
Elements	Wholesale energy cost Supply costs		Individual taxes financing general state budget Ear-marked levies financing policies Impact of meeting obligations

Source: ECOFYS Study https://ec.europa.eu/energy/sites/ener/files/documents/report_ecofys2016.pdf

In Europe, electricity retail price varies significantly amongst customer segments and countries:

- **Households & Residentials:**
  - On average, the energy share constitutes 20-30% of electricity retail price with significant discrepancies from one country to the other,
  - Network costs typically constitute 40% of the total retail price, out of which distribution costs account for 70% in average with few countries' exceptions,
  - In countries with large shares of renewable energy sources (RES) in the electricity mix, taxes and levies (that typically include support to RES) can significantly increase the total price. Their share can amount to up to 68% of the total price (including VAT) as it is the case in Denmark and Germany,

- **Small and Medium Enterprises (SMEs) & Small Industries:**
  - In the taxes & levies component, RES support, and environmental taxes are the most relevant price elements. Their share in total price varies between 1% and 46%,
  - The share of the network component accounts on average for 40% of the total retail price,

- **Energy-Intensive Industries:**
  - Prices are significantly lower than for other customers segments and differ in their structure,
  - In several Member States, taxes and levies imposed on energy-intensive customers are recoverable and significant reductions and exemptions exists,
  - The energy component is dominant with a 65% to 75% share in the total retail electricity price,
  - Network costs represent a share of 17% on average. Energy-intensive industries are typically connected to medium-voltage or high-voltage level and, de facto, contribute less to costs of the distribution grid.

3.2. Renewable generation impact on retail prices

There are many analyses showing that RENewable electricity generation (REN) increases overall retail electricity prices for three reasons:

- First, intermittency means that ancillary services costs to maintain reliability increase substantially. For example, given current cost structures, the installation of renewables is frequently paired with the construction of natural gas "peaker" plants in some countries that can quickly and relatively inexpensively cycle up and down, depending on the availability of the intermittent resource;

- Second, renewable power plants requiring ample physical space, are sometimes located offshore, are often geographically dispersed, and are frequently located away from population centers, all of which raises transmission costs above those of schedulable plants;

- Third, renewable energy penetration growth can also raise total energy system costs by prematurely displacing existing productive capacity, especially in a period of flat or declining electricity consumption. Adding new renewable installations, along with associated flexibly dispatchable capacity, to a mature grid infrastructure may create a glut of installed capacity that renders some existing baseload generation unnecessary. The costs of these "stranded assets" do not disappear and are borne by some combination of generating companies, end consumers and ratepayers. Thus, the early retirement or decreased utilization of such plants can cause retail electricity rates to rise even while "near zero marginal cost renewables" are pushing prices down in the wholesale market.

  According to a study of University of Chicago in May 2019, comparing renewable portfolio standard (RPS) states vs. non-RPS states in the US, electricity prices increase substantially after RPS adoption. The estimates indicate that in the 7th year after RPS adoption, average retail electricity prices are 11% higher. And, 12 years later, they are 17% higher. The largest estimated increases are met in the residential sector, but there are economically significant price increases in the commercial and industrial sectors too.

How could REN integration cost be minimized?

Several studies show that REN integration costs can be minimized if system flexibility is increased notably by adding stationary storage on the grid, increasing interconnections and increasing Demand Side Response (DSR) by Time-of-Use tariffs or direct remote control for instance.

Imperial College analyzed several flexibility scenarios on UK grid costs for 2030:

- They assumed different scenarios of PV/wind penetration bundled with various ranges of DSR, distributed storage or interconnections shares:

1. **Mid Flexibility ("Mid Flex"):** Central scenario with high wind deployment, reaching up to 31 GW of offshore and 20 GW of onshore wind in 2030. This scenario has moderate levels of nuclear (8.2 GW), assuming the addition of 4.5 GW of new capacity by 2030, and 20 GW of PV capacity. It also has a moderately high deployment level of flexible options: 10 GW of new distributed storage, 50% of DSR uptake and 11.3 GW of interconnection capacity,

2. **Low flexibility ("Low Flex"):** Same as Mid Flex, but with less ambitious deployment of flexible options: 5 GW of new storage, 25% DSR uptake and 10 GW of interconnection,

3. **Modernization:** Same as Mid Flex, but with a range of measures to improve system operation (concerning wind predictability, capability to provide ancillary services etc.),

4. **High flexibility ("Mega Flex"):** Scenario with similar generation mix as the Mid Flex, but with enhanced flexibility i.e. higher storage (15 GW) and interconnection capacity (15 GW) and greater DSR uptake than the Mid Flex (100%),

5. **Onshore Capped:** Scenario with no new onshore wind deployment beyond today's level (dropping to around 8 GW by 2030 due to decommissioning) but compensated by a more intensive expansion of offshore wind until 2030. Nuclear and PV capacity are at the Mid Flex level,

6. **Nuclear Centric:** This represents a theoretical alternative technological solution to a high variable LCGT[60] mix for achieving the UK's decarbonization agenda. Whilst a more ambitious nuclear expansion in this scenario (16.4 GW in 2030) seems unachievable to deliver from today's perspective, this scenario nevertheless offers a useful benchmark to assess the cost-effectiveness of an energy mix with high levels of variable LCGT. The scenario therefore has slower wind development (up to 21 GW of offshore and 12.5 GW of onshore wind, compared to 5.1 GW of offshore and 9 GW of onshore today),

7. **No progress ("No Flex"):** Same as Mid Flex, but with no new storage, zero DSR uptake and low interconnection capacity and is broadly reflecting today's situation. Although largely theoretical, this scenario nevertheless offers a useful benchmark to assess the benefits of flexibility,
   - ➜ Then, they analyzed OPEX and CAPEX impacts of those scenarios on UK grid in 2030;
   - ➜ The overall system cost in 2030 is by far the highest in the No Flex scenario, while the Low and Mid Flex scenarios deliver savings of about £3.5 billion per year and £4.0 billion per year, respectively, over the No Flex scenario;
   - ➜ Scenarios with modest levels of flexibility already deliver substantial cost savings over the No Flex scenario because they require less low-carbon generation to meet the carbon target, less conventional generation to meet the security criterion and less distribution CAPEX due to reduced peak loading driven by the utilization of distributed storage and DSR. These savings are only slightly offset by the additional cost of storage and interconnection;
   - ➜ It is worth noting that already in the Low Flex scenario, which is broadly half way between the No Flex and Mid Flex scenarios in terms of flexibility deployment, the net system cost savings amount to about 80% of those found in the Mid or Mega Flex scenario.

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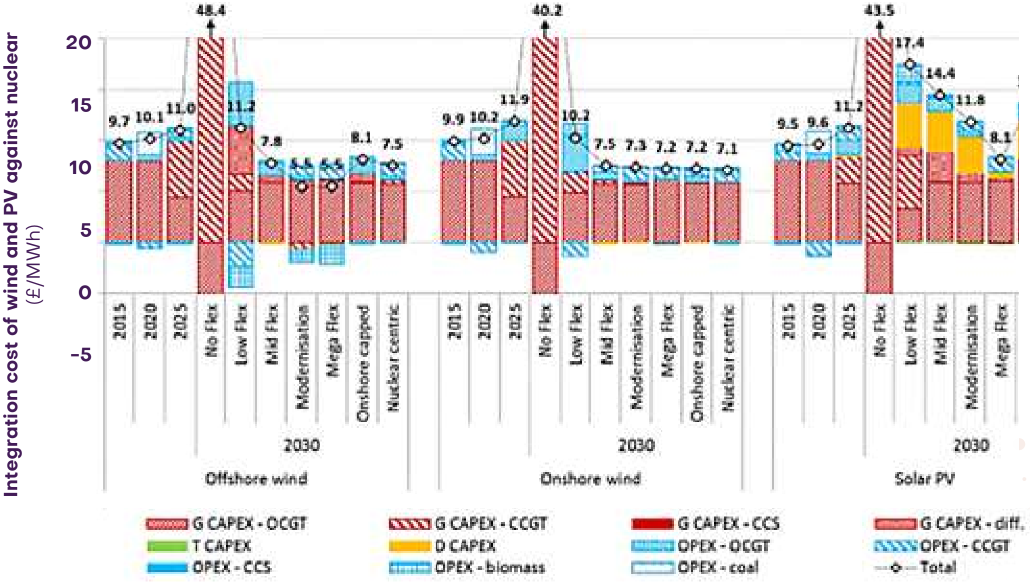
[60] LCGT: Low Carbon Generation Technology

- The overall system cost in 2030 is by far the highest in the No Flex scenario, while the Low and Mid Flex scenarios deliver savings of about £3.5 billion per year and £4.0 billion per year, respectively, over the No Flex scenario;
- Scenarios with modest levels of flexibility already deliver substantial cost savings over the No Flex scenario because they require less low-carbon generation to meet the carbon target, less conventional generation to meet the security criterion and less distribution CAPEX due to reduced peak loading driven by the utilization of distributed storage and DSR. These savings are only slightly offset by the additional cost of storage and interconnection;
- It is worth noting that already in the Low Flex scenario, which is broadly half way between the No Flex and Mid Flex scenarios in terms of flexibility deployment, the net system cost savings amount to about 80% of those found in the Mid or Mega Flex scenario.

Fig 28: Estimate 2030 system integration costs for offshore wind (left), onshore wind (center) and solar (right)



Note: No flex reflects today's situation. Low/mid flex add 5/10GW of new storage and 6/7GW of new interconnectors. CAPEX refers to capital costs for generation (G), local distribution networks (D) and regional transmission networks (T). OCGT and CCGT are open cycle and combined cycle gas turbines respectively. CCS is carbon capture and storage

Source: Imperial College

Several other studies go in the same direction and demonstrate that grid flexibility, even if REN generate some extra-operating costs for ancillary services, can limit REN system integration costs and make their business case attractive vs. scenario without flexibility. As a last example, let's look at how CRE (French Energy Regulator) "advised" RTE, the French TSO, about its 2030 investment plan:

> **"the integration of flexibility solutions – beyond production limitations – into the dimensioning of the network is a potential savings lever which must be better considered by RTE. The flexibilities could manage congestion and, thus, delay or even avoid network developments and reinforcements. They should be systematically considered before making an investment decision."**

3.3. Dynamic consumption tariffs enable Demand Side Management

Renewable intermittent generation increasing share of the electricity mix, combined with new consumption patterns, makes balancing electricity supply and demand more complex.

With tools such as weather forecast, renewable supply-side management has improved. One way to improve demand-side management and to allow, in the same time, consumers to benefit from low prices when renewable generation is high, is to implement dynamic pricing.

Presently, dynamic pricing is offered by retailers even if it could also be implemented by grid operators, helping them achieving a more cost-efficient system.

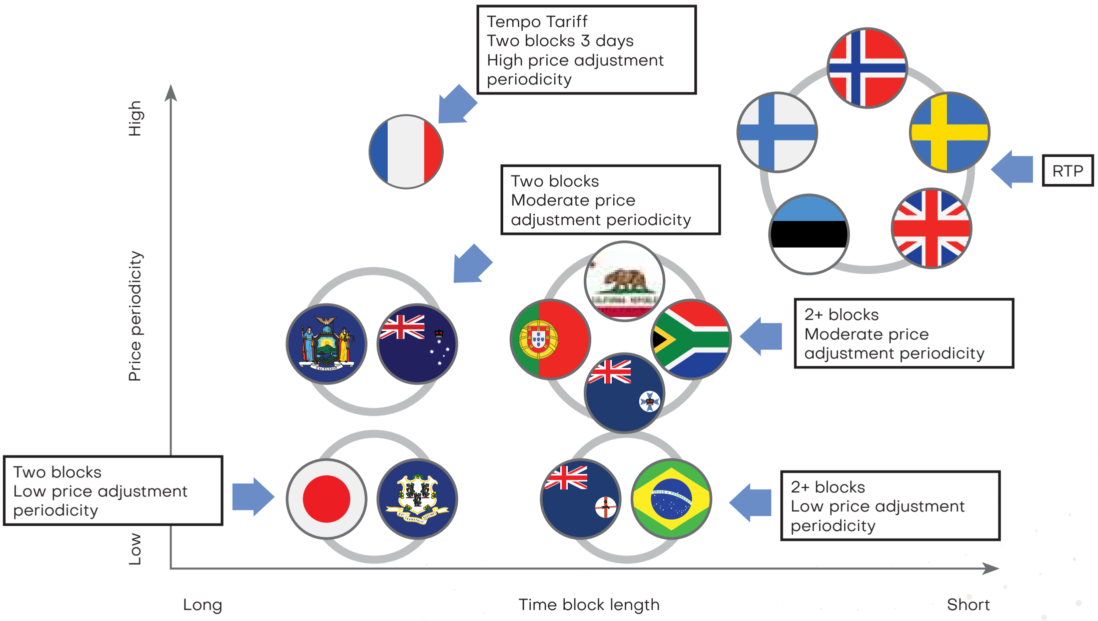
Dynamic pricing is widely used by the industry sector that has been equipped, for a long time, with smart meters.

The deployment of smart meters for residential customers, given they are equipped with the adequate functionalities, paves the way to the implementation of dynamic tariffs and other ancillary services for consumer segments.

Dynamic tariffs vary from Time-of-use (ToU) tariffs, in which the time blocks and the price corresponding to each time block are periodically revised to real-time pricing (RTP), where the price varies following changes in the wholesale electricity market prices. Other types of dynamic tariffs lie between these two extremes: in critical peak pricing (CPP), when market electricity rates are the highest or the grid is extremely constrained, the consumer pays a higher price at different periods of the day or for different days during the year. In peak time rebates (PTR) the customer receives a discount for reducing the load.

In Europe, Norway, Sweden, Finland, Estonia, and Great Britain have high price periodicity, and thus are the most advanced European countries when it comes to the adoption of dynamic tariffs. In these five countries, electricity retailers provide real-time pricing offerings to their customers.

Fig 29: Types of dynamic retail tariffs in different countries



Source: Dynamic Retail Electricity Tariffs: Choices and Barriers, April 2020 - Florence School of Regulation

Spain, where the regulated tariff for electricity is set hourly, offers interesting innovative tariffs. For example, Iberdrola and Endesa offer customizable time slots or days of rebate or variable discount rates. As an Iberdrola customer, one can choose eight consecutive off-peak hours to be scheduled at convenience, special rates for nighttime or weekends, special rates for summer or winter. And as an Endesa customer, one can choose two free hours per day, one free day per week, a special rate for nighttime or an offer providing supplementary and progressive discounts if more than 50% of electricity if consumed during off-peak periods.

Austria is also very innovative, particularly with the retailer's flexible offers aWATTar and its hourly prices that vary according to the weather. Prepaid tariffs exist in the UK and soon in Italy, as a way to combat fuel poverty[61].

The UK is one of the most mature markets in Europe. Regulated tariffs do not exist anymore, and several hundreds of retailers compete in this market, even though six major companies total 80% market shares. 82% of the residential segment is equipped with a smart device (offered by retailers) providing them with real-time information on their consumption (in kWh and in £); customers testify that this incentivize them to adapt their behavior. Contrarily, in France, only 1.5% Linky users have created an online customer account however, Linky's deployment is recent and customers are still going through a learning curve. EDF and Engie have launched special weekends offers with lower tariffs. Total-Direct Energie, the third biggest retailer, proposes super off-peak prices (50% rebate compared to normal tariff) between 2 a.m. and 6 a.m..

However, to gain the maximum potential of dynamic end-user prices, dynamic network tariffs and dynamic electricity price on the spot market should be combined. Of course, such transparency and richness of possibilities will make tariffication more complex: contracts could be more difficult to read for consumers and solid IT management would be required to operate huge data repositories, adequate forecasting, and reporting tools.

On the customers side, home insulation improvements and behaviors changes are also needed to save money on bills.

3.4. Remote control curtailment aggregation is enabled by technology progress

While the key feature of innovative energy markets is often described to be the shift from pure consumer to mixed consumer-producer ("prosumer") attitudes, demand shaving or simply demand postponement may be an even more powerful and "universal" shift.

From a network perspective, such consumption avoidance is similar to distributed production (it, indeed, constitutes "negative generation"). Some specific devices are needed to organize and perform real-time consumption adjustment in communication with the electricity supplier for residential consumers; for corporate consumers, the communication can be directly with the TSO (ensuring the market balancing).

The historical version of this process has been manually implemented by the TSOs in coordination with large industrial sites. In said cases, often the customer had subscribed for a discounted contract accepting not to pull electricity from the grid at certain time intervals or during peak days. The technical system ensuring customers curtailment was a phone call from the electricity supplier to the industrial facility informing them ahead of time (typically the evening for next day) that their demand would be curtailed.

Regulation evolved and schemes emerged, enabling curtailment operations either by the supplier or by another entity (e.g. NEBEF[62] , MA[63]), but the practical implementation question of automatic demand response remains a challenge. Notably, how to technically access the existing resources for peak demand shaving?

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[61] A household is said to be in fuel poverty when its members cannot afford to keep adequately warm, given their income

[62] Notification d'Echanges de Blocs d'Effacement https://www.services-rte.com/fr/decouvrez-nos-offres-de-services/valorisez-des-effacements-nebef.htm

[63] https://bilan-electrique-2018.rte-france.com/balancing-mechanism/?lang=en

Such demand flexibility can be obtained by widely and automatically aggregating "atomic" individual saving potentials with IoT solutions. Electrical devices, such as public lighting, air conditioning, or electric heaters can be connected via IoT solutions and controlled remotely by aggregators, who slightly tune the consumption of such devices to discharge electrical networks. AIoT automated solution can operate large-scale aggregated real-time consumption adjustments and balancing out demand peaks and regulating the electrical network. AIoT is the key to automation, aggregation and real-time control of individually small loads which, otherwise, could not have made a valuable impact.

Technical aggregators have become experts in understanding the electric consumption of their clients and how to optimize it, be they industrial plants (e.g. Energypool) or residential housing (e.g. Voltalis). They equip relevant electric devices (electric heaters for Voltalis) with connected controllers and remotely run demand response, as seamless as possible for their clients.

In that regard, two phenomena happen to be critical: consumption postponement and rebound effect. Consumption postponement arises from the fact that nominal consumption is a priori already minimal, hence an almost constant quantity of energy is needed for operations, and it is mostly the time of use of this energy which is shifted. As the energy will be consumed at some point, it still has to be produced. For instance, a 100% postponement effect has been observed in experimental implementation of demand response using residential water heating[64] . Rebound effect is a consequence of device resynchronization to its standard setpoint after demand response. Rebound can reach up to 50% of the power saving but can be controlled with specific and progressive restart of devices.

Revenues are twofold: the cost savings for the consumer, and the regulation revenue for the aggregator. Because technical aggregation requires important IoT infrastructure equipment, the economic model is sustainable only if the investment made by the aggregator is compensated by the regulation revenue[65]. The mitigation of consumer unavailability becomes key when it comes to securing residential housing aggregation revenue and can be addressed combining a critical mass of consumer.

The aggregator's remuneration depends also on the financial amount it must return to the supplier. For example, in the US, regulation is more favorable to the aggregator than it is in France.

Benefits for the network are clear, but demand response does not directly compete with total electricity generation because of the postponement effect. On the contrary, generation strengthening and demand response are two very complementary tools when facing demand peak.

Because of the Covid-19 crisis, nuclear generation will be lower than expected, consumption flexibility, notably through demand response, will be crucial on French electricity market for the winter 2020-2021[66].

Demand flexibility represents a true opportunity for decentralization and modernization of electrical networks, complementing electrical network investment with IoT network development. Technical aggregators can address energy saving reservoir equipping industrial sites, buildings, or residential homes with intelligent devices connected to the internet and controlled remotely. The successful implementation of such system relies on the availability of a system able to collect a wide range of information flows and to control a large number of diverse smart devices while running real-time optimization.

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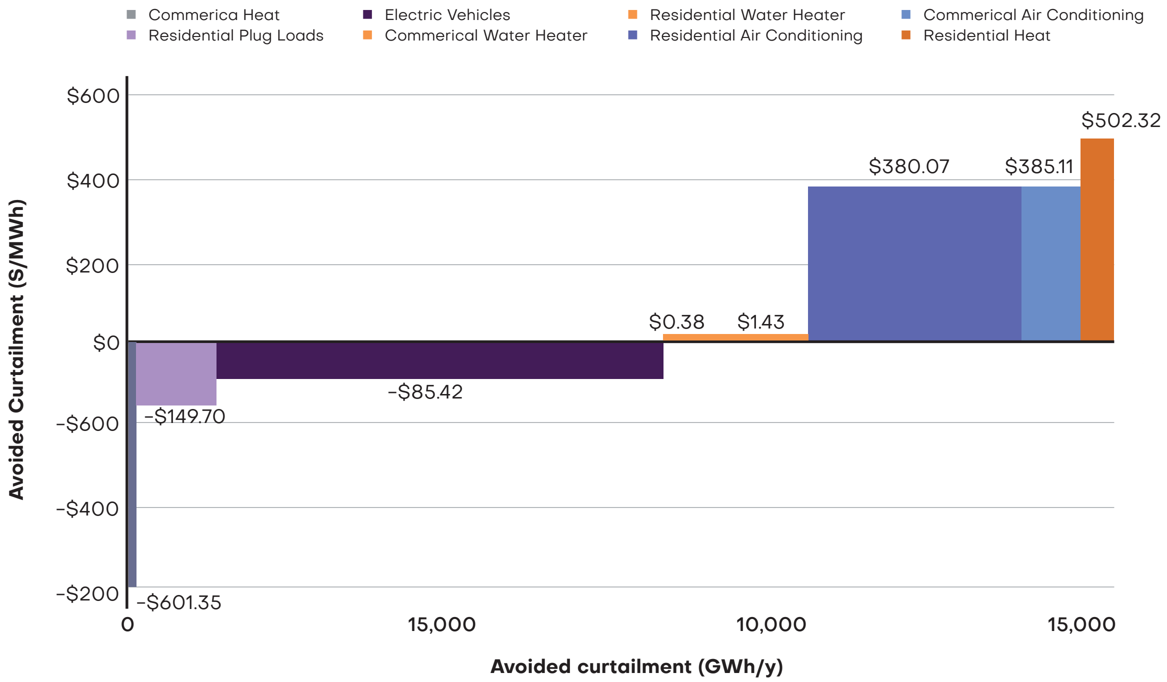
[64] Systèmes Electriques Intelligents Premiers résultats des démonstrateurs, ADEME.

[65] Systèmes Electriques Intelligents Premiers résultats des démonstrateurs, ADEME.

[66] https://media.rte-france.com/point-securite-d-approvisionnement-en-electricite-des-francais/

Fig 30: Avoided curtailment



Source: https://www.ee.co.za/article/demand-flexibility-key-enabling-low-cost-low-carbon-grid.html

Analysis of demand flexibility sources in Texas:

Commercial space heating, plug loads, EVs and electric water heaters are inexpensive opportunities to reduce peak net load and renewable energy curtailment. Water heaters, EVs and plug loads require only a relatively minor investment in communications technologies to enable flexibility. Commercial building-space heating requires additional capital investment in dedicated thermal storage capacity but this incremental cost is more than justified by peak-net load reduction; even after other end uses reduce peak summer net loads in a highly renewable Texas grid, space heating can still significantly reduce remaining winter peaks.

By combining a portfolio of demand flexibility strategies, it is possible to achieve approximately 90% of the total benefits of demand flexibility at a net cost savings. This cost-effective portfolio would avoid approximately $1.5 billion per year in annualized generator and transmission & distribution capital costs, $400 million in avoided fuel costs, and 6 million tons per year of CO^2 emissions (i.e. approximately 20% of annual emissions).

3.5. Self-consumption is developing, boosted by renewables and helped by regulators.

3.5.1. Self-consumption definition and market context

Self-consumption is mainly composed of three types of prosumers group[67]:

- Individual self-consumption: electricity is produced and consumed simultaneously in a given location by one household;
- Collective self-consumption (CSC): it concerns electricity produced and consumed by several consumers and producer(s) located on the same low-voltage grid;
- Energy Communities: this qualifies entities that are set up as a legal entity, effectively controlled by their shareholders or members, with the primary objective to provide environmental, economic and social community benefits rather than financial profits. Energy communities can be categorized in three sub-categories:

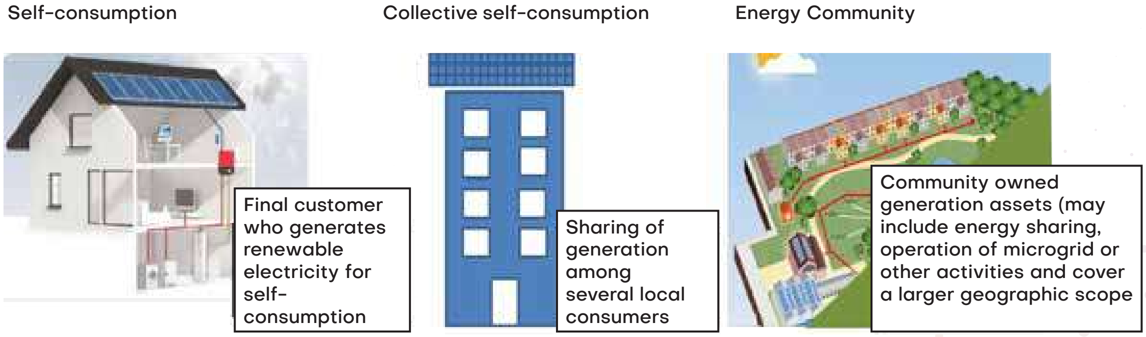
    - ➜ Community-owned generation assets: this is currently the most common type of energy community. The members of such communities usually do not self-consume the energy produced but rather sell it to a supplier. The income is typically shared between members and/or reinvested in energy projects. The activities of such communities can be larger and can include a social component – for example the provision of energy efficiency services – but usually do not consist of an active role in energy markets,

    - ➜ Virtual sharing over the grid: some energy communities, which own and operate generation assets, do not only share the profits but also share the energy produced among their members. This type of sharing can be organized through a common supplier who takes care of the matching between production and consumption and supplies additional energy if needed. A community can also be a vehicle to organize collective self-consumption e.g. in France,

    - ➜ Sharing of local production through community grids: physically sharing energy through a community grid constitutes the actual essence of the project. These kinds of communities have emerged in specifically demanding contexts such as on islands without connection to the mainland. Such communities are not new phenomenon and have emerged from a need to generate electricity away from the main grid. More recent initiatives aim at setting up local grids in areas with existing grid connections. Such initiatives can be driven by the wish to consume local energy or can be organized by energy companies willing to experiment microgrids. Post Covid-19 societal evolutions could be favorable to such emerging trends but this is too early to tell.

Energy sharing, be it directly or within energy communities, blurs the classical market definitions. Energy communities may act as a supplier, as a service provider (e.g. providing aggregation services) or, if allowed by the relevant European Member State, as a grid operator. These activities fall under the realm of the Electricity Market Regulation and, consequently, call for attention.

Fig 31: Diagram showing self-consumption, collective self-consumption and energy community



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[67] https://www.compile-project.eu/wp-content/uploads/COMPILE_Collective_self-consumption_EU_review_june_2019_FINAL-1.pdf

Self-consumption rate (i.e. consumption divided per self-production) will vary per customer group:

- Standard residential consumers are likely to self-consume about 30%, while the rate can be increased to 65-75% thanks to demand-side management and decentralized energy storage;
- Commercial customers (e.g. department stores, office buildings etc.) with PV installations, can exhibit high rates of self-consumption (e.g. 50%-80%) thanks to the relatively good match between the consumption load profile and the onsite production (i.e. mainly day activities).

Those different prosumers profile & self-consumption rate will target different business models:

Fig 32: Prosumer business models

Optimising self-consumption rates without using the public grid
- Individual self-consumption optimised with storage and energy management systems (EMS)
- Collective self-consumption optimised with storage & EMS in a building
- Microgrid with Solar, storage and EMS

Optimising local self-consumption rates using the public grid
- Collective self-consumption with solar and EMS at neighbourhood level
- Peer to peer trading

Providing flexibility services at system level
- Aggregated solar & storage self-consumers (Virtual Power Plants)

Source: Solar Power Europe

With significant recorded and expected PV and storage costs reductions, interest for self-consumption in Europe is increasing:

- In Germany, in 2018, residential PV already accounts for 1,000,000 systems and 6 GW installed which is more than 40% of the newly installed national PV capacity;
- In Spain, around 1 GW of self-consumption solar is already installed, according to the Spanish Association of Renewable Energy Enterprises (APPA). Around 800 MW of this was installed in the last three years, half of it in 2019;
- In France, the French DSO (Enedis) counted 20,000 self-consumers end of 2019.

By 2035, French TSO (RTE) considers that self-consumption could represent ~10 GW of production and concern 3.8 million households, when Enedis, the French DSO envisions, for the same time horizon, 2 to 3 times more self-consumption volumes than French TSO.

3.5.2. Regulatory context

While individual self-consumption is possible in most Member States, collective self-consumption is a more emerging concept. Some Member States have already put forward legal frameworks for collective self-consumption or are in the process of developing new ones.

In 2016/2017 important legislative changes were introduced in Austria, France, Germany, and Switzerland related to the direct use of locally generated electricity, by the tenants in multi-family houses or commercial buildings, via a private grid. In 2016, Greece passed a law on virtual net metering which was complemented by a law on energy communities in 2018. Wallonia and Slovenia recently adopted laws on CSC[68] and energy communities. On 1 January 2020, the new Portuguese legal regime entered into force. The new Portuguese legislation aims at simplifying the licensing process and the guiding rules applied to self-consumption plants (UPAC) and to speed up the obtention of regulatory authorizations. In addition, not only is self-production of energy now possible, but also is sharing electricity with neighbors and surrounding dwellings.

In a few Member States, collective self-consumption exists outside of a dedicated regulatory framework. In several cases, CSC is allowed by regulatory exceptions. For examples:

- In the UK, it is permitted to connect to a neighbor via a private line. In this way, a chain of properties can be formed if there are no breaks caused by public roads or non-participating properties. However, it is prohibited to connect the private system to the public grid at any point. This also applies to communal buildings;
- In Finland, collective self-consumption is currently only allowed in locations where the connections are under an industrial network or a real-estate network that does not cross public land.

Several Member States aim at linking regulatory boundaries to physical boundaries of the energy system, materialized, for instance, by the Low Voltage and/or the Medium Voltage transformer station (e.g. Austria or Spain). This approach inks physical and regulatory features, in terms of grid management or tariff setting in relation to the used network segment. Several Member States are currently developing local grid tariffs (e.g. Austria and Belgium). Tariff setting is a core parameter to support energy community concepts but remains challenging as it must take into account the impact of energy communities on the system and guarantee a reasonable distribution of system costs over all customer groups.

3.5.3. Self-consumption tariffs

The self-consumed electricity is mainly exempted from payment of variable grid costs and other system charges.

In theory, self-consumption could reduce the need for grid extension on a local level, even if the consumption and generation profiles are never perfectly coinciding. Additionally, distribution systems usually face peak demand in the evening, when PV production is not available and thereby cannot have positive impact on the distribution system dimensioning.

Consequently, distribution grids are still dimensioned as if there was no self-consumption and the DSO must dimension the grid capacity to deliver the requested demand at any time during the year. The total grid costs are not significantly decreased with the increased level of self-consumption, as the grid costs are mainly driven by the system capacity.

As a paradox, self-consumption is even reducing the surface over which fixed grid costs are distributed (as part of the demand is no more using the grid, without enabling it to downsize, though), making fixed grid costs proportionally more important as a share of the delivered electricity bill.

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[68] CSC: Collective self-consumption

This issue is becoming more relevant with the large-scale deployment of self-consumption and it led some countries to change their legal framework by introducing capacity tariffs to be paid by prosumers (Belgium Wallonia in 2015) or to make retroactive introduction of additional system costs for self-consumed electricity (Spain for a capacity higher than 10 kW named as the "grid back-up toll").

The question of cross-subsidization among consumers' categories and the question of DSO cost recovery are inherent to self-consumption. The cross-subsidization will benefit to prosumers if volumetric grid tariffs are used instead of the capacity-based tariffs: Self-consumption, if exempted from paying the grid costs, causes shifting of these costs to other consumers without own distributed generation system. The opposite holds true: in case of capacity-based tariff, prosumers will not yield benefits from their reduced usage of the common network.

Volumetric tariffs are directly encouraging self-consumption, as the grid costs are being fully avoided. If the grid costs are charged only through the capacity-based tariffs, grid costs for the prosumer are reduced only if self-consumption reduces the peak load. Hybrid models exist, combining a flat component (€/consumer), a capacity-based component accounting for the maximum mobilizable capacity and volumetric tariffs.

An increased share of self-consumption can have additional negative effect on DSO cost recovery, especially in countries with longer regulatory pricing period. In some of the observed countries, the net distributed electricity is decreased to such an extent that DSOs are exposed to a volume risk that they cannot control, with possible financial consequences

For those reasons, in current context, we can expect that:

- Prosumers will continue to be charged for fixed grid costs through capacity tariffs for prosumer's tariff group;
- Volumetric grid tariffs for prosumer's tariff group will reflect the variable network and system costs.

This context will change rapidly, as storage becomes affordable, allowing prosumers to use their daylight production in the evening peak load without resorting to the grid. Incentive can be put in place to push prosumers to store and get even more independent from the grid, even for peak hours. In such context, and with a growing share of self-consumption in Europe in the coming years, each Member State regulator will have a difficult equation to solve between opportunity to avoid capacity investments and risks to shift fixed grid costs to non-prosumers profiles.

BI-DIRECTIONAL V2G

PROSPECTIVE REVENUE

Broader EV adoption will come with challenges: significantly higher electricity demand compared to other electric loads of a classic house or building, unknown consumption pattern, intrinsic instability linked to fast ramp up. As an early adopter and the host country for the largest fleet of electric vehicle deployed to date, China is already facing those challenges. In large modern cities like Shanghai, the power grid reached such limitations that additional EV charge points cannot be added in parking lots. This is becoming a limiting factor for potential EV buyers, be they companies or individuals. Work around solutions are emerging such as prosuming (producing locally, in a microgrid mode, part of the needed electricity), storage (refilling batteries during night so that employees can charge in parallel from the grid and from batteries during their day time presence at the office) or even robot mobile chargers (Envision developed such a product under the brand name Mochi).

However, EVs can be as much a solution as they can be a problem… As electric vehicles sit idle 95% of the time, potentially connected to the power grid, they can provide in a near future a major source of flexibility complementary to stationary batteries. Considered as a distributed park of highly reactive battery systems, they can offer unparalleled grid services revenue opportunities offsetting partially extra EVs costs without deteriorating drivers' expectations with respect to car autonomy.

Mono-directional (from the grid to the EV) services offer possibilities of demand reduction during "rush hours" (so-called peak shaving). Instead of starting the charge at 8 a.m. or 7 p.m., when "everyone" arrives at work or back home, cumulating with other peak loads of the workplace or the residential building, smart chargers can ensure a phased charging of the various vehicles connected to the same local network supply point. Smart charging can provide local and regional optimization to flatten the demand profile as needed by the grid operators and utilities. This can avoid triggering the costliest and environmentally impacting generation tranches to meet peak demand. In addition, some vehicles (among which the pioneer Nissan Leaf) are already suitable for bi-directional (so-called "vehicle-to-grid" or "V2G") services that can benefit both to end-users, utility services providers and Balance Responsible Party (BRP). Not only can the car battery charge "at the most convenient time of the day" but it can also store electricity and reinject in into the grid to support supply at peak times. Another emerging model is "vehicle-to-house" ("V2H") by which the car battery is not used to reinject into the public grid but to support the electricity needs of the household at peak time. From the end-user point of view, EV can be used as a storage system to enhanced renewable self-consumption, storing power when real-time production exceeds consumption. The flexibility brought by EV batteries allows the driver to consume electricity when it is the cheapest, be it to "fill the car" or even to fulfil house's needs. This flexibility also enables the car owner to limit its power capacity subscription (hence the associated fixed costs of the electricity cost) as the EV battery allows to smooth out power demand along the day. Last, the car owner can provide remunerated ancillary services to the grid if bidirectional charging (V2G) is possible. Billing and Time-of-Use strategy can generate in average $250/kW-year[69] . EV batteries can be used as well as a backup power source in case of blackout, instead of investing in a complementary home fuel power generator.

From a driver's standpoint, observed saving range from around €200 per car per year for monodirectional peak shaving in Germany to £2000 per car per year for bidirectional "true" V2G optimized by a fleet of vehicles in UK[70].

But benefits and savings impact the whole value chain and not only the car owner or the driver.

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[69] This figure and all following are taken from: Andrew W. Thompson, Yannick Perez. Vehicle-to-Anything(V2X) Energy Services, Value Streams, and Regulatory Policy Implications. 2019. hal-02265826. Average are understood to be with respect to different markets.

[70] Envision internal data

From a utility service provider point of view, V2G services include congestion relief: EV batteries can be used as a local network reinforcement, allowing more users to connect to the network without upgrading further its capacity. Peak shaving can be achieved as well, postponing charging during peak hours or discharging the EV battery as a complementary power source. Demand response strategies can generate in average $90/kW-year. As a reminder, car batteries show between 17.6 kWh in the Smart EQ ForTwo[71], up to 100 kWh in the Tesla Model S and Model X[72]. When aggregated, EV batteries, as actionable capacities, can participate to capacity market. This can generate in average $100/kW-year. As a consequence, it makes possible to postpone capacity investments, which is known as T&D deferral and is the most profitable perspective on V2G from a utility services provider's standpoint, with an average saving of $120/kW-year.

BRPs can benefit from bidirectional aggregated V2G as it allows for voltage and frequency regulation services, generating in average $50/kW-year. Energy arbitrage, using the stored energy in a fleet of EV to participate to intra-day market and use power trading value to generate profit only generates a modest revenue of $25/kW-year in average, as most of the energy cost today is infrastructure-related. Last but not least, EVs capacity can be used as a network ignitor in case of black start, avoiding to solicit more an already tensed network, and limiting additional power generator investments.

However, unlocking those revenue and saving opportunities implies to implement some critical prerequisites.

Smart meters are needed to get Time-of-Use tariffs and even more for any more sophisticated services. They are not in place yet in most countries.

Smart chargers are also mandatory to be able to command charging, taking into account driver's range need, battery's health and good charging practices as well as, of course, overall economic and technical signals (electricity costs, BRP's needs). Properly controlling battery charging, and even more battery discharging into the grid, to ensure battery life expectancy and state of health are protected, must remain the priority. A premature deterioration of the battery would significantly impact the residual value of the car as the battery represents around 40% of typical vehicles' value. An inappropriate use of the battery for V2G would even wave the car manufacturer's guarantee obligations.

Last but not least, the multi-criteria, optimized, orchestration of charging requires the proper software:

- Bringing sensing and control capacity to detect battery's current status and trigger charging (and discharging) thanks to IoT (Internet of Things) capabilities,
- And bringing, as well, the optimization ability to process various information spanning from BRP needs, electricity price, battery's health and driver's preferences to define the optimal charging schedule tanks to AI (Artificial Intelligence).

Only a robust, reliable and resilient, performant and scalable technology will be able to connect numerous EVs, aggregate their capacities, integrate market and user constraints, optimize revenue, then schedule and dispatch corresponding charging or discharging orders. Cutting-edge algorithms are key to enable a real-time optimization of battery-use cost, V2G services value and drivers' autonomy expectations. But provided proper integration of hardware (chargers and meters), software (AI and IoT) and installation / services is assembled, unlocking "V2G" as a source of flexibility will massively impact, for the best, the electricity value chain from generation to transmission, distribution and consumption.

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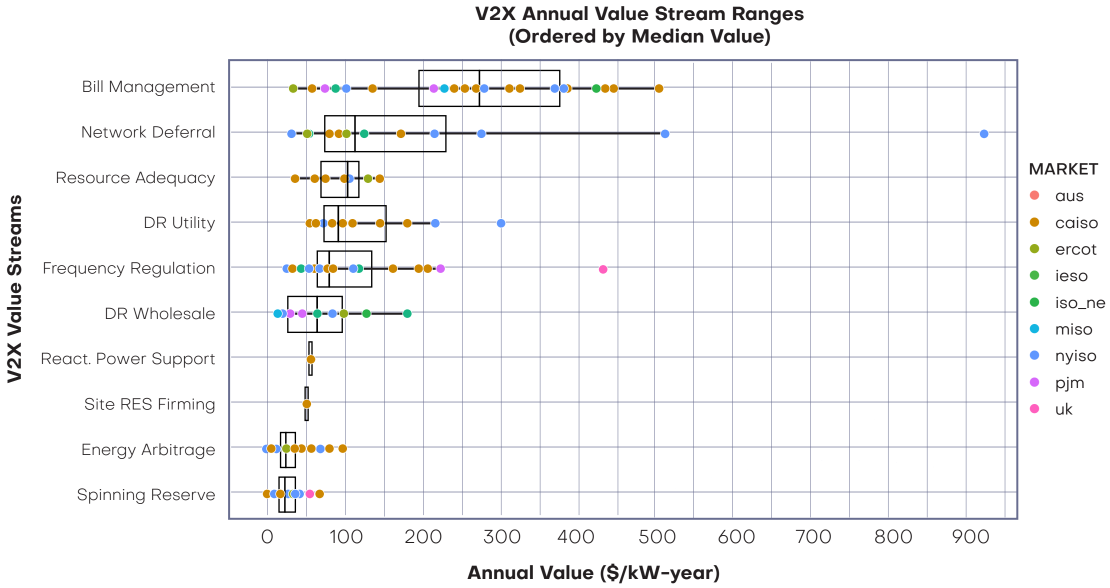
[71] https://ev-database.org/car/1132/Smart-EQ-fortwo-coupe

[72] https://ev-database.org/car/1194/Tesla-Model-S-Long-Range

Fig 33: **V2X annual value stream meta-analysis**



Note: This data visualization shows overall economic potential of key V2X value streams in terms of annual revenue ($/kW-year) which are ordered by median value via boxplots where the individual data points are color-coded by wholesale market to show clustering and outliers

Source: Lazards LCOS 3 & 4, RMI: Economics of battery storage

3.6. Electric vehicle-grid dual interactions

By the end of 2019, the global electric vehicle park reached 7.2 million, and sustained growth is expected leading to an estimated park of 140-240 million EVs worldwide by 2030[73]. Along with the development of electric transport will come battery capacity increase.

These devices can represent a significant challenge for grid operators who may have to deal with more severe peak loads when all EV owners plug in their cars simultaneously to charge in the morning or in the evening. But they can also represent an opportunity if chargers and EVs are smart (allowing to schedule, differ and control charge time) or even bi-directional (enabling “vehicle to grid” reverse energy injection into the grid).

EV will be able to proactively contribute to grid stability thanks to scheduled and controlled charging (incentivized by time-of-use tariffs and made possible by the typical high degree of idleness of passenger cars). More advanced smart chargers, leveraging AIoT technologies, will be able to provide remunerated ancillary services to the grid (including the most demanding primary reserves) and to inject electricity back when prompted to. This will require aligned incentive schemas, handy processes which will adequately address driver’s need but also reliable technologies to protect battery health and life expectancy.

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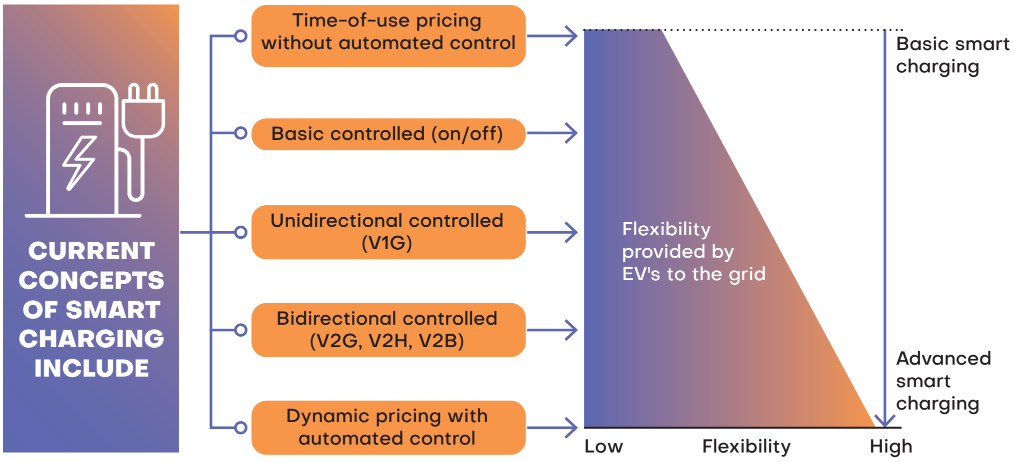
[73] IEA Global Electric Vehicles Outlook, May 2020

Fig 34: Smart charging enables EVs to provide flexibility



Source: IRENA

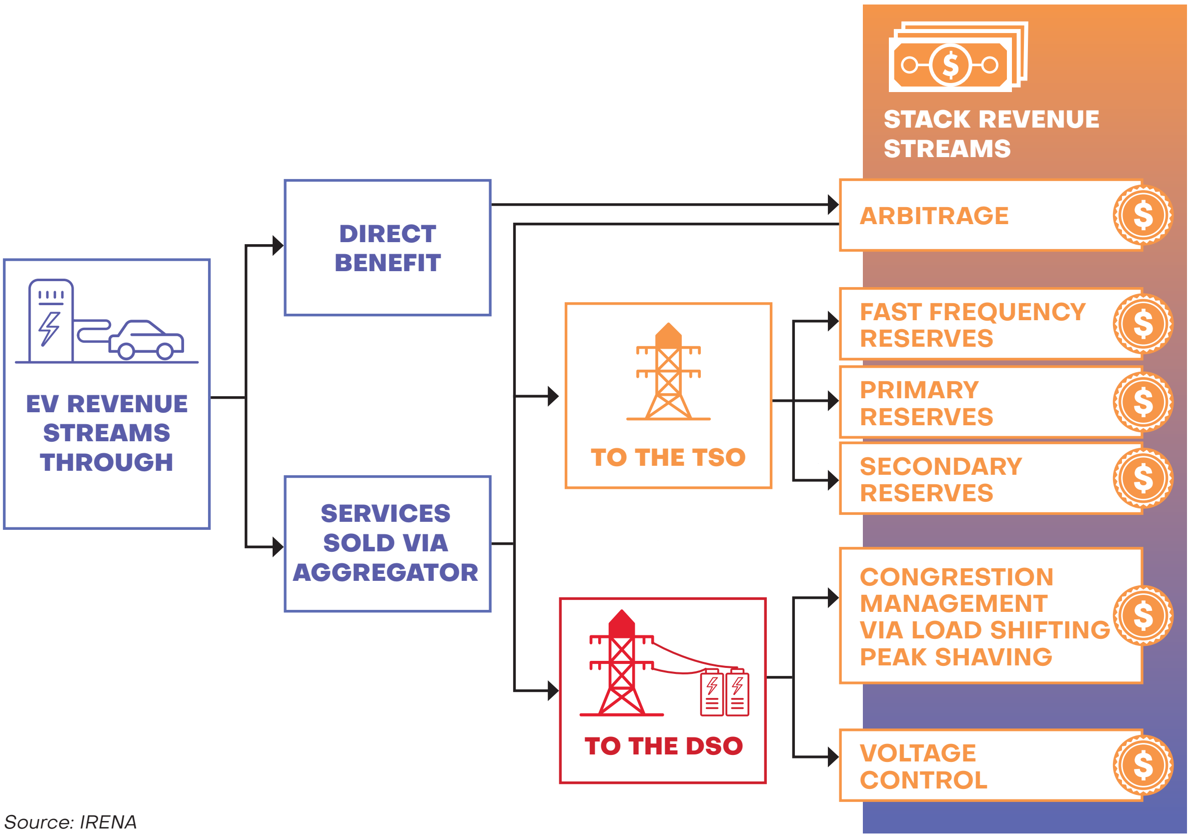
Several demonstrators or projects exist, amongst which are:

- **Los Angeles Air Force Base:** launched in 2015, it is the first large-scale, market-integrated project with the objective to demonstrate full vehicle-to-grid capability. It consists in a fleet of 42 light and medium-duty plug-in electric and hybrid vehicles and their bi-directional charging stations which are estimated to represent a 700 kW electricity capacity, enough to provide power to 140 residentials. Preliminary results of this experience by the Berkeley Lab suggest an estimated gain of $100 per vehicle and per month for the fleet operator for the flexibility services, to be compared with extra costs linked to V2G: about $500 per military site and per month for the purchase and installation of bi-directional systems, the communication between the smart meters and the grid operator, etc.;

- **Parker project in Denmark:** a cooperation between automotive and power companies with the objective to demonstrate the role that EVs can play in integrating variable renewable energies. This project reveals that V2G do provide grid flexibility and increase EVs' revenue (yearly revenue estimated between €1,700 and €2,500 per car) despite a number of drawbacks which still need to addressed: batteries degradation over their lifetime and frequency of use, need of common communication standards and marketing of new business models for consumers;

- **Flexitanie in France (Occitanie region):** in autumn 2020, bi-directional charging stations will be deployed by EDF and Nuvve for ten industrial sites. These stations will be able to charge one hundred Nissan Leaf electric vehicles, that would then be used to store electricity which could be reinjected in the grid to provide electricity to a building, a district or even the energy system depending on the needs.

Fig 35: Possible EV revenue streams that can be stacked



Source: IRENA

4. CONCLUSION

Electricity networks are central “veins” of the energy systems but can become bottleneck or limiting factors to decarbonization if proper flexibility levers are not pulled.

This was prefigured during the Covid-19 crisis: the conjunction of strong renewables generation, thanks to favorable weather conditions, and low demand due to reduced economic activity, led to high percentages of intermittent energy in the mix (up to 60% some days in the UK), creating close-to-unmanageable flexibility challenges to the network.

To prepare for further electrification of the energy mix (notably thanks to electro-mobility) and further decarbonization of electricity mix, it is necessary to develop the right level of flexibility via a set of converging and complementary actions:

- **Invest in the network equipment and lines of course, but this cannot be the only answer for several reasons:**
    - The returns on such CAPEX investment is insufficient as these investments are only necessary for a limited number of peak hours (similarly to a large highway only used to rush hours!),
    - If customers strongly favor self-consumption or if micro-grids developed quickly, the electricity flow on the grids will decrease and impact negatively TSOs revenues. The return on those investment is thus even more at risk,
    - The environmental impact of these capacity extensions is significant,
    - Delays of construction of such new lines hampers the adoption of renewable energy,
- **Improve system intelligence with digital solution, including software and AI, spanning from forecasting systems, to optimization algorithms and actual reliable real-time control capabilities;**
- **Develop electrical system fast demand response and flexibility thanks to stationary batteries, vehicle-to-grid systems, and virtual power plants;**
- **Review system operators’ remuneration framework to reward AIoT, software and algorithms, solutions as an alternative to traditional infrastructure investment;**
- **Reground the role and remuneration of the existing network in extreme scenarios of strong development of self-consumption and micro-grids;**
- **Revise network pricing accordingly (fixed part financing the infrastructure, variable part financing the electricity flow);**
- **Adapt electricity market’s rules, notably allowing for some renewable curtailment or renewable penalties (as in certain regions in China) as those sources of energy become mainstream;**
- **Develop economic tools to compensate for flexibility:**
    - Encourage residential and industrial consumers to use excess (fatal) electricity produced by renewables. One solution would be the industrial production of “green” hydrogen because as inter-seasonal storage of electricity, as soon as part time curtailment electrolysis will become economically viable,
    - Better remunerate the use of idle electric vehicle batteries by the grid (for example for frequency control),
- **Give access to data (in compliance with GDPR[74] and other data privacy regulations) to:**
    - Improve grid operations and flexibility services thanks to better forecast, optimization algorithm and control capabilities,
    - Gamify energy consumptions and drive desirable behaviors,
    - Detect emerging trends and opportunities to adapt to a fast-changing production, storage and consumption reality,
- **Allow more transparent, collective, end-to-end grid optimization to allow collective management of harsher congestion points (e.g. foster prosuming and storage in the most challenged areas, mobilize to address a specific bottleneck substation and unlock local capacity etc.).**

In conclusion, we strongly believe that decarbonization is a pressing urgency, that transformation has started and is bringing its load of challenges that only collective mobilization of all parties (individuals and corporates, public and private, producers and consumers, generators and networks) can address. Last but not least, AIoT technology adoption is the key enabler which can transform an oxymoron into an opportunity, ensuring than green will fuel economic growth.

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[74] GDPR: General Data Protection Regulation

In order to offset the environmental impact of the production of this book, Envision Digital is making a donation to the One Trillion Tree Campaign.

ABOUT THE
ONE TRILLION TREE CAMPAIGN

The Trillion Tree Campaign is a project announced at the 2020 World Economic Forum in Davos which aims to plant one trillion trees worldwide by the end of the decade. It is looking to repopulate the world's trees and combat climate change as a nature-based solution.

It is run by the youth-led not-for-profit Plant-for-the-Planet Foundation in support of United Nations Environment Programme (UNEP).

https://www.trilliontreecampaign.org

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