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BỘ KHOA HỌC VÀ CÔNG NGHỆ

# Energy Transition, Solar Energy, Smart Grid and Digital Transformation: from Research, Technology Development and Innovation to Applications

May 10th, 2023

Bộ Khoa học và Công nghệ

113 Trần Duy Hưng, Trung Hòa, Cầu Giấy, Hà Nội

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CEA – INES (National Institute for Solar Energy)

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# CEA-Liten & INES

**Liten:** Institut d'Innovation pour les Technologies des Energies Nouvelles et les Nanomatériaux

leti liten list

**CEATech**
Tech. Research (DRT)
4500 p, 550 M€/yr
500 patents/yr

**CEA: Nuclear Energy and Alternative Energy Commission**
*10 research centers*
*16,000 persons*
*4,5 B€/yr budget*
*650 patents/yr*

| Solar Energy & Smart grid | Electric Mobility | Materials Processes | Biomass & Hydrogen |
|---|---|---|---|
| Solar PV, CSP,CPV<br>Smart Grid<br>Building & mobility<br>Storage | Batteries<br>Fuel Cells<br>Vehicles integration | Nanomaterials<br>µ-sources<br>Energy recovery<br>Organic electronics | Bioressources<br>H2 Production<br>H2 Storage<br>Usages |

**INES: French National Institute for solar energy** - Institut National de l'Energie Solaire (400 p)

**Activities: Silicon; Solar cells; Solar modules; PV Systems; Solar mobility (Electric Vehicle); Smart grids; Microgrids, Energy Storages & Buildings**

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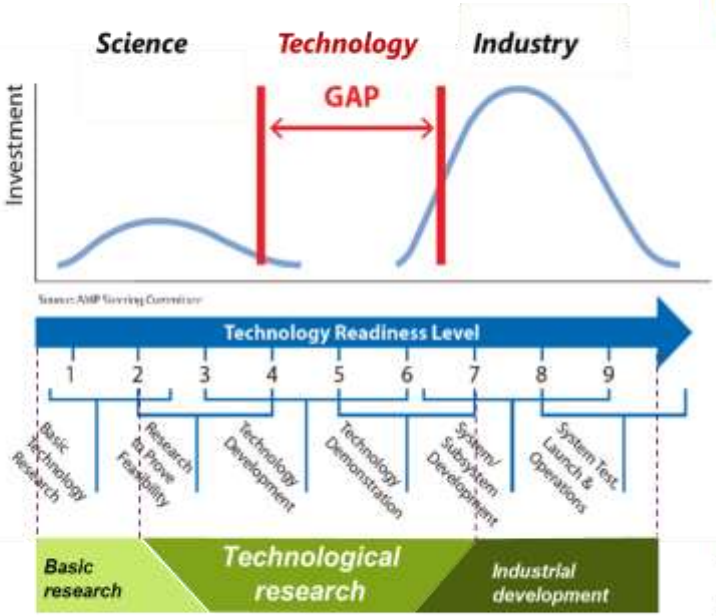
# CEA: the world's most Innovative Research Institutions




Technology | Tue Mar 8, 2016 12:36pm EST

Related: SCIENCE, TECH

## The World's Most Innovative Research Institutions

BY DAVID EWALT


Silicon Valley's hoodie-wearing tech entrepreneurs are the poster kids of innovation. But the innovators who are really changing the world are more likely to wear labcoats and hold government-related jobs in Grenoble, Munich or Tokyo. That's the conclusion of Reuters' Top 25 Global Innovators – Government, a list that identifies and ranks the publicly funded institutions doing the most to advance science and technology.

Topping the list is France's Alternative Energies and Atomic Energy Commission (CEA), for its research into areas including renewable power, public health, and information security. Rounding out the top three: Germany's Fraunhofer Society and Japan's Science and Technology Agency.

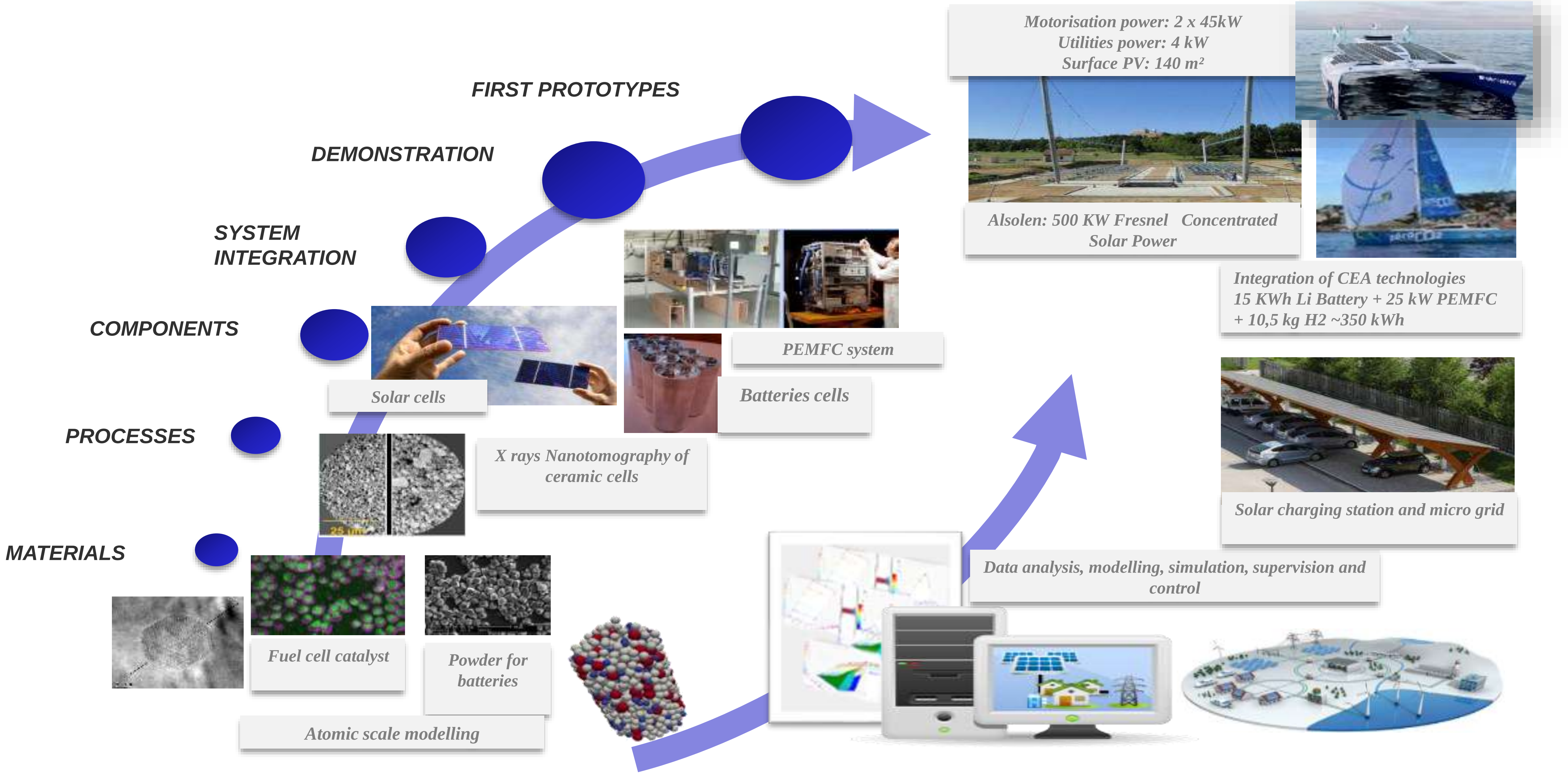
**TOP 25 INSTITUTIONS | 2015 RANKINGS**

| | | |
|---|---|---|
| 1 | Alternative Energies and Atomic Energy Commission | FRANCE |
| 2 | Fraunhofer Society | GERMANY |
| 3 | Japan Science & Technology Agency | JAPAN |
| 4 | U.S. Department of Health & Human Services | USA |
| 5 | National Center for Scientific Research | FRANCE |
| 6 | Korea Institute of Science & Technology | SOUTH KOREA |
| 7 | National Institute of Advanced Industrial Science & Technology | JAPAN |
| 8 | U.S. Department of Energy | USA |

**The 2017 top 25 institutions are listed here:**

1. **Health & Human Services Laboratories *(United States)***
2. **Alternative Energies & Atomic Energy Commission *(France)***
3. **Fraunhofer Society *(Germany)***
4. Japan Science & Technology Agency *(Japan)*
5. National Institute of Advanced Industrial Science & Technology *(Japan)*
6. Korea Institute of Science & Technology *(South Korea)*
7. Medical Research Council *(UK)*
8. National Center for Scientific Research *(France)*
9. French Institute of Health & Medical Research *(France)*
10. Agency for Science Technology & Research *(Singapore)*

# LITEN covers the entire value chain from materials to systems

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# University of Grenoble –Alpes - UGA

| Université Grenoble Alpes | Grenoble INP | Sciences Po Grenoble | ENSAG | Université de Savoie |
|---|---|---|---|---|
| 45 000 étudiants<br>5 500 personnels<br>2200 pers. académiques | 5 500 étudiants<br>1 000 personnels<br>395 pers. acad. | 1 700 étudiants<br>150 personnels<br>77 pers. acad. | | 15000 étudiants<br>1 300 personnels |

ministère de l'enseignement supérieur, de la recherche, et de l'innovation | ministère de la culture | MESRI

## ORGANISMES NATIONAUX

« personnels académiques » (dossier Idex 2016)

| CEA | CNRS | Inria | Irstea | Inserm | INRA |
|---|---|---|---|---|---|
| 1800 (32 %) | 800 | 60 | 75 | 60 | Non membre du consortium Idex |

INRA et IRSTEA sont devenus INRAE en 2020

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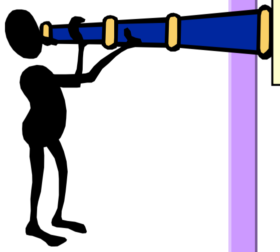
# Plan



- PRESENTATION
- **Context and Energy Transition**
- Solar Energy
- Energy Transition in France and the World
- Research and Technology for Energy Transition
- Smart Grid
- Digital Transformation
- Conclusion

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# Energy transition – Context & Challenges

- Reduce greenhouse gas emissions (COP 21, Paris; COP 26, Glasgow) => **Net zero**
- Transition away from fossil fuels to renewable
- Transition to a more sustainable, low-carbon future
- Energy crisis of late 2021 and Ukraine war (24/2/2022) => Energy independence
- Decrease in energy consumption, increase in the electricity in the mix
- Technology: development of industry, role of nuclear, hydrogen & storage, EV, digitalization
- Impacts on Technical, Economical, Environmental, Societal
- Protection of public health
- Vietnam: Engagement of **Primary Minster** in Cop 26, RES development, Master Plan 8
- **Training, human resource development**

➡ **Solar Energy, Energy Transition, Digital Transformation and Smart Grid: from Research, Technology Development and Innovation to Applications**

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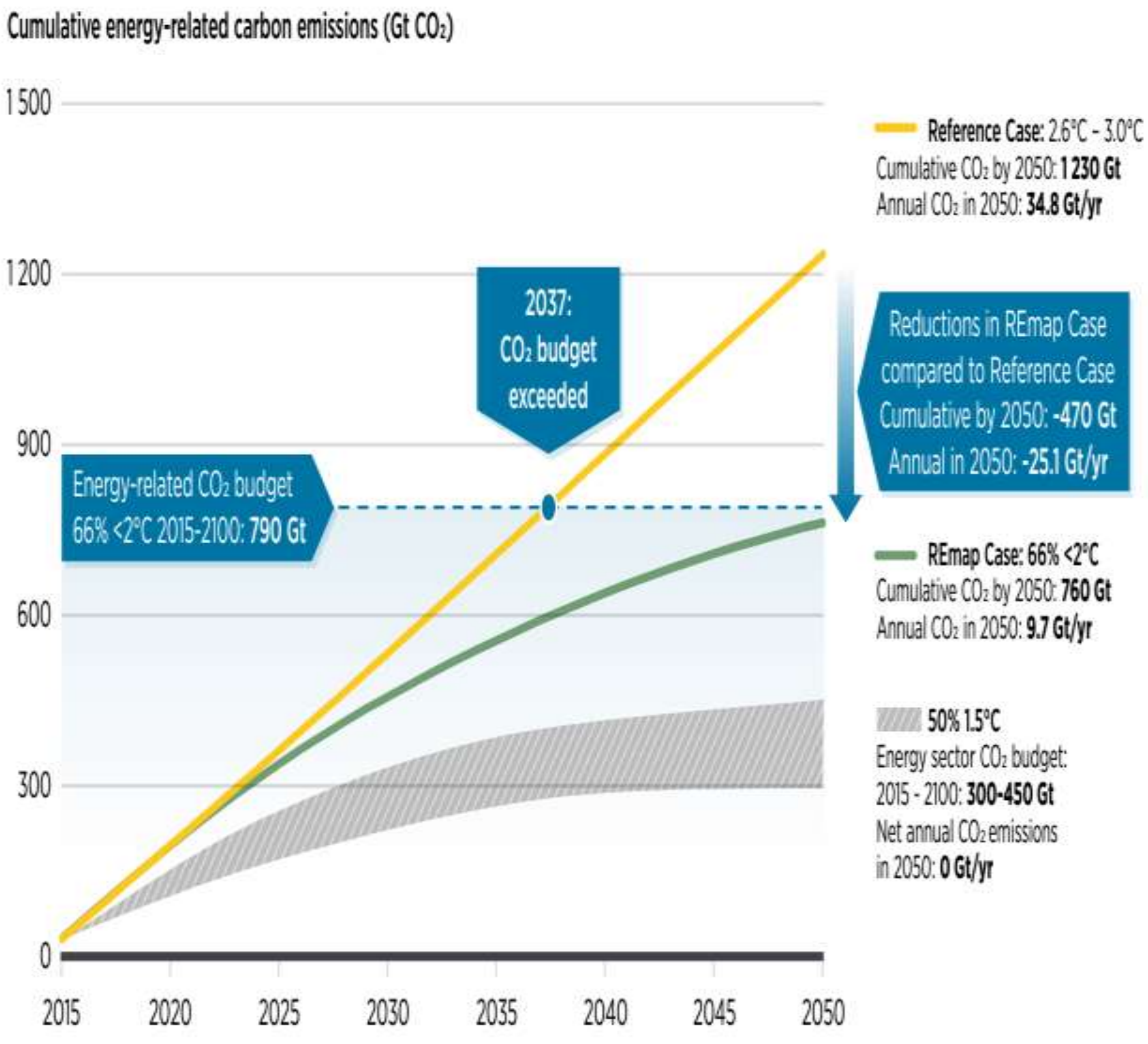
# Energy transition – What?

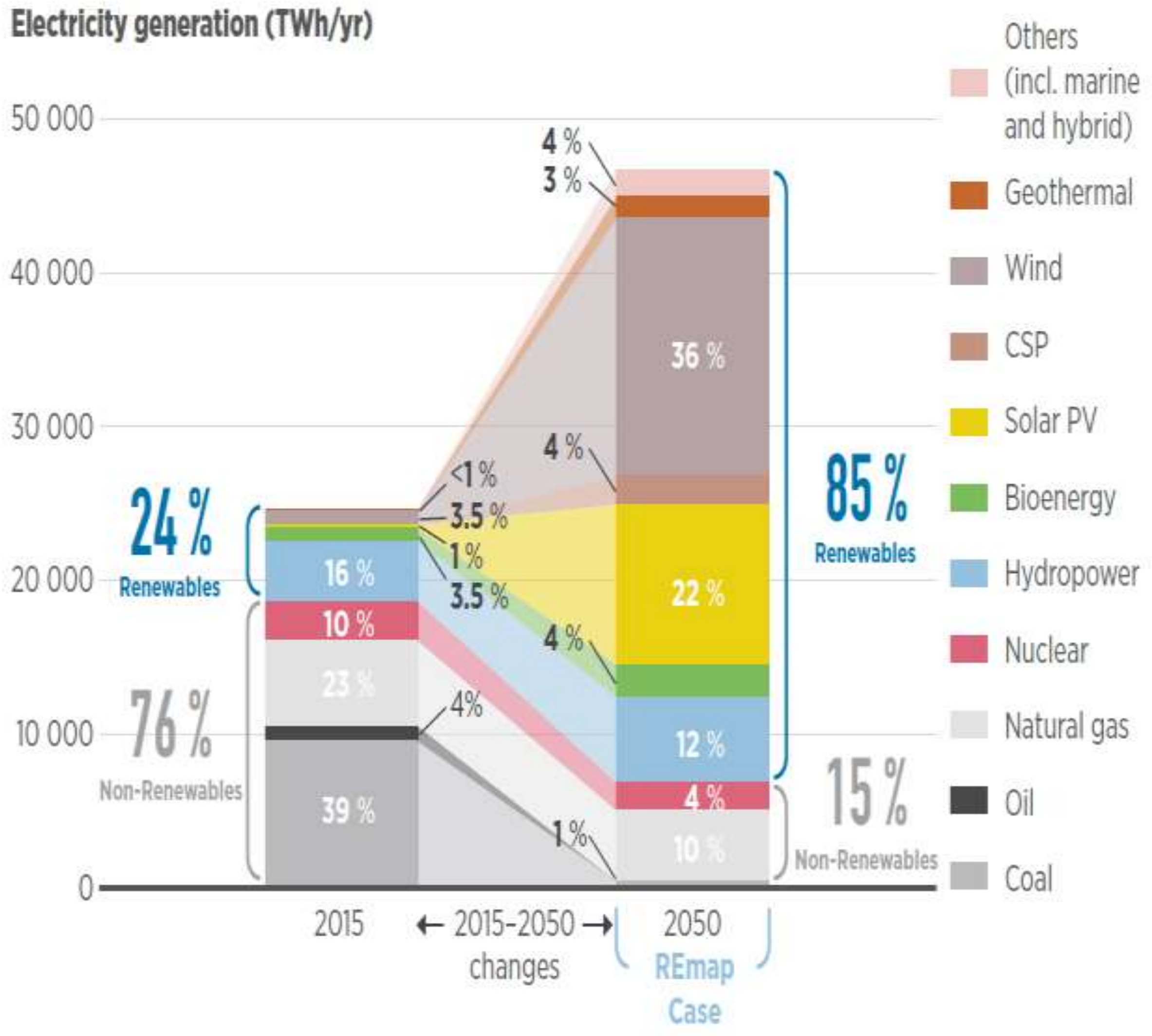
**IRENA**: The **energy transition** is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century. At its heart is the need to **reduce energy-related $CO_2$ emissions** to limit climate change. Decarbonisation of the energy sector requires urgent action on a global scale, and while a global energy transition is underway, further action is needed to reduce carbon emissions and mitigate the effects of climate change. Renewable energy and energy efficiency measures can potentially achieve 90% of the required carbon reductions.
The energy transition will be enabled by **information technology, smart technology, policy frameworks and market instruments**.

**Definition by France**: La **transition énergétique** désigne une modification structurelle profonde des modes **de production, de distribution et de consommation** de l'énergie.
=> **Net zero, Renewable energy, Energy mix**

# CO2 emissions and Renewable




*Cumulative energy-related $CO_2$ emissions and emissions gap, 2015-2050 (Gt $CO_2$)* (IRENA)




Forecast for renewable energies until 2050 (IRENA)

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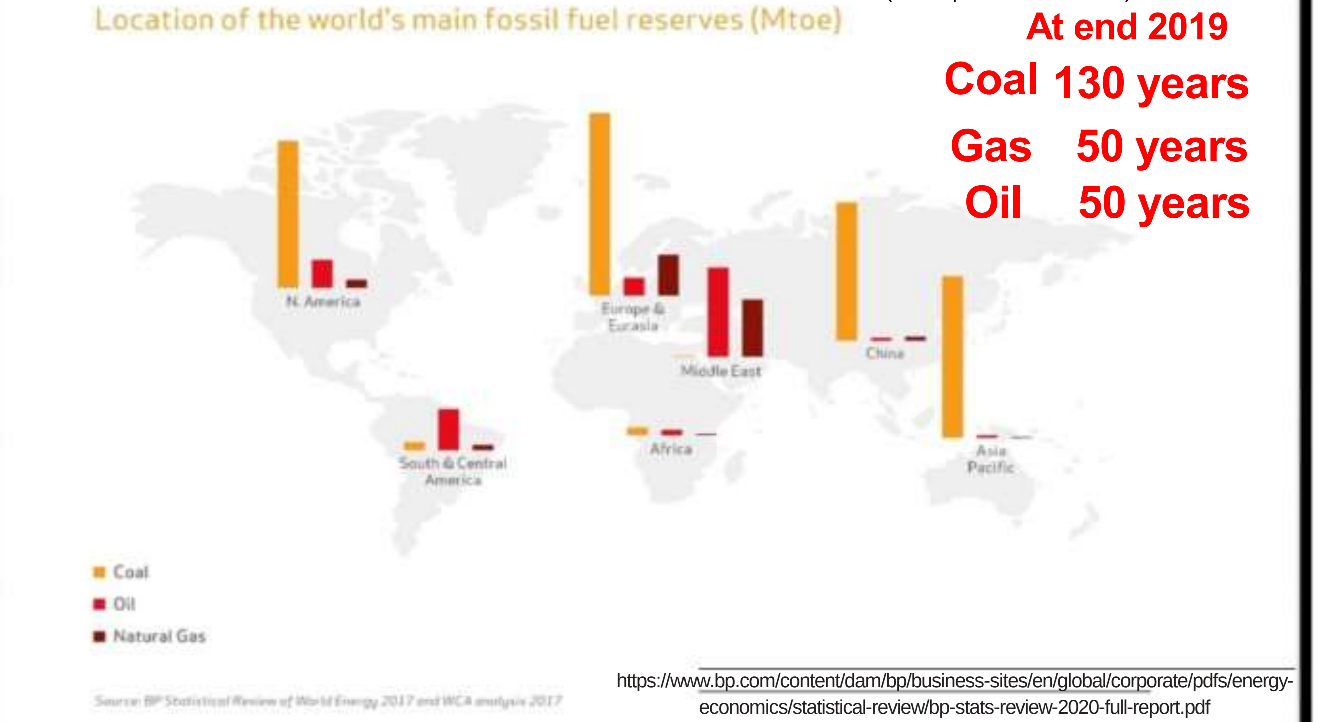
## Final Energy Consumption (UN - IEA)

| 1900 | 1950 | 2000 | 2020 | 2050 |
|---|---|---|---|---|
| 1.6 billion | 2.5 billion | 6 billion | 7.8 billion | 10 billion people |
| 1 billion toe | 2 billion toe | 7 billion toe | 10 billion toe | 13.5 billion toe |

## Energy - World - Fossil Fuel Reserves (AIE-BP)

(current policies scenario IEA)




At end 2019

Coal 130 years

Gas 50 years

Oil 50 years

https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

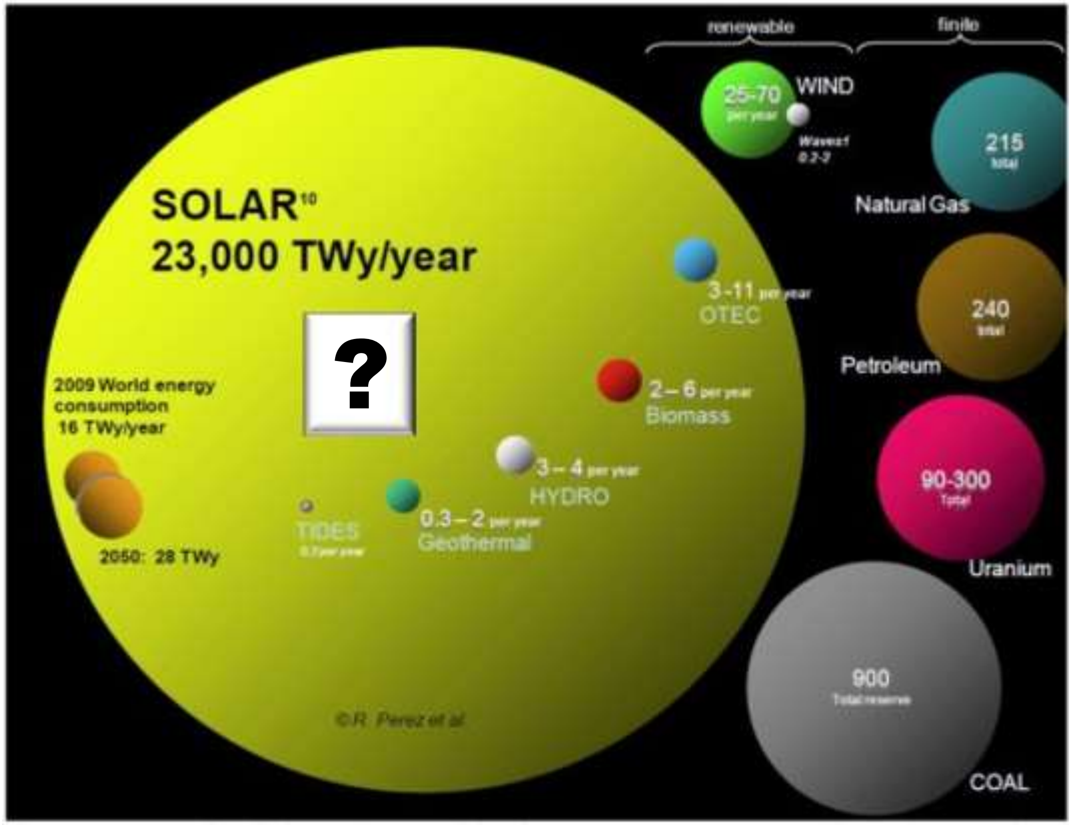



*Figure 1: Comparing finite and renewable planetary energy reserves (Terawatt-years). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables (source: Perez & Perez, 2009a)*

Source IEA-BP

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# Solar PV energy development - World

| | | Cum. Capa. 2022 (GW) | Cum. Capa. 2021 (GW) | Prod./cons 2020 (TWh) |
|---|---|---|---|---|
| 1 | China | (+87.4) 393 | (+52.618) 306.973 | 6.2% |
| 2 | USA | (+17.8) 113 | (+19.637) 95.209 | 6.0% |
| 3 | Japan | (+4.6) 78.8 | (+7.191) 74.191 | 8.3% |
| 4 | Germany | (+8) 66.5 | (+4.678) 58.461 | 51.4 (9.7%) |
| 5 | India | (+13.4) 63.1 | (+10.473 ) 49.684 | 6.5% |
| 6 | Australia | (+7.7) 26.8 | (+1.4499) 19.076 | 10.7% |
| 7 | Italy | (2.4) 25.1 | (+1.098) 22.698 | 8.3% |
| 8 | Brasil | (+10) 24.1 | (+5.827) 14.2 | 3.8% |
| 9 | Netherlands | (+8.4) 22.6 | (+4.036) 14.249 | 8.9% |
| 10 | South Korea | (+3) 21 | (+3.586) 18.161 | 3.8% |
| 11 | Spain | (+5) 20.5 | (+1.863) 15.952 | 9% |
| 12 | Vietnam | (+1.8) 18.5 | (+10.909 2020) 16.683<br>2018 (86 MW) | 27.75 TWh (11%) |
| 13 | France | (+3.3) 17.4 | (+2.985) 14.718 | 18.6 (2.8%) |
| | World | (+203.6) 1053 | (+135) 849.473 | (3.7%) |

## Installed capacity in 2020

| Ranking | Country | P_Installed | P_Accumulated |
|---|---|---|---|
| 1 | China | 49.655 | 254.355 |
| 2 | United States | 14.890 | 75.572 |
| 3 | Vietnam | 10.909 | 16.504 |
| 4 | Spain | 5.378 | 14.089 |
| 5 | Germany | 4.583 | 53.783 |
| 6 | India | 4.122 | 39.211 |
| 7 | Japan | 4.000 | 67.000 |
| 8 | Netherlands | 3.488 | 10.213 |
| 9 | South Africa | 3.429 | 5.990 |
| 10 | South Korea | 3.375 | 14.575 |
| | World total (GW) | 133.210 | 714 |

**2022**

**RES: 8 300 TWh (+8%)**

**PV: 1200 TWh (+191 GW; +22.5%)**

**Wind: + 275 TWh (75 GW; +9%)**

Source: wikipedia

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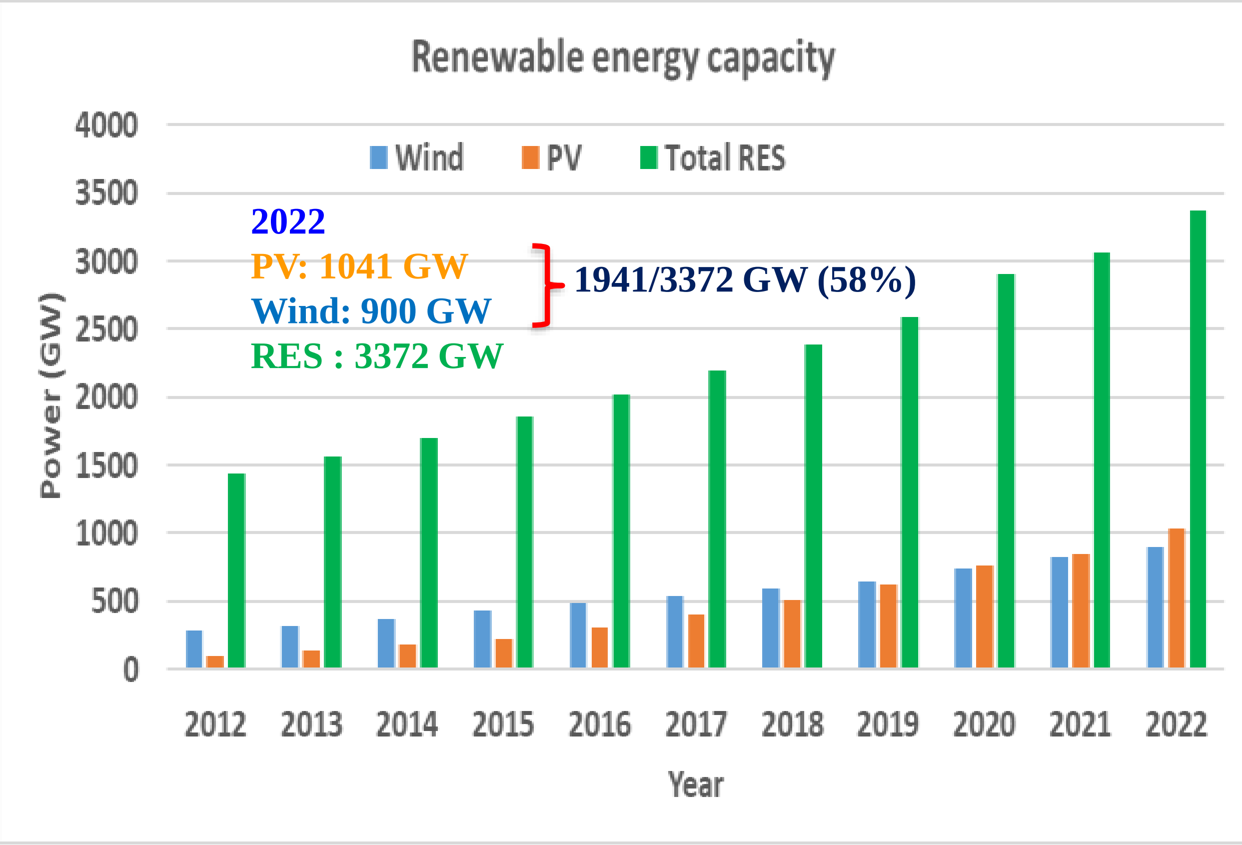
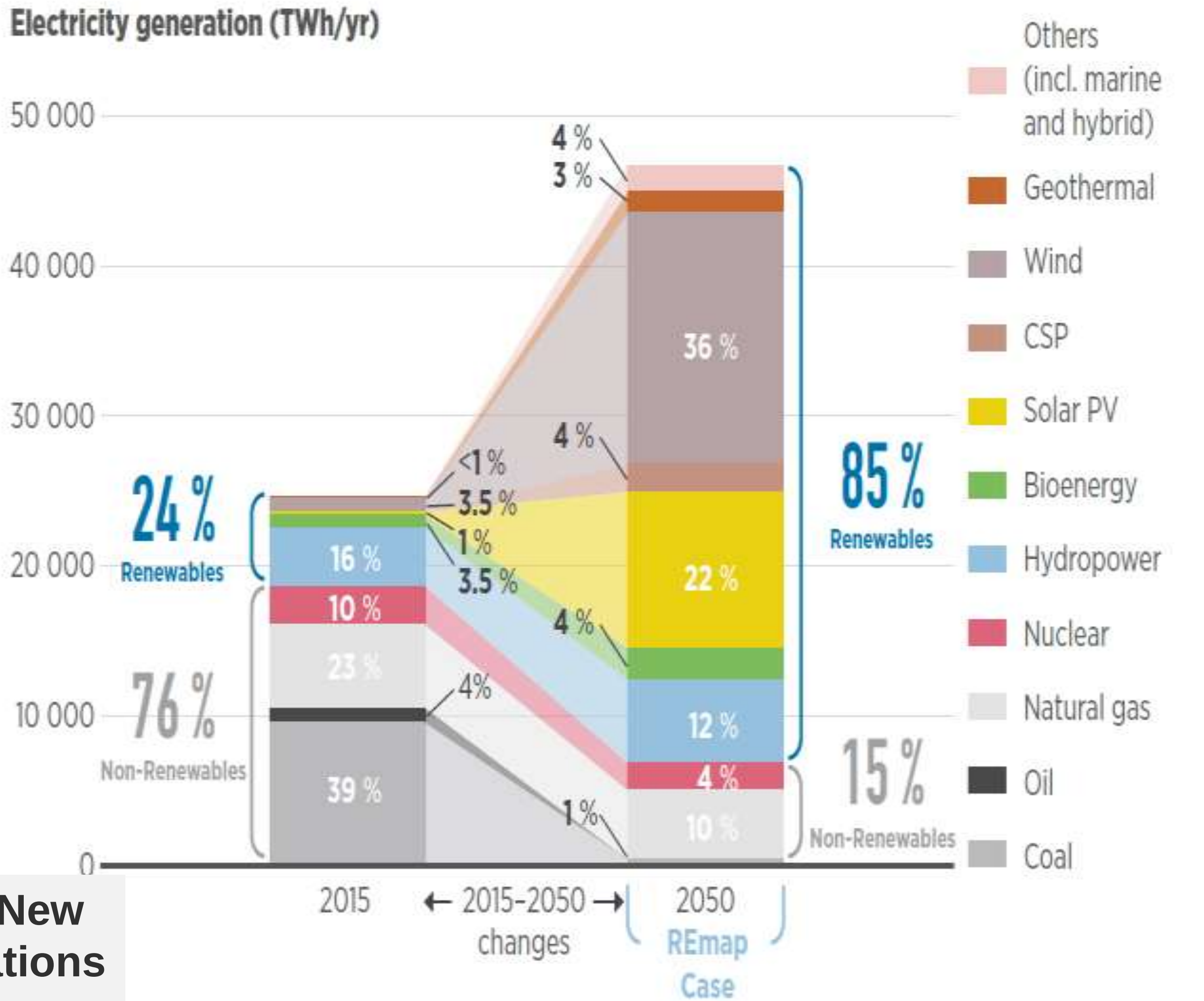
# Renewable Energy
## 2022 installed capacity in the world




https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2023.pdf

Forecast for renewable energies until 2050 (IRENA)

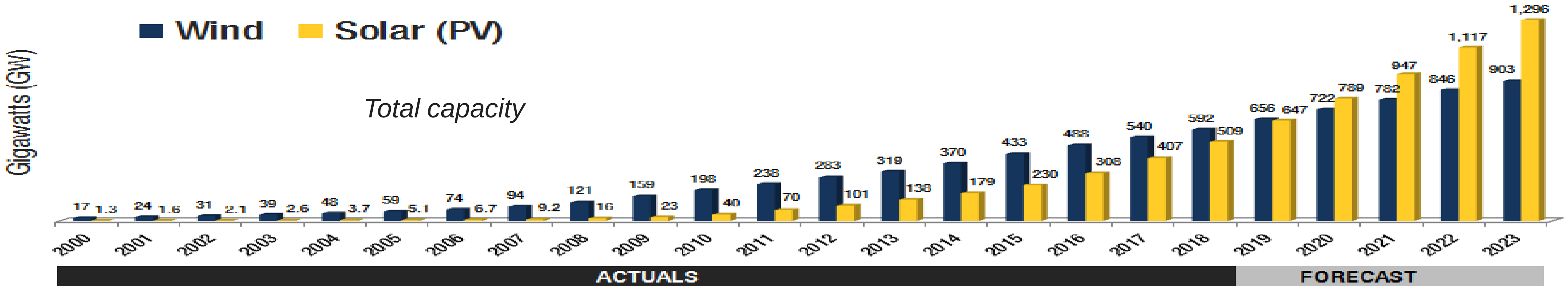


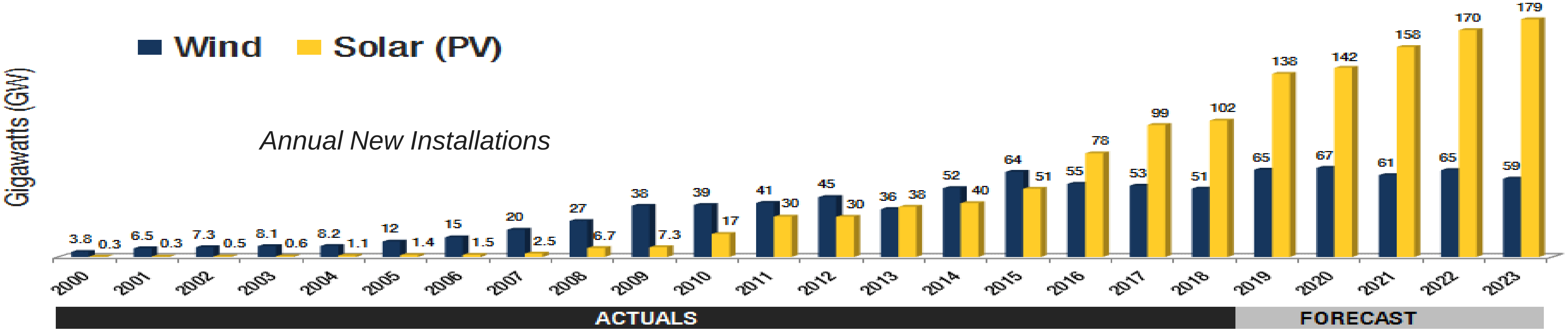

| Worldwide | Wind Total Capacity | Wind New Installations | Solar Total Capacity | Solar New Installations |
|---|---|---|---|---|
| 2022 (GW) | 900 | 75 | 1041 | 191 |

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/viewer.html?pdfurl=https%3A%2F%2Fwww.irena.org%2F-%2Fmedia%2FFiles%2FIRENA%2FAgency%2FPublication%2F2018%2FApr%2FIRENA_Report_GET_2018.pdf&clen=4135242&chunk=true

# PV+Wind power

| Worldwide | Wind Total Capacity | Wind New Installations | Solar Total Capacity | Solar New Installations |
|---|---|---|---|---|
| 2022 (GW) | 900 | 75 | 1041 | 191 |




Source: Renewable Energy

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# Vietnam: Generation & consumption

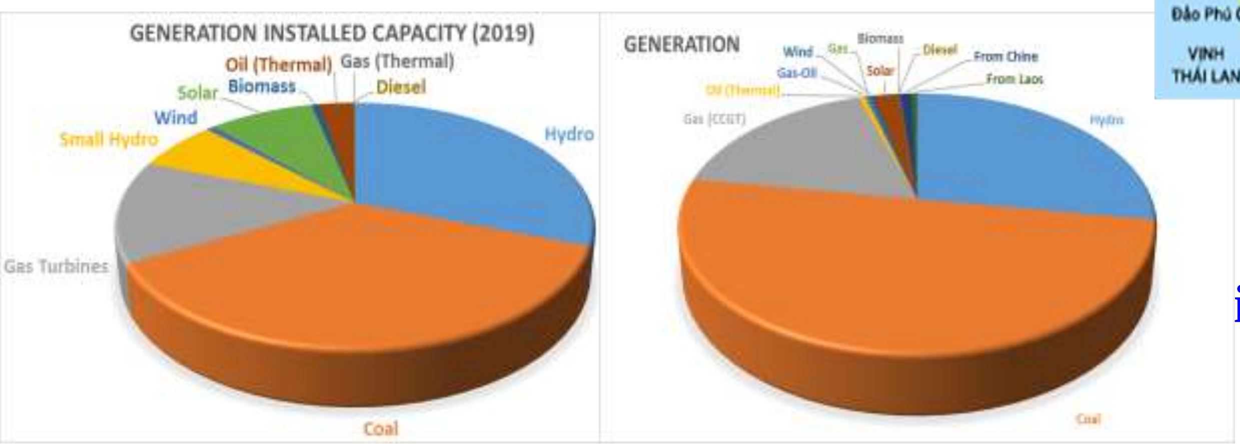


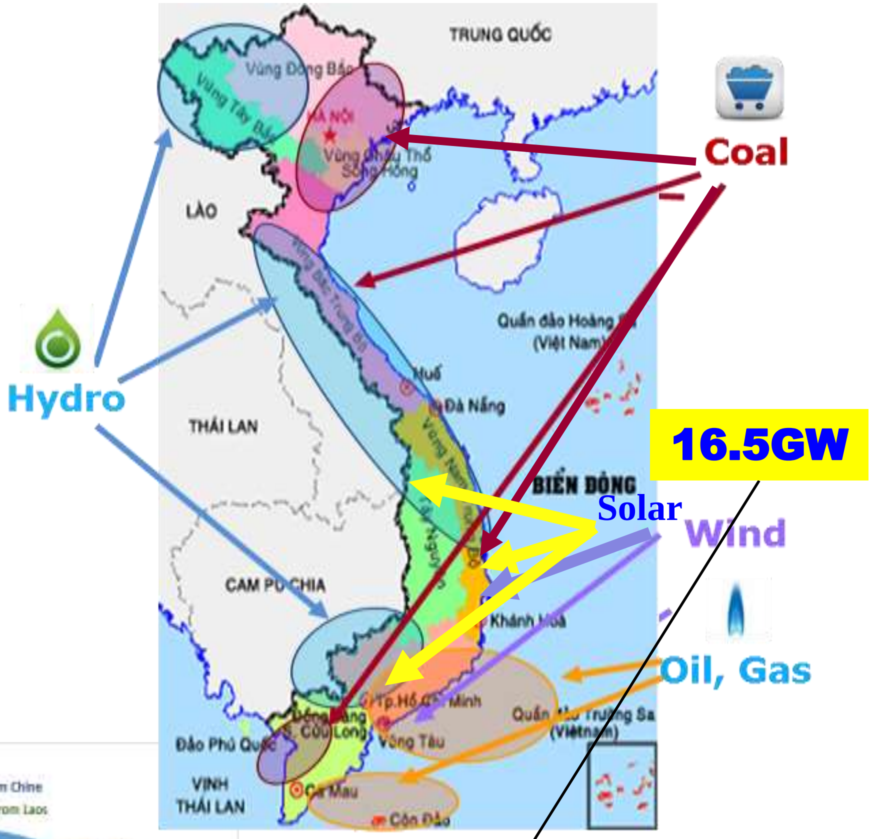
| Type | P (MW) | % |
|---|---|---|
| Hydro | 22999 | 28,50% |
| Coal | 26087 | 32,32% |
| Gas + Oil | 9001 | 11,15% |
| Wind | 5059 | 6,27% |
| Solar | 16568 | 20,53% |
| Biomass | 395 | 0,49% |
| Others | 595 | 0,74% |
| Total (2022) | 80704 | 100% |

| Type | TWh | % |
|---|---|---|
| Hydro | 66117 | 27.54% |
| Coal | 120158 | 50.04% |
| Gas (CCGT) | 42402 | 17.66% |
| Oil (Thermal) | 1239 | 0.52% |
| Gas-Oil | 822 | 0.34% |
| Gas | 105 | 0.04% |
| Wind | 722 | 0.30% |
| Solar | 4818 | 2.01% |
| Biomass | 350 | 0.15% |
| Diesel | 53 | 0.02% |
| From Chine | 2198 | 0.92% |
| From Laos | 1118 | 0.47% |
| Total (2019) | 240101 | 100% |
| Total (2020) | 261456 | |

## 2023 estimated

| Type | TWh | % |
|---|---|---|
| Hydro | 89770 | 31,86% |
| Coal | 121356 | 43,07% |
| Gas | 27103 | 9,62% |
| Oil (Thermal) | 0 | 0,00% |
| Wind | 10921 | 3,88% |
| Solar | 26454 | 9,39% |
| Biomass | 1039 | 0,37% |
| Others | 730 | 0,26% |
| Import | 4386 | 1,56% |
| Total TWh (2023) | 281759 | 100,00% |




55% PV
in distribution network

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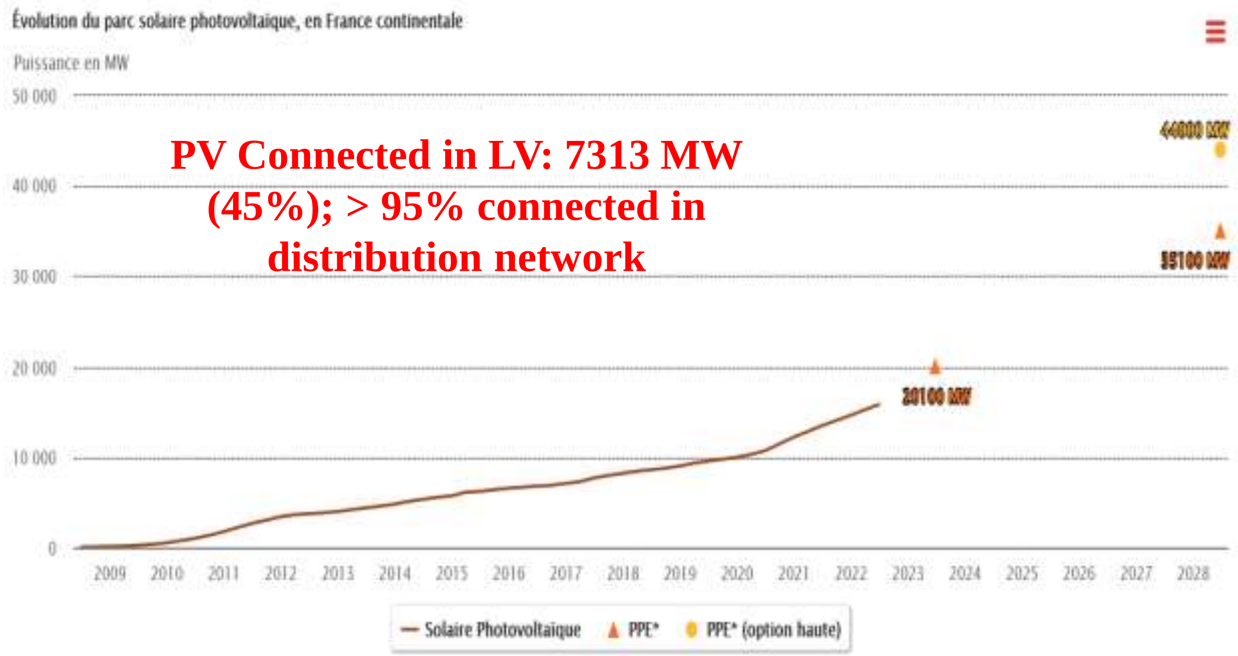
# Solar PV energy development - France



**Répartition des installations photovoltaïques raccordées par tranche de puissance**

| | Parc au 31 décembre 2022 | | |
|---|---|---|---|
| **Tranches de puissance** | **Nombre d'installations** | **Puissance (en MW)** | ***dont métropole*** |
| ≤ 3 KW | 423 072 | 1 102 | *1 094* |
| > 3 et ≤ 9 KW | 172 870 | 1 022 | *1 017* |
| > 9 et ≤ 36 KW | 28 210 | 685 | *643* |
| > 36 et ≤ 100 KW | 32 524 | 2 796 | *2 736* |
| > 100 et ≤ 250 KW | 9 192 | 1 707 | *1 658* |
| > 250 KW | 2 671 | 9 020 | *8 702* |
| **Total** | **668 539** | **16 333** | ***15 851*** |




## France in 2022

**Generation**

**144.3 GW**

| Nuclear | Fossil | Hydraulic | Bio-energies | Wind | Solar |
|---|---|---|---|---|---|
| 61.4GW | 17.7 GW | 25.9GW | 2.3GW | 21.2GW | 15.7GW |
| 42.6% | 1é;".% | 17.9% | 1.6% | 14.7% | 10.9% |

**445.2 TWh**

| Nuclear | Fossil | Hydraulic | Bio-energies | Wind | Solar |
|---|---|---|---|---|---|
| 279 TWh | 49.2 TWh | 49.6 TWh | 10.6 TWh | 38.1 TWh | 18.6 TWh |
| 62.7% | 11,1% | 11,1% | 2.4% | 8.6% | 4.2% |

## France in 2022

**Wind: 20.915 GW**
**PV Solar: 16.333 GW**
**PV:18.6 TWh (4.2%)**
**Total: 37/90 GWCons.**

https://www.statistiques.developpement-durable.gouv.fr/publicationweb/

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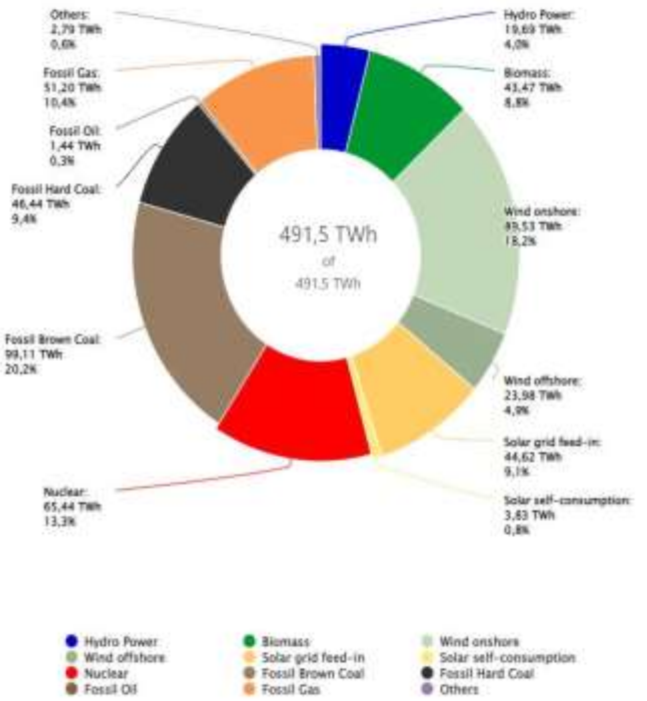
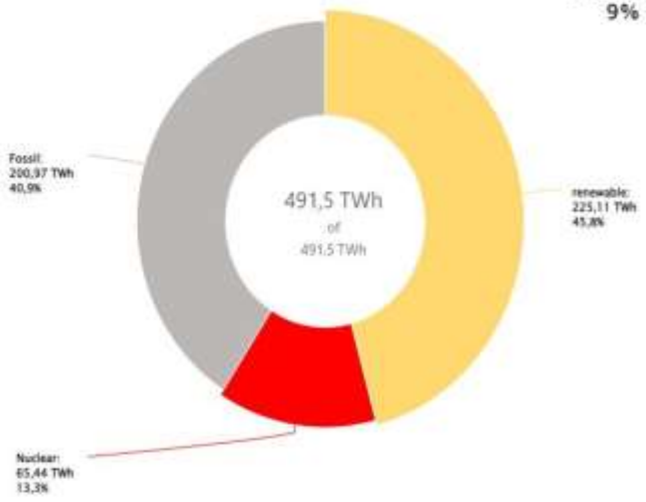
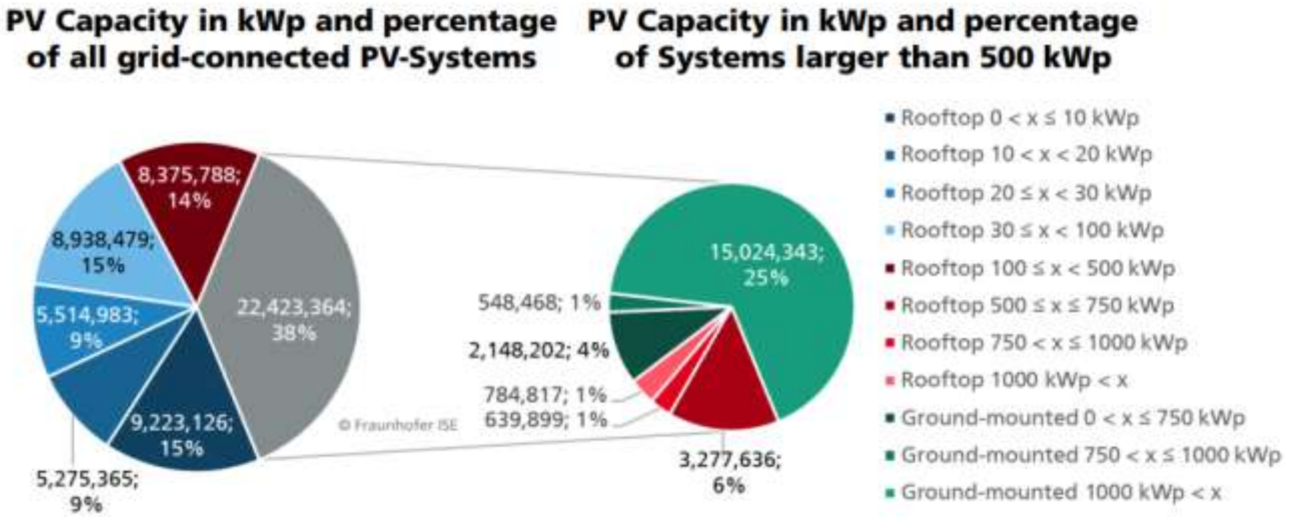
# Solar PV energy development -Germany

| | |
|---|---|
| **2021** | **2022** |
| **Wind: 64.04 GW** | **67.4 GW (117 TWh: 25.9%)** |
| **Solar: 59.8 GW** | **66.5 GW** |
| **PV:48.6 TWh (9.9%)** | **62 TWh (11.4%)** |
| **Total: 123.8/80 GWCons.** | **134/80** |

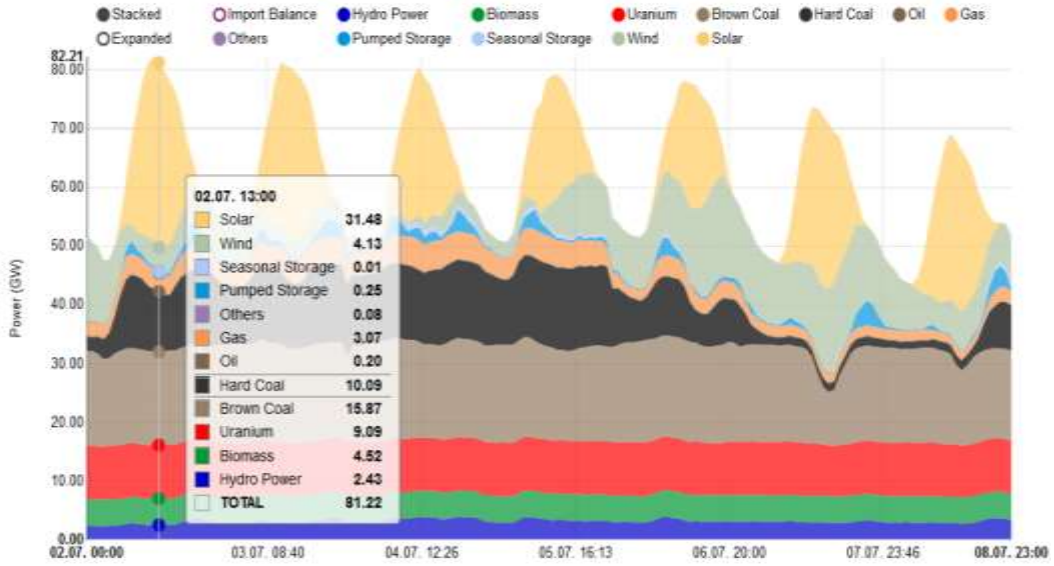
**RES in 2022: 45.8%** **224 TWh 49.6%**




**60% connected in LV distribution**




Source Fraunhofer

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# Main challenges of RES integration

**Non-Technical challenges:**

- Cost
- $CO_2$
- Land use, water use

…

**Technical challenges:**

- System operations :
  - Voltage variation
  - Frequency variation
  - Stability problem
  - Protection problem
  - Congestion …
- Grid reinforcement

…

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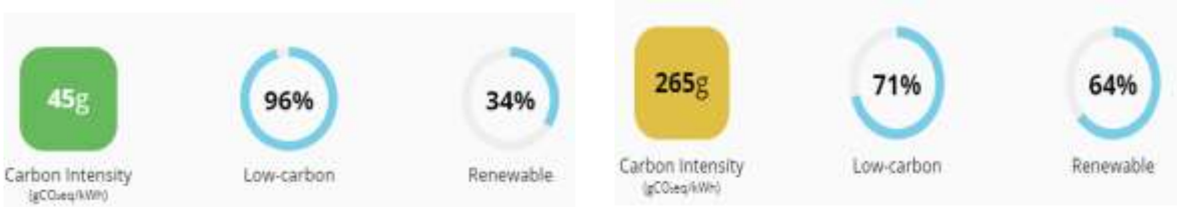
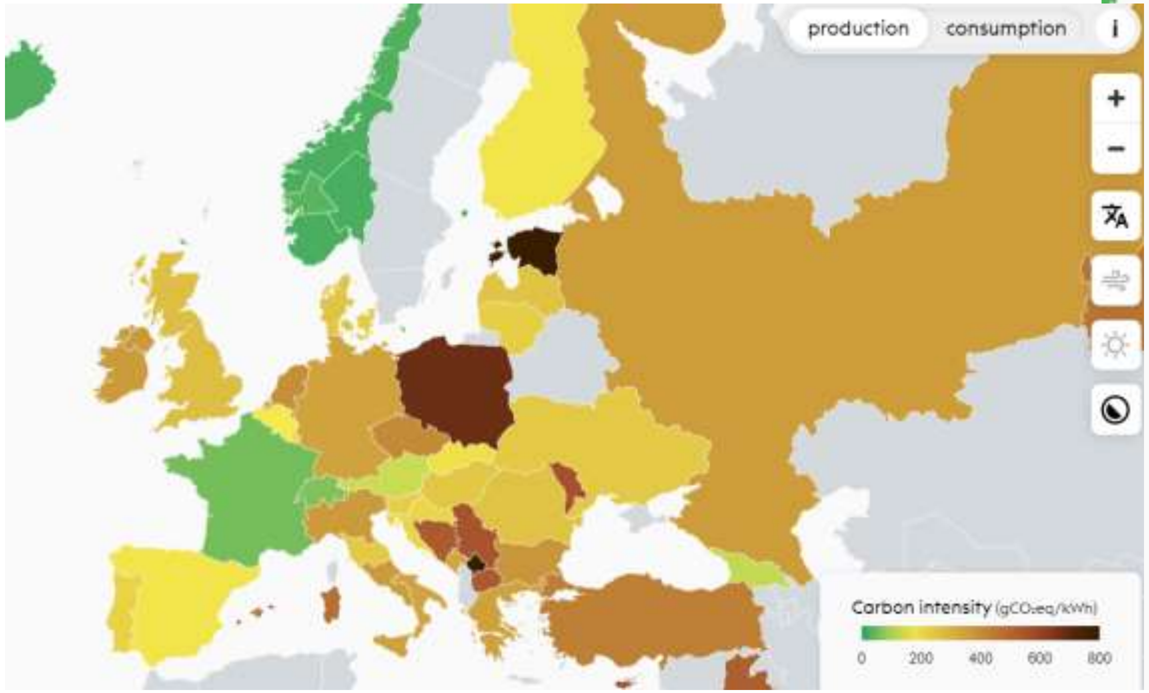
# $CO_2$ emissions - Generation

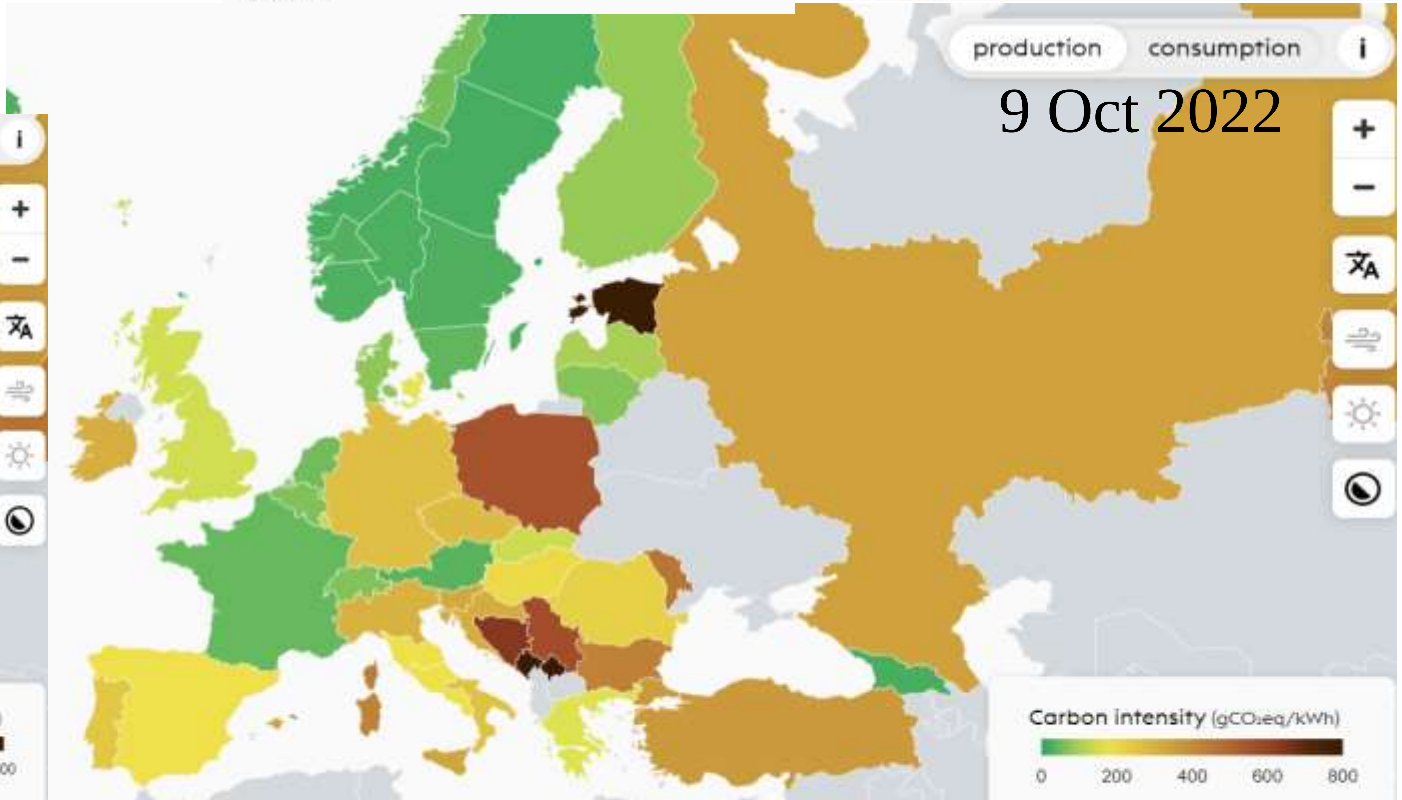


As a rough guide coal has a carbon intensity of about 1,000 $gCO_2$/kWh, oil is 800 $gCO_2$/kWh, natural gas is around 500 $gCO_2$/kWh, while nuclear (6$gC0_2$/kWh), hydro, wind and solar are all less than 50 $gCO_2$/kWh => Potential of RES to reduce emissions




Average for past 5 years

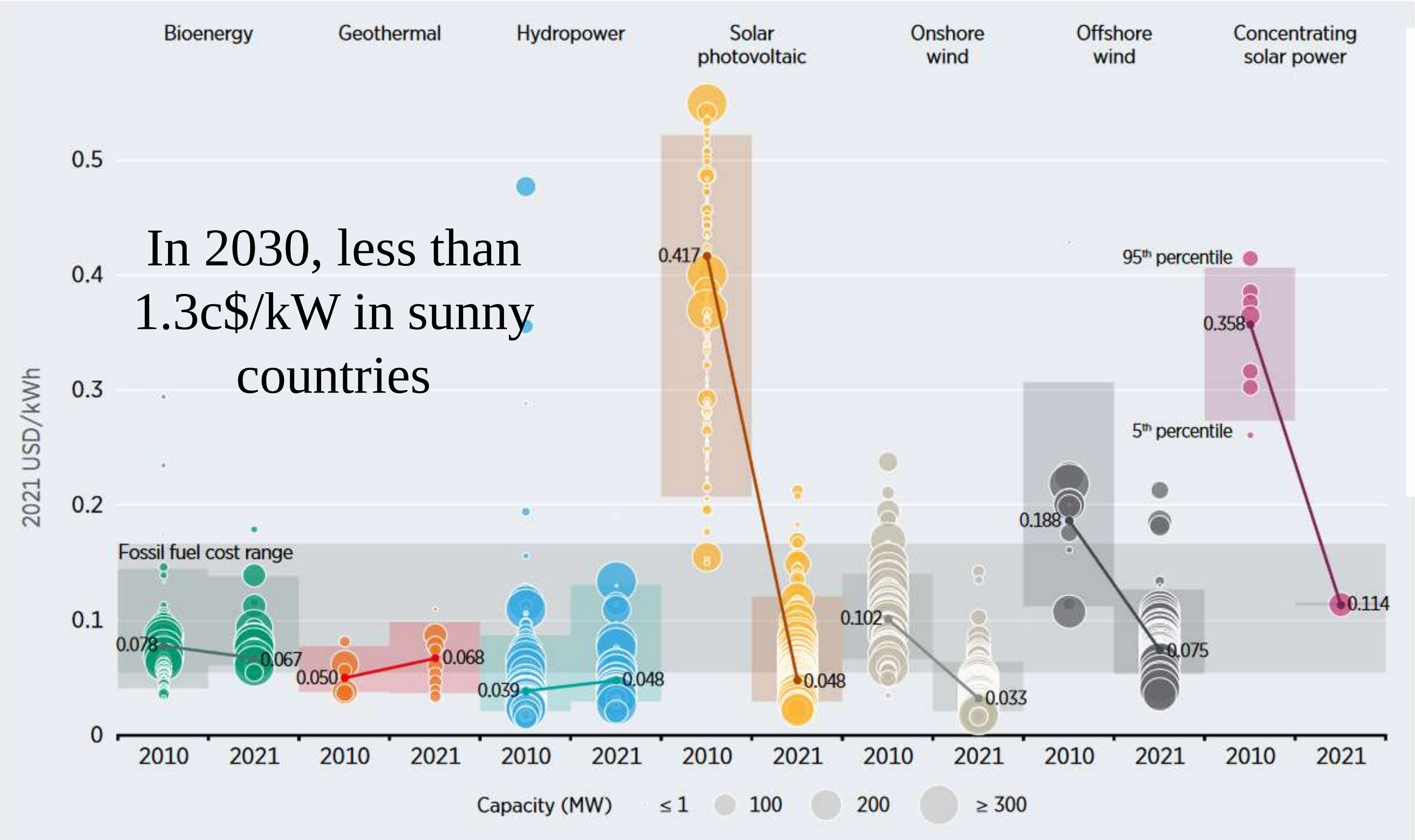



 https://www.electricitymap.org

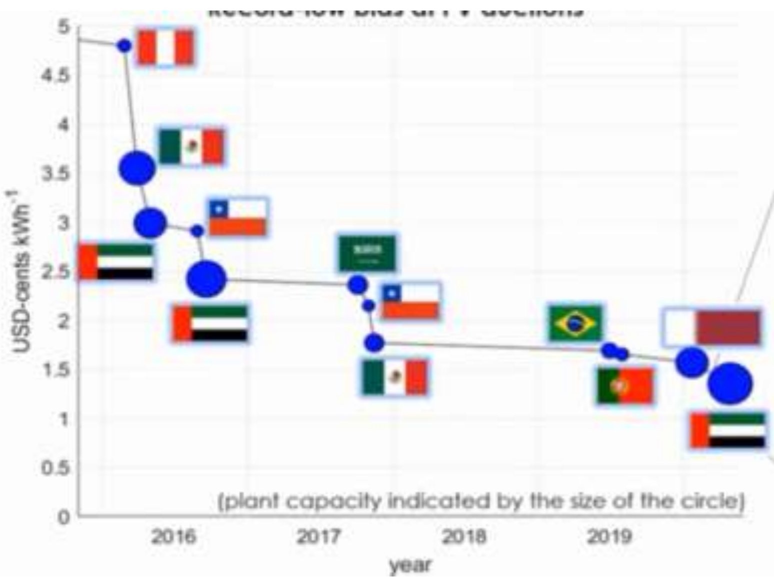
# Levelised cost of electricity (LCOE)






In 2030, less than 1.3c$/kW in sunny countries

Source IRENA




**AUGUST 24, 2020**

**Portugal's second PV auction draws world record low bid of 1.32c$/kWh (700 MW);**
1.12c€/kWh, slightly lower than the 1.35c$/kWh (June 2020) submitted by French energy group EDF and China's JinkoPower in a 2 GW tender held in Abu Dhabi,

https://www.pv-magazine.com/2020/08/24/portugals-second-pv-auction-draws-world-record-low-bid-of-0-0132-kwh/

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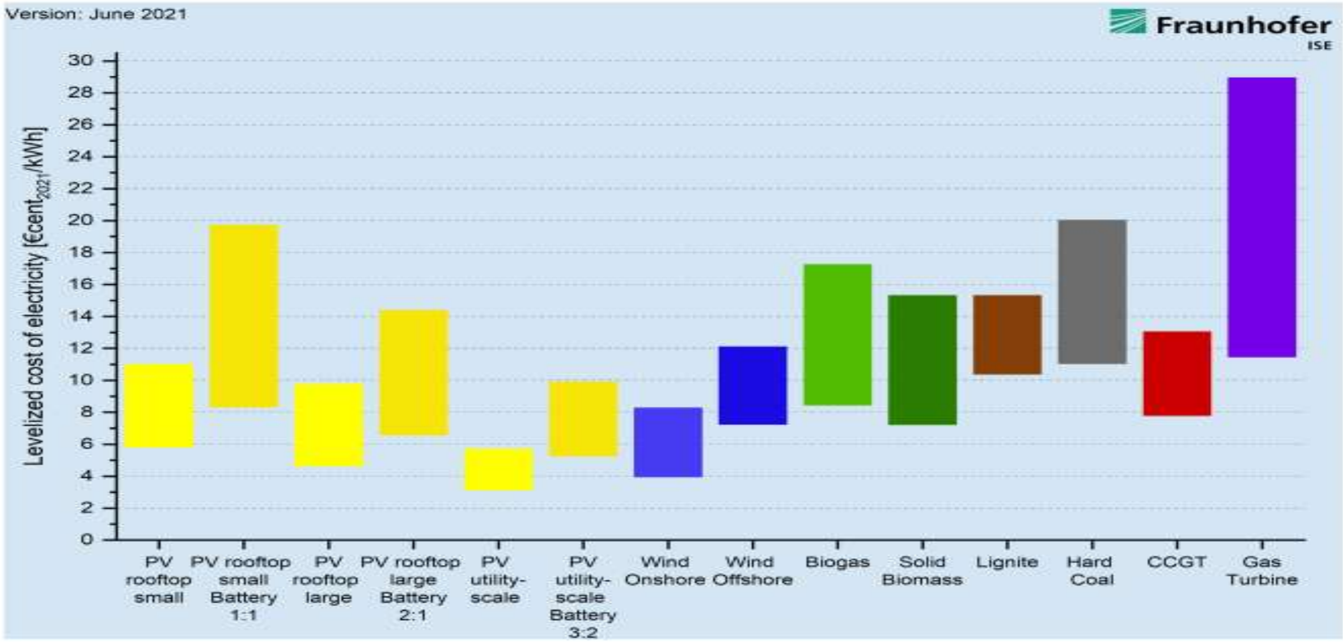
# Levelised cost of electricity (LCOE)




15/9/2022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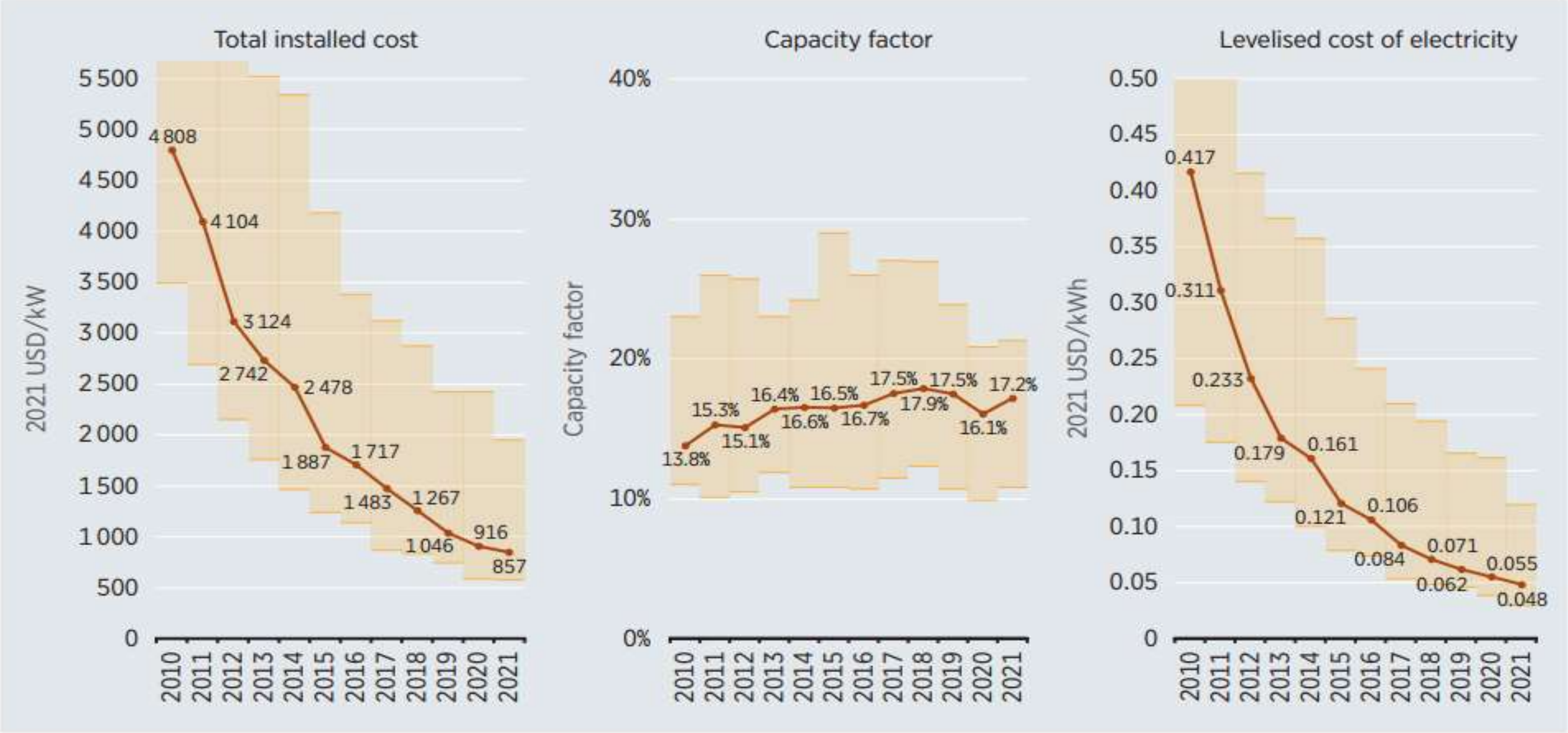
# Total installed costs, capacity factors and LCOE for PV, 2010–2021




*Source: IRENA Renewable Cost Database.*

# Purchase price (France)

## Purcharse price (c€/kWh) – Total sale (Whole sale)

| P (kWp) | 1-3/2022 €/kWh | 4-6/2022 €/kWh | 7-9/2022 €/kWh | 2-4/2023 €/kWh |
|---|---|---|---|---|
| ≤ 3 | 0,1789 | 0,1951 | 0,2022 | **0,2349** |
| ≤ 9 | 0,1521 | 0,1658 | 0,1718 | **0,1996** |
| ≤ 36 | 0,1089 | 0,1187 | 0,1231 | **0,1430** |
| ≤ 100 | 0,0947 | 0,1033 | 0,1070 | **0,1243** |
| ≤ 500 | 0,0980 (Up to1100 kWh / kWp then 0,0400 €/kWh) | 0,1068 (Up to 1100 kWh / kWp then 0,0400 €/kWh) | 0,1107 (Up to1100 kWh / kWp then 0,0400 €/kWh) | 12,87 c€ (Up to 1100 kWh / kWp then 5,00 c€/kWh) |

## Self consumption bonus (€/kWc) and Surplus sale (€/kWh), >100 kWp: no bonus

| | 7-9/2022 | | 2-4/2023 | |
|---|---|---|---|---|
| P (kWp) | Surplus sale €/kWh | Bonus €/kWp | Surplus sale €/kWh | Bonus €/kWp |
| ≤ 3 | 0,10 | 430 | 0,1323 | 500 |
| ≤ 9 | 0,10 | 320 | 0,1323 | 370 |
| ≤ 36 | 0,06 | 180 | **7,88** | 210 |
| ≤ 100 | 0,06 | 90 | **7,88** | 110 |

| P (kWp) Bonus | 1-3/ 2022 €/kWp | 4-6/ 2022 €/kWp | 7-9/ 2022 €/kWp | 2-4/ 2023 €/kWp |
|---|---|---|---|---|
| ≤ 3 | 380 | 410 | 430 | 500 |
| ≤ 9 | 290 | 310 | 320 | 370 |
| ≤ 36 | 160 | 170 | 180 | 210 |
| ≤ 100 | 80 | 90 | 90 | 110 |

# Renewable energy



21/QĐ-BCT (7/1/2023)

| Type | đ/kWh | c$/kWh |
| --- | --- | --- |
| Ground PV | 1.184,90 | 5,02 |
| Rooftop PV | 1.508,27 | 6,39 |
| Onshore wind | 1.587,12 | 6,73 |
| Offshore wind | 1.815,95 | 7,69 |

No. 13/2020/ QĐ-TTg 6/4/2020 (9.35c$/kWh 2019)

| < 31/12/2020 | Đồng/kWh | c$/kWh |
| --- | --- | --- |
| Floatting PV | 1783 | 7.69 |
| Ground PV | 1644 | 7.09 |
| Rooftop PV | 1943 | 8.38 |

39/2018/QĐ-TTg - 2018 (<1/11/2021)

| | Đồng/kWh | c$/kWh |
| --- | --- | --- |
| Wind off shore | 2223 | 9.8 (8.21) |
| Wind on shore | 1928 | 8.5 (7.02) |

**EVN quyết định điều chỉnh giá bán lẻ điện bình quân là 1.920,3732 đồng/kWh (chưa bao gồm thuế giá trị gia tăng) từ ngày 4/5/2023. Mức điều chỉnh này tương đương mức tăng 3% so với giá điện bán lẻ bình quân hiện hành.**

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# Electricity market - France

# Levelised cost of electricity (LCOE) - 2022

In a base comparison, without considering subsidies, fuel prices, or carbon pricing, utility-scale solar and wind have the lowest LCOE of all sources.

- Utility-scale solar PV: from $24/MWh to $96/MWh, while
- Onshore wind from $24/MWh to $75/MWh.
- Offshore wind's LCOE is between $72/MWh and $140/MWh.

For comparison, under the same criteria,

- gas peaking comes in at $115/MWh to $221/MWh,
- nuclear is $141/MWh to $221/MWh,
- coal is $68/MWh to $166/MWh,
- and gas combined cycle is $39/MWh to $ 101/MWh.

Unsubsidized residential rooftop PV has an LCOE between $117/MWh and $282/MWh, while the LCOE of community and commercial and industrial (C&I) solar ranges between $49/MWh and $185/MWh.

Source PV Magazine/

# RES: Land use and Water use

Source Wikipedia

**Largest PV power stations**

| Name | Country | Capacity $MW_p$ | Size $km^2$ | Year |
|---|---|---|---|---|
| **Bhadla Solar Park** | India | 2700 | 160 | 2018 |
| **Longyangxia Dam Solar Park** | China | 2400 | | 2015 |
| **Huanghe Hydropower Hainan Solar Park** | China | 2200 | 50 | 2020 |
| **Pavagada Solar Park** | India | 2,050 | 53 | 2019 |
| **Benban Solar Park** | Egypt | 1650 | 37 | 2019 |
| **Tengger Desert Solar Park** | China | 1,547 | 43 | 2016 |

## Water Use

- Solar Photovoltaic: 45 litres/MWh
- Wind: ~0
- Coal: 2.60 $m^3$/MWh
- Nuclear: 2.54 $m^3$/MWh
- Natural gas: 0.75 $m^3$/MWh

| Product | Primary energy source | | Land use intensity [$m^2$/MWh] U.S. data[a)] | U.S. data[b)] | EU data[c)] | UNEP[d)] | Typical[e)] |
|---|---|---|---|---|---|---|---|
| Electricity | Nuclear | | 0.1 | 0.1 | 1.0 | | 0.1 |
| | Natural gas | | 1.0 | 0.3 | 0.1 | 0.2 | 0.2 |
| | Coal | Underground | 0.6 | 0.2 | 0.2 | | 0.2 |
| | | Surface ("open-cast") | 8.2 | 0.2 | 0.4 | 15.0 | 5.0 |
| | **Renewables** | Wind | 1.3 | 1.0 | 0.7 | 0.3 | 1.0 |
| | | Geothermal | 5.1 | | 2.5 | 0.3 | 2.5 |
| | | Hydropower (large dams) | 16.9 | 4.1 | 3.5 | 3.3 | 10 |
| | | Solar photovoltaic | 15.0 | 0.3 | 8.7 | 13.0 | 10 |
| | | Solar – concentrated solar power | 19.3 | | 7.8 | 14.0 | 15 |
| | | Biomass (from crops) | 810 | 13 | 450 | | 500 |

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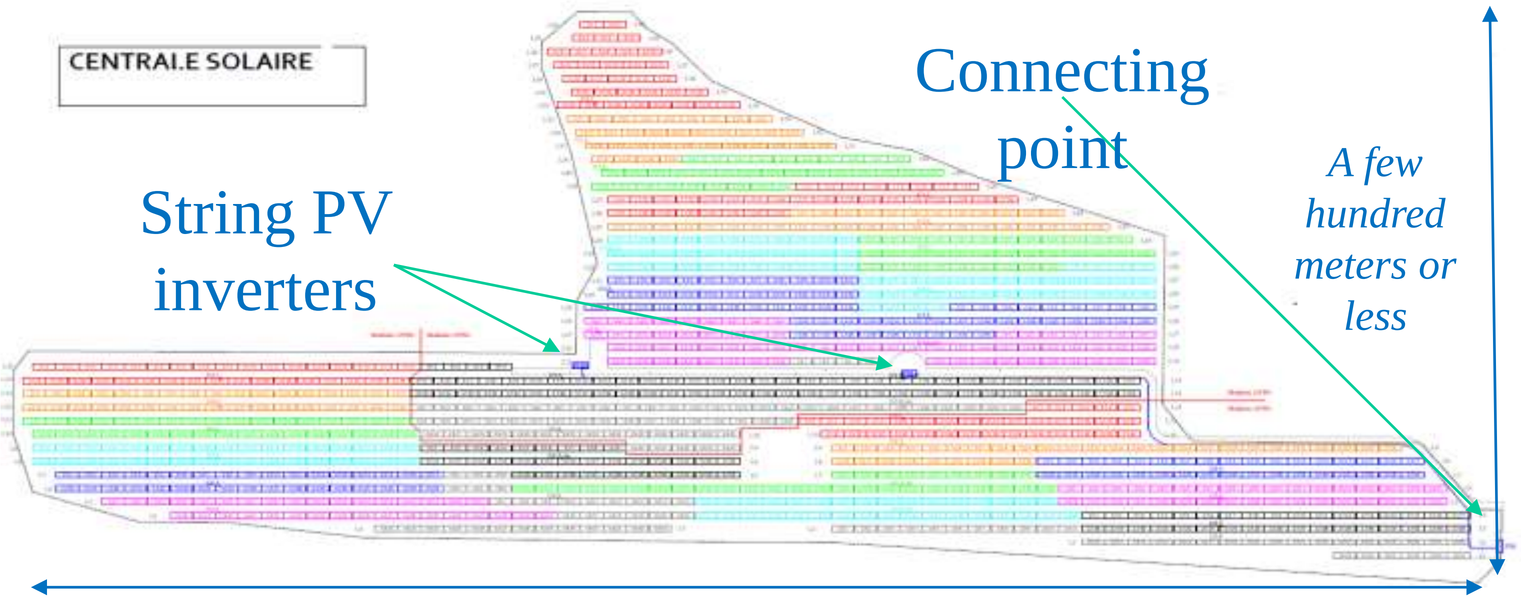
# Linear PV power plants




String PV inverters

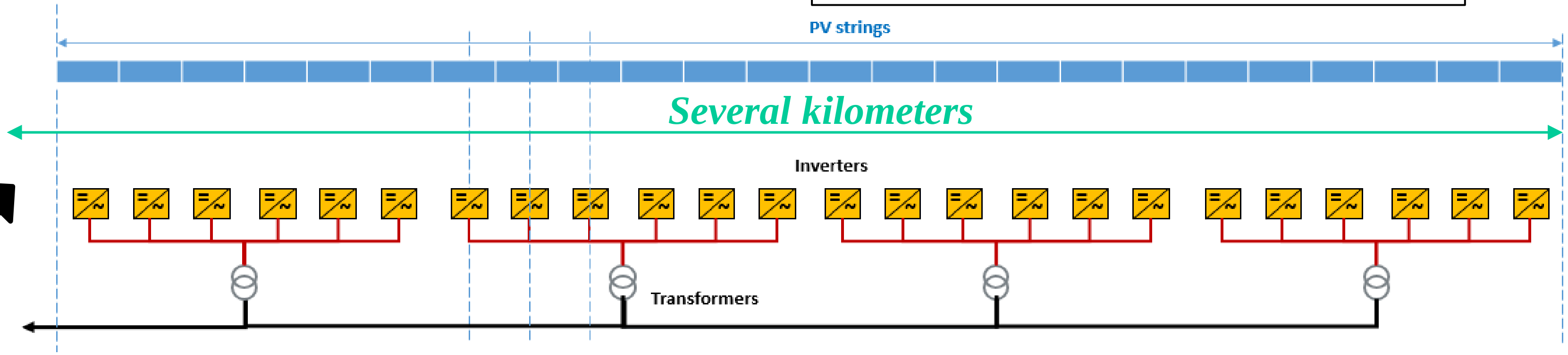
Connecting point

*A few hundred meters or less*

*A few hundred meters or less*

## Classical PV power plant

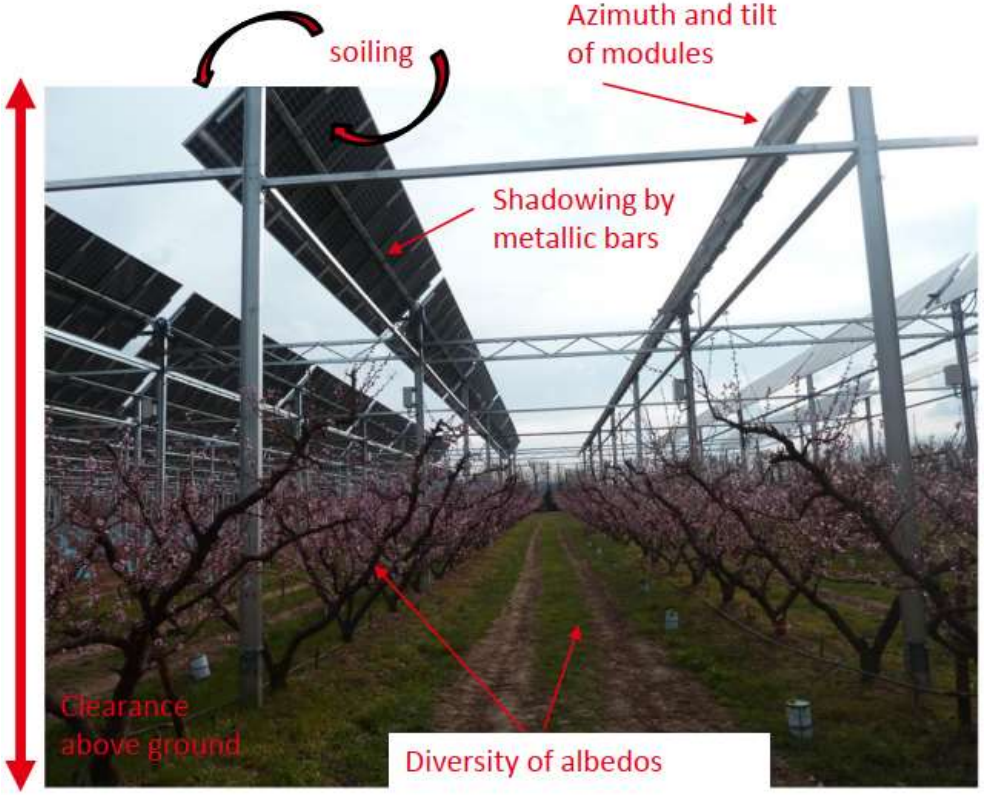
## Linear PV power plant



## An application favorable to the development of bifacial technologies

(source TSE)

(source Next2Sun)




- High clearance of modules above the ground (up to several meters to give way to agricultural machinery)
- Space between modules rows (to limit the shadow projected on the ground)
- Use of glass-glass modules for higher resistance (mist, agricultural chemicals, …)
- Bifacial modules are appropriate and may operate in good conditions to provide an energy gain

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# PV solar: Applications


# CEA Solution: Applications













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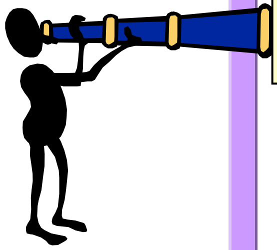



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# Solar PV energy development

| Parameter | Value | Status | Reference | Date of data |
|---|---|---|---|---|
| ***Germany / EU27 / Worldwide*** | | | | |
| PV installation market | 4.9 / 18.2 / 126 GW<br>5.3 / 25.9 / 174 GW | End of 2020<br>End of 2021 | BNA / SPE / IEA<br>BNA / SPE / IEA | 11/2021; 12/2020; 09/2022<br>02/2022; 12/2021; 09/2022 |
| Cumulative installation | 59.8 / 164.9 / 945 GW | End of 2021 | ISE / SPE / IEA | 07/2022; 12/2021; 09/2022 |
| PV power generation | $48.6_{net}$ / $160.4_{gross}$ / $1032.5_{gross}$ TWh | 2021 | ISE / BP / BP | 06/2022; 06/2022; 06/2022 |
| PV electricity share | $9.9\%_{net}$ / $5.5\%_{gross}$ / $3.6\%_{gross}$ | 2021 | ISE / BP / BP | 08/2022; 06/2022; 06/2022 |
| ***Worldwide*** | | | | |
| c-Si share of production | 95% | 2021 | ISE | 08/2022 |
| Record solar cell efficiency: III-V MJ (conc.) / mono-Si / CIGS / multi-Si / CdTe | 47.1 / 26.7 / 23.4 / 24.4 / 21.0% | 06/2021 | Green et al. | 06/2021 |
| ***Germany*** | | | | |
| Price PV rooftop system | 1,050 to 1,650 €/kWp | 2022 | BSW | 05/2022 |
| LCOE PV power plant | 3.1 to 5.7 ct€ / kWh | 2021 | ISE | |
| Lowest/Latest PV-Tender Price | 4.33/5.00 ct€ / kWh | 02/2018; 11/2021 | BNA | 11/2021 |

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FHG-SK: ISE-PUBLIC

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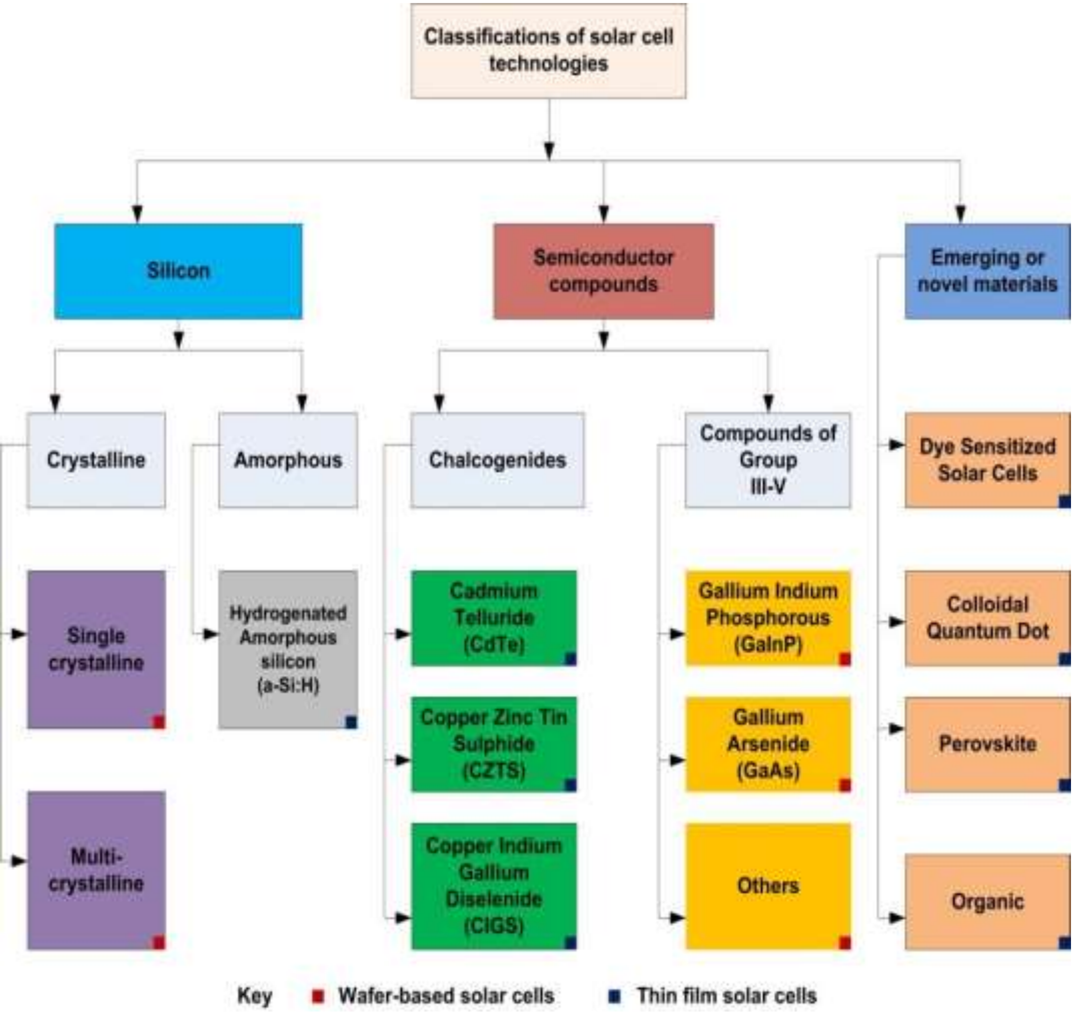
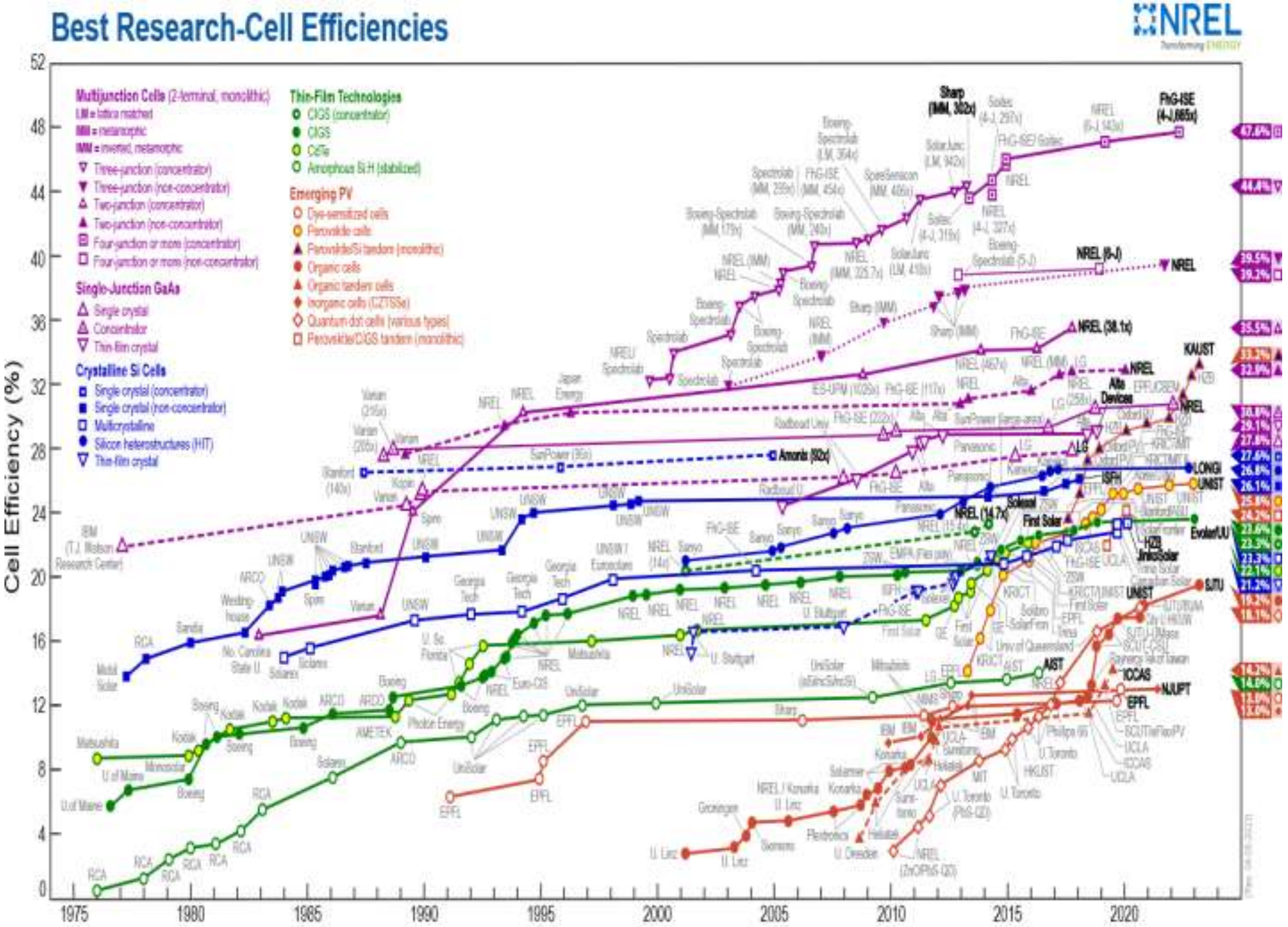
# PV FAMILIES





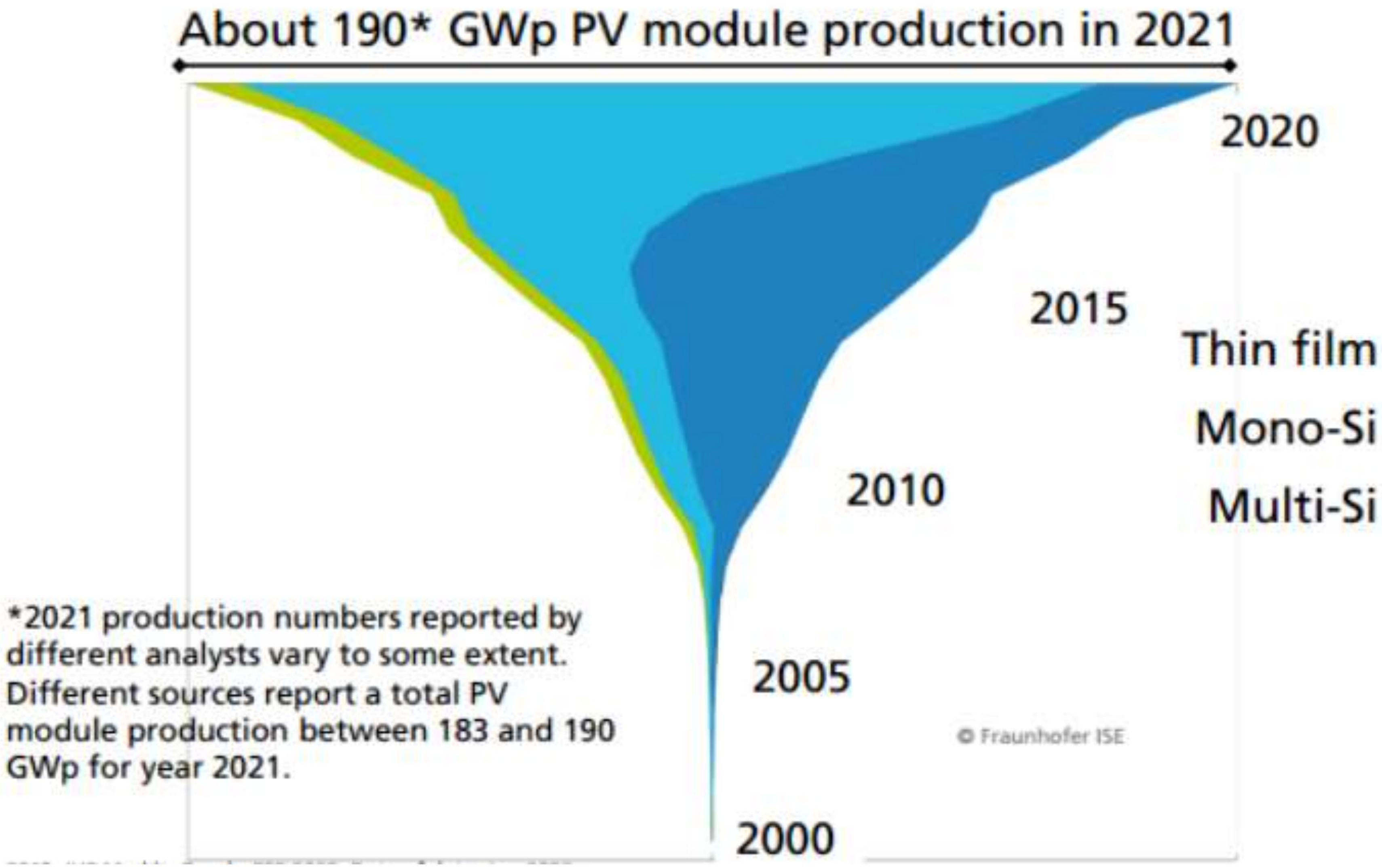




The final application will drive the technology selection

Source NREL

T. Ibn-Mohammed et al, Renewable and Sustainable Energy Reviews, Volume 80, 2017, Pages 1321-1344

# Annual PV Production by Technology Worldwide (in GWp)




10 GW: 5%

20 GW: 10%

160 GW, 85%

Data: from 2000 to 2009: Navigant; from 2010 to 2021 IHS Markit; from 2022 IEA. Graph: PSE 2022 . Date of data: July 2022

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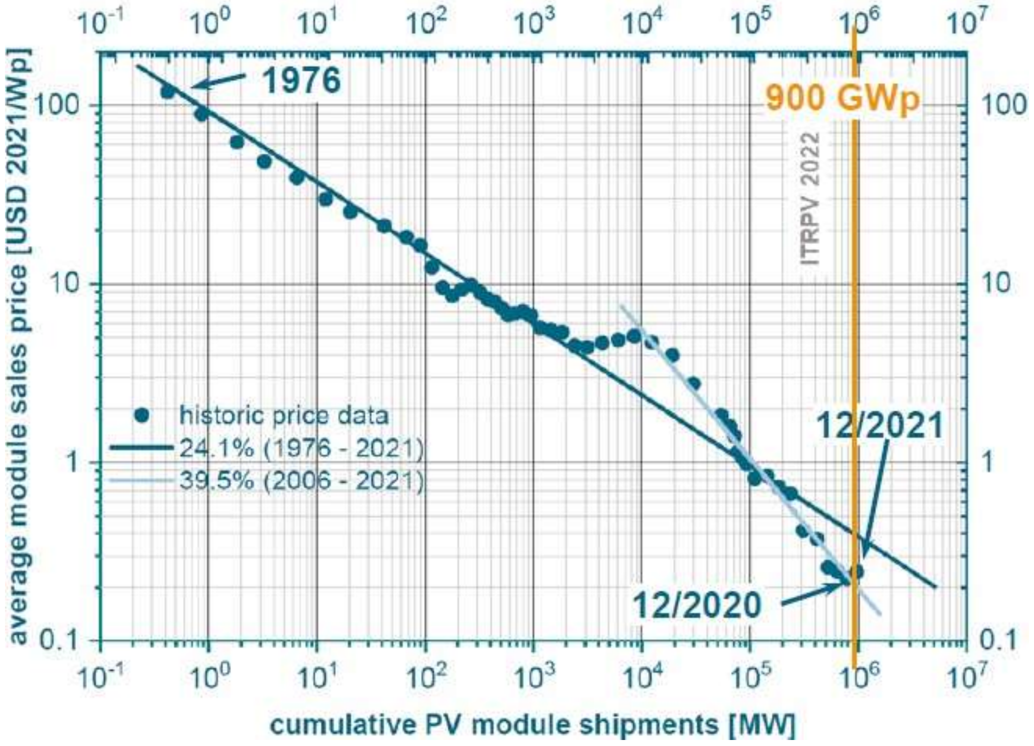
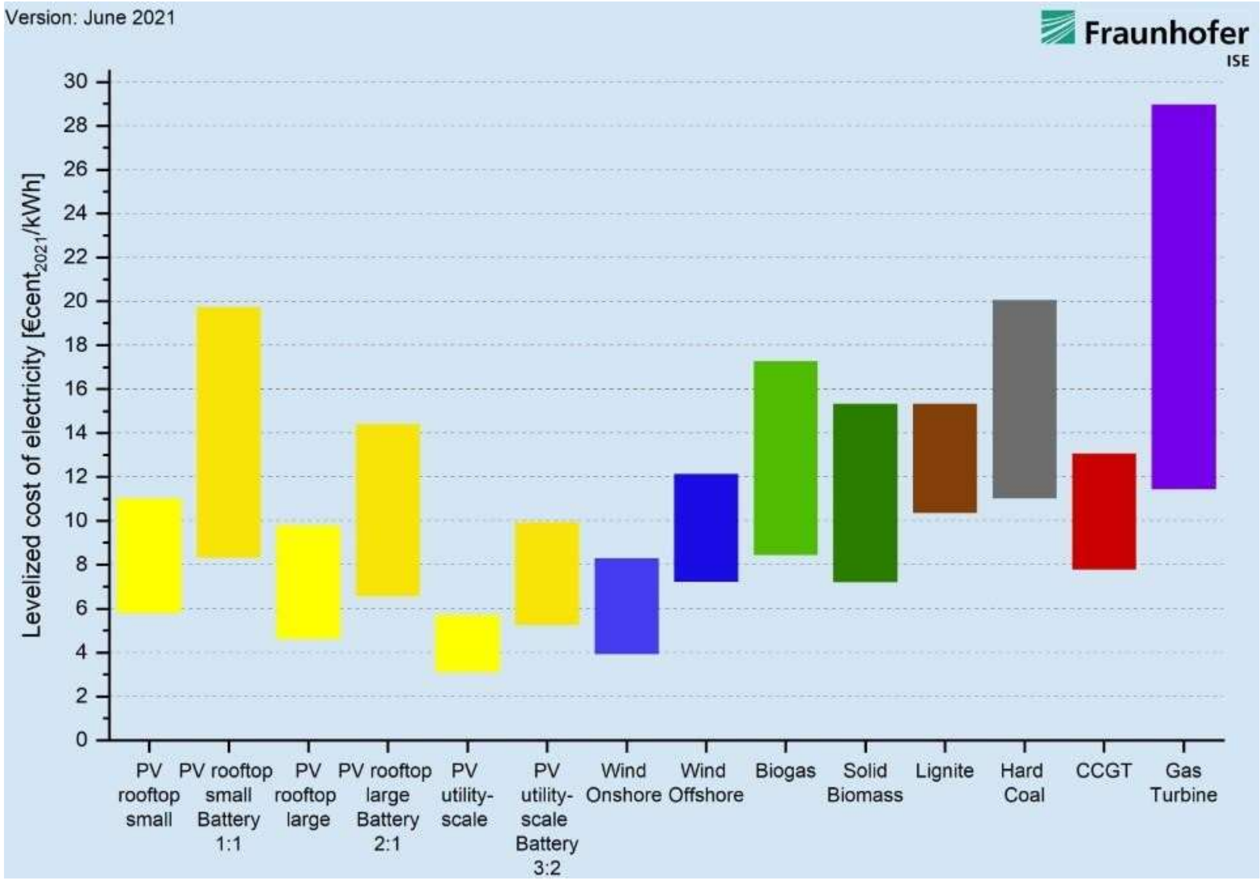
# PV MODULES TECHNOLOGIES, COST



## PV learning curve

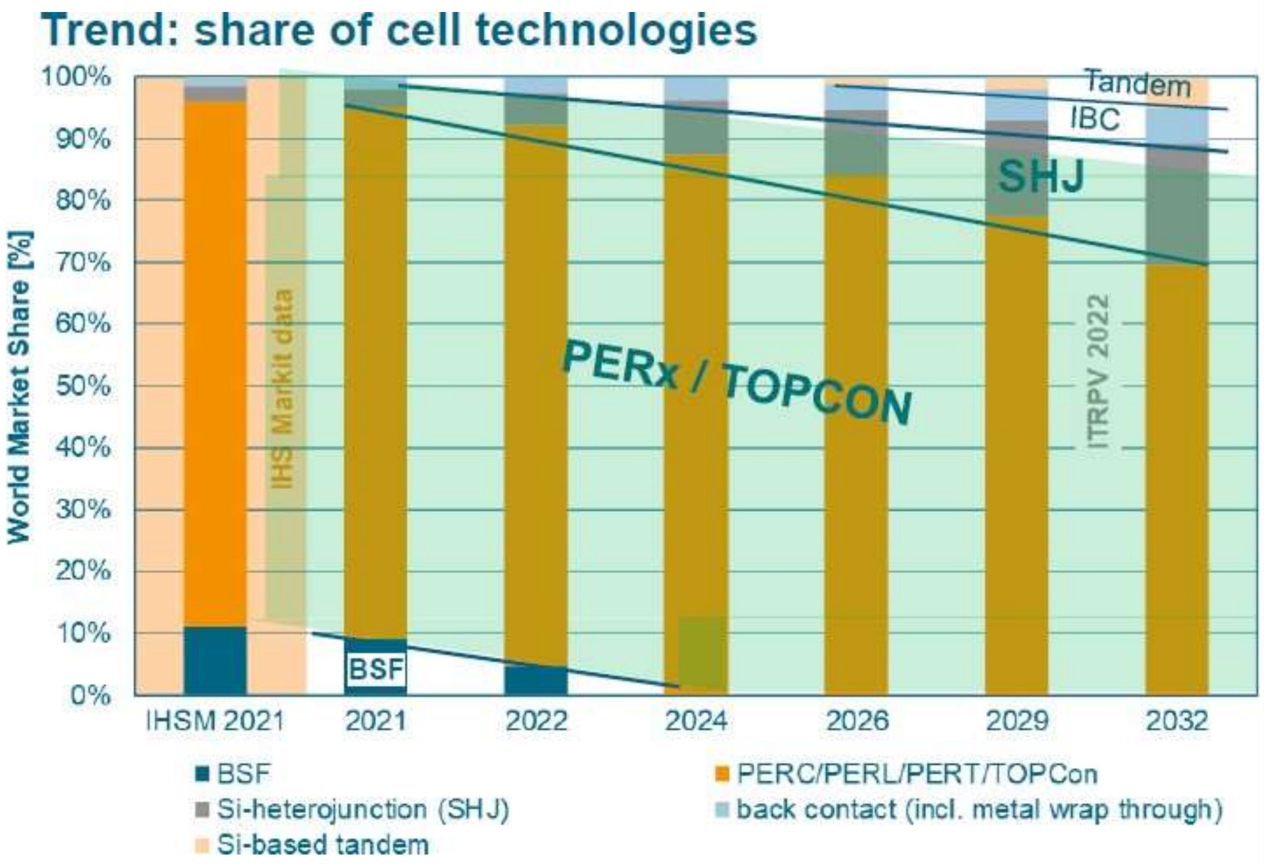


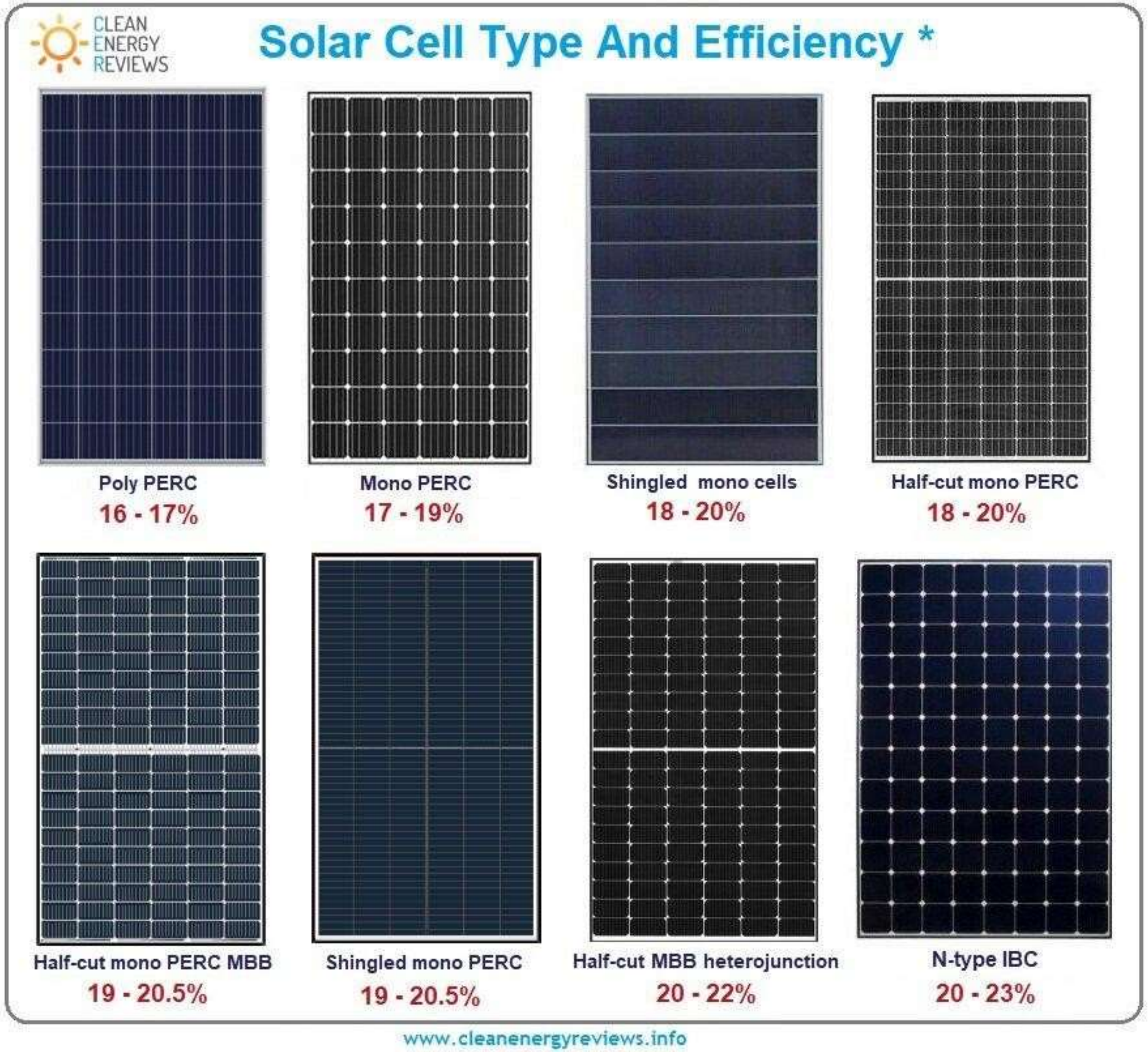

## Cost of Energy



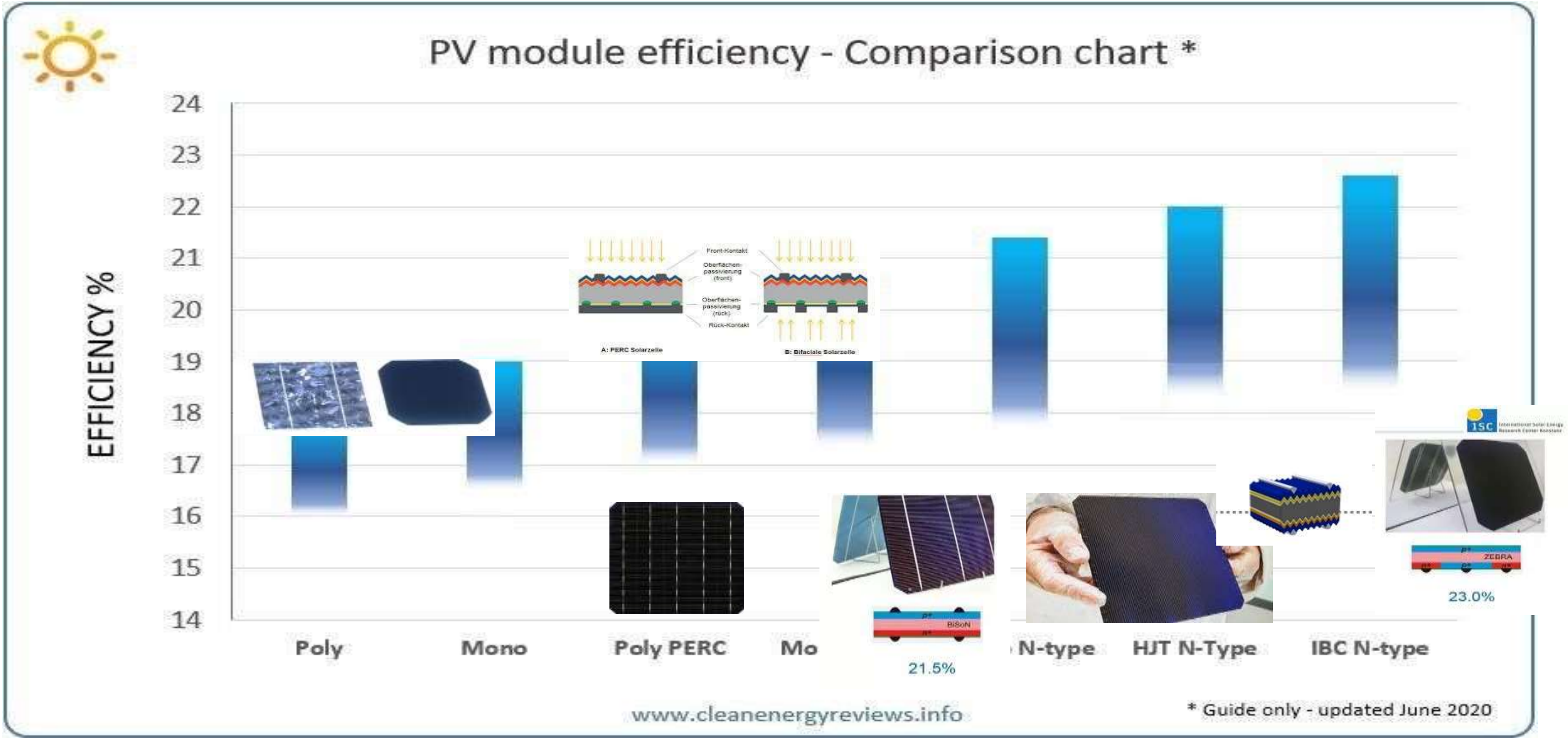
# VARIETY OF C-SI SOLAR CELLS & EFFICIENCY





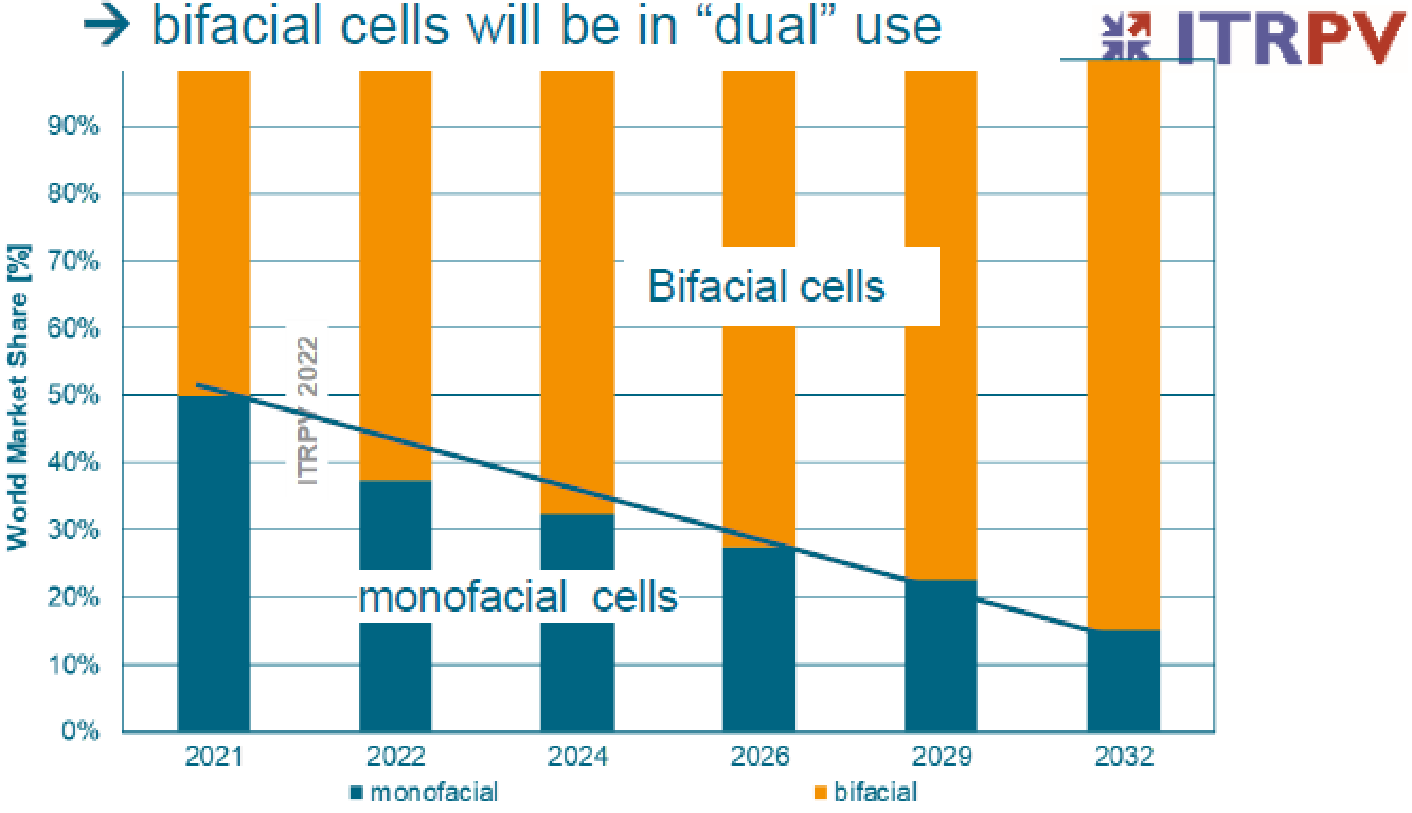



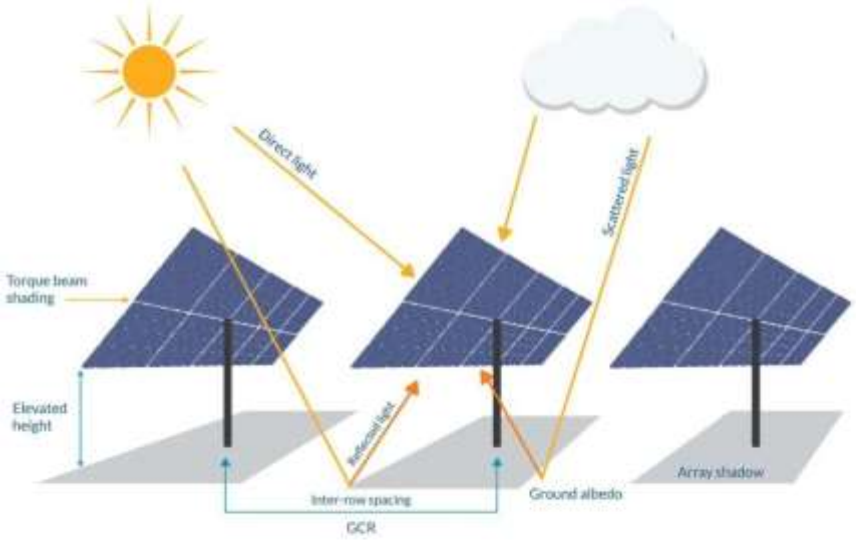
# VARIETY OF C-SI SOLAR CELLS & EFFICIENCY



## Trend: Bifacial cells

→ bifacial cells will be in "dual" use

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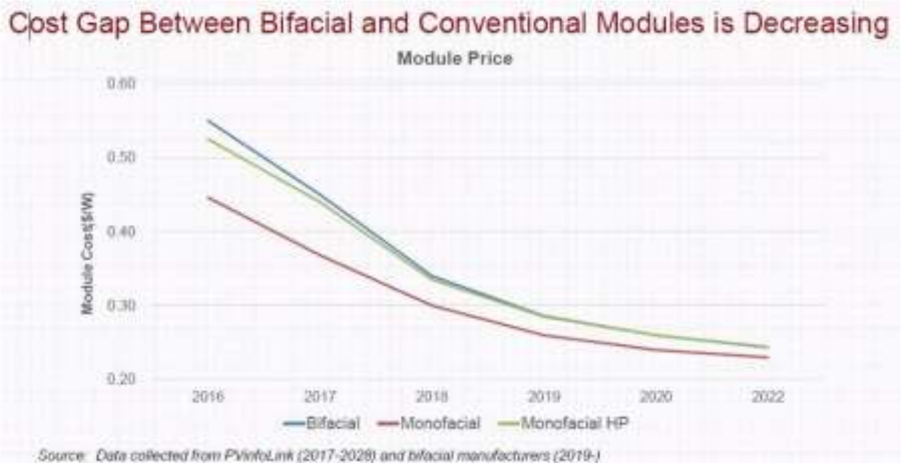
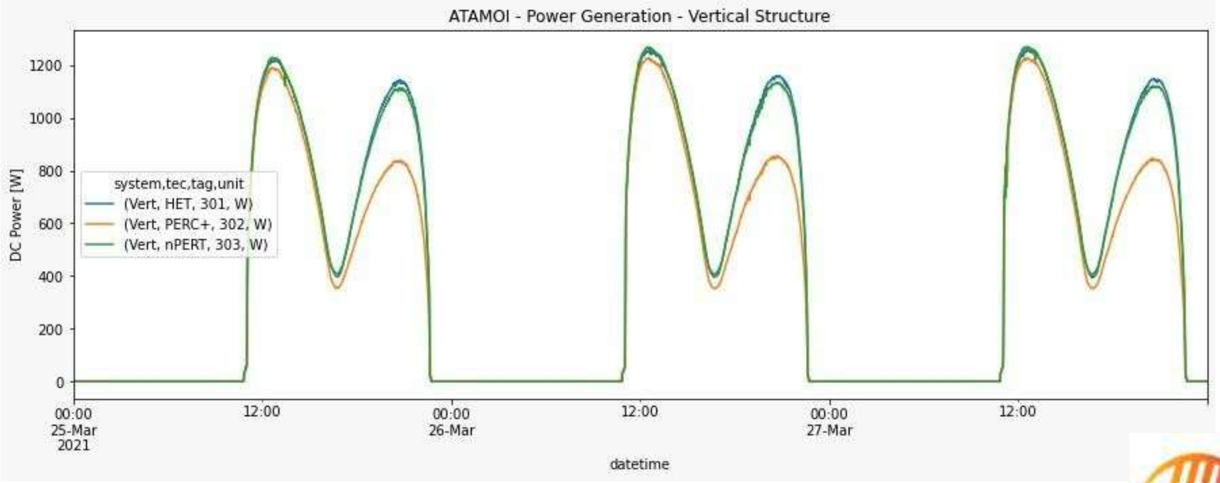
# BIFACIALITY IS HERE AND IT IS THE MAINSTREAM FOR UTILITY SCALE

Solar generation capacity up to 25% depending on:

1. Solar cell and module technology
2. Site selection: Albedo, Land cost, latitude…
3. Height, row distance, tracker, tilt,
4. Meteorological conditions



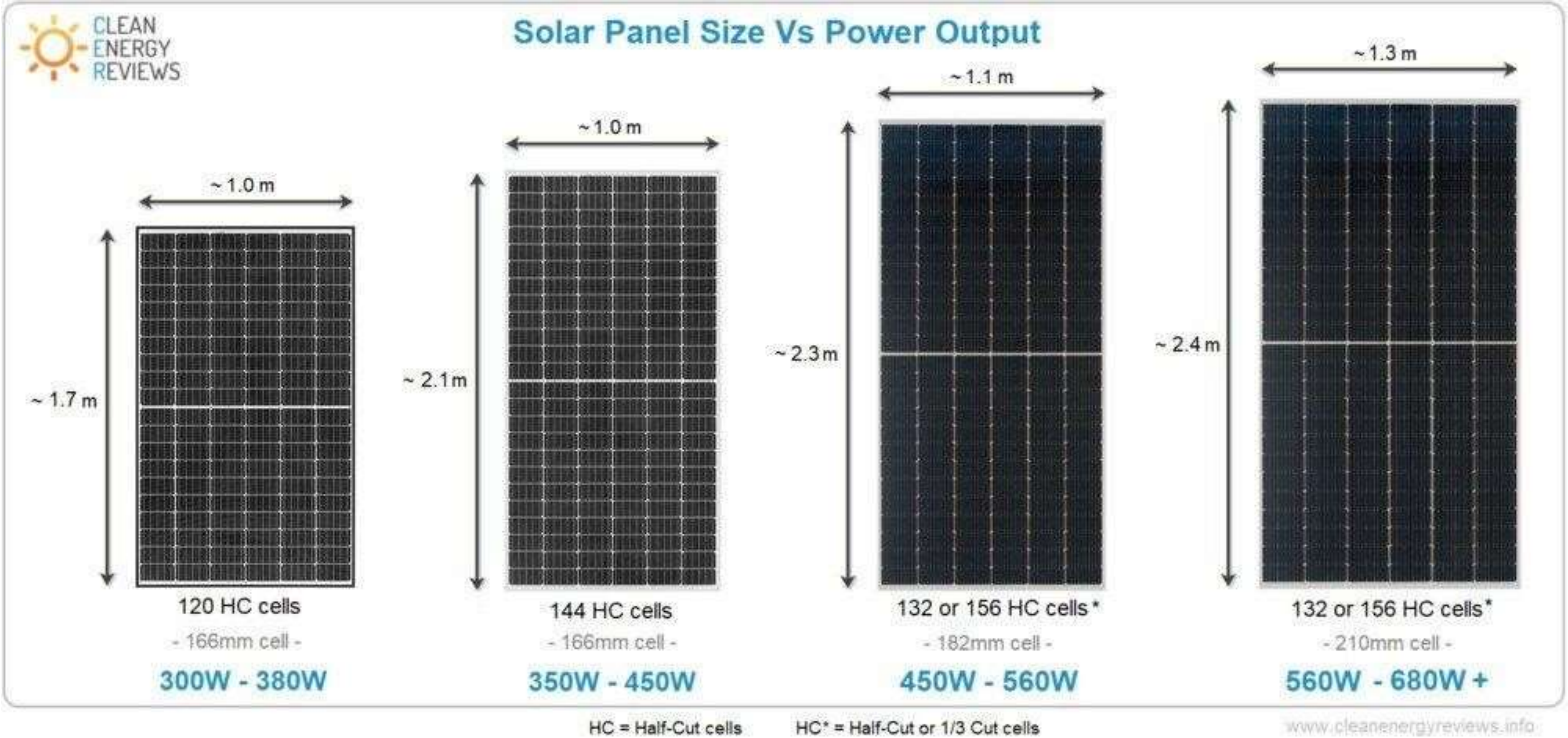

A bifacial, single axis tracking (1T) pv plant can cost approximately 15% more than a comparable monofacial non tracking PV plant.



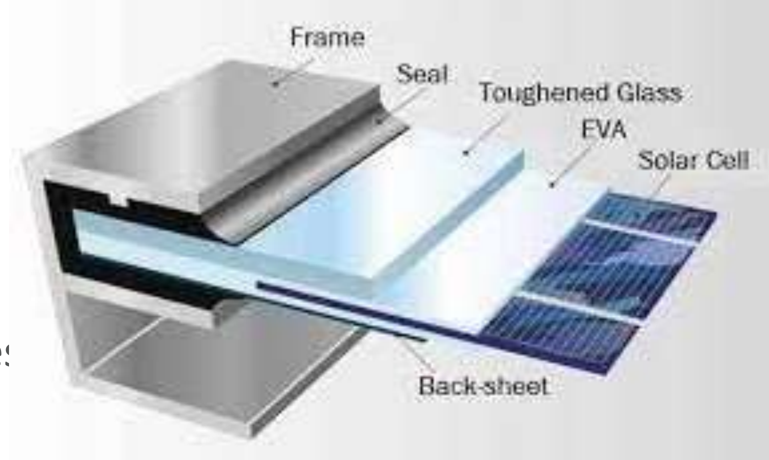

YIELD: a bifacial 1T plant **can be well above 20%,** up to **35 to 39% in some cases** if conditions can be optimized.

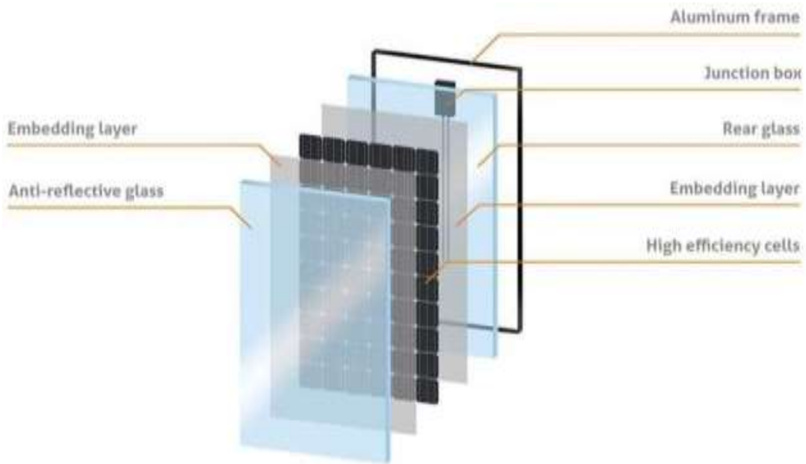
CORFO ATAMOSTEC

# LARGE AREA MODULES: MORE POWER / MODULE



# FRAME OR FRAMELESS?




**Advantages :**

1. Reduces impact of potential-induced degradation (PID) – enabling longer lifes
2. No corrosion, no Aluminum
3. Easy to recycle
4. Less soiling and snow issues
5. increases the aesthetic appeal

**Drawbacks:**

1. Specific structures
2. Cost higher / 2 glasses, high weight
3. edges of the panels can be little weak

DOI: 10.1109/PVSC40753.2019.8981389
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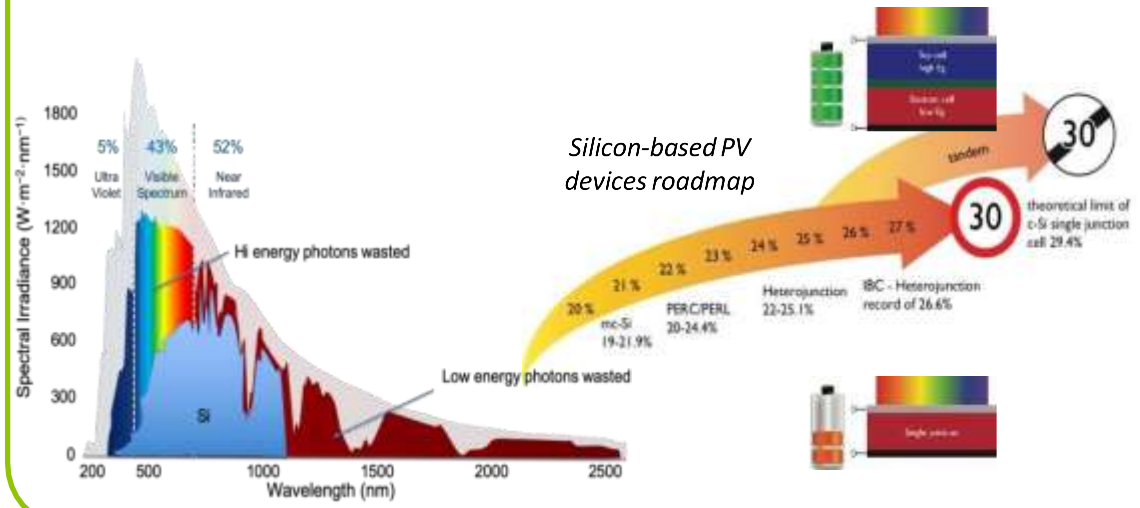
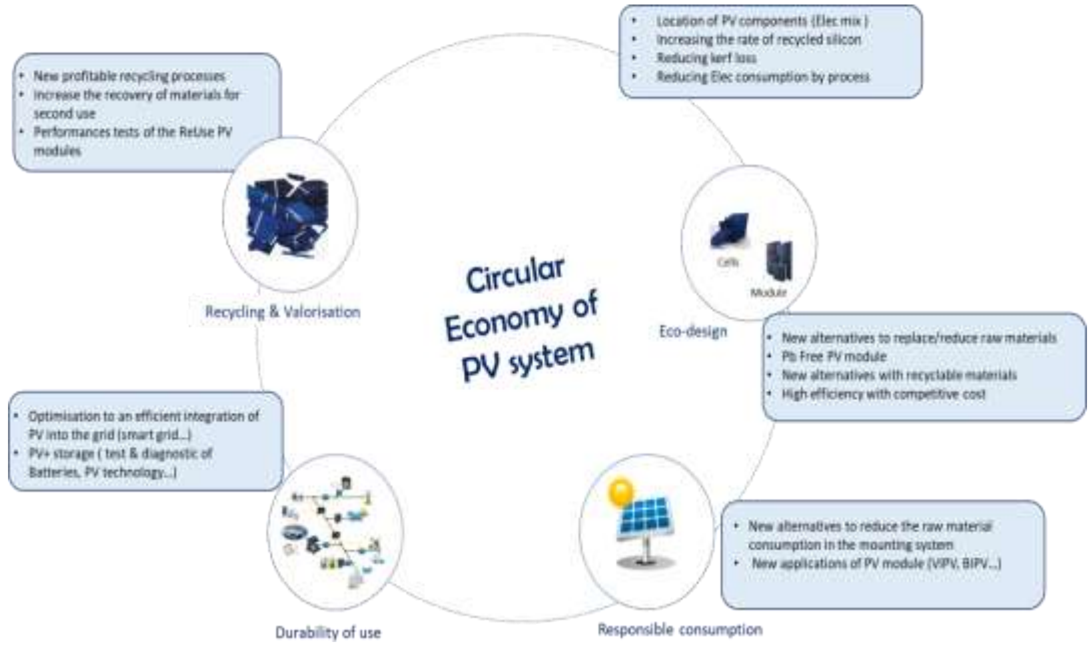
Tandem technologies > 30% efficiency

Maximizing solar spectrum use or varying which spectrum part is used for energy




**Efficiency, Cost, Reliability**

**Sustainability, Eco-design, Recyclable**

**Integrated, adapted**

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# CONCLUSION ON PV MODULES TECHNOLOGIES



- New paradigm for PV modules
- Not more a standard for everything
- Module has to be adapted to the application
- The total cost of the system is calculated not only with LCOE basis (other KPI needed)
- Reliability is a must
- The system and O&M costs will depend on the module techology chosen
- Modelling is mandatory to select the best technology


Each agrivoltaic installation can adapt PV module technology

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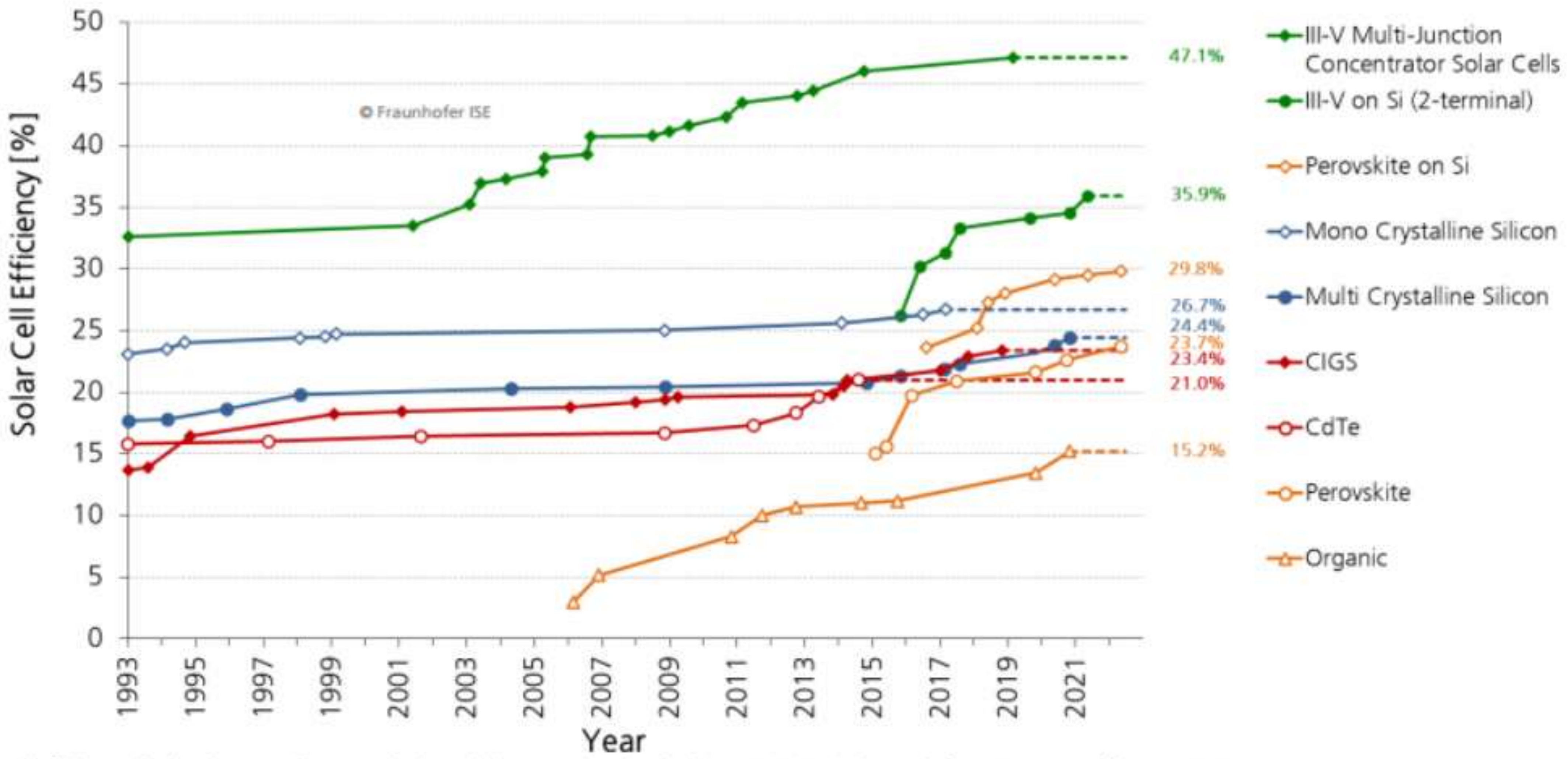
# Development of Laboratory Solar Cell Efficiencies




Data: Solar Cell Efficiency Tables (Versions 1 to 60), Progress in Photovoltaics: Research and Applications, 1993-2022. Graph: Fraunhofer ISE 2022. Date of data: May 2022

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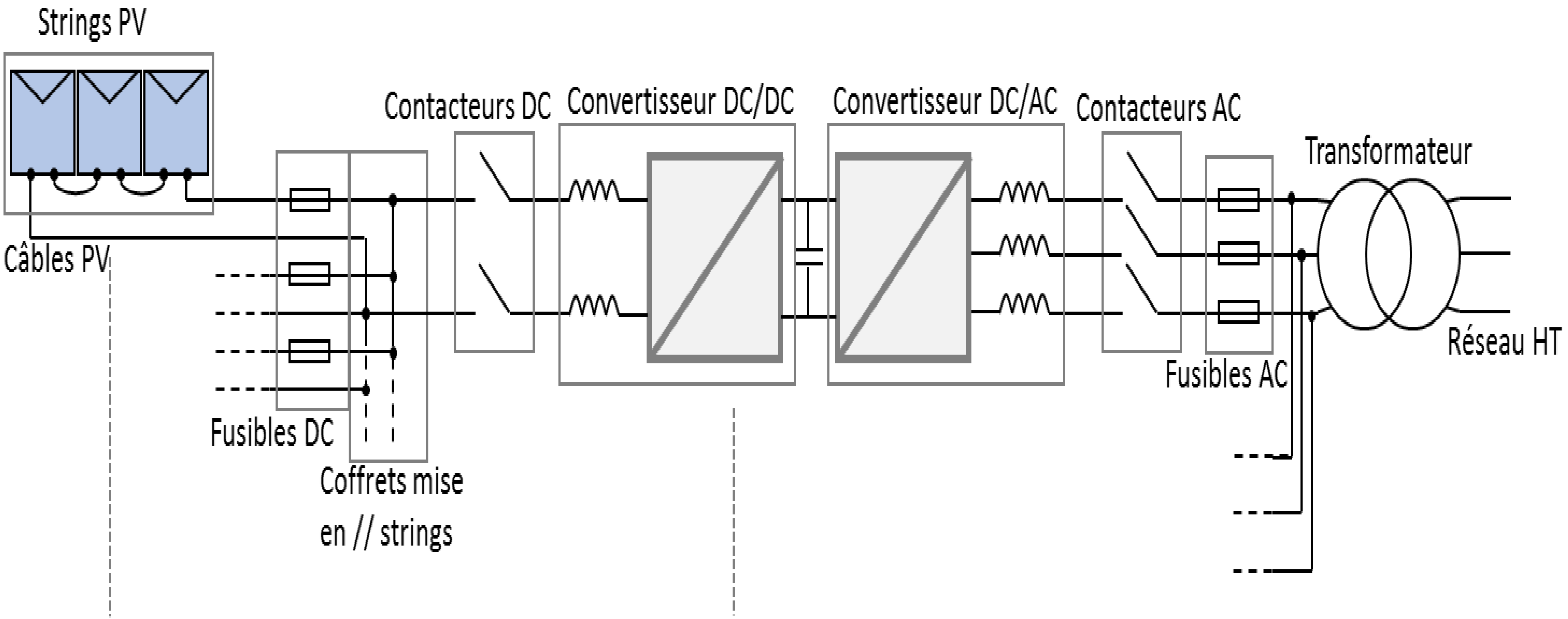
# Instalation

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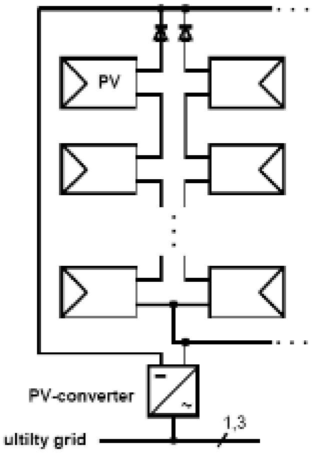
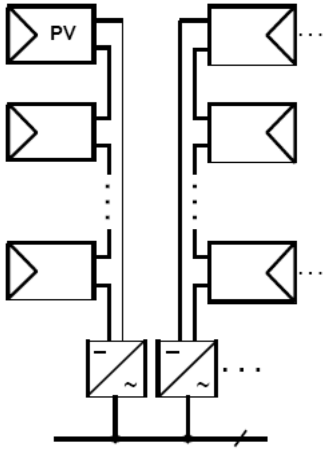
# Instalation

## Centralized system



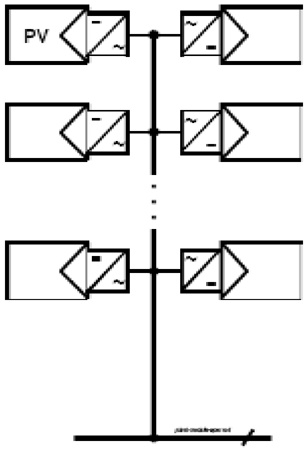

Central converter
- Parallel connection and / or DC side
- A converter for all PV modules
- Rated power of converter up to several MWp

## Modular system




Modular converter
- several modules connected in series on the DC side
- Connected in parallel side to AC
- Power converted to qqs kW

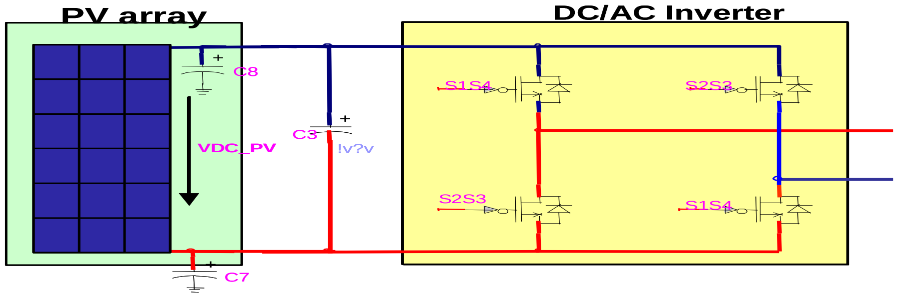
## Decentralized system



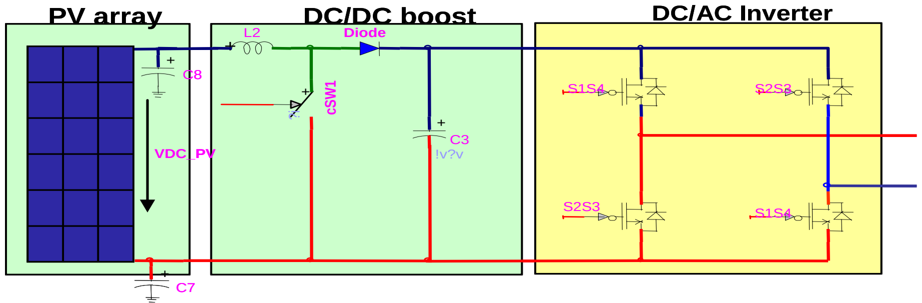

A converter by
- Module (50 W- 400 W)
- No DC wiring
- Connected parallel in AC

# Inverter modelling

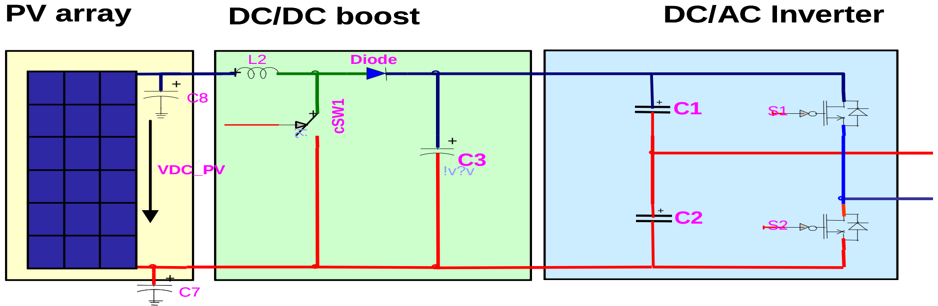
## T1 : Full-bridge inverter – no DC/DC converter- transformerless



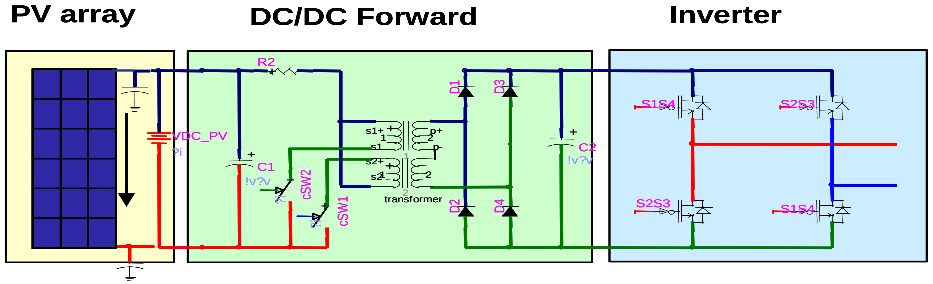

## T2 : Full-bridge inverter – DC/DC boost converter – transformerless



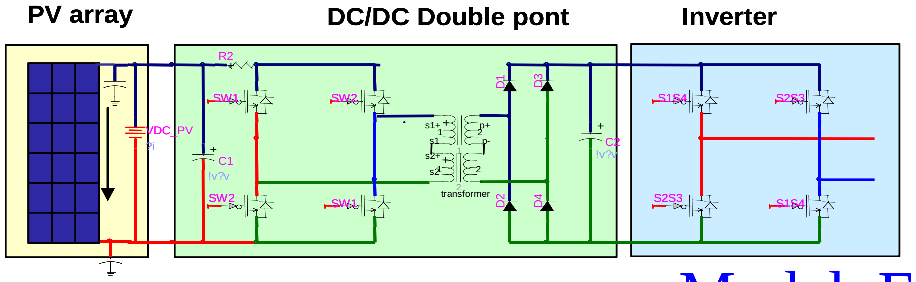

## T3 : Half bridge inverter – DC/DC boost converter – transformerless



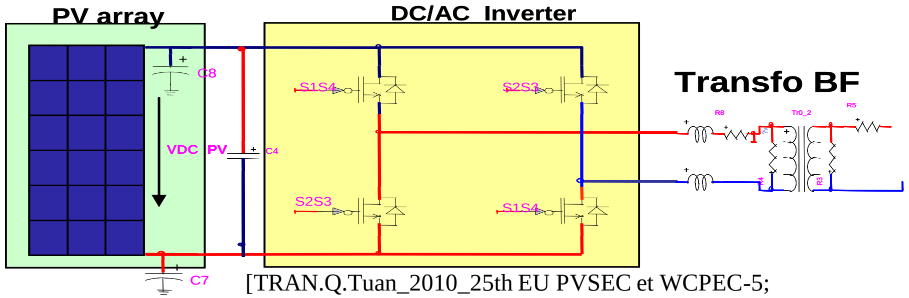

## T4 : Full-bridge inverter – DC/DC Forward converter –HF transformer




## T5 : Full-bridge inverter – DC/DC full-bridge converter –HF transformer




## T6 : Full-bridge inverter – no DC/DC converter – BF transformer

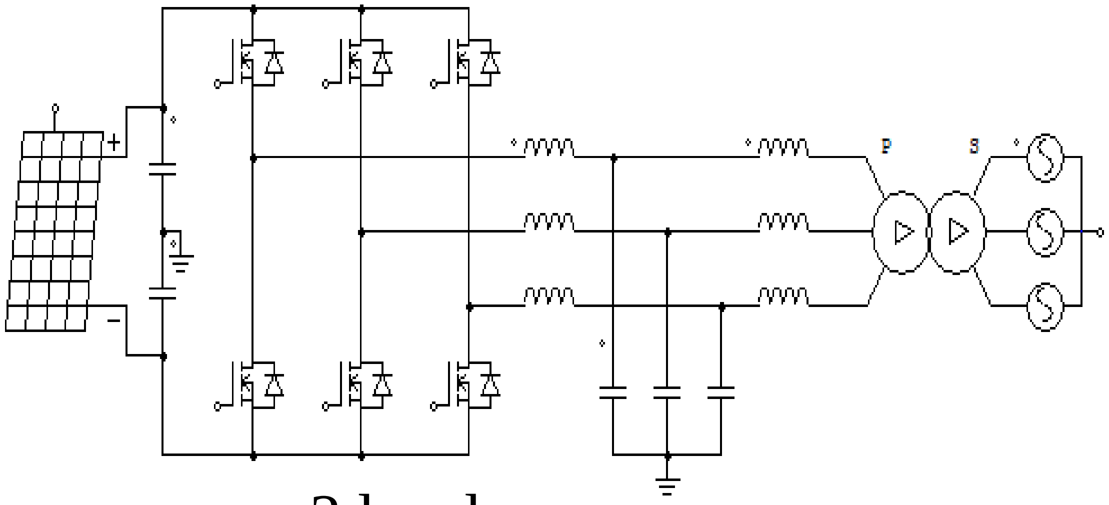



Model EMTP-RV

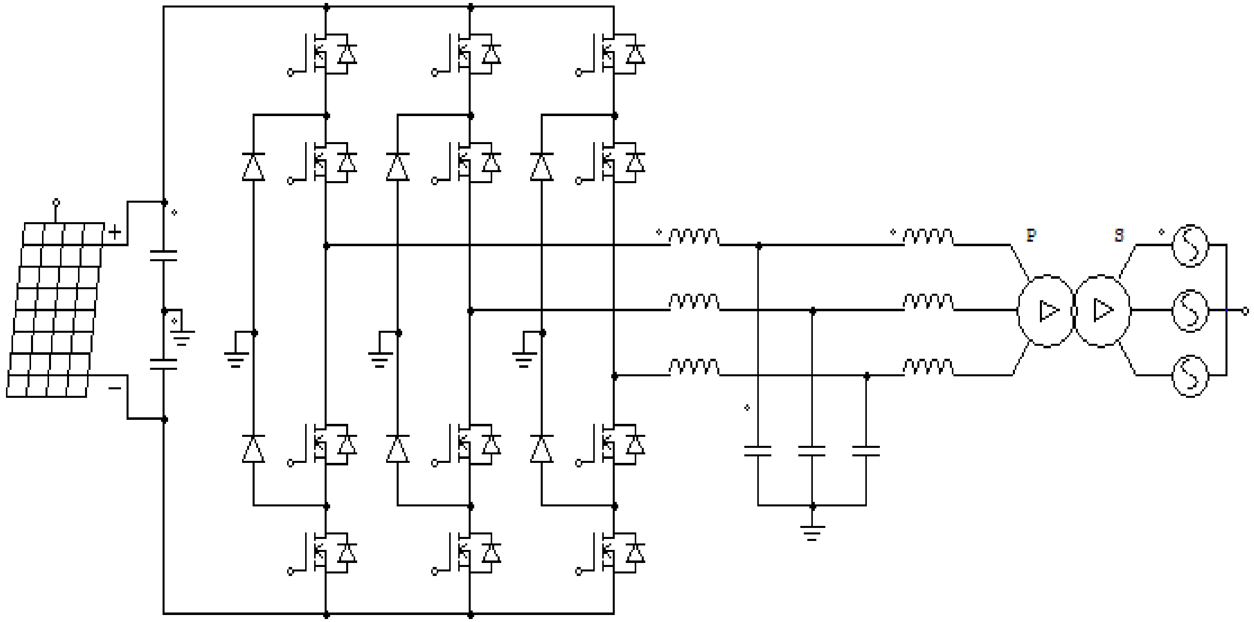
[TRAN.Q.Tuan_2010_25th EU PVSEC et WCPEC-5; Chapitre6; La distribution d'énergie électrique en présence de production décentralisée, Lavoisier]

# Inverter modelling – three phase

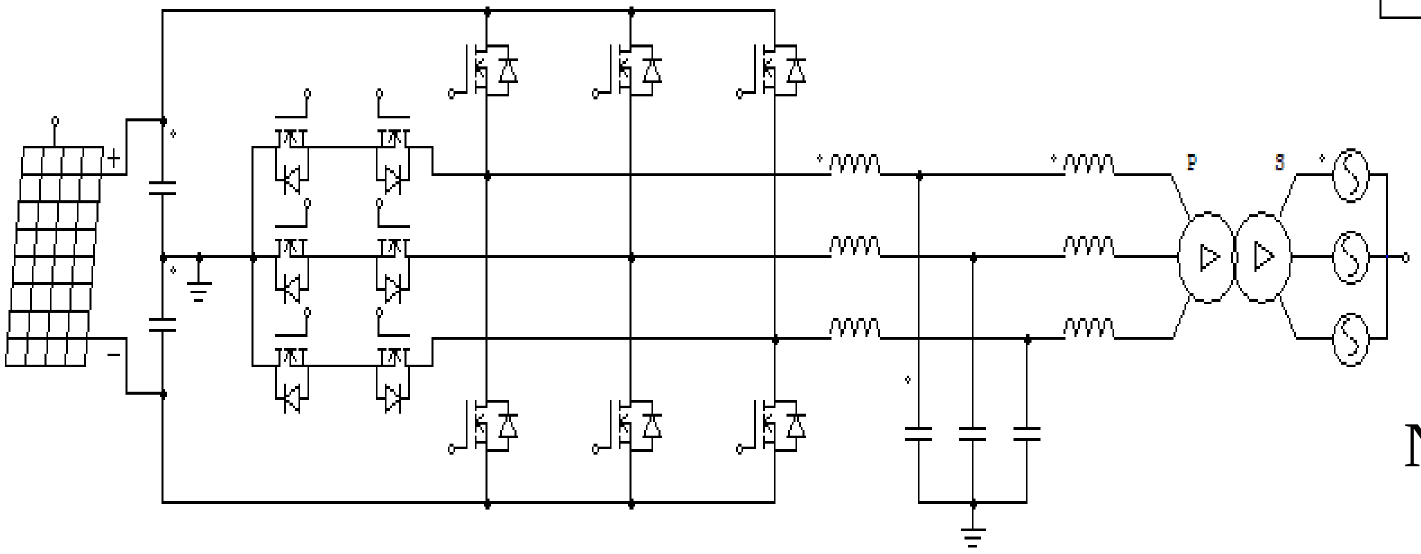





2 levels




NPC (Neutral Point Clamped)




NPC (Neutral Point Clamped), modified MNPC or T-type

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## *Etat de l'art*

### Marché
**Basse tension (BT)**
**$1.5kV_{DC}$-$1kV_{AC}$**

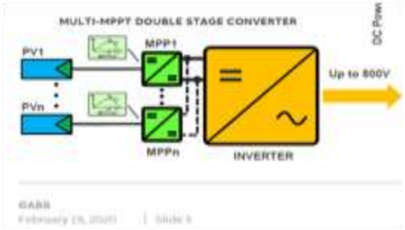
Top-10 Power Plants

**Puissance > 1GW !**

| TOP | Power (MWp) | Country | Description | Year |
|---|---|---|---|---|
| 1 | 2700 | India | Bhadla Solar Park | 2018 |
| 2 | 2400 | China | Longyangxia Dam Solar Park | 2015 |
| 3 | 2200 | China | Huanghe Hydropower Hainan Solar | 2020 |
| 4 | 2050 | India | Pavagada Solar Park | 2019 |
| 5 | 1650 | Egypt | Benban Solar Park | 2019 |
| 6 | 1547 | China | Tengger Desert Solar Park | 2016 |
| 7 | 1313 | U.A.E. | Mohammed bin Rashid…Solar Park | 2020 |
| 8 | 1200 | India | NP Kunta | 2021 |
| 9 | 1177 | U.A.E. | Noor Abu Dhabi | 2019 |
| 10 | 1030 | China | Jinchuan Solar Park | 2019 |
| 20 | 750 | India | Rewa Ultra Mega Solar | 2018 |
| 30 | 550 | China | Wenzhou Taihan Solar Farm | 2021 |

Source: Wikipedia https://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations (15/03/2022)

Grid voltage at the injection point
300Vac → 800Vac




PV strings : $600V_{DC}$ → $1500V_{DC}$

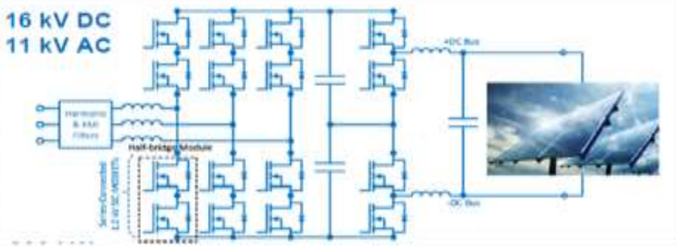
| | 1000V system | 1500V system |
|---|---|---|
| Number of strings (blocks/strings) | 22 | 32 |
| Power per string (W/string) | 5500 | 8000 |
| Number of connected string | 1818 | 1250 |
| Power per array (W/array) | 110000 | 160000 |
| Number of Arrays | 91 | 63 |

Source :
[1] Bruno Burger, Fraunhofer – ISE
[2] https://www.pvresources.com/en/pvpowerplants/top50pv.php
[3] https://www.mornsunpower.com/html/about/content/1800402.html

- ☹ Section de Cu/Al
- ☹ Qté de semi-conducteurs de puissance
- ☹ Volume/coût composants réactifs
- ☹ **Puissance max des strings PV atteinte**
- ☹ **Limite en courant maximum atteinte**

### R&D
**Moyenne tension (MT)**
**$1.5kV_{DC}$-$75kV_{DC}$ – $1kV_{AC}$-$50kV_{AC}$**

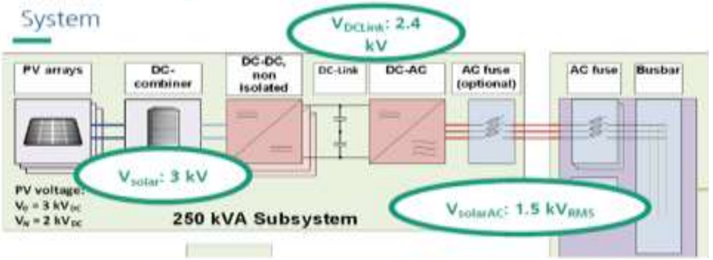
ETH zürich, Oak Ridge National Laboratory, Virginia Tech, CPES, Fraunhofer IISB ISE IWES, SuperGrid Institute, GE




CPES-USA

cea liten

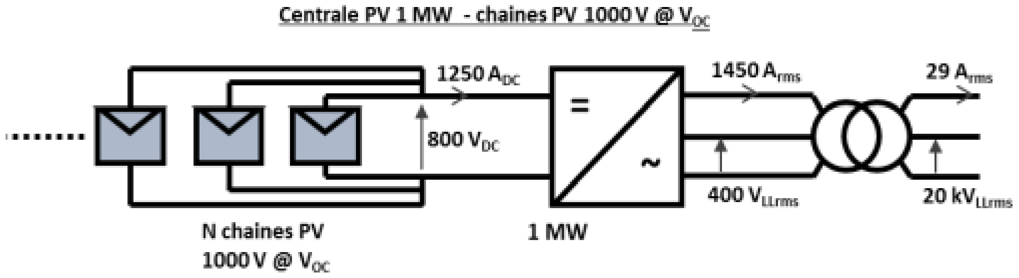
PV Strings $3kV_{DC}$ (DTS/LIRE)

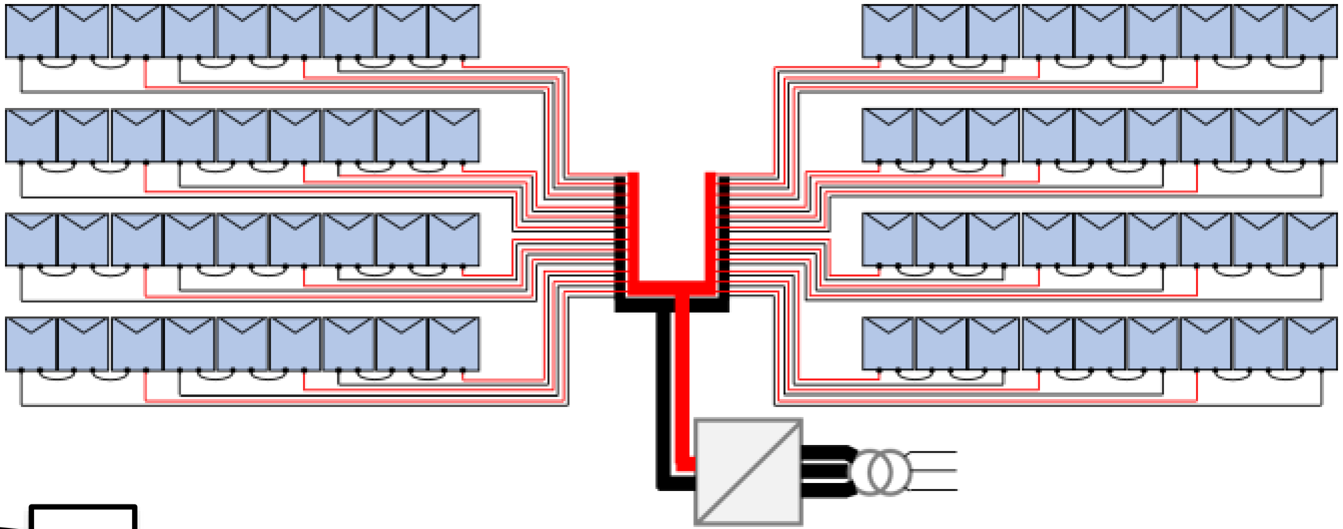



Fraunhofer ISE-DE

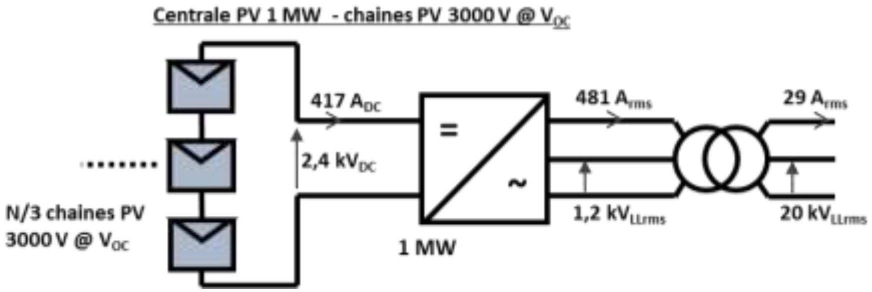
Module PV à isolement renforcé (DTS/SMSP) $V_{iso}$=14kV

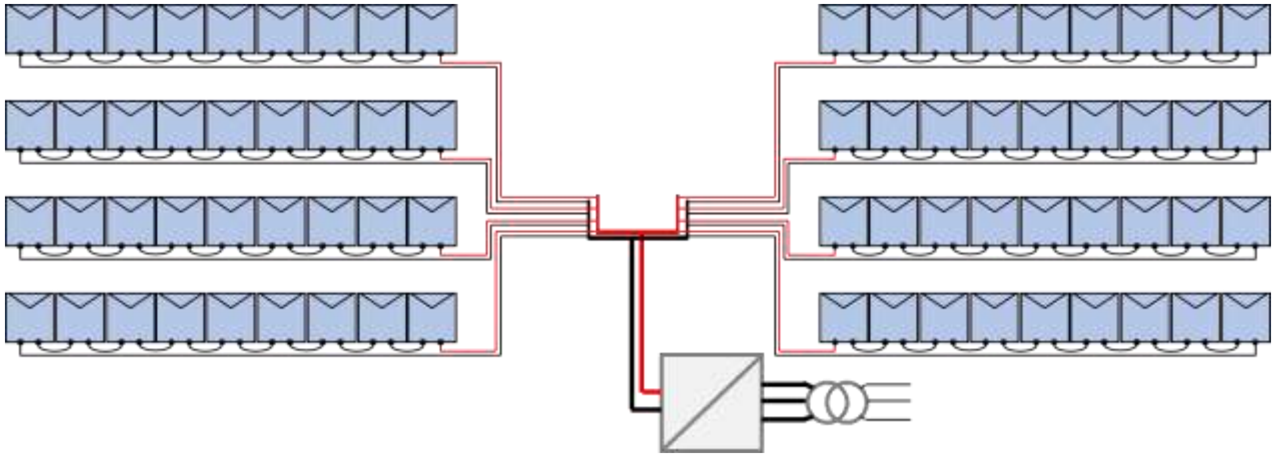
- ☺ **Cu et semi-conducteurs ↘**
- ☹ **Isolement du système (dV/dt, PWM ageing) ↗**
- ☺ **Puissance des strings PV ↗**
- ☺ **Puissance des convertisseurs statiques ↗**
- ☹ **Disponibilité des composants ↘**



VS



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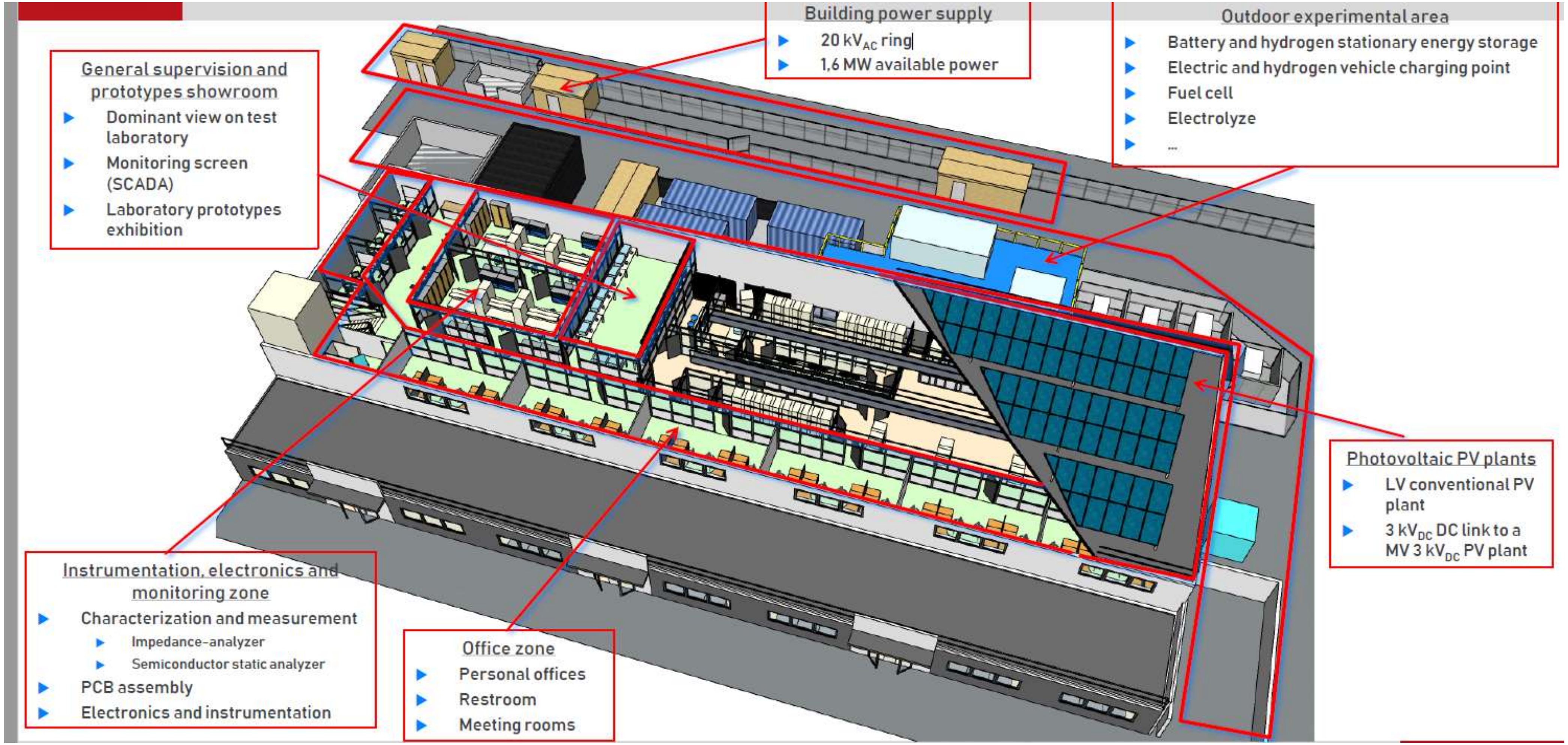
# New platform PUMA1 – CEA INES

***Moyens expérimentaux internes (CEA)***

- **Logiciels** de conception **multi-physique** (Ansys, PTC, Powersys ...)
- Bâtiment **d'électronique de puissance MT**
- **Chaînes PV 3kV** uniques au monde
- **Puissance d'alimentation disponible : 1.6MW**
- **Boucle : 20kV$_{AC}$-3~**

Mise en service du PUMA 1 : 9/6/2023

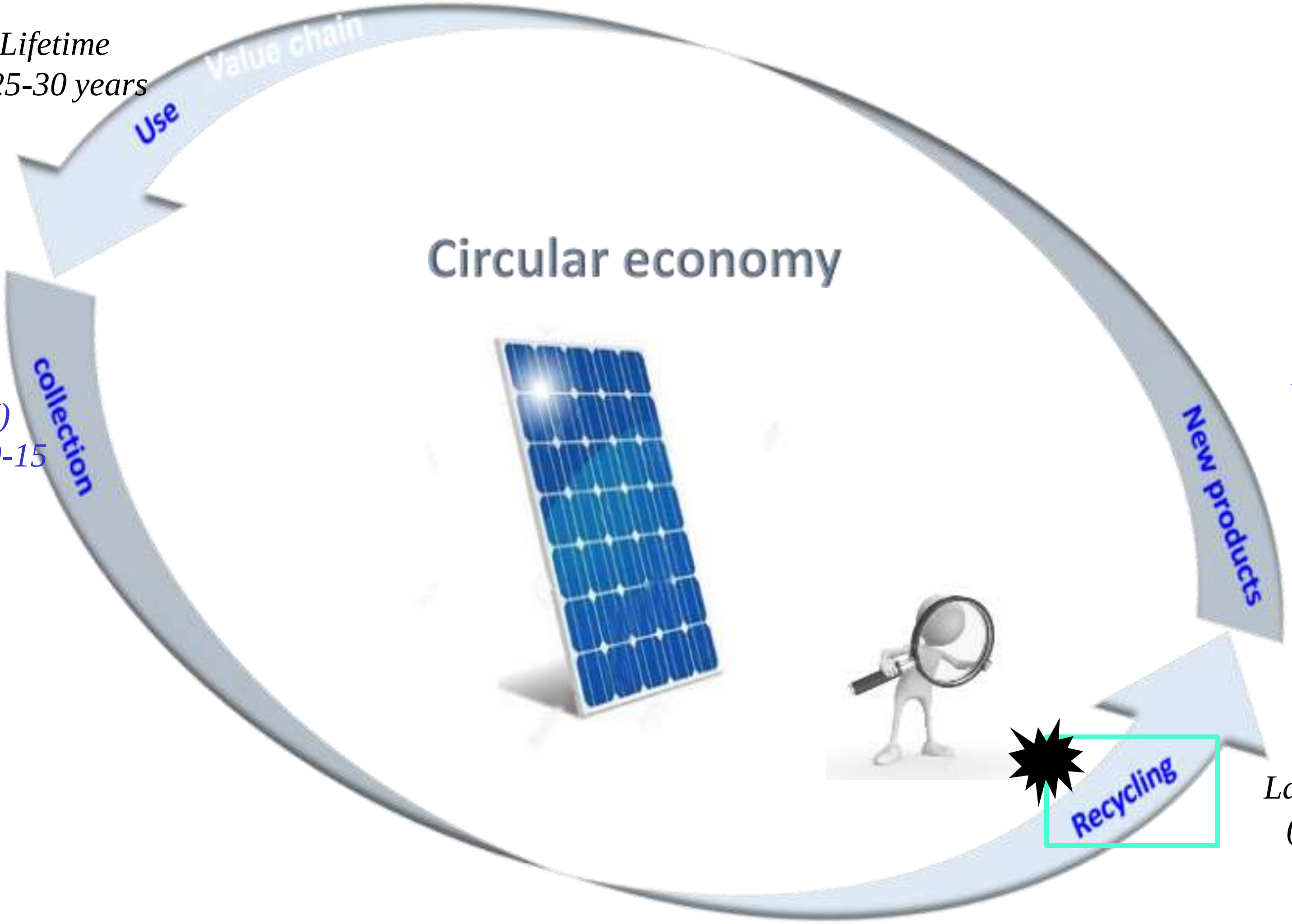


# PV Recycling



*Lifetime*
*~ 25-30 years*

*PV cycle (EU)*
*Storage for ~ 10-15 years*




*Ecodesign - development of new materials, designs (lifespan, recycling, etc.)*

*Landfill, Shredding => recovery of critical (CRM-EC) and precious materials "not addressed" to date*

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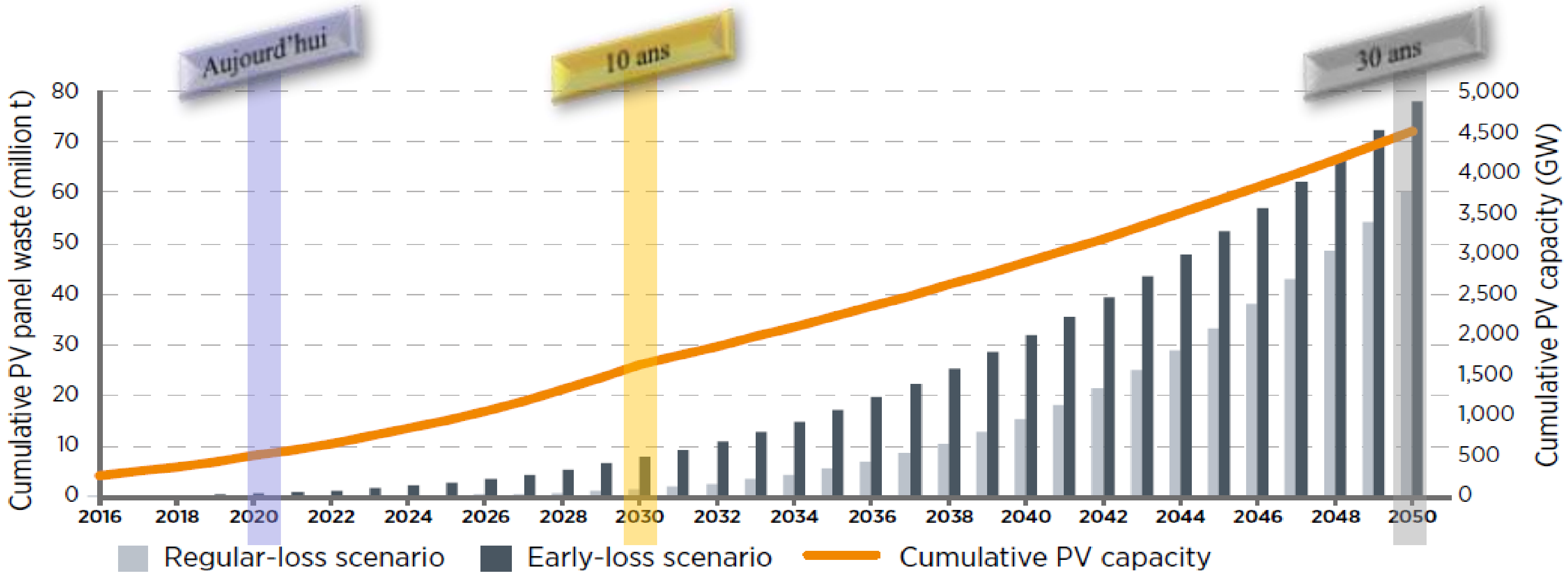
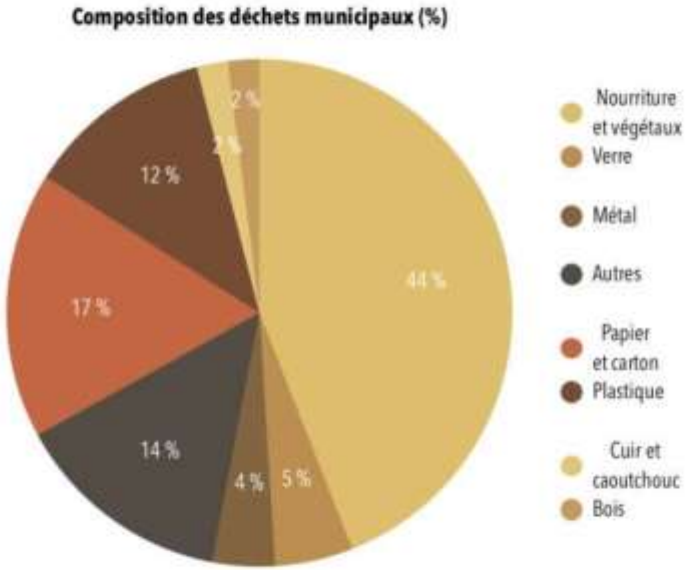
## Estimation of the cumulative volume of end-of-life panel waste




How many tons of waste per year in the world?
2018: 2 billion
2050: 3.4 billion




# Cumulative volume of end-of-life panel waste

| | | 2020 | 2030 | 2050 |
|---|---|---|---|---|
| **World** | Early loss | 850 000t | **8Mt** | **78Mt** |
| | Regular loss | 100 000t | **1,7Mt** | **60Mt** |
| **Europe** | Early loss | 325 200t | **2Mt** | **10,8Mt** |
| | Regular loss | 27 600t | **0,6Mt** | **9,6Mt** |

**In comparison**
**Hà Nội** phát sinh khoảng 6.500 tấn **rác/ngày**
Eq: 2 372 500 t/năm
Vietnam : 25 triệu tấn/năm

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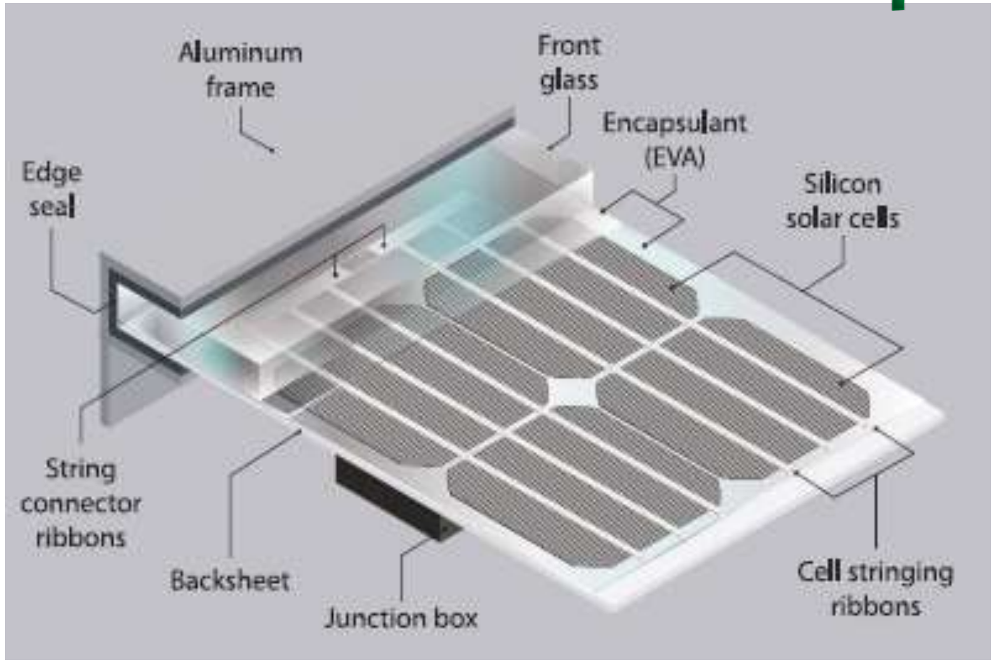
# Context: A PV module vs waste?

**Technology c(-Si)** ~ 95% market

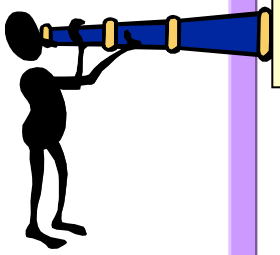



| Component | Metals | % Mass | 2030 |
|---|---|---|---|
| Border | Al | 8% | 7% |
| Front face | Glass | 76% | 80% |
| Back side | Tedlar (polymer) | 10% | ~9% |
| Interface | EVA (ethylene vinyl acetate) | | |
| Cellules | Si | 5% | 3% |
| Ribbon | Cu | 1% | 1% |
| Metals | Ag, Pb, Sn, Se | < 0,1% | < 0,1% |

Potential: More than 95% recyclable

| | Collected | Recycling / recovery rate | |
|---|---|---|---|
| **Actually** | **70%** | **80%** | **85%** |

# Plan



- PRESENTATION
- Context and Energy Transition
- Solar Energy
- **Energy Transition in France and the World**
- Research and Technology for Energy Transition
- Smart Grid
- Digital Transformation
- Conclusion

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# Energy transition law in France

**In France, the objectives in terms of energy transition** were officially concretized by the promulgation, on August 17, 2015, of **LOI n° 2015-992 relating to the energy transition for green growth**. It has 8 main objectives to be achieved:

- **Reduce greenhouse gas emissions (divide them by 4 by 2050 compared to 1990 levels)**
- **Reduce energy consumption (halve it by 2050 compared to 2012 levels)**
- **Reduce primary energy consumption of fossil fuels (-30% by 2030 compared to 2012 levels)**
- **Increase the share of renewable energies in our energy consumption (up to 32% in 2030)**
- **Technology: smart grid, digital, Take the share of nuclear power in electricity production to 50% by 2025 (this objective has since been modified)**
- **Improving the energy performance of buildings**
- **Fight against energy poverty and affirm the right to access for all to energy without excessive cost in terms of household resources;**
- **Reduce our waste production**

**Macron's program (2022) for 2050**:

- Build 6-14 new nuclear reactors (No nuclear reactors closed)
- 100 GW PV
- 40 GW off-shore and ~40 GW on-shore
- Thermal renovation of houses, electrification of vehicles

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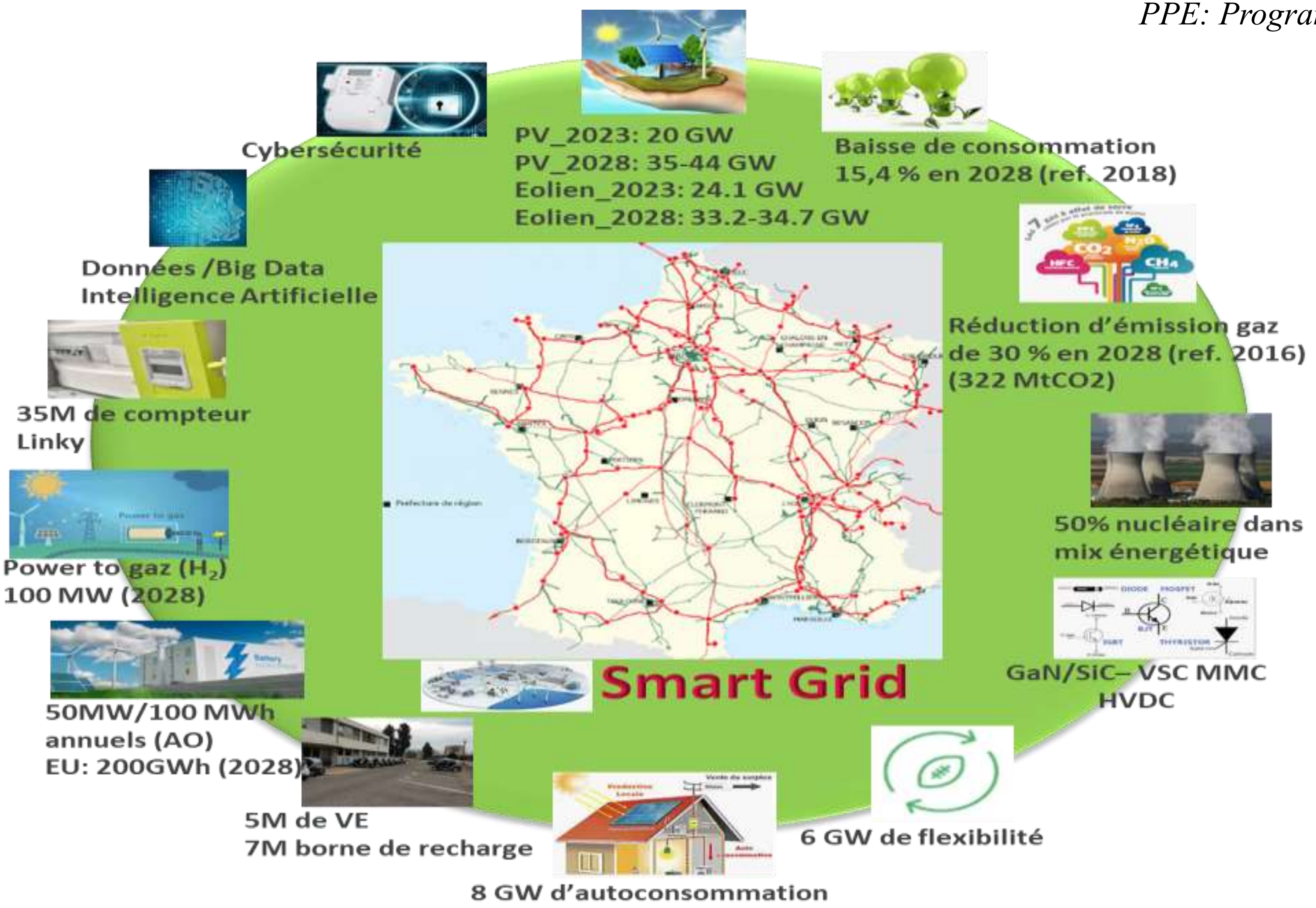
*PPE: Programmation Pluriannuelle de l'énergie*

Vision in medium terme 2023
Vision in long terme 2028



# France: Energy Pathways to 2050


**1 Technical**

- Full description of the system (generation – network – consumption), in energy and power terms, in 2030, 40, 50, 60
- Projections with IPCC's RCP 4.5 and 8.5 scenarios and resiliency analysis with climate stress tests (heat wave – drought – extreme cold – absence of wind in Continental Europe)

**2 Economic**

- Full cost to society
- Analysis of sensitivity to different parameters, notably the cost of capital
- Specific analysis of the ability of each scenario to integrate relocation/reindustrialisation plans

**3 Environmental**

- Carbon footprint at each stage of the trajectory, factoring in the lifecycle of materials
- "Materials footprint" of each scenario (in association with issues of criticality)
- Land use (network + production)
- Waste and pollutant volumes

**4 Societal**

- Conceptualisation of impacts on lifestyles and conditions of validity of the scenarios (telework *vs.* mobility, electricity consumption, level of sufficiency desired vs. required, level of flexibility of uses)

*Energy Pathways to 2050* does not take a position on the desirability of these factors

Source: RTE

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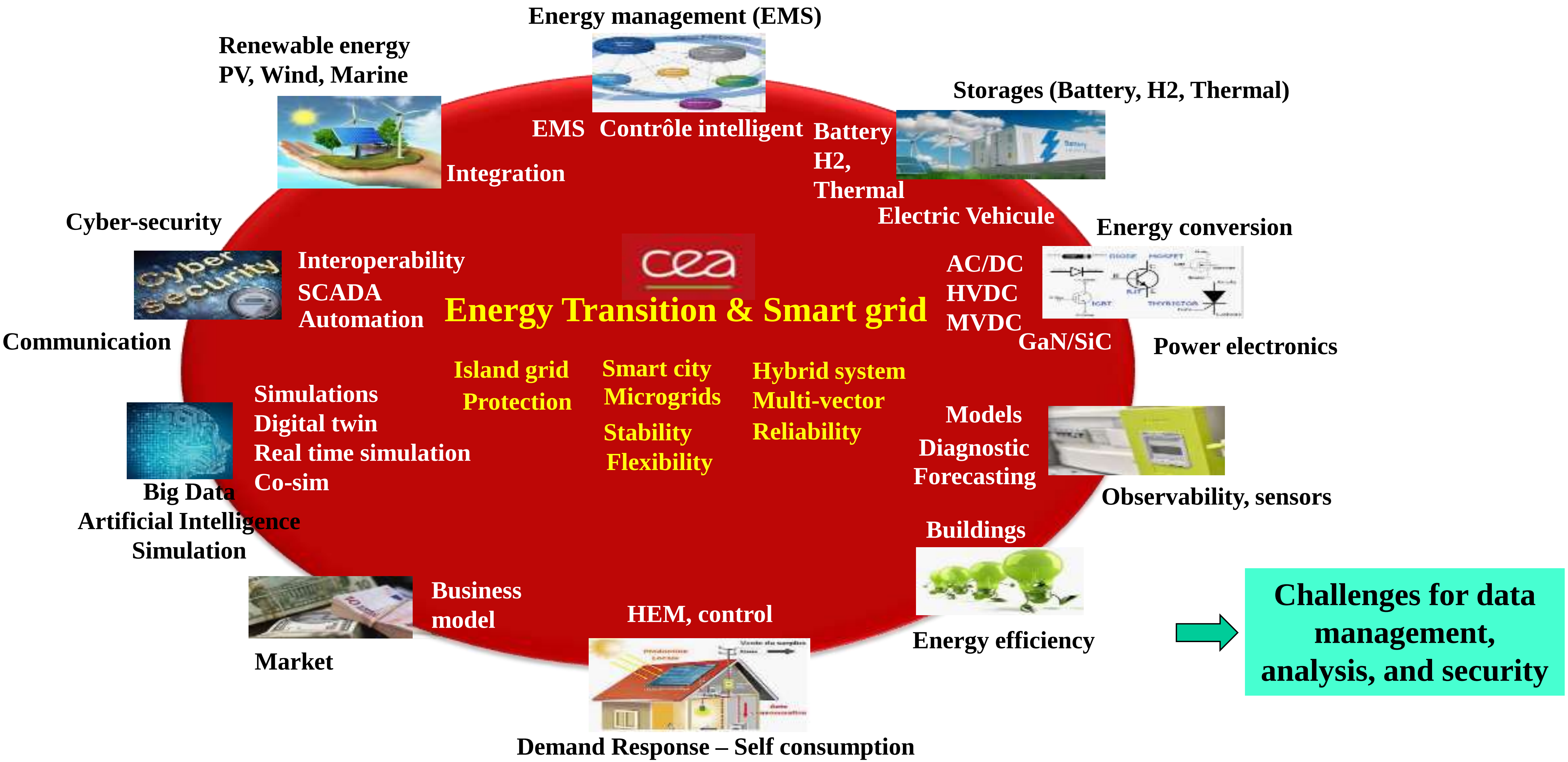
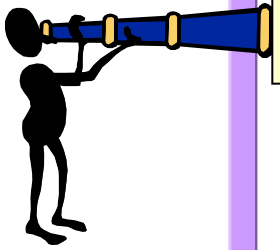
# Energy Transition & Smart Grid activities at CEA



# Plan





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# Energy transition – Actions

**1) Renewables - Renewables for the energy transition**

The growing use of renewable energy sources is the cornerstone of the energy transition: thanks to continuous innovation, these are becoming increasingly efficient and competitive, while new technologies are on the horizon.

**2) Electrification - Let's electrify the world!**

This is the decade of electrification: electricity generated by renewables is the pivotal energy vector in spearheading the energy transition towards decarbonization.

**3) Decarbonization - how to transition from fossil fuels to renewables**

Although the ultimate aim of the energy transition is a move to renewables, in the shorter term, grid stability and resilience need to be guaranteed as we move away from the use of coal. Natural gas will have a key role to play in this.

**4) Digitalization - From power plants to grids: the digitalization of energy**

The digital transformation is aiding the transition of the entire energy sector, from power plant management to new consumer services and smart grids.

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# Technologies for energy transition

**Machine learning and AI-assisted decision-making digital technologies will be essential for the energy transition** for:

- **Energy management:** Monitoring and optimizing energy usage based on demand, time-of-day, weather, usage patterns, peak demand, demand fluctuations, etc.
- **Energy mix optimization:** Optimizing energy mix based on pre-defined targets and demand/supply patterns and switching accordingly between electricity from source-specific power supplies. Digitally-enabled demand forecasting and supply planning for coordinating supply and energy storage and discharging in a decentralized renewable-based power system will be a huge help in this.
- **Smart grids:** AI-assisted operation of grids, predictive maintenance, exception-based surveillance, remote control, automated electricity trading and transactions, etc. will be core features of the future smart grids.
- **Smart building and installations:** Use of mobility sensors, electricity usage patterns, peak demands, time-of-day algorithms to optimize energy spending and savings, etc. will lead to improve energy efficiency and usage. Digitalization will be a key driver in making a range of technologies, processes and transportation more energy efficient.
- **Smart metering**: Devices recording information on consumption of electric energy to be shared with suppliers and prosumers for monitoring, to inform about demand and as basis for billing and electricity transactions.
- **Smart energy storage:** Autonomous charging and discharging of batteries linked to renewables power installations/plants for energy management and energy mix optimization.
- **EV and smart transportation:** Prediction of transportation patterns and peak demand as well as App-and IoT-based supply/demand balancing from communication between transport vehicles and suppliers/grid/EV power stations will lead to an operation and energy efficient electricity-based transportation system.
- **Automation and RPA in all sectors:** Digital-enabled automation processes, transport and operations will lead to energy (and cost) saving and energy efficient solutions. This could be e.g. in the O&G, manufacturing, chemical, mining and transport sector.
- **Transactions and cybersecurity:** Digital technologies such as Block-chain will be important to ensure regulatory compliance, data privacy and cybersecurity in the new decentralized network of energy trading among several entities, including private and industrial prosumers and utilities.

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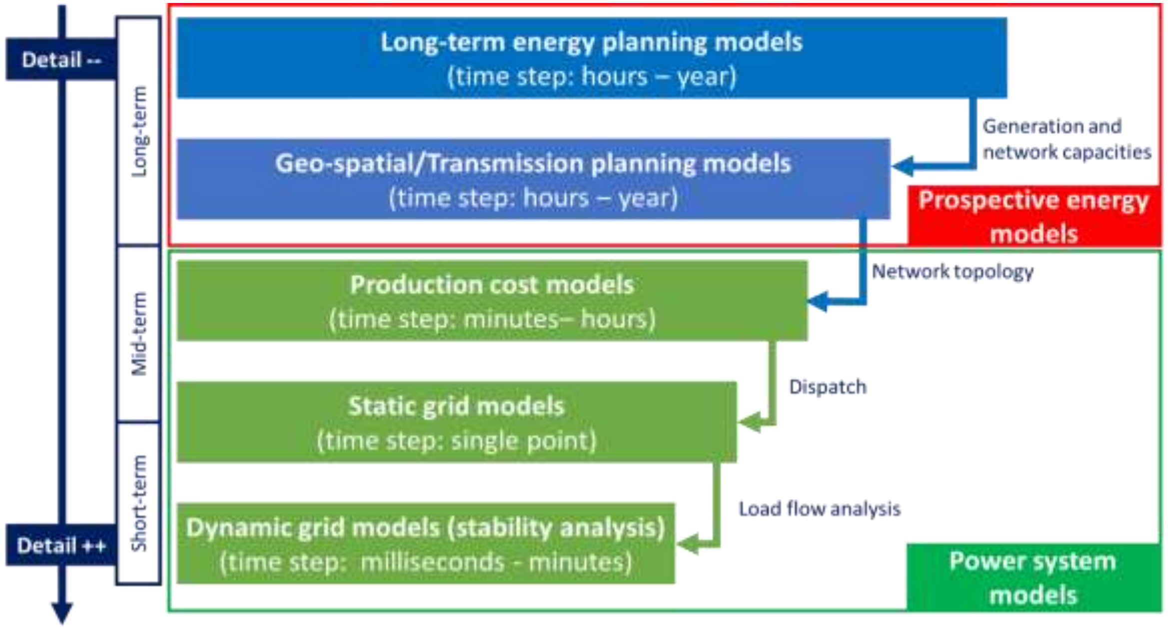
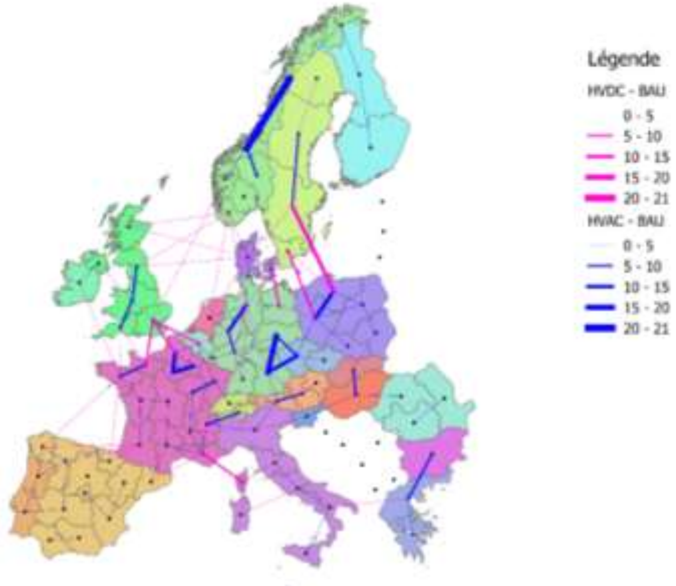
# Energy Pathways to 2050

Stephane PhD Thesis

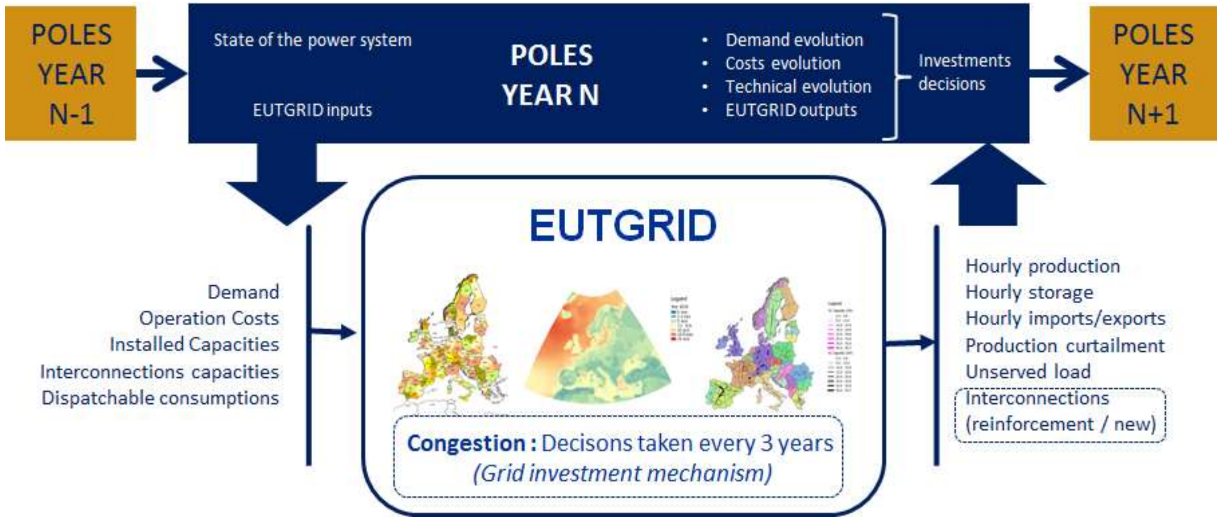


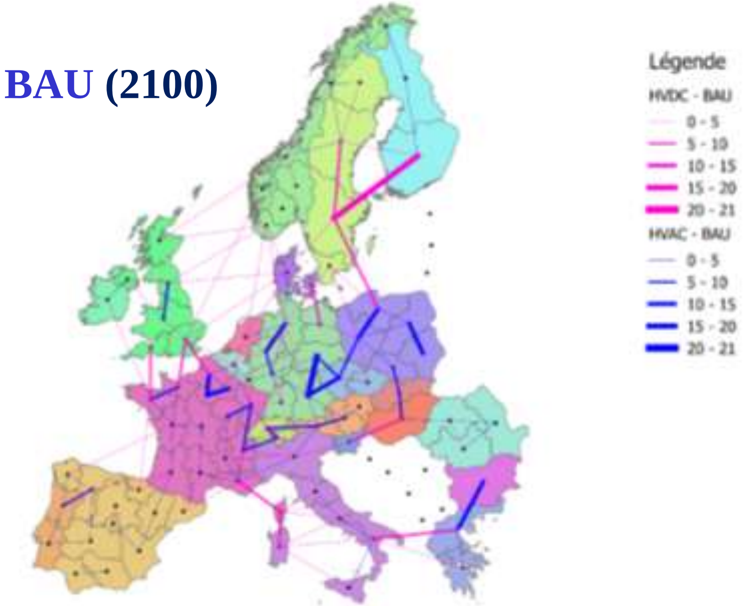



Interactions between long-term energy and power system models




Total added reinforcement BAU (2100)




Total added reinforcement 2°C (2100)

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# Multi-Energy management

Lara PhD Thesis

Project DISTRISIM

Edge computing

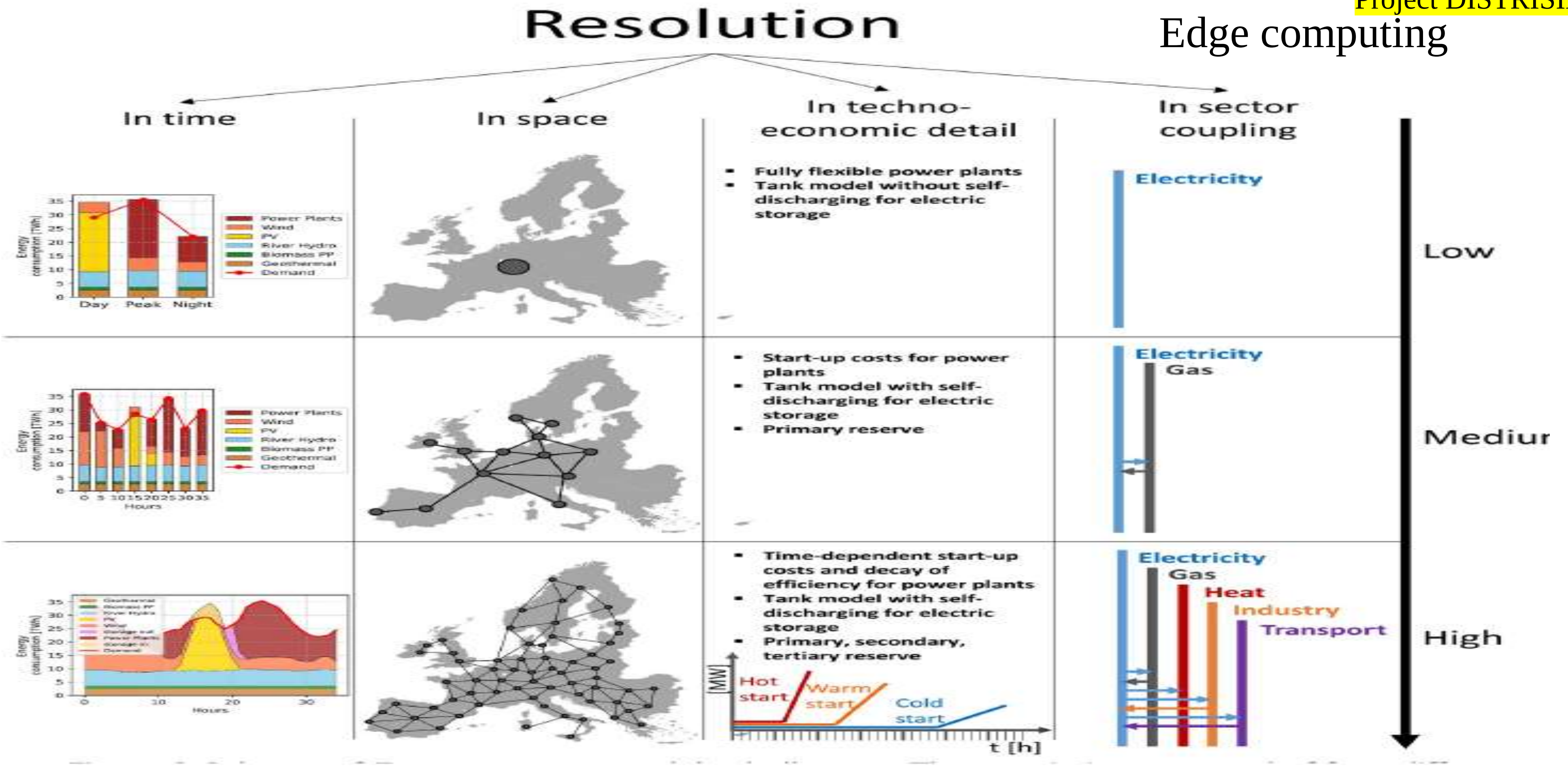
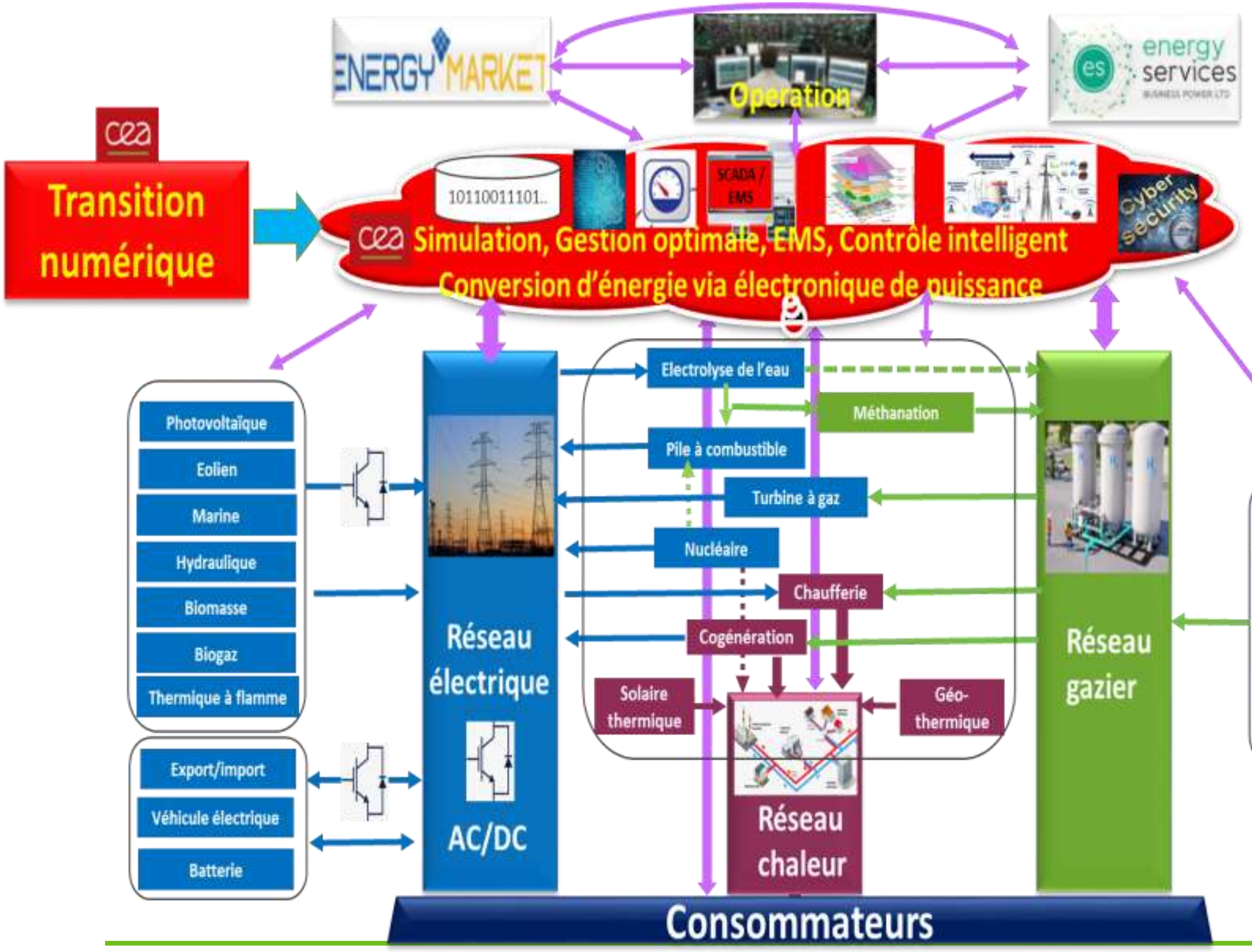



Fig. 2. Scheme of Energy system models challenges. The matrix is composed of four different resolution fields and three levels of resolution.

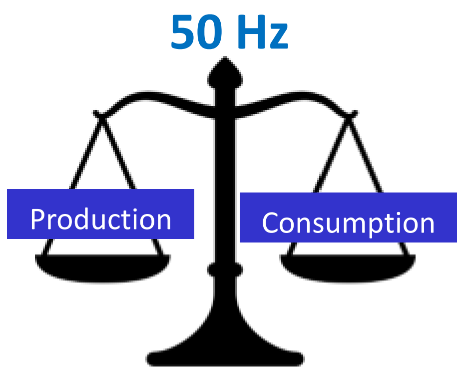
# Simulation and control of a cyber-physical system: why?




Smart-grid: multi-physical, multi-domain (electrical, thermal, ICT, market, etc.) => Cyber-Physical Energy System

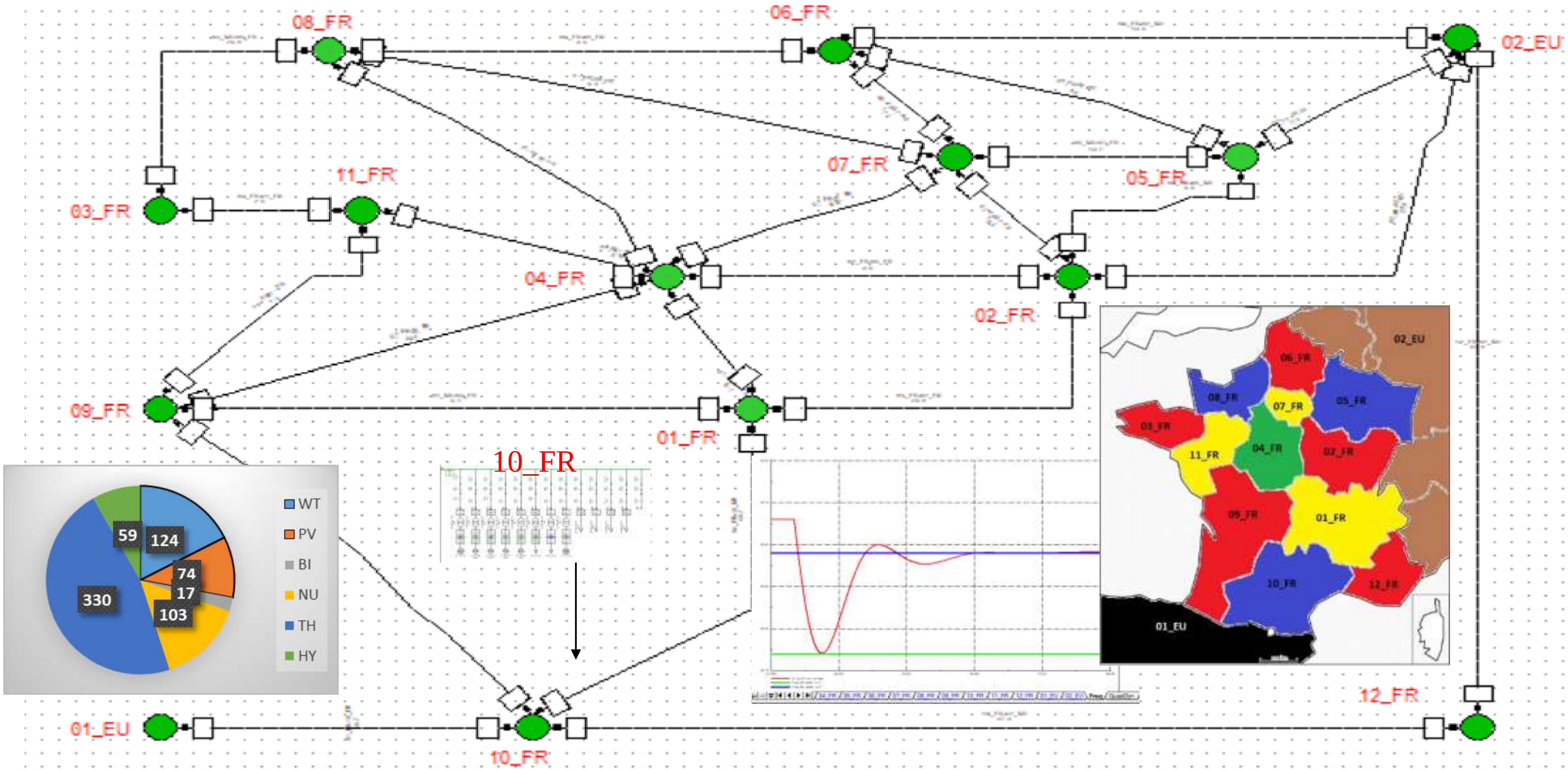
Grid with a high rate of renewable energy:
- Intermittency (uncertainty, variability)
- Low inertia (EP)

⇒ **Impacts on operation and stability**

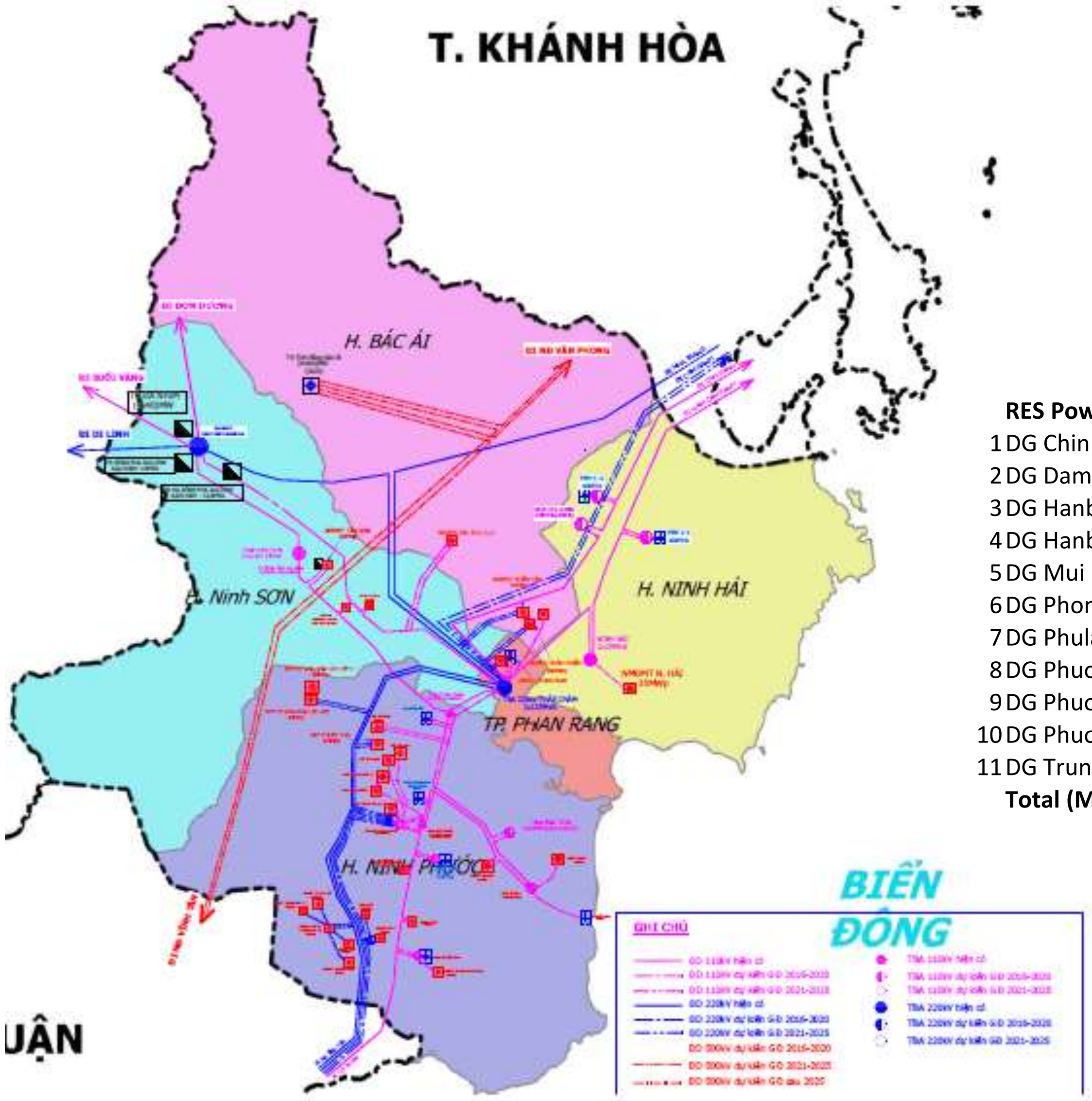



⇒ Need: simulation and intelligent control strategies

Laurent, Cuong PhD thesis



# EVN RES:Ninh Thuan+Binh Thuan+K Hoa




| | RES Power plants | Type | Pn (MW) |
|---|---|---|---|
| 1 | DG ChinhThang | wgen | 50 |
| 2 | DG Dam Nai | wgen | 40 |
| 3 | DG HanbaRam2 | wgen | 40 |
| 4 | DG Hanbaram1 | wgen | 16.1 |
| 5 | DG Mui Dinh | wgen | 35 |
| 6 | DG PhongDien1 BT | wgen | 30 |
| 7 | DG Phulac | wgen | 24 |
| 8 | DG PhuocHuu | wgen | 30 |
| 9 | DG PhuocMinh | wgen | 48 |
| 10 | DG PhuocThe | wgen | 30 |
| 11 | DG Trung Nam | wgen | 40 |
| | **Total (MW)** | | **383.1** |

| | RES Power plants | Type | Pn (MW) |
|---|---|---|---|
| 1 | DMT AMI | pv | 50 |
| 2 | DMT BIM | pv | 30 |
| 3 | DMT BIM2 | pv | 200 |
| 4 | DMT BIM3 | pv | 40 |
| 5 | DMT BP Solar | pv | 40 |
| 6 | DMT Bau Ngu | pv | 40 |
| 7 | DMT BauZone | pv | 20 |
| 8 | DMT BinhAn | pv | 40 |
| 9 | DMT CMX | pv | 131.2 |
| 10 | DMT CamLamVN | pv | 45 |
| 11 | DMT DL MienTrung | pv | 50 |
| 12 | DMT Eco Seido | pv | 32 |
| 13 | DMT GELEX | pv | 40 |
| 14 | DMT Hacom Solar | pv | 44.6 |
| 15 | DMT Ho Nui Mot | pv | 40 |
| 16 | DMT HoaLuoi | pv | 10 |
| 17 | DMT My Son | pv | 50 |
| 18 | DMT My Son 2 | pv | 40 |
| 19 | DMT My Son 2 HoangLocViet | pv | 150 |
| 20 | DMT My Son HoangLocViet | pv | 42.5 |
| 21 | DMT NinhPhuoc6.1+6.2 | pv | 47 |
| 22 | DMT PhanLam | pv | 29.5 |
| 23 | DMT PhanLam2 | pv | 40 |

| | | | |
|---|---|---|---|
| 24 | DMT PhongPhu | pv | 34 |
| 25 | DMT PhuocHuu | pv | 50 |
| 26 | DMT PhuocHuu-DL1 | pv | 24 |
| 27 | DMT PhuocMinh ADANI | pv | 40 |
| 28 | DMT PhuocNinh | pv | 36 |
| 29 | DMT PhuocThai | pv | 172 |
| 30 | DMT SP INFRA | pv | 40 |
| 31 | DMT Sin Energy | pv | 40 |
| 32 | DMT SongBinh | pv | 42 |
| 33 | DMT SongGiang | pv | 30 |
| 34 | DMT TTC Nhiha | pv | 53 |
| 35 | DMT Tan Son | pv | 24 |
| 36 | DMT Thien Tan | pv | 40 |
| 37 | DMT ThuanNam-DucLong | pv | 43 |
| 38 | DMT ThuanNam12 | pv | 40 |
| 39 | DMT Trung Nam | pv | 204 |
| 40 | DMT TuyPhong | pv | 24 |
| 41 | DMT VSP2 | pv | 26 |
| 42 | DMT VinhHao | pv | 42 |
| 43 | DMT VinhHao4 | pv | 31 |
| 44 | DMT VinhHao6 | pv | 41 |
| 45 | DMT VinhTan | pv | 35 |
| 46 | DMT Xuan Thien | pv | 200 |
| | **Total (MW)** | | **2562.8** |

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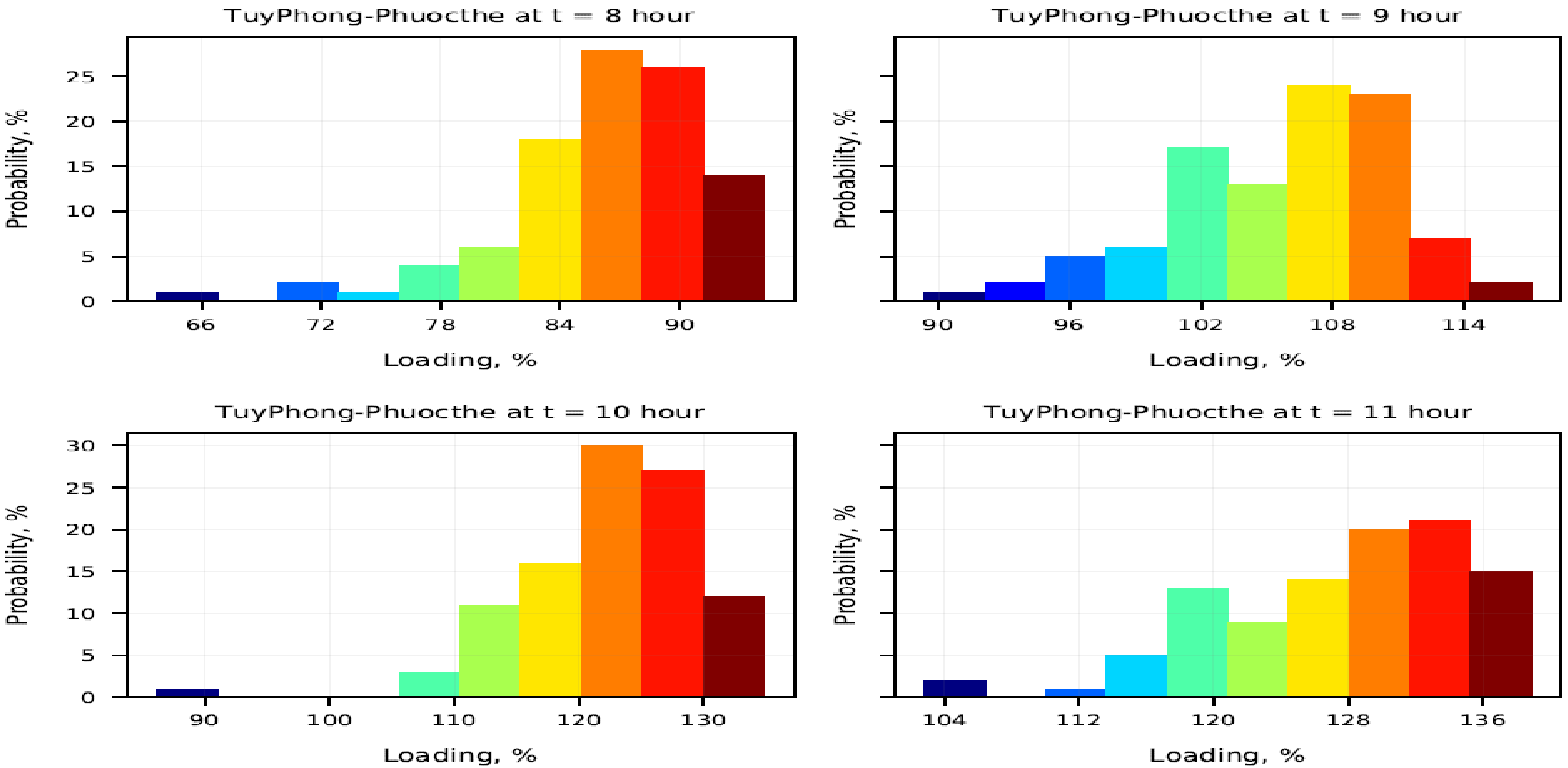
# Congestion problem – Stochastic approach




*110 kV Tháp Chàm - Hậu Sanh - Tuy Phong - Phan Rí : 260-360%; 110 kV Phan Rí - Sông Bình - Đại Ninh: 140%; 110 kV Đa Nhim - Đơn Dương: 123%; Transfo A 550 kV Di Linh: 140%; Transfo 220 kV Đức Trọng - Di Linh : 110 %...*

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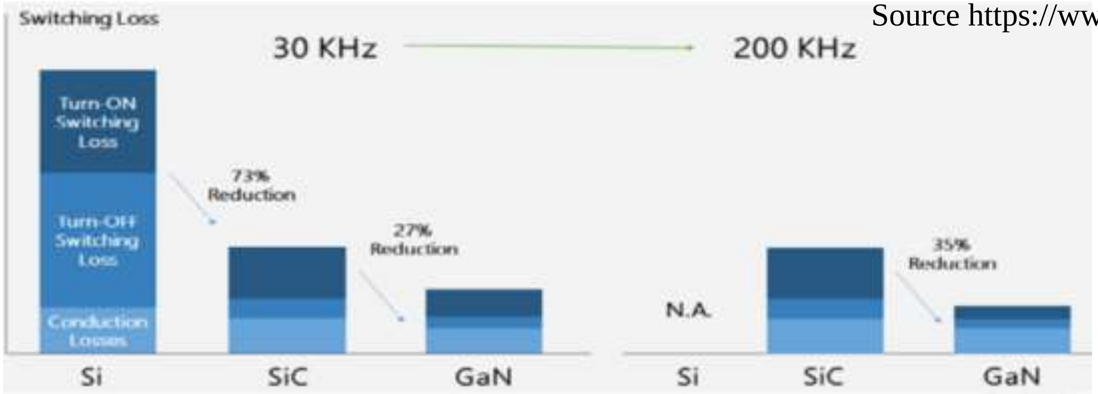
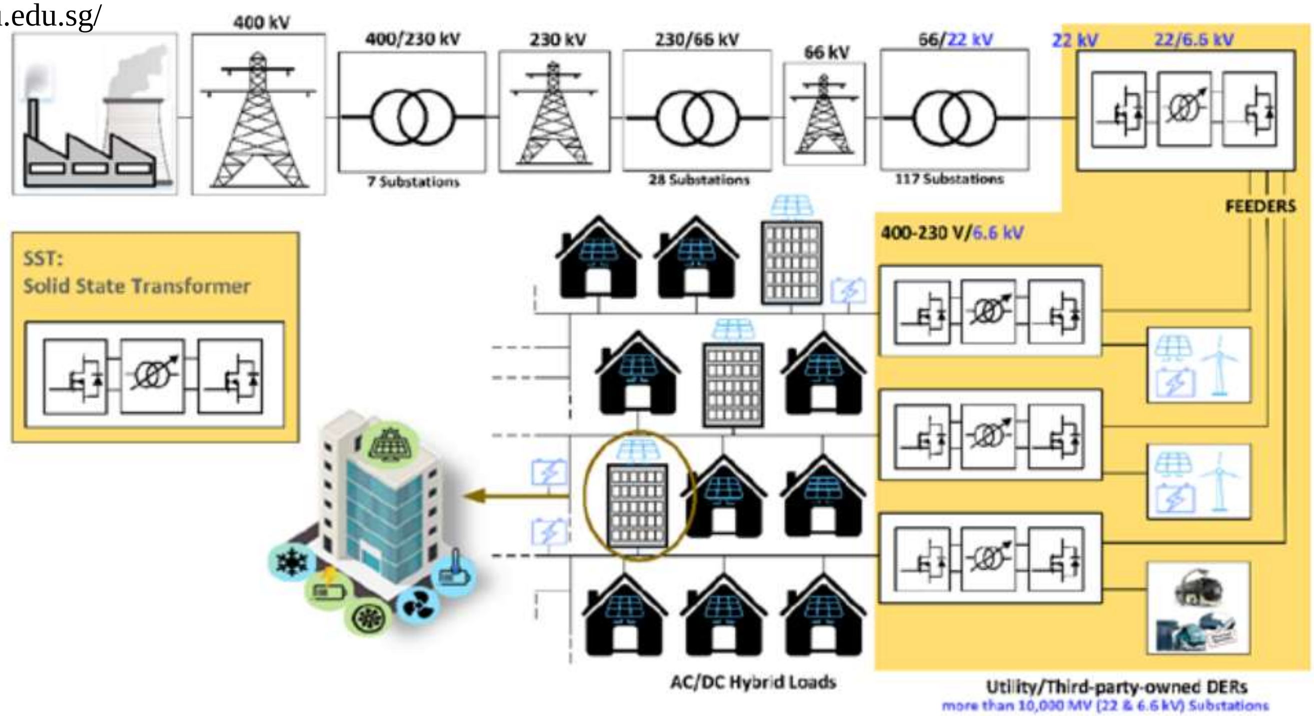
# Power electronic for energy transition

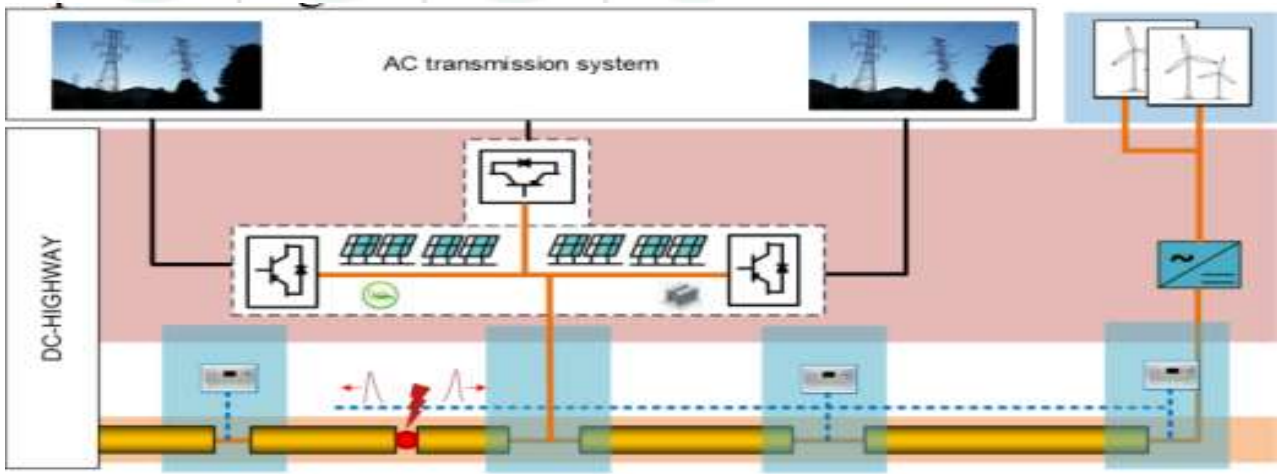
Source https://www.ntu.edu.sg/







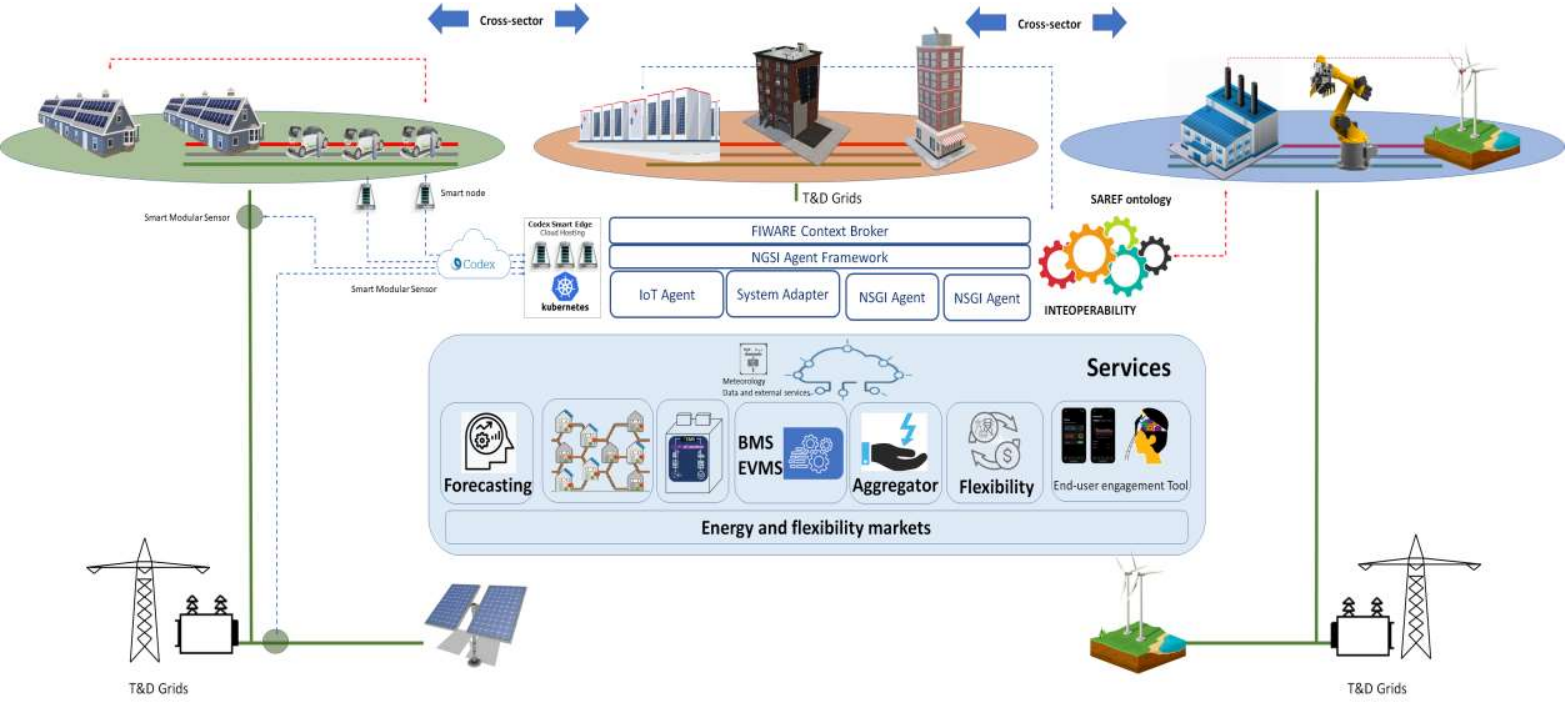

AC/DC grids



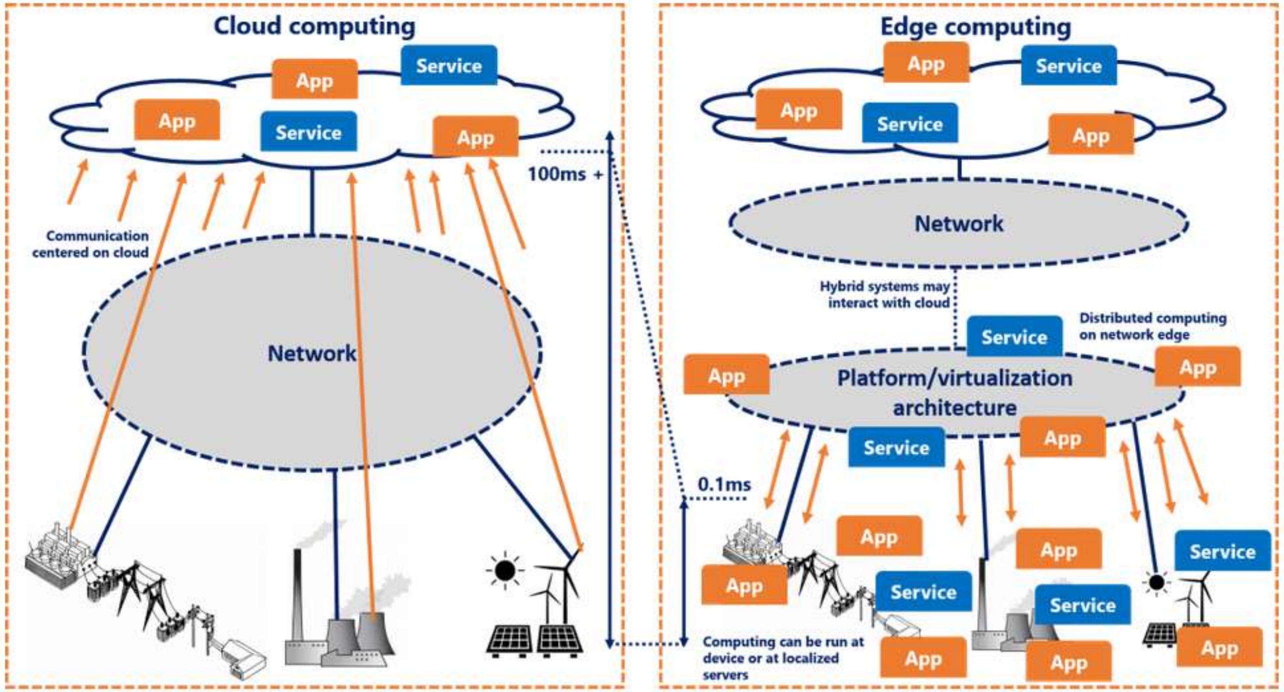

Projet H2020 DC Highway
Patents: Tran Q Tuan CEA

# Energy management for energy transition

Projet H2020: OPERA

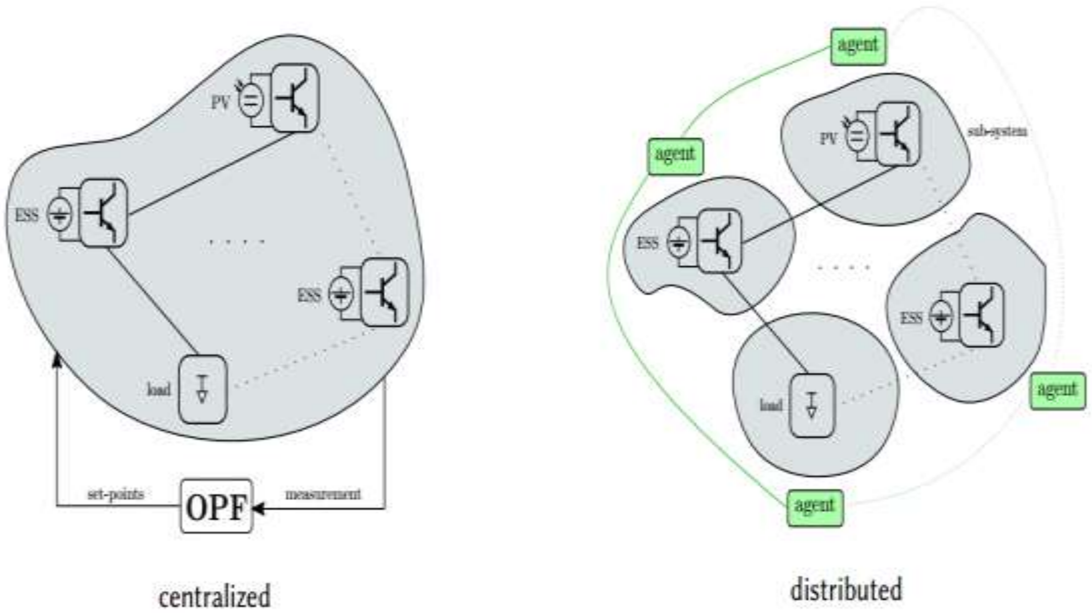


# Edge/clouds computing



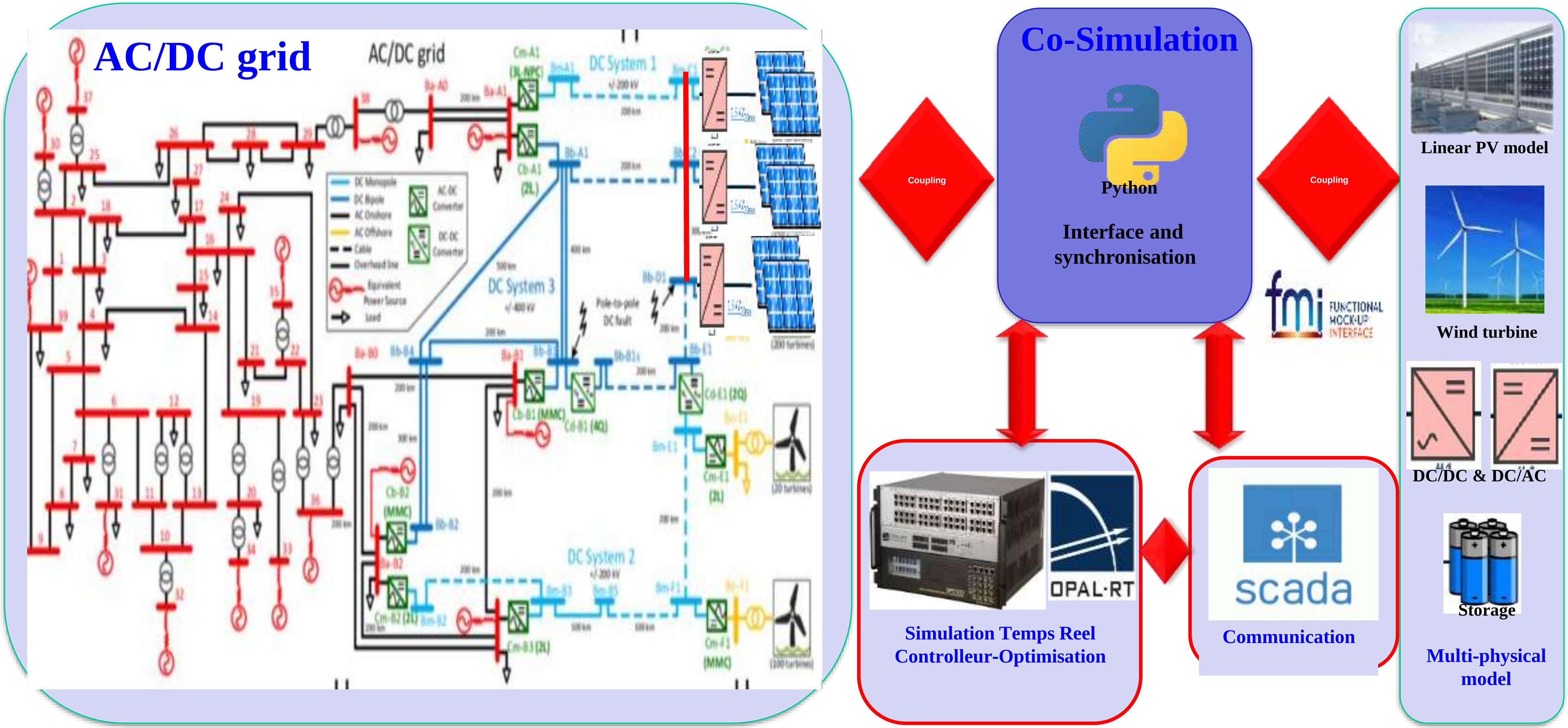

Find out the amount of power generated at each generator that makes the systems operate in an optimal state

- **objectives**
  - generation cost
  - total power losses
  - voltage deviation
- **constraints**
  - power flow
  - bus voltage limit
  - line power limit
  - generator power limit



# Co-simulation for energy transition

Le Minh Tri PhD Thesis

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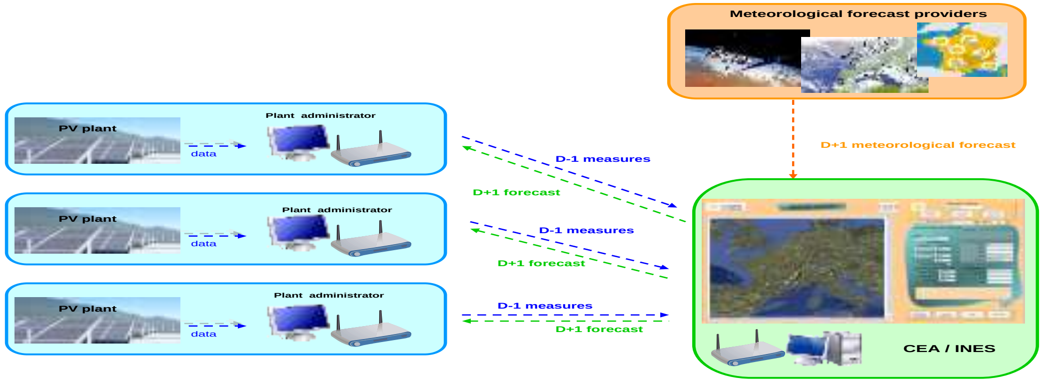
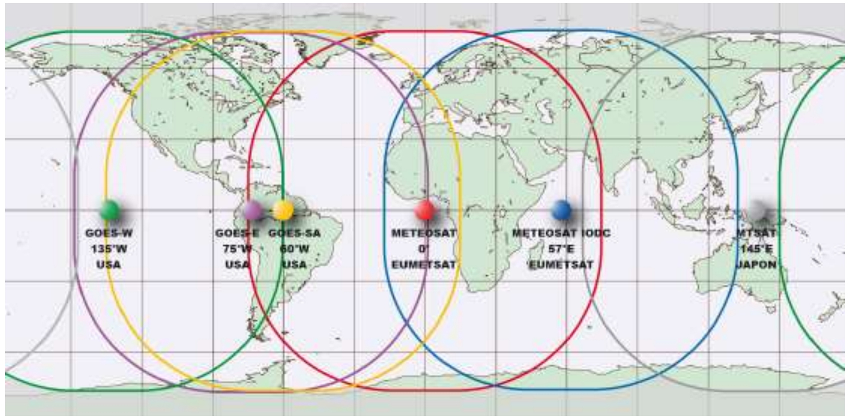
# PV forecasting (Developped by CEA INES)

**1** Day-ahead forecasting based on meteorological data




**2** Short-term forecasting based on satellite images (hourly)




**3** Very short-term forecasting based on sky camera (a few minutes)


With funding from the European Community's Horizon 2020 Framework Programme under grant agreement 773717

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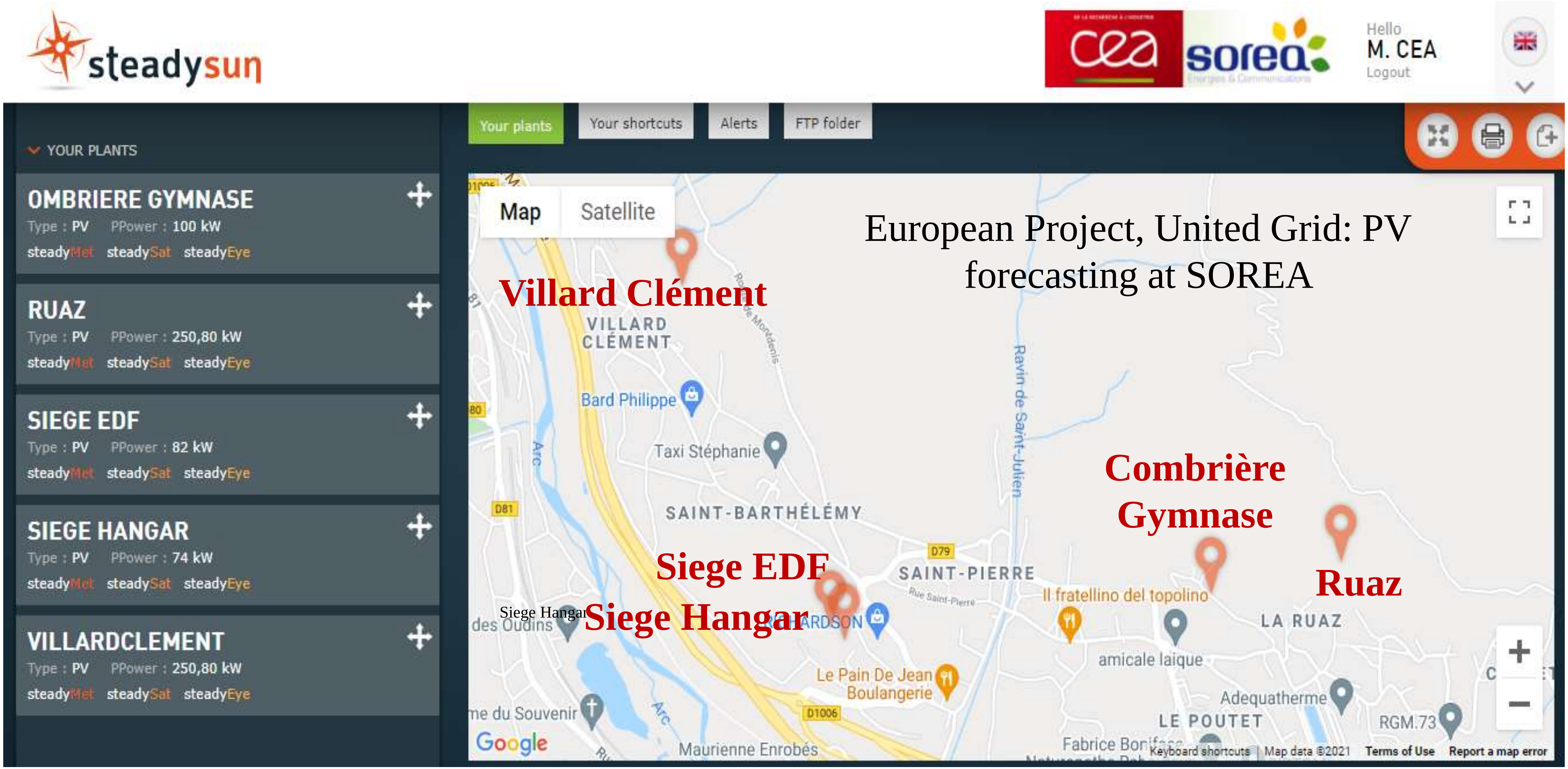
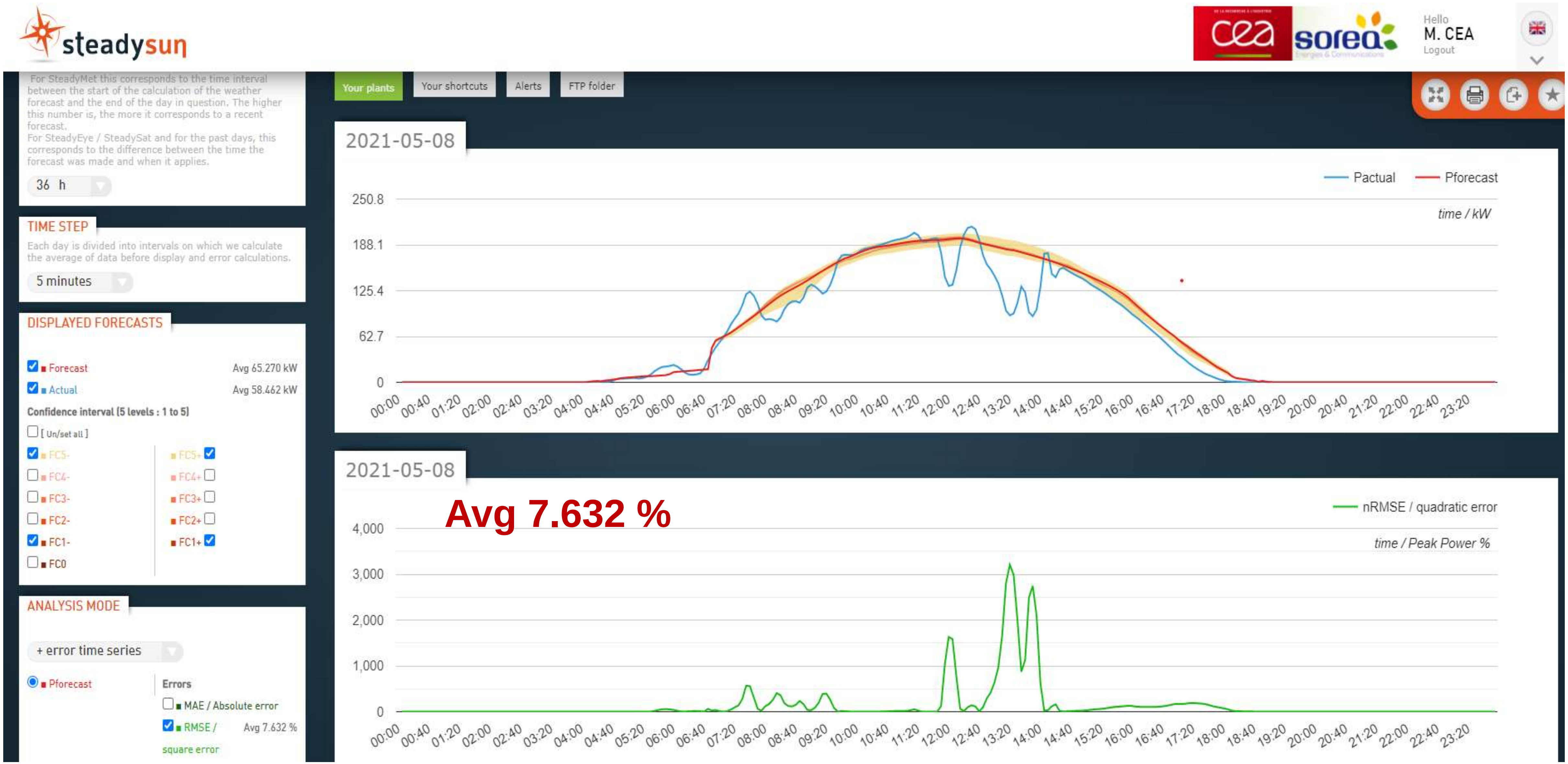
# Ex: PV forecasting – EU project

United grid Project



# 1- PV forecasting based on meteorological data (day)

**United grid Project**

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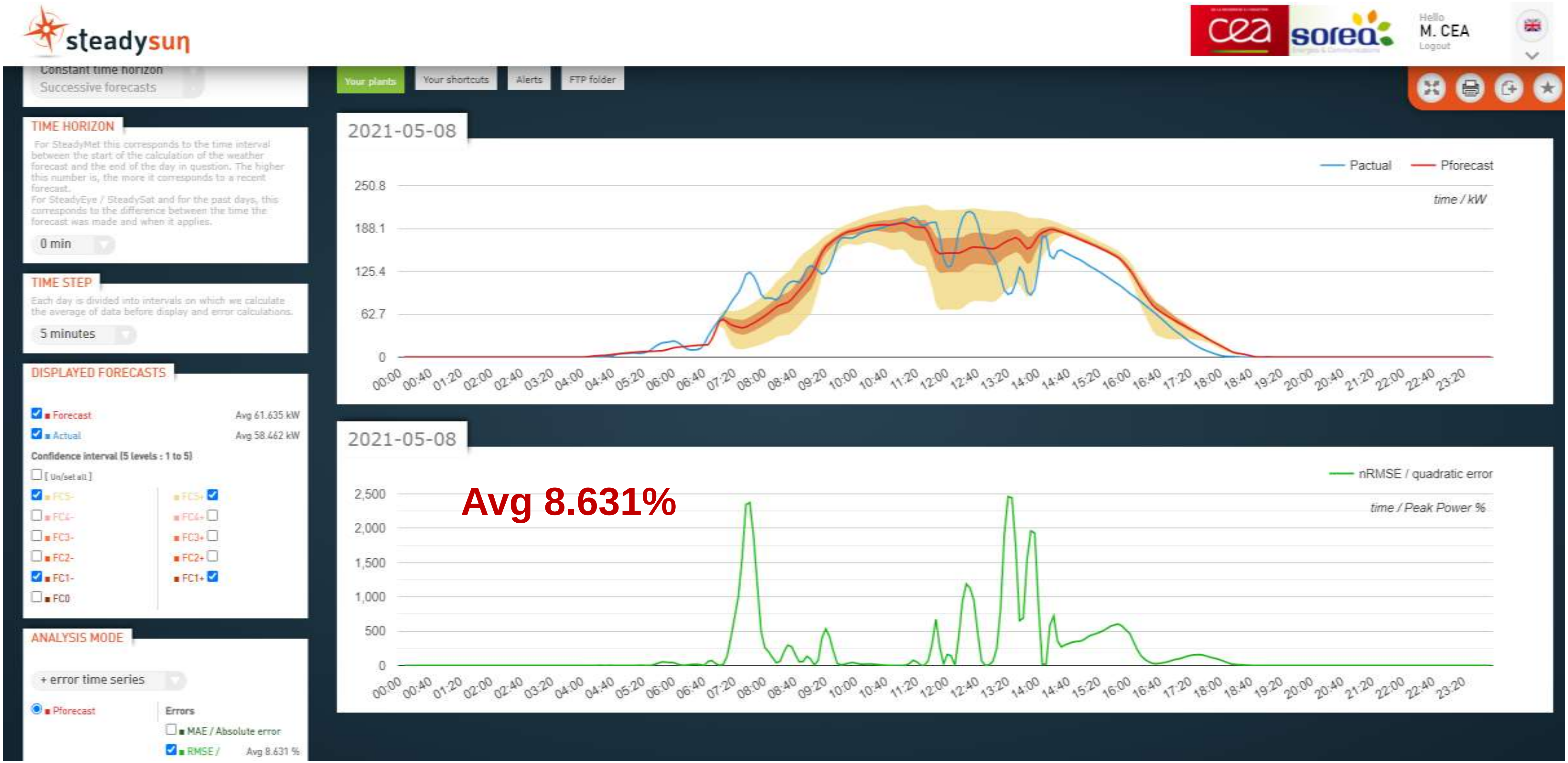
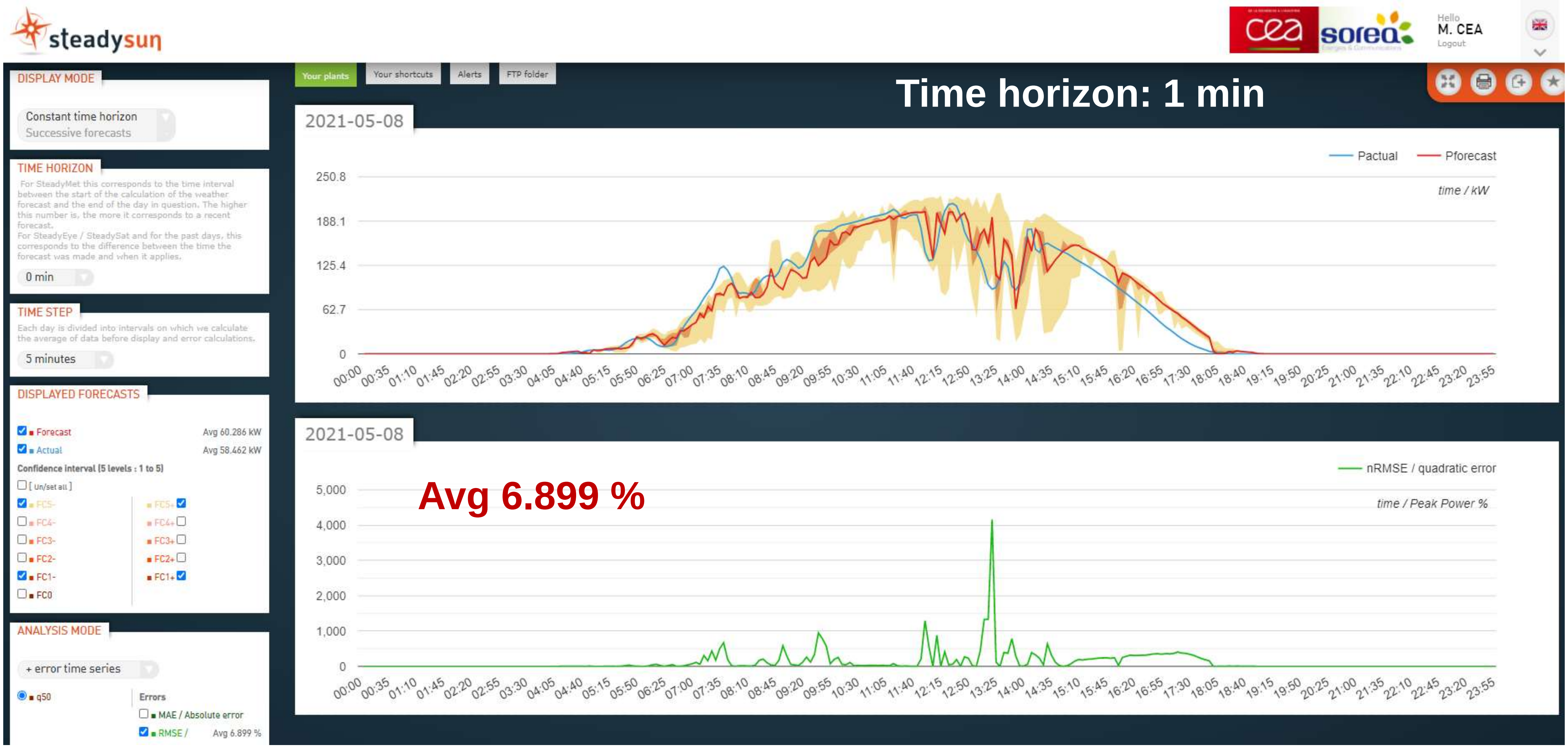
# 2- PV forecasting based on satellite images (Hour)

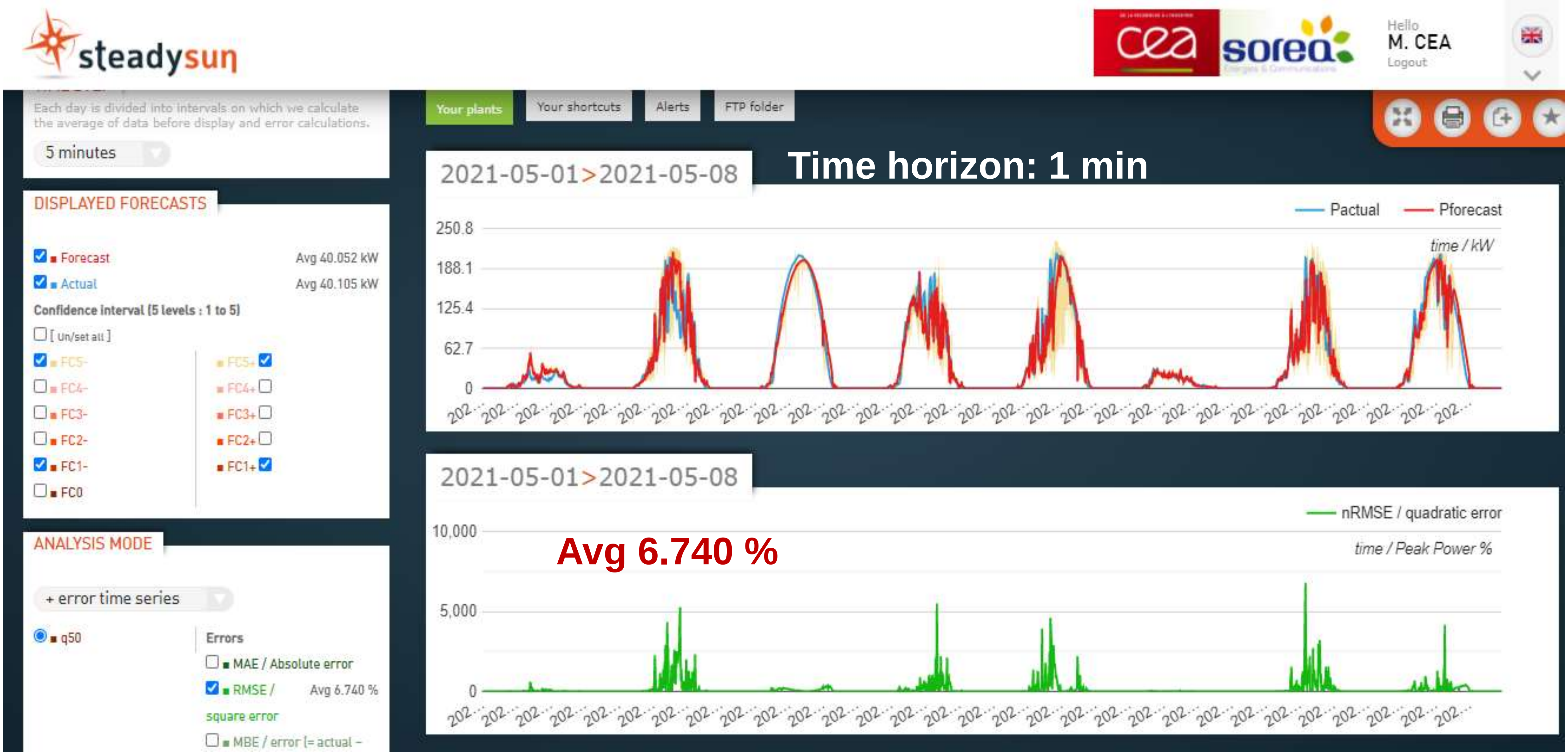
United grid Project



# 3- PV forecasting based on sky camera (min)

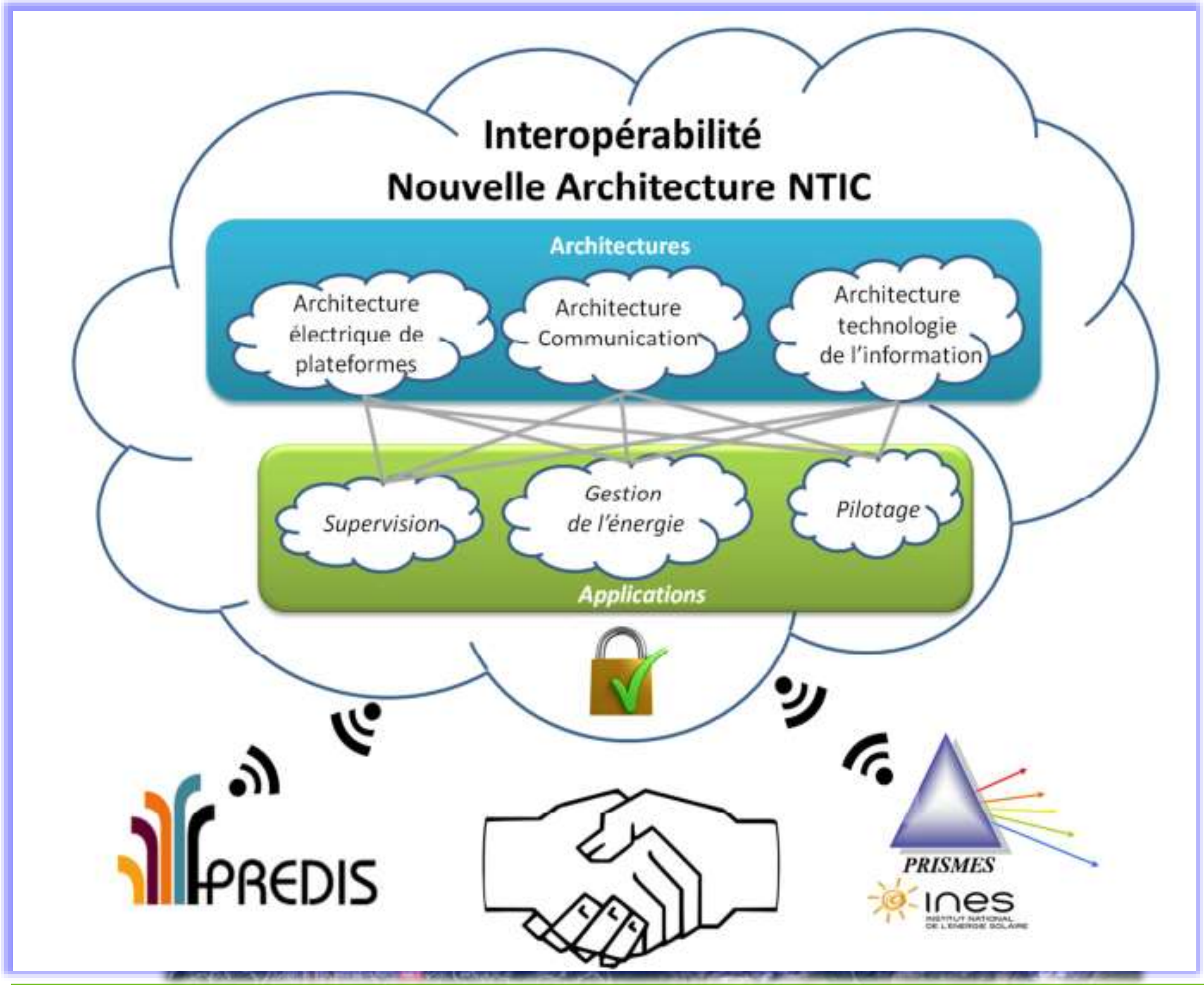


# PV forecasting



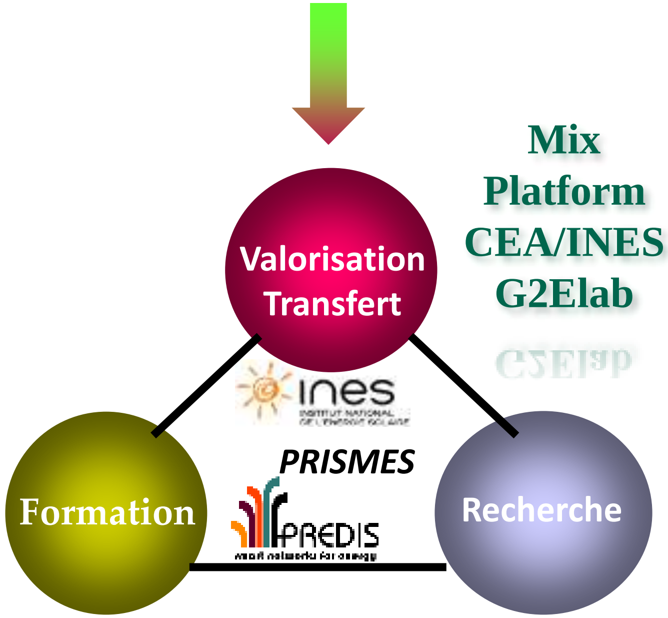
# Interoperability between PRISMES-PREDIS

PPInterop Project




Challenges Smart Grid


Mix Platform CEA/INES G2Elab



Routing: finding the efficient transmission paths

- a new routing algorithm is proposed based on the graph theory
- minimize the overall power losses with respect to congestion and reliability

Power routers losses (Wi): $$W_i = \left[(1-eff_{i-port}) + (1-eff_{o-port})\right] \times P_i \quad (1)$$

Power lines losses (Wi-j): $$\Delta W_{i-j} = \frac{r_{i-j}}{V_{i-j}^2} \times \left( (\Delta P_{i-j} + P_{i-j}^{old})^2 - (P_{i-j}^{old})^2 \right) \quad (2)$$

Total losses of a route: $$W_{total} = \sum_{R_i \in path} \Delta W_i + \sum_{L_{i-j} \in path} \Delta W_{i-j} \quad (3)$$

$$\min C = \sum_{P \in paths} W_{total}^P \quad (4)$$

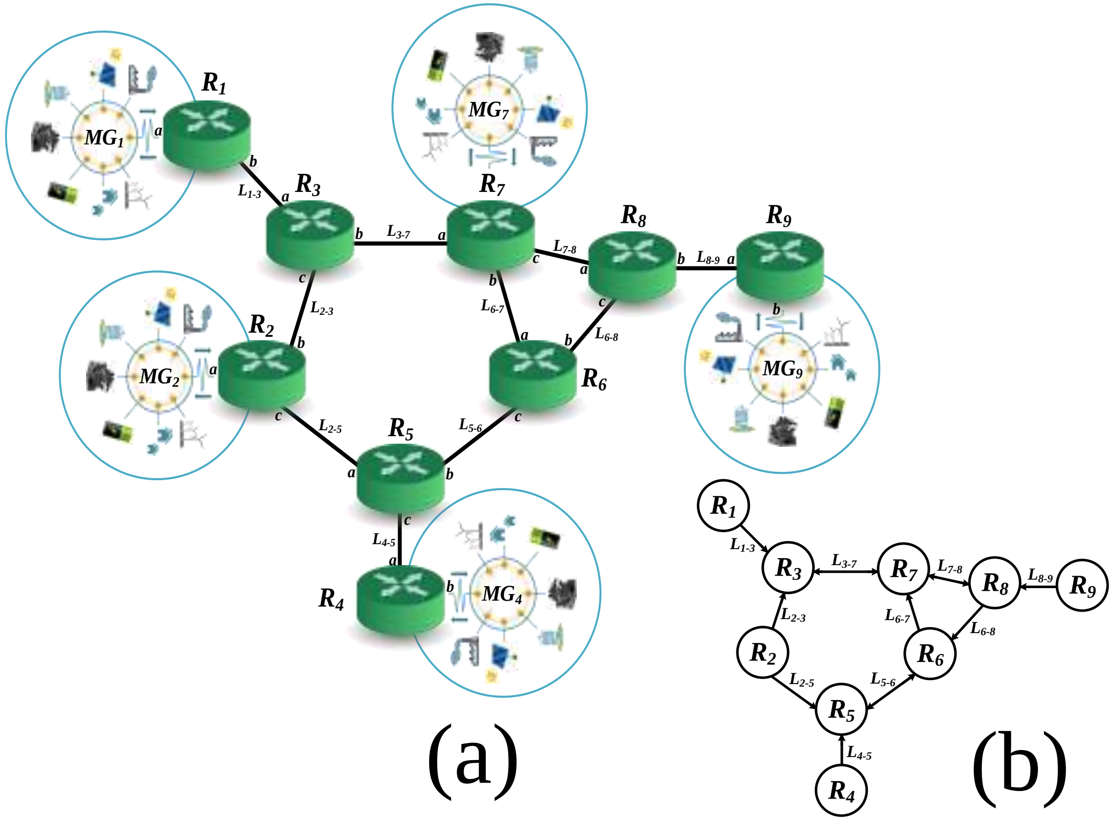
$$st: \sum P_{Load} = \sum P_{Source} \quad (5)$$

$$P_{exchange} \le P_{lines\,(S \to L)}^{available} \quad (6)$$

$$P_{exchange} \le P_{source}^{available} \quad (7)$$

$$P_{exchange} \ge W_{total} \quad (8)$$

$$V_{i-\min} \le V_i \le V_{i-\max} \quad (9)$$




(a) Desired structure of the MMG system,
(b) Equivalent digraph of the MMG system

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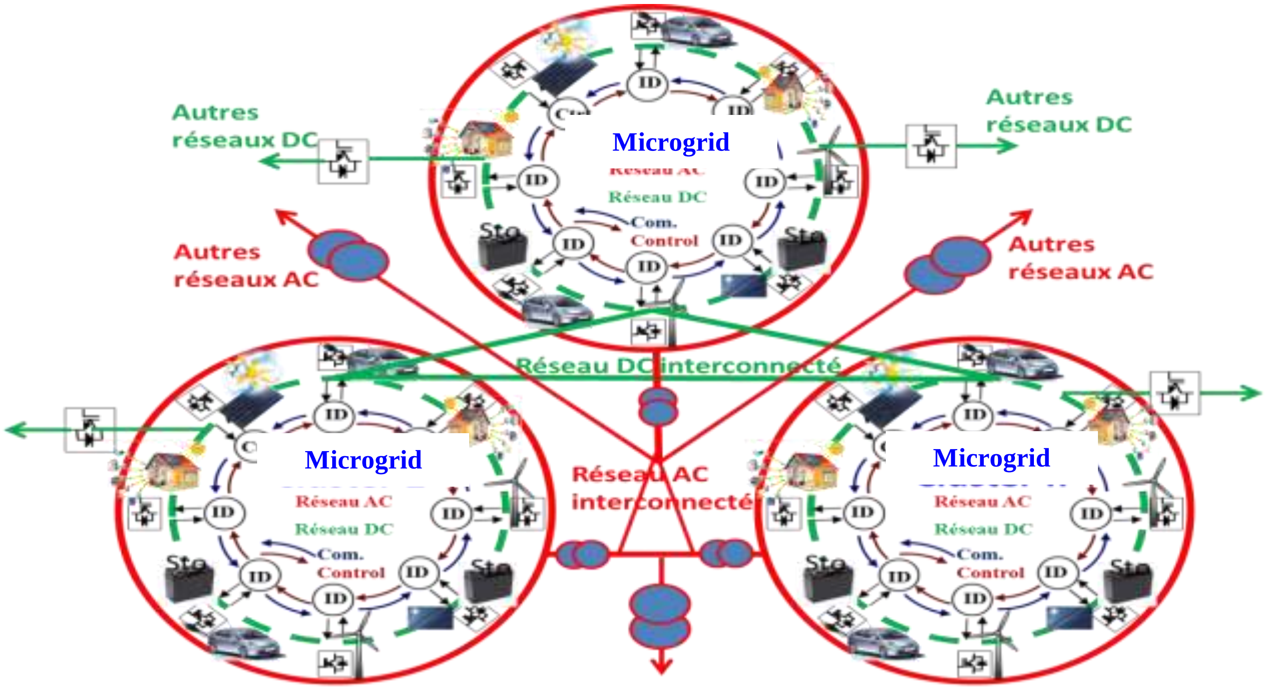
# MICROGRID

Paradis project




Solution to maximize RES integration into grid => **Microgrid**

**Microgrid:** mutualisation of DER (RES), storages and loads

Possible to islanded mode operation

**Microgrid with high RES intergration**

**Intermittent characteristics**

**Economic Environment**

**Operation difficulties; Voltage and frequency fluctuations; Instability;**

DER: Distributed Energy Resources
RES: Renewable Energy Sources
DSS: Distributed Storage System

Classical solution: coupling with diesels => expensive & polluted

**Necessary to find innovated solution for Microgrids:**

**Secure, reliable, economical & environmental**

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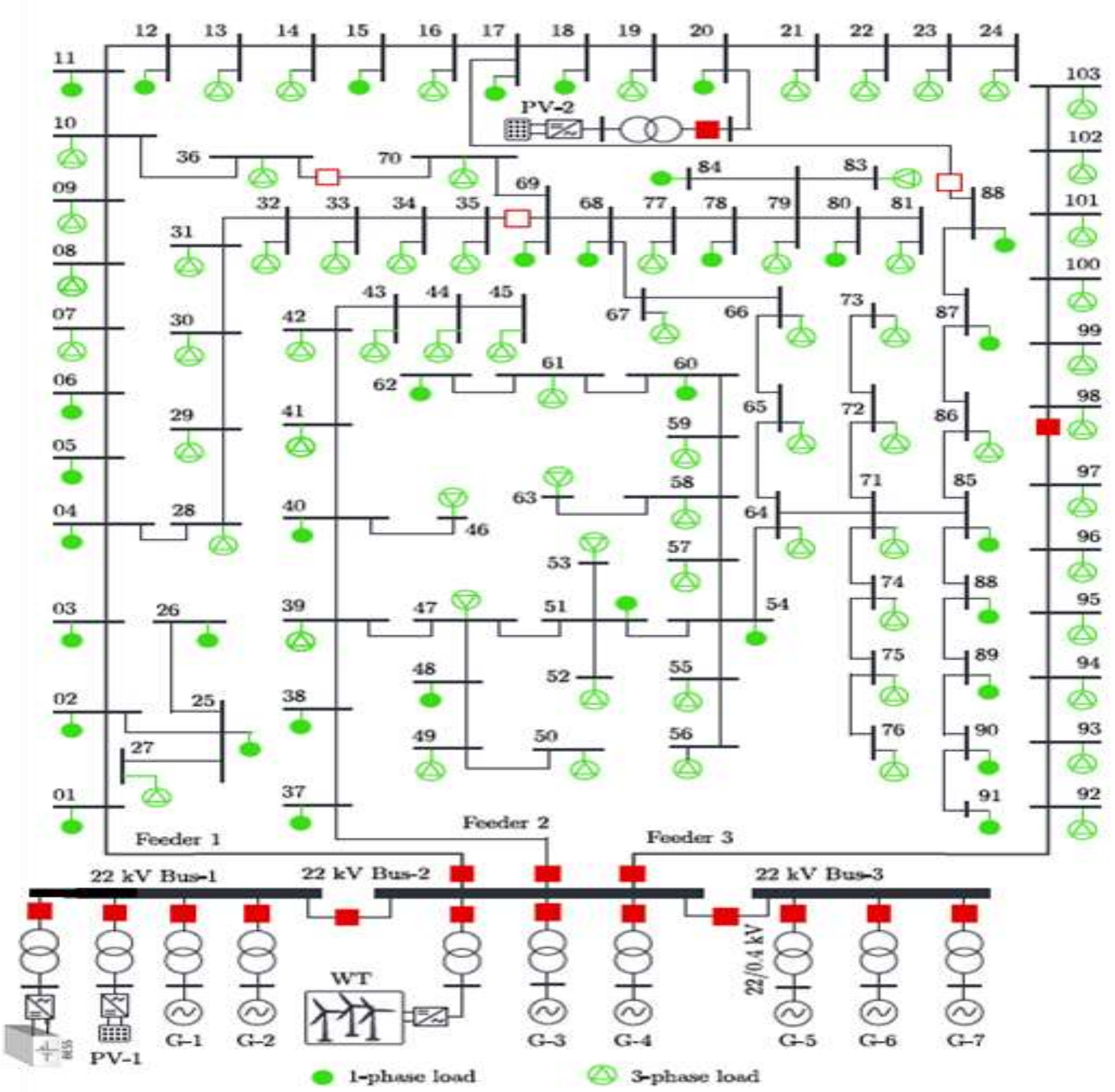
# Con Dao – Vietnam : Island microgrid

Con Dao project


The Con Dao Island district consists of 16 islands of various sizes and is situated around 185 km from Vung Tau city and 230 km from Ho Chi Minh City. The district covers an area of 76.7 km2, out of which Con Son Island is the largest area with 51.51 km2 wide where most of the socio-economic activities of district take place.

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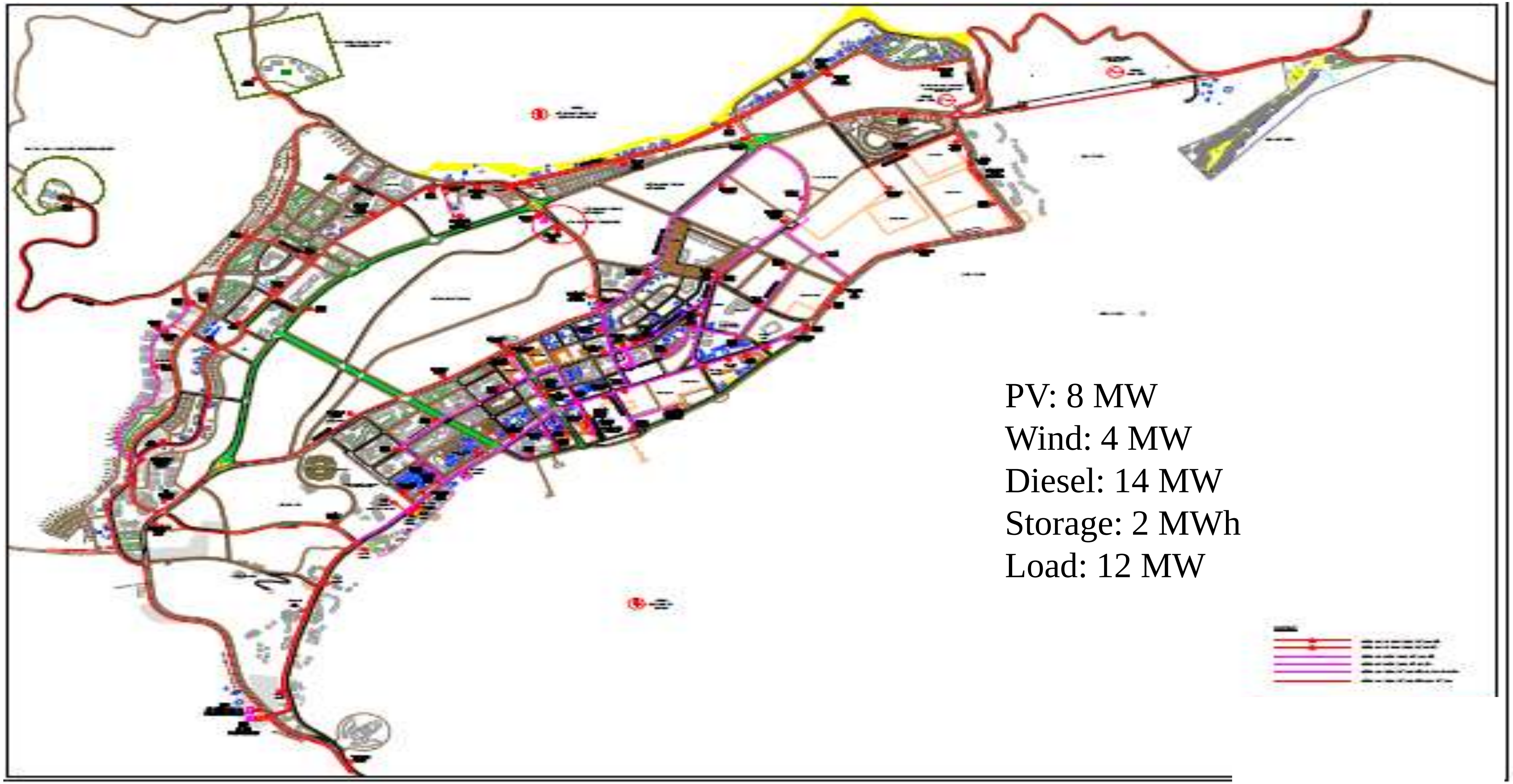
# Con Dao – Vietnam : Island microgrid

Con Dao project



PV: 8 MW
Wind: 4 MW
Diesel: 14 MW
Storage: 2 MWh
Load: 12 MW

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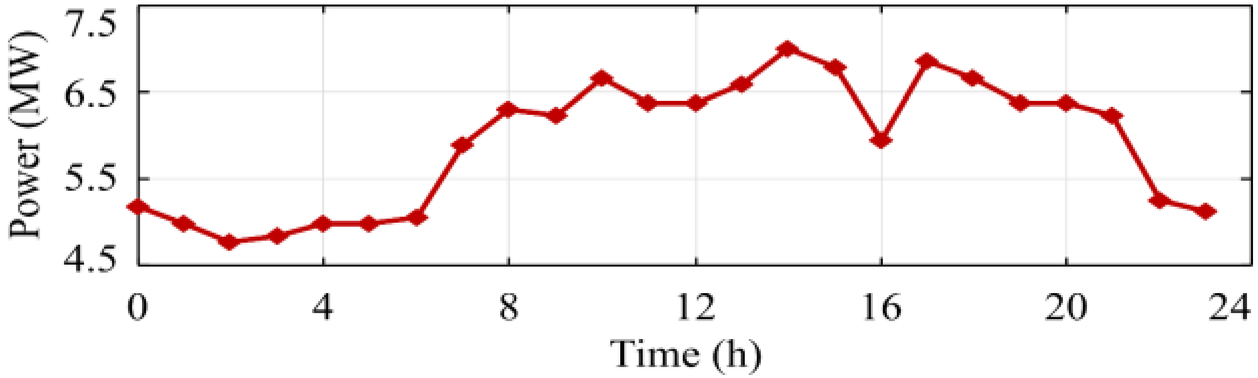
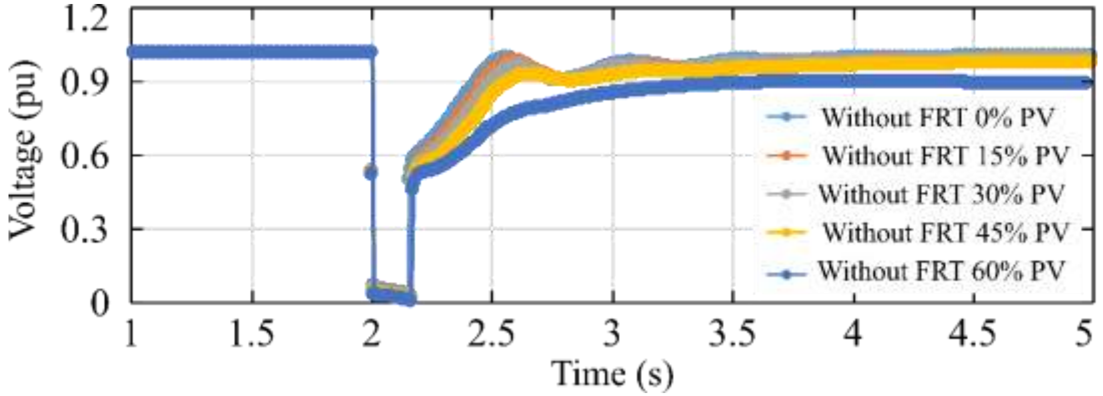
# Con Dao – Vietnam : Island microgrid

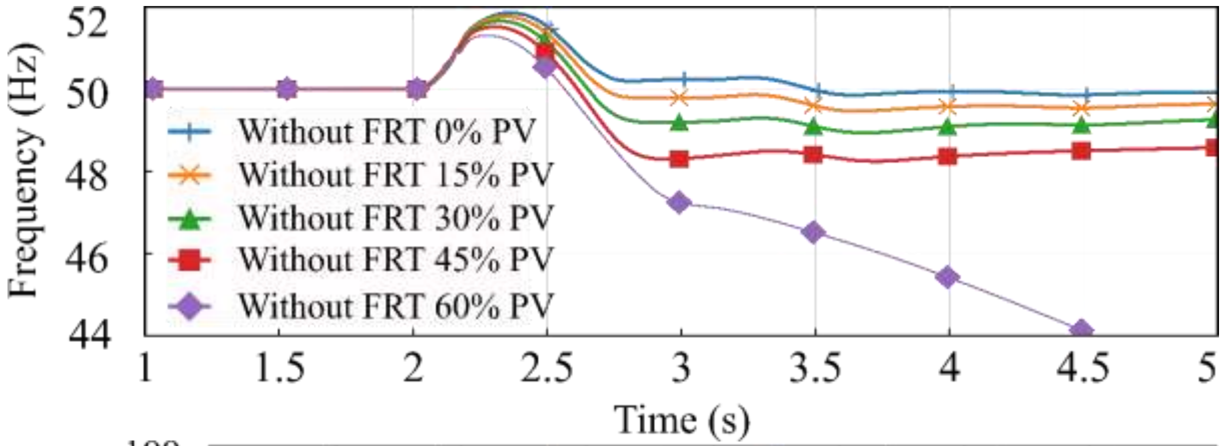


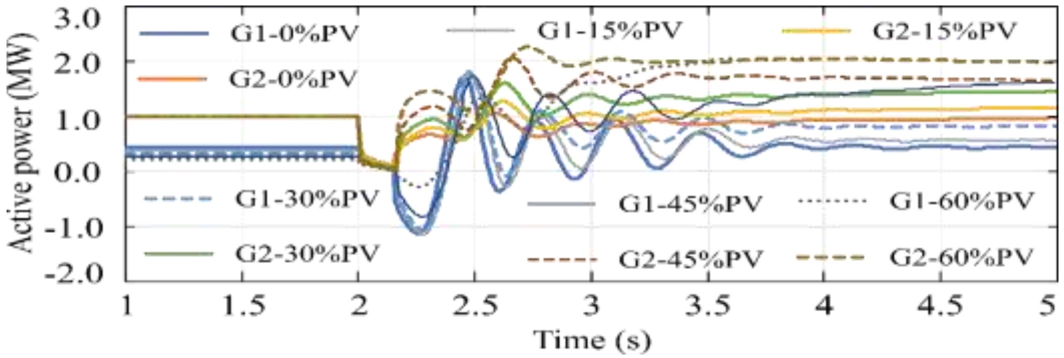

***Case A: Diesel generator G1 as slack bus without BESS***

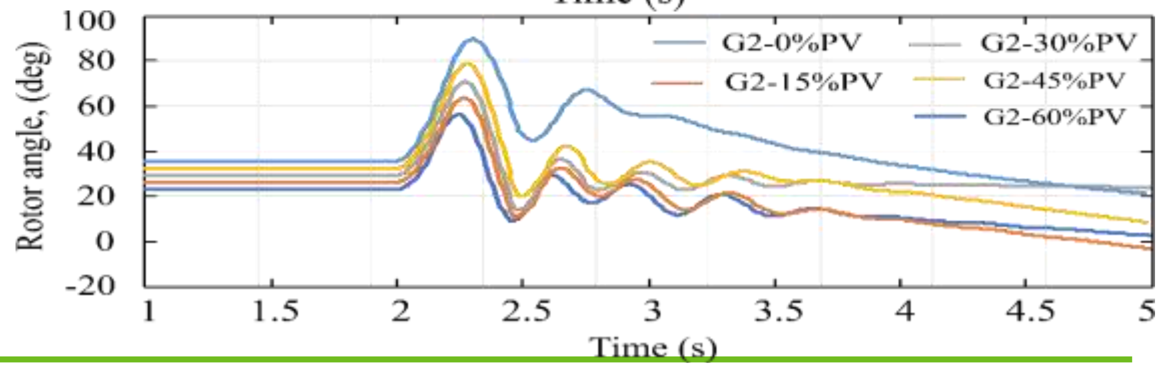
***PV systems without FRT capability***

| PV level | Diesel | PV, (MW) | WT (MW) | PV + WT RES Rate (%) | $H_{sys}$ (s) |
|---|---|---|---|---|---|
| PV0% | G1-G6 | 0 | 1.5 | 21.4 | 4.82 |
| PV15% | G1-G5 | 1.05 | 1.5 | 32.1 | 4.02 |
| PV30% | G1-G4 | 2.1 | 1.5 | 51.4 | 3.21 |
| PV45% | G1-G3 | 3.15 | 1.5 | 66.4 | 2.41 |
| PV60% | G1-G2 | 4.2 | 1.5 | 81.4 | 1.61 |

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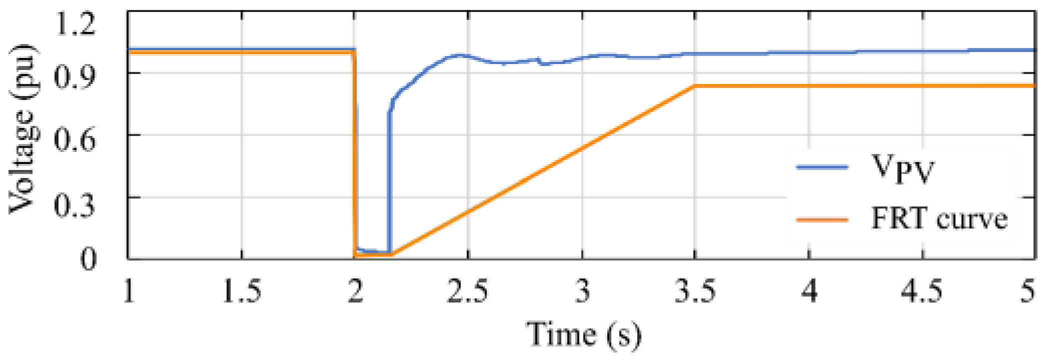
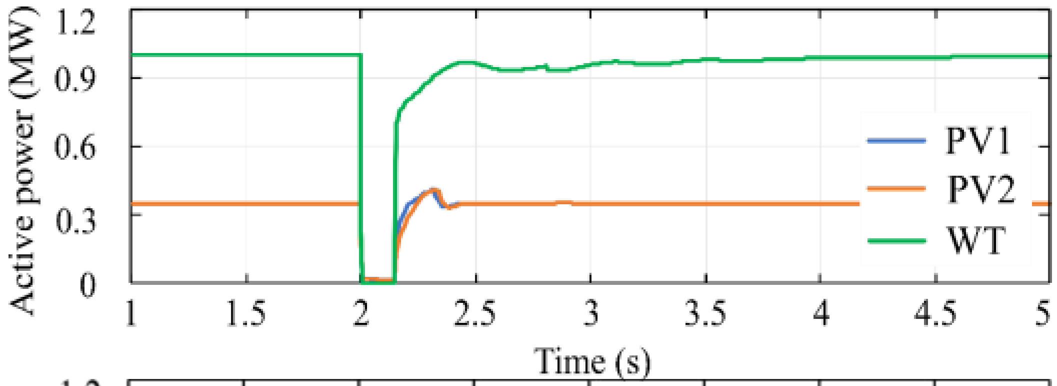
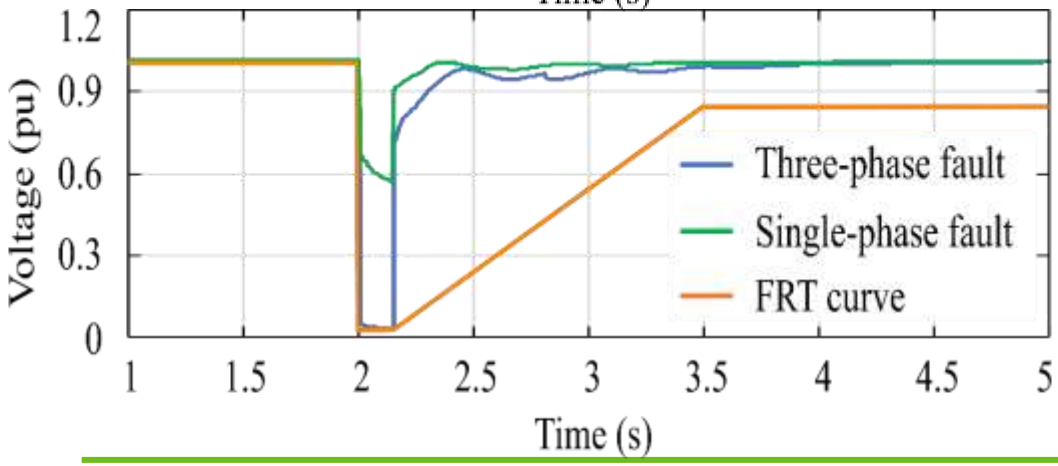
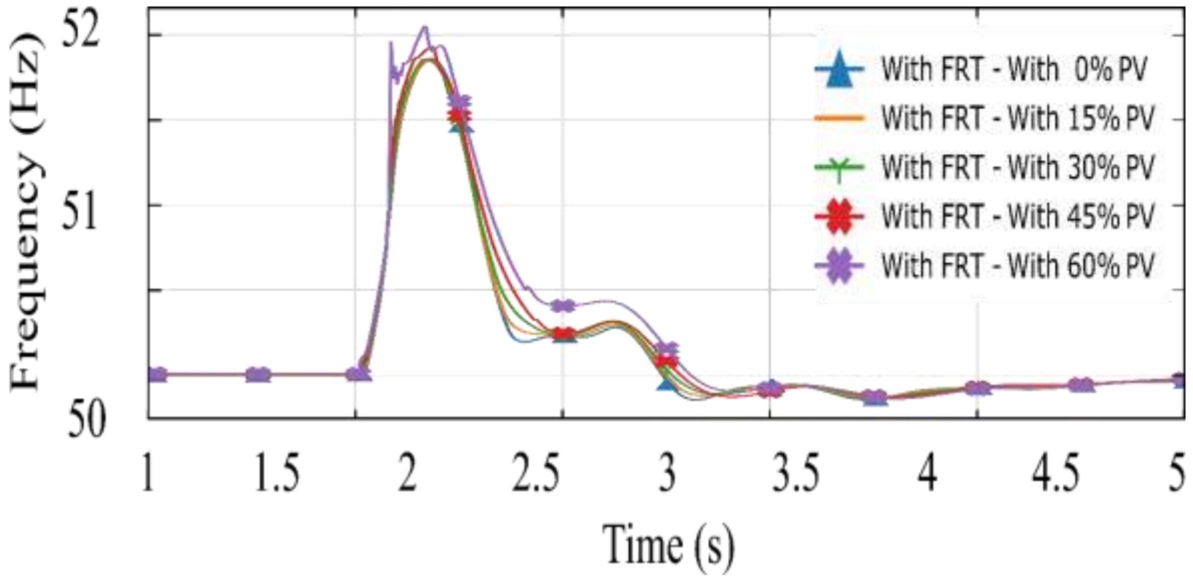
# Con Dao – Vietnam : Island microgrid

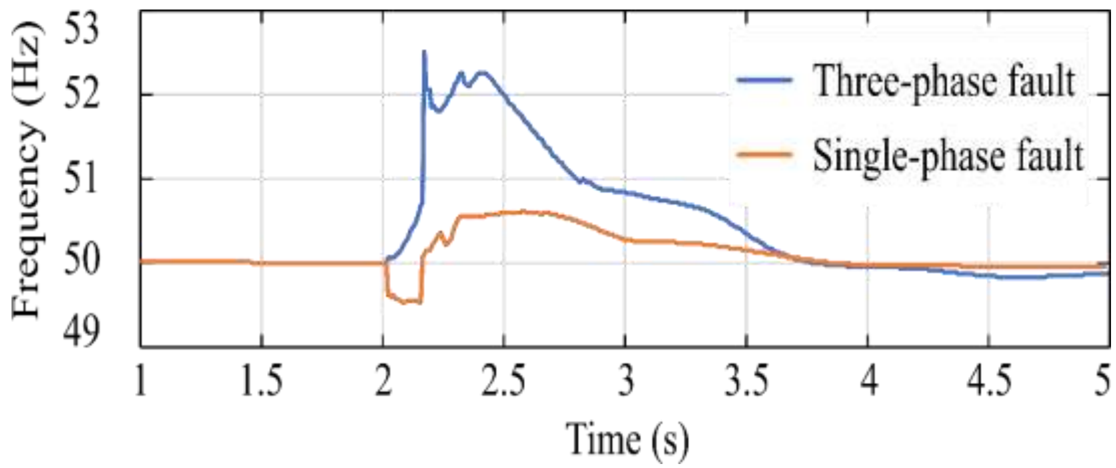



***PV systems without FRT capability***

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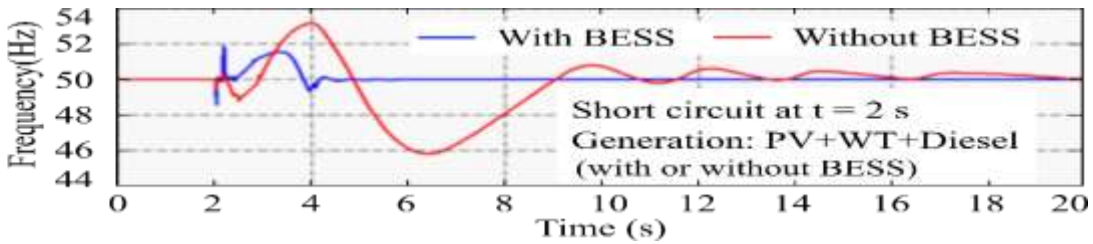
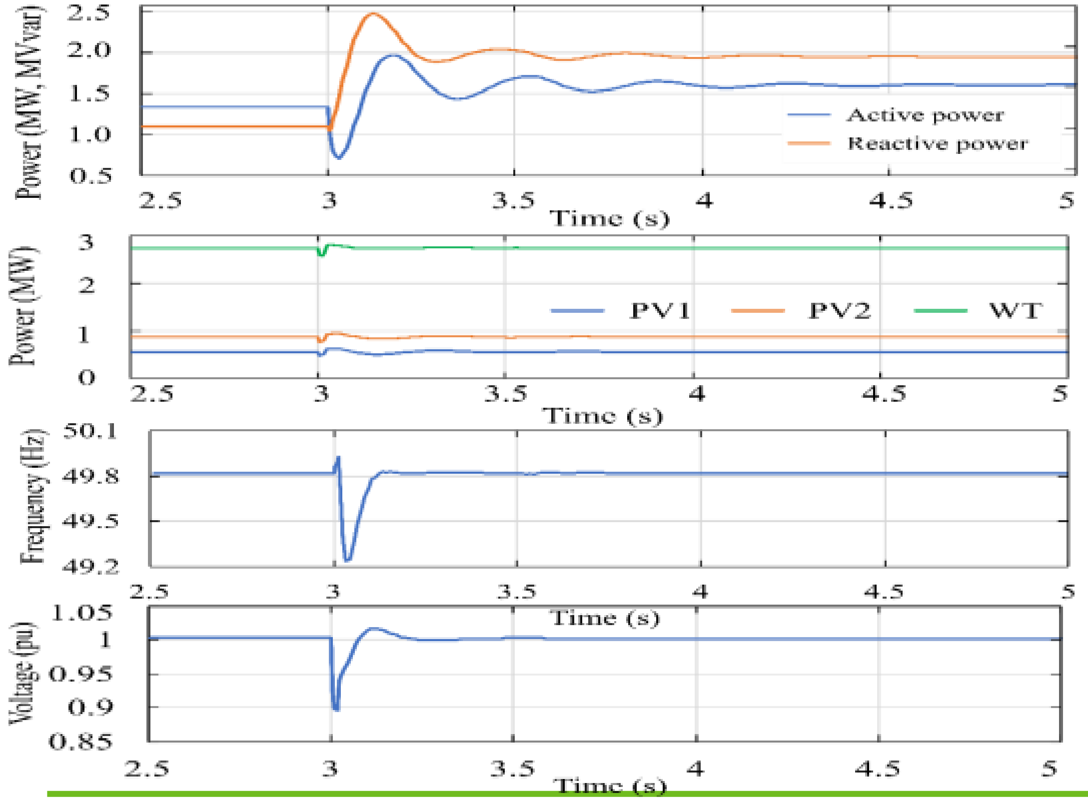
# Con Dao – Vietnam : Island microgrid

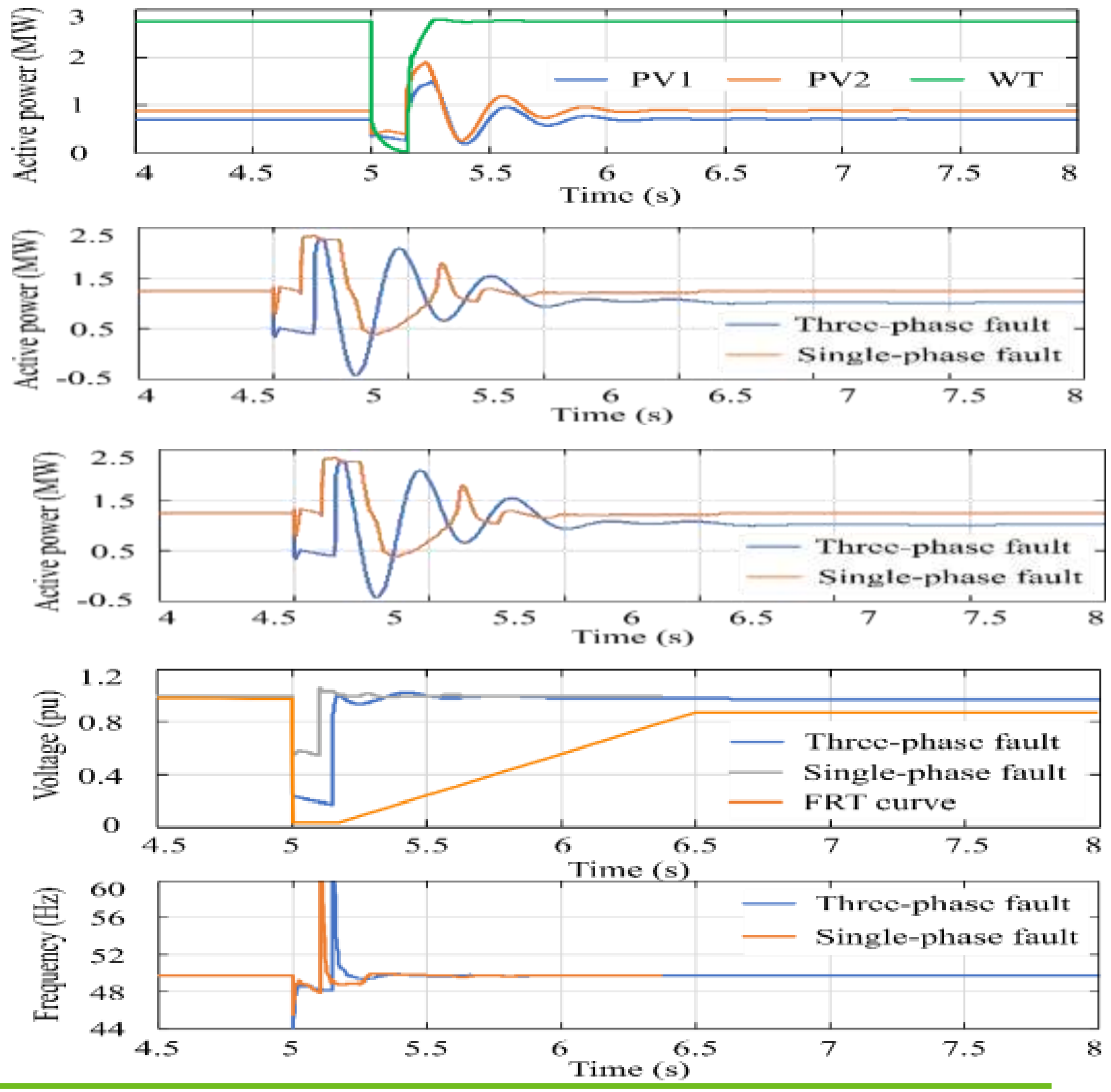
***Case B: BESS as slack bus***




***Outage of diesel generator G1***




***Short circuit without synchronous machines***

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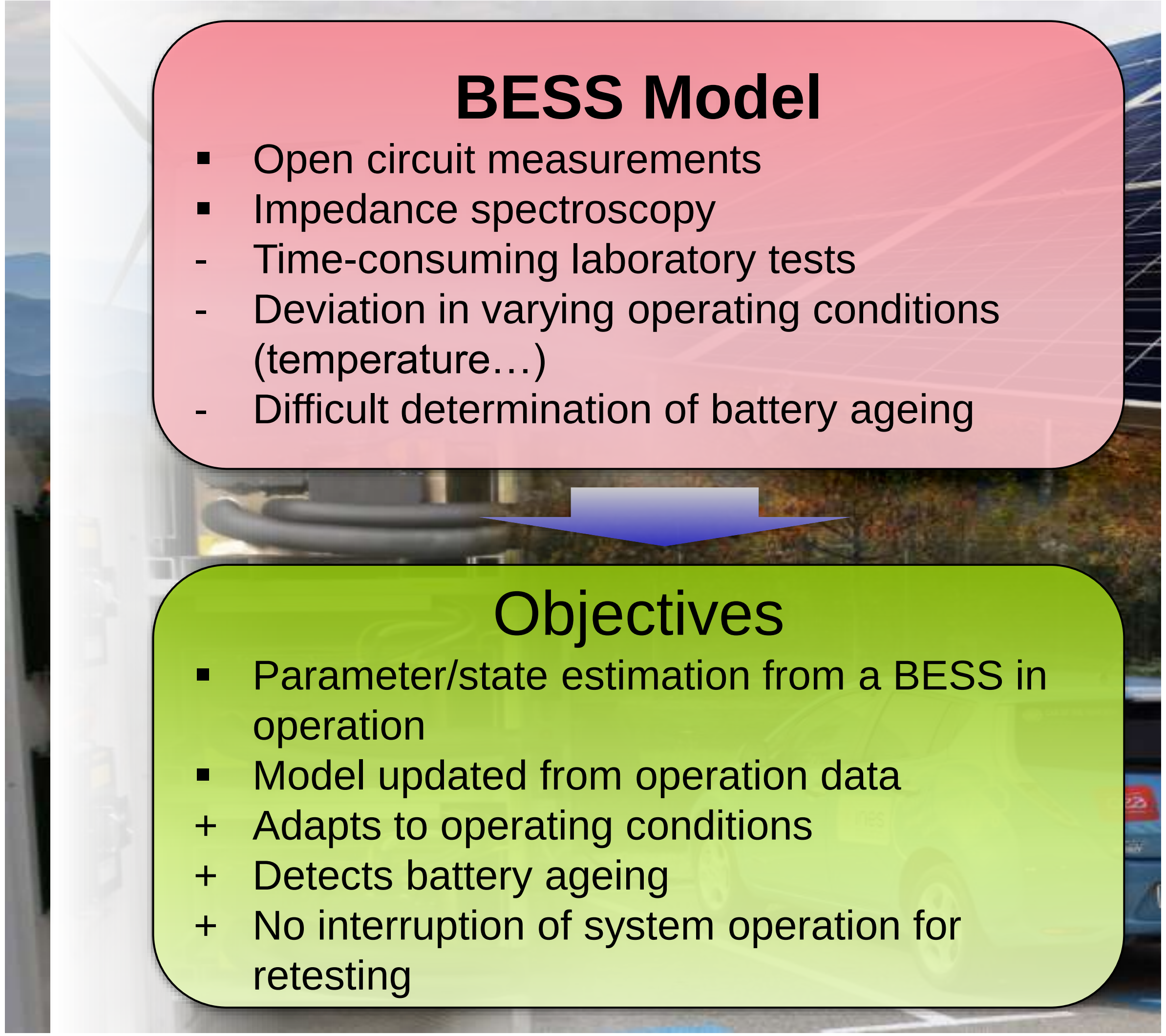
# Modelling: Adaptive battery models

- **New battery storage applications**
  - Consumer electronics
  - Electric vehicles
  - Balancing of renewable energies
  - Smart Grid applications
- **New user needs**
  - Fast and robust direct control
  - Minimal interference with system operation
  - Operation planning and optimization
    - ✓ Available energy estimation
    - ✓ Available power estimation
    - ✓ Loss estimation
    - ✓ Ageing estimation.

  »Performance indicators

  »Adaptability



## BESS Model

- ▪ Open circuit measurements
- ▪ Impedance spectroscopy
- \- Time-consuming laboratory tests
- \- Deviation in varying operating conditions (temperature…)
- \- Difficult determination of battery ageing

## Objectives

- ▪ Parameter/state estimation from a BESS in operation
- ▪ Model updated from operation data
- \+ Adapts to operating conditions
- \+ Detects battery ageing
- \+ No interruption of system operation for retesting

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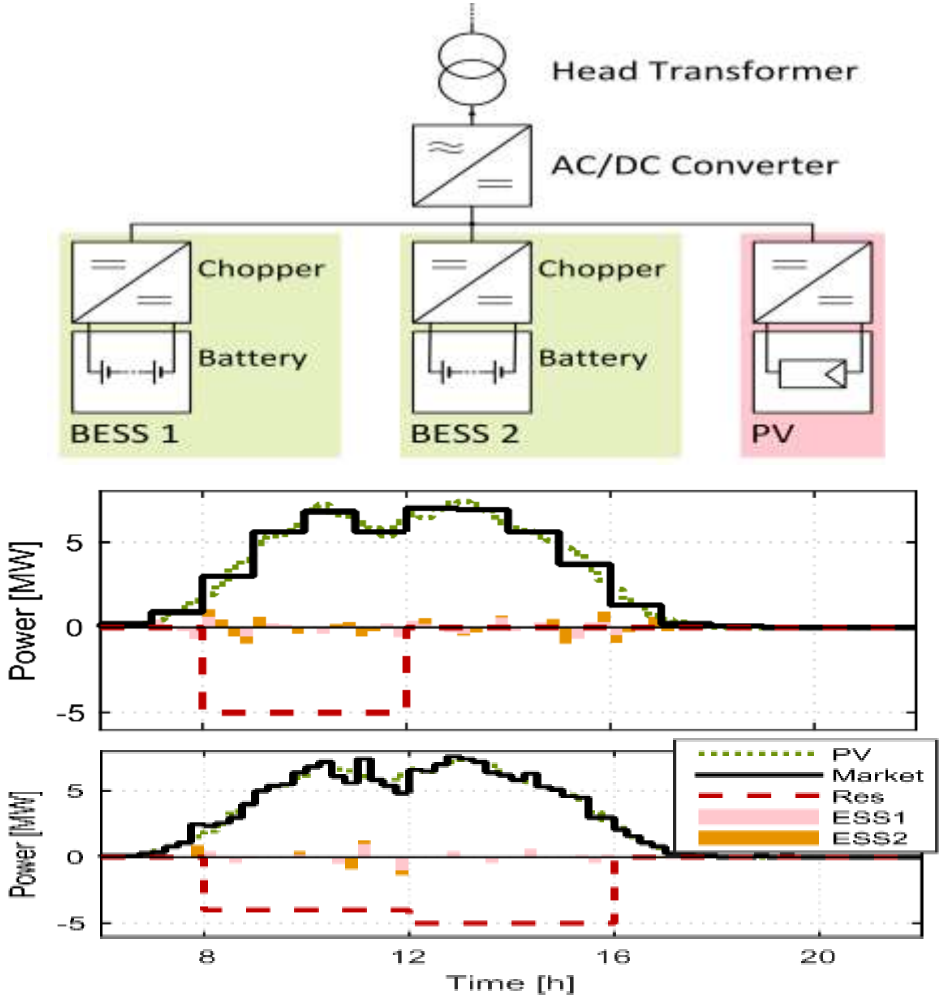
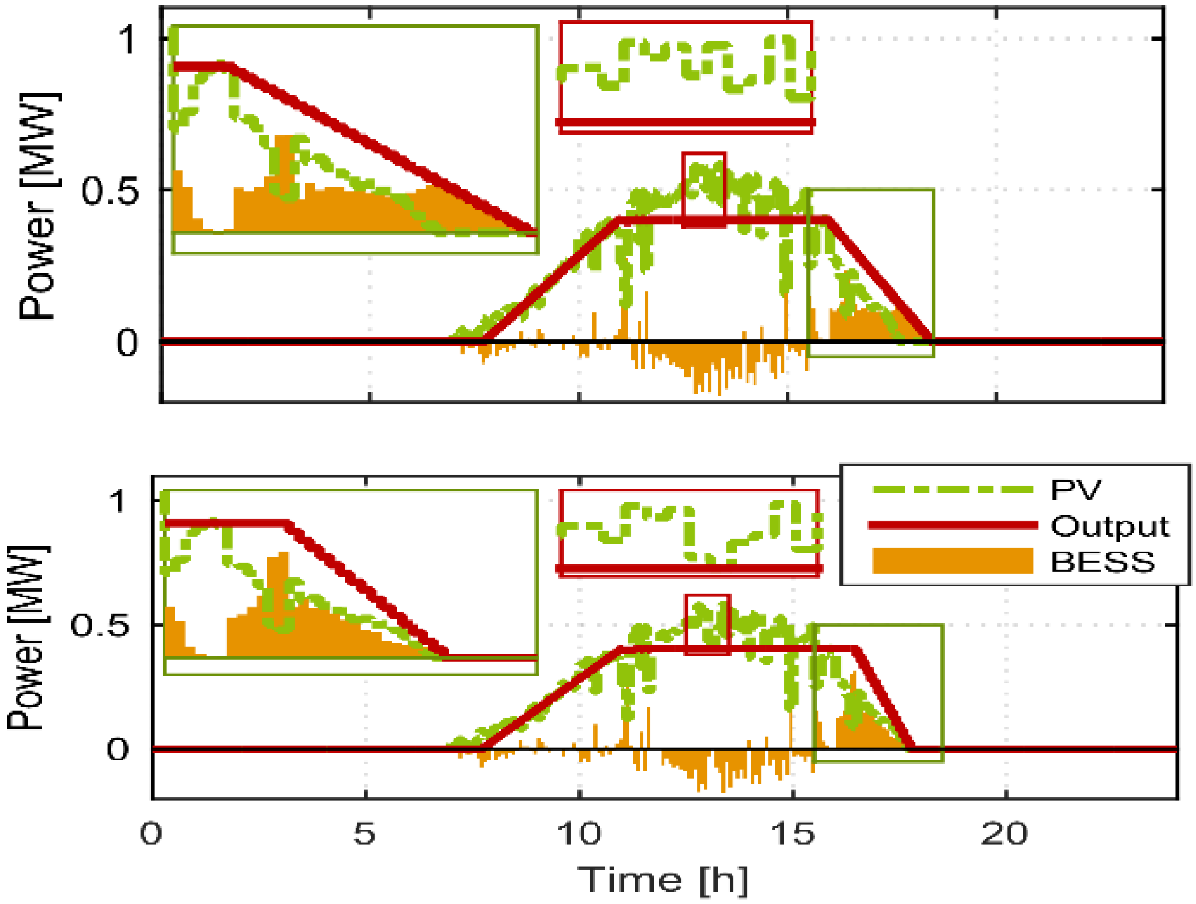



One-day production schedule of two ESSs and a PV power plant in a VPP, as well as net market bids in the day-ahead energy (Market) and tertiary reserve market (Res). Top: current German market rules, bottom: quarter-hourly energy market contracts and relaxed minimal reserve amount constraint




Plant production schedule, PV generation and BESS solicitation resulting from optimization. Top: without aging cost, bottom: with aging cost (average aging approach)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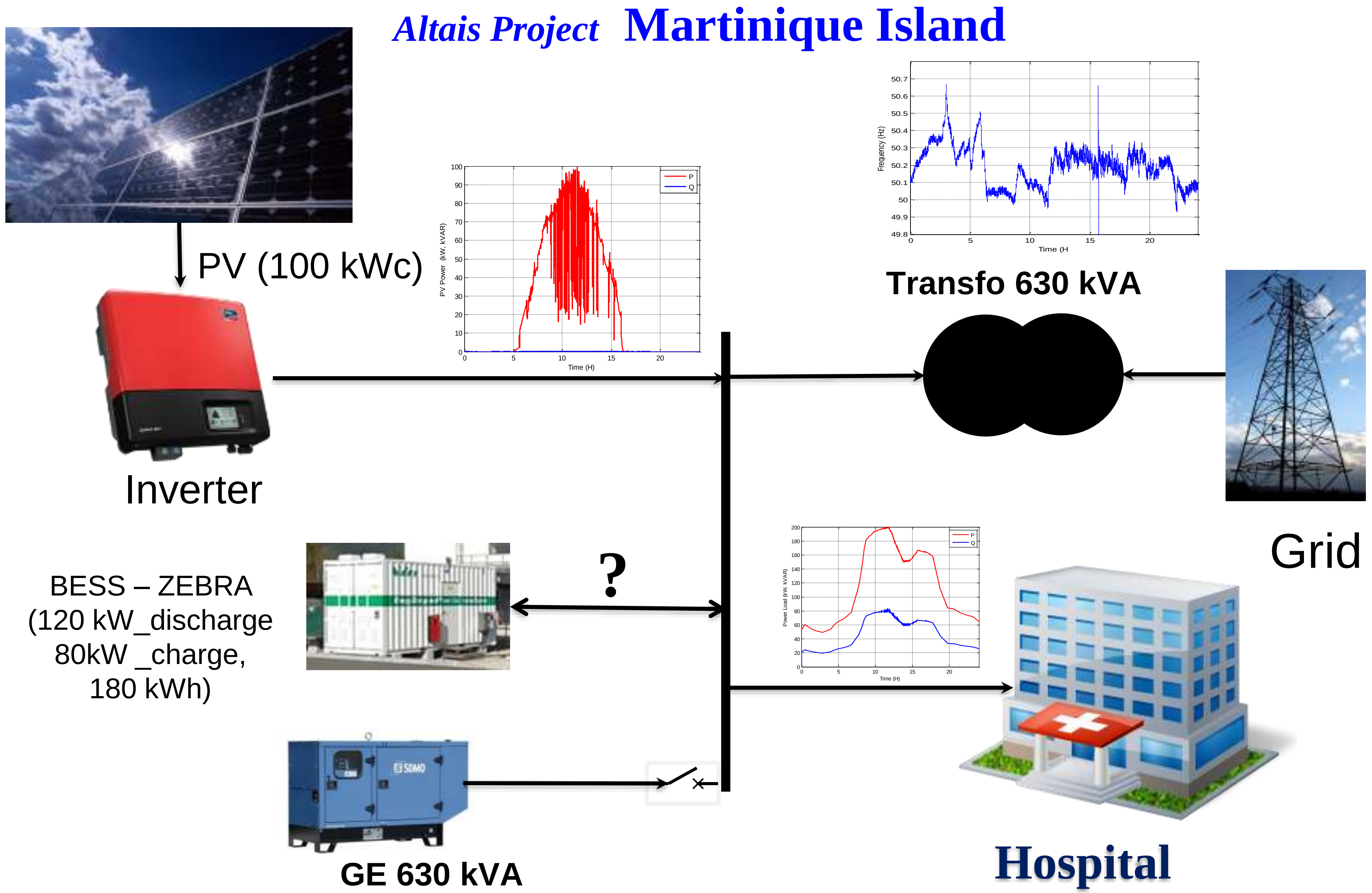


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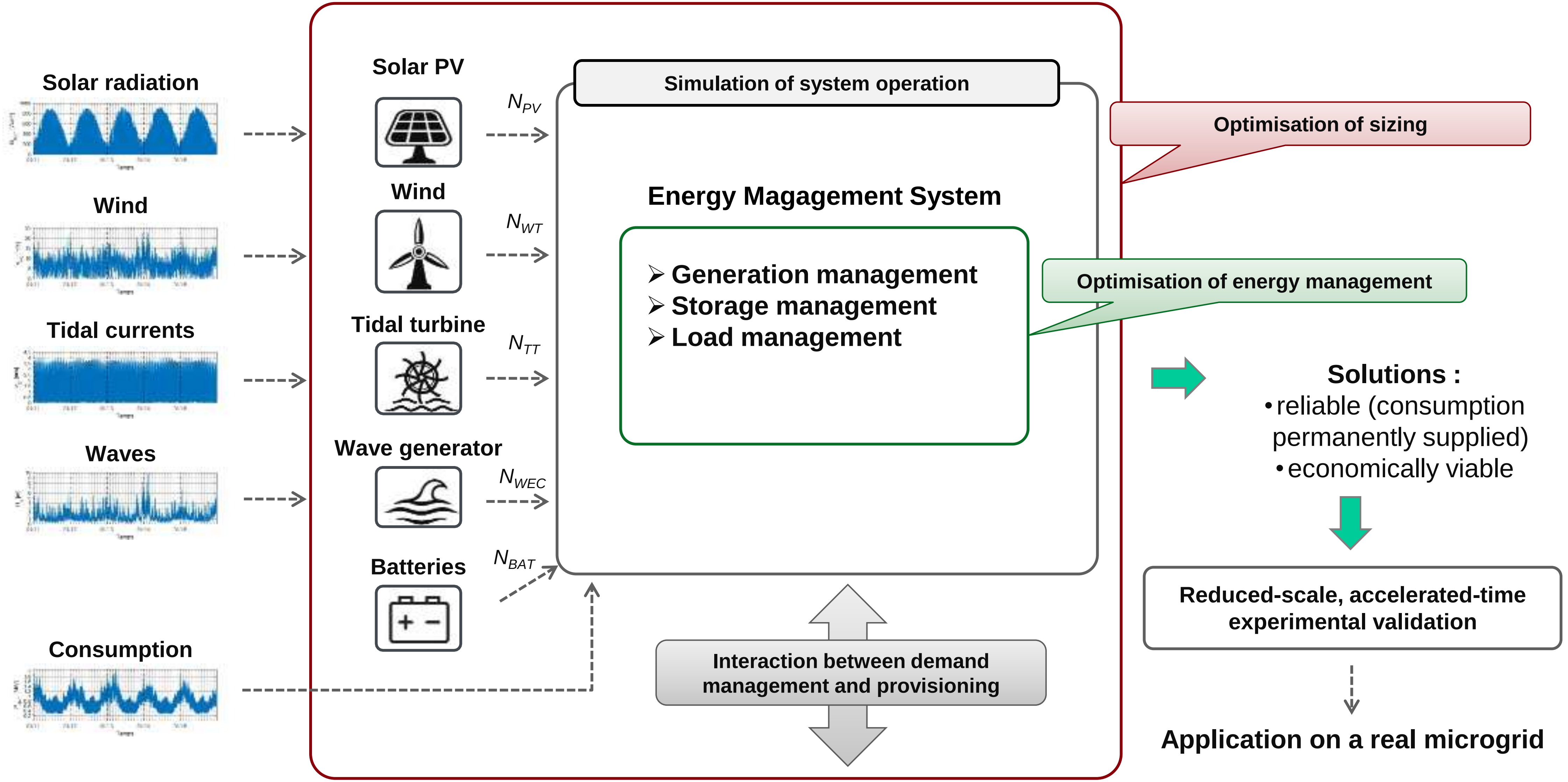
# Marine energy

*Anthony PhD Thesis*

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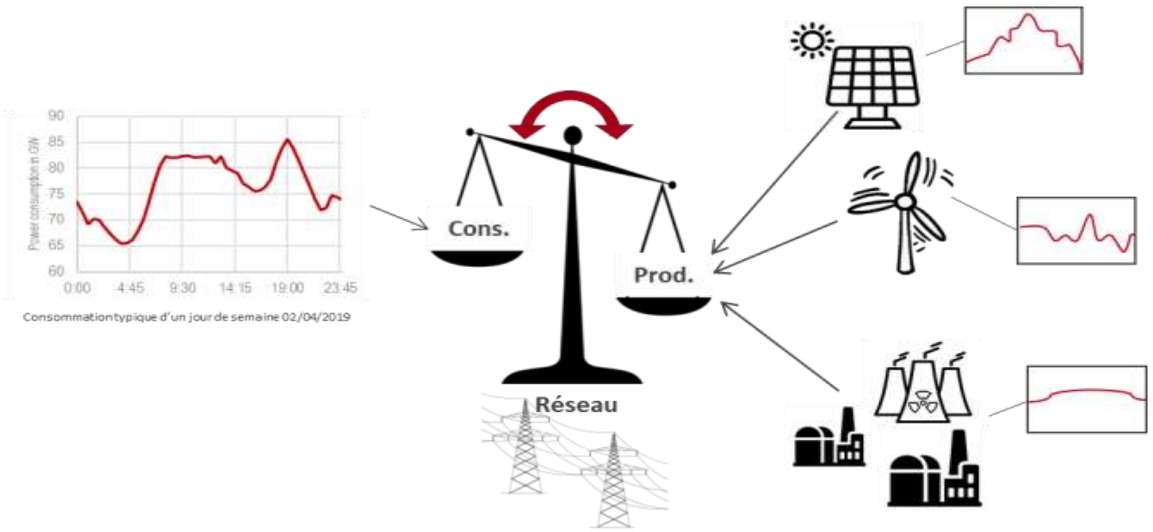
# RES and Nuclear

Anne Laure PhD Thesis




| Gradient max | |
|---|---|
| Hydro | > 25%Pn/min |
| Diesel | 25%Pn/min |
| Gas turbine | 20%Pn/min |
| Combined gas turbine | 5-10%Pn/min |
| Coal | 5%Pn/min |
| Nuclear | 5%Pn/min* |

*IAEA (2018)

- Is it possible to characterize the requirements of the electrical network in full transition?
- If ok, how to quantify these
- requirements?

- Is it possible to integrate flexibility requirements as a design criterion in a nuclear reactor?
- If so, what impact of these requirements on reactor design?

**Face to new demands, to what extent does nuclear can it inherently be more flexible ie. meet network requirements?**

*Phong PhD Thesis, Ademe project*

**Equipment Identification**
- Load Identification
- DRES Identification

**Topology Validation**
- PowerFlow Validation
- Angle Validation

**Earthing and Protection**
- Mechanics Replication
- Parameter Identification

**Comm Infrastructure**
- Architecture Replication
- Characteristics

**System Observability**
- Sensor location Identification

**Sensor Deployment**
- I/O Time

**Comm Si(E)mulation**
- Power/Comm Interraction

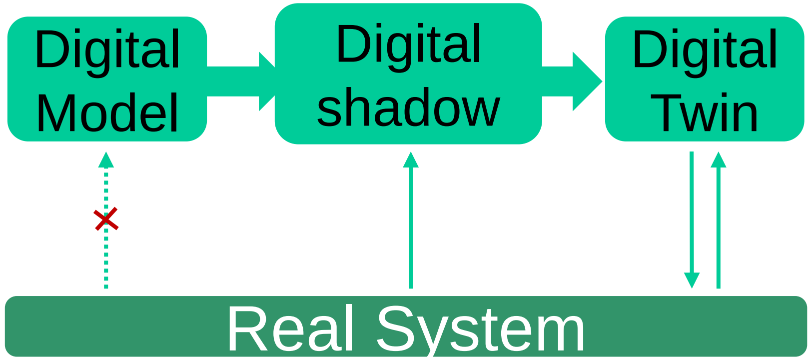
**Synchronization**
- Trade Off
- Detail/Performance
- Real-time Condition

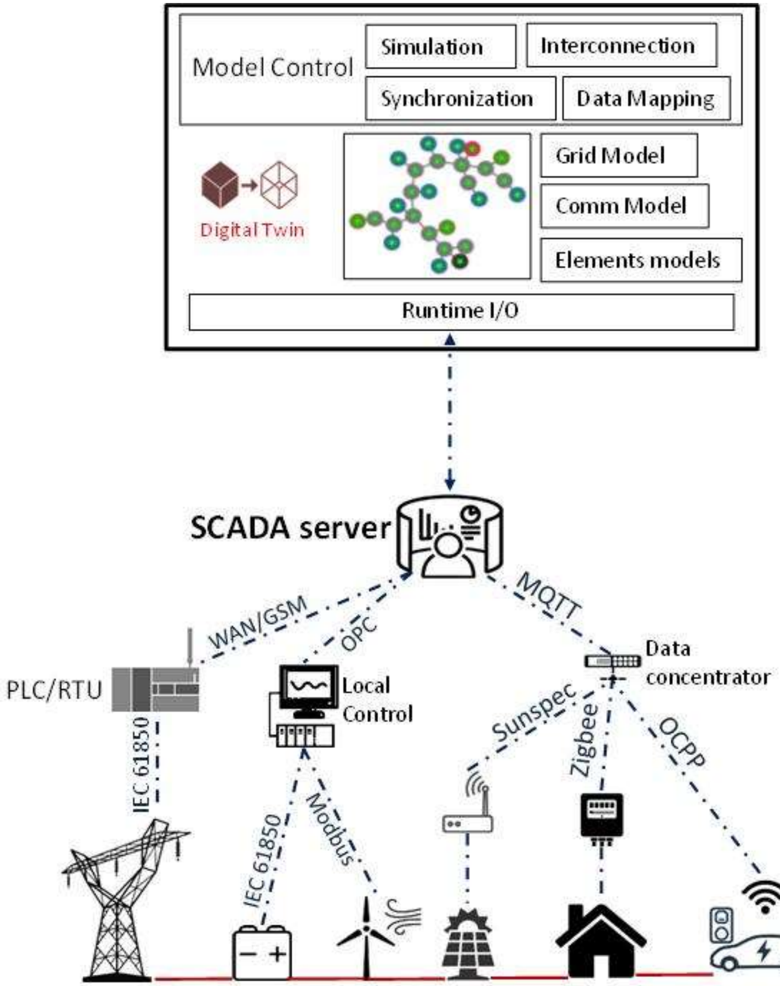
**System Controlability**
- Stability/Convergence

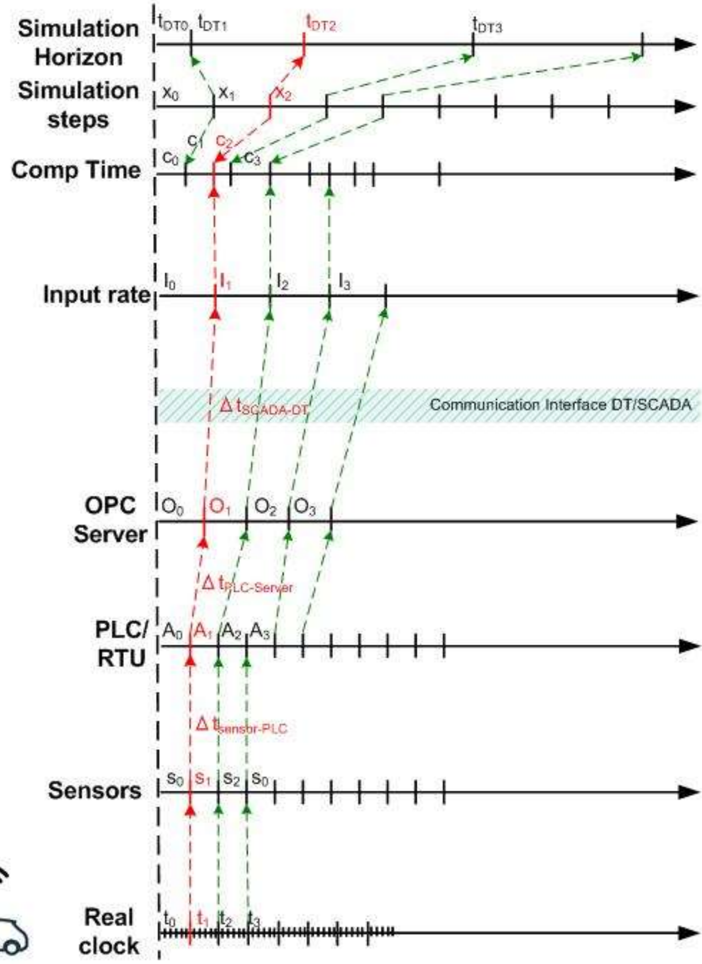
**Control Implementation**
- Mechanics
- Automate activation

**Integration**
- As a SuT
- As a Environment

**Uncertainty Propagation**
- Local Approach
- Global Approach

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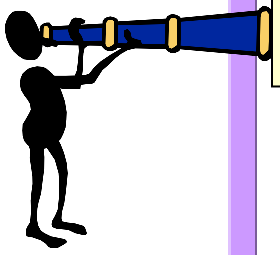
# Plan





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# Smartgrid: Definition

Intelligent electrical networks (REI) or Smart Grids (SM) aim to efficiently integrate the actions of all users (producers and consumers) in order to guarantee a sustainable, safe and low-cost electricity supply. They use innovative products and services as well as observation, control, information & communication technologies in order to:

- Facilitate the connection and operation of all means of production, in particular renewables, by significantly reducing the environmental impact of the complete electrical system;
- Allow the consumer to play an active role in the optimized operation of the electrical system;
- Optimize the level of reliability, safety and quality of electricity, and improve current services in an efficient manner;
- Supporting the development of an integrated European electricity market;
- Increase the resilience of the electrical system.

Source Réseaux intelligents: Feuille de route

***DEFINITION (European Technology Platform for SmartGrids):***
***SmartGrids are «electricity networks that can intelligently integrate the behavior and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.»***

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# Smart-grid

Smart grids can be defined according to four characteristics in terms of:

- **Flexibility:** they make it possible to more finely manage the balance between production and consumption;
- **Reliability:** they improve network efficiency and security;
- **Accessibility:** they facilitate the energy transition and promote the integration of renewable energy sources throughout the network;
- **Economy:** thanks to better management of the system, they provide energy savings and a reduction in costs (both in production and consumption).

**Keywords**

- **Intelligent distribution network**
- **Smart meters (ex: Linky)**
- **Renewable energy sources (RES), DG**
- **Energy storage (Battery, H2, FW, S Capa, thermal…)**
- **Electrical vehicles (EV)**
- **Flexibility**
- **Demand – Response (smart appliances)**
- **Power electronics (GaN, SiC, MVDC, HVDC)**
- **Smart control**
- **Smart protection**
- **Energy management system (EMS)**
- **Security, Reliability**
- **Self healing**
- **ICT: big data, cyber security, Edge/Cloud**
- **Cost-effective**
- **Interoperability**
- …

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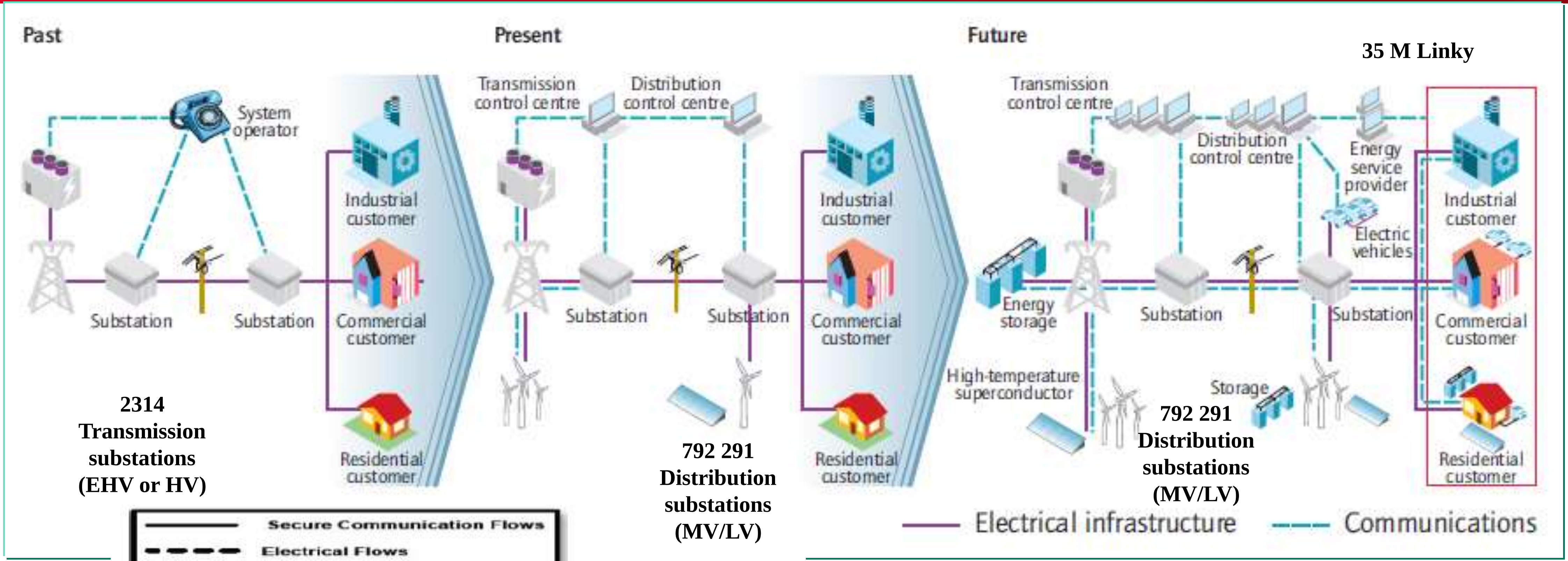
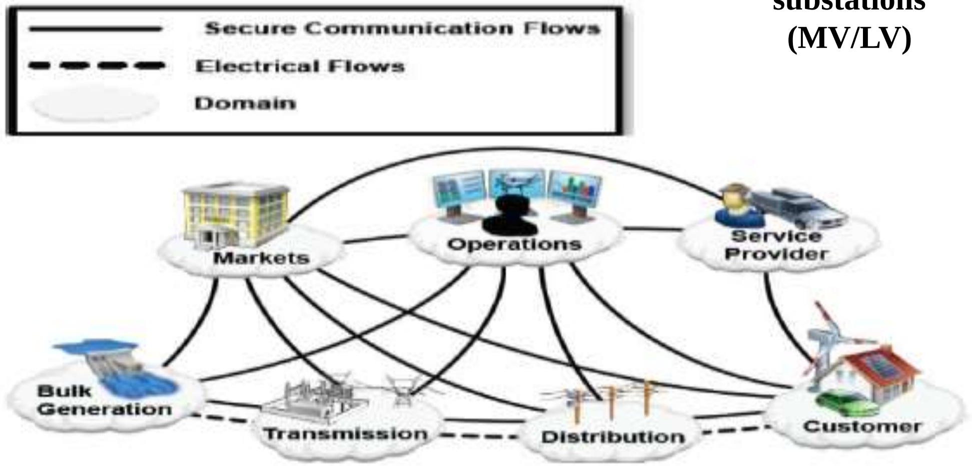
# Smart-grid




Smart infrastructure systems

Smart management and control systems

Smart protection systems

# Traditional grid and Smart grid

| Traditional Grid | Smart Grid |
| --- | --- |
| Mechanization | Digitization |
| One-way communication | Two-way real-time communication |
| Centralized power generation | Distributed power generation |
| Radial Network | Dispersed Network |
| Less data involved | Large volumes of data involved |
| Small number of sensors | Many sensors and monitors |
| Less or no automatic monitoring | Great automatic monitoring |
| Manual control and recovery | Automatic control and recovery |
| Less security and privacy concerns | Prone to cyber-security and privacy issues |
| Human attention to system disruptions | Adaptive protection |
| Simultaneous production and consumption of energy/electricity | Use of storage systems |
| Limited control | Extensive control system |
| Slow response to emergencies | Fast response to emergencies |
| Fewer user choices | Vast user choices |

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# Smart grid criteria (Singapore)

"Power systems are being upgraded worldwide as part of a transition toward climate-neutral systems. One of the main drivers of this transition is the need for a full digitalization of the electricity supply chain."


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# SMART GRID INDEX 2022



## 7 DIMENSIONS OF A SMART GRID

**SMART GRID INDEX**

Measures the smartness of electricity grids globally, in seven key dimensions. The benchmarking also identifies best practices to build smarter grids that deliver better value to customers.

| | | |
|---|---|---|
| 01. | MONITORING & CONTROL | . SCADA<br>. DMS / ADMS |
| 02. | DATA ANAYTICS | . Smart Meter Coverage<br>. Data Analytics Application |
| 03. | SUPPLY RELIABILITY | . SAIDI<br>. SAIFI |
| 04. | DER INTEGRATION | . Management of DER Integration<br>. Grid Scale Energy Storage |
| 05. | GREEN ENERGY | . Renewable Energy Penetration<br>. EV Facilitation |
| 06. | SECURITY | . IT Cyber Security<br>. OT Cyber Security |
| 07. | CUSTOMER EMPOWERMENT & SATISFACTION | . Real-time data to Customers<br>. Customer Satisfaction Feedback |

**Evaluation & Classification by SPGroup in 2022:**

- 94 utilities across 39 countries
- **Enedis (France) ranking**: 1st position
- **EVNHCMC ranking**: **47/94 utilities**, Best practices: Control and Monitoring;
- EVN Hanoi: 63/94
- EVN CPC: 66/94

https://www.spgroup.com.sg/sp-powergrid/overview/smart-grid-index

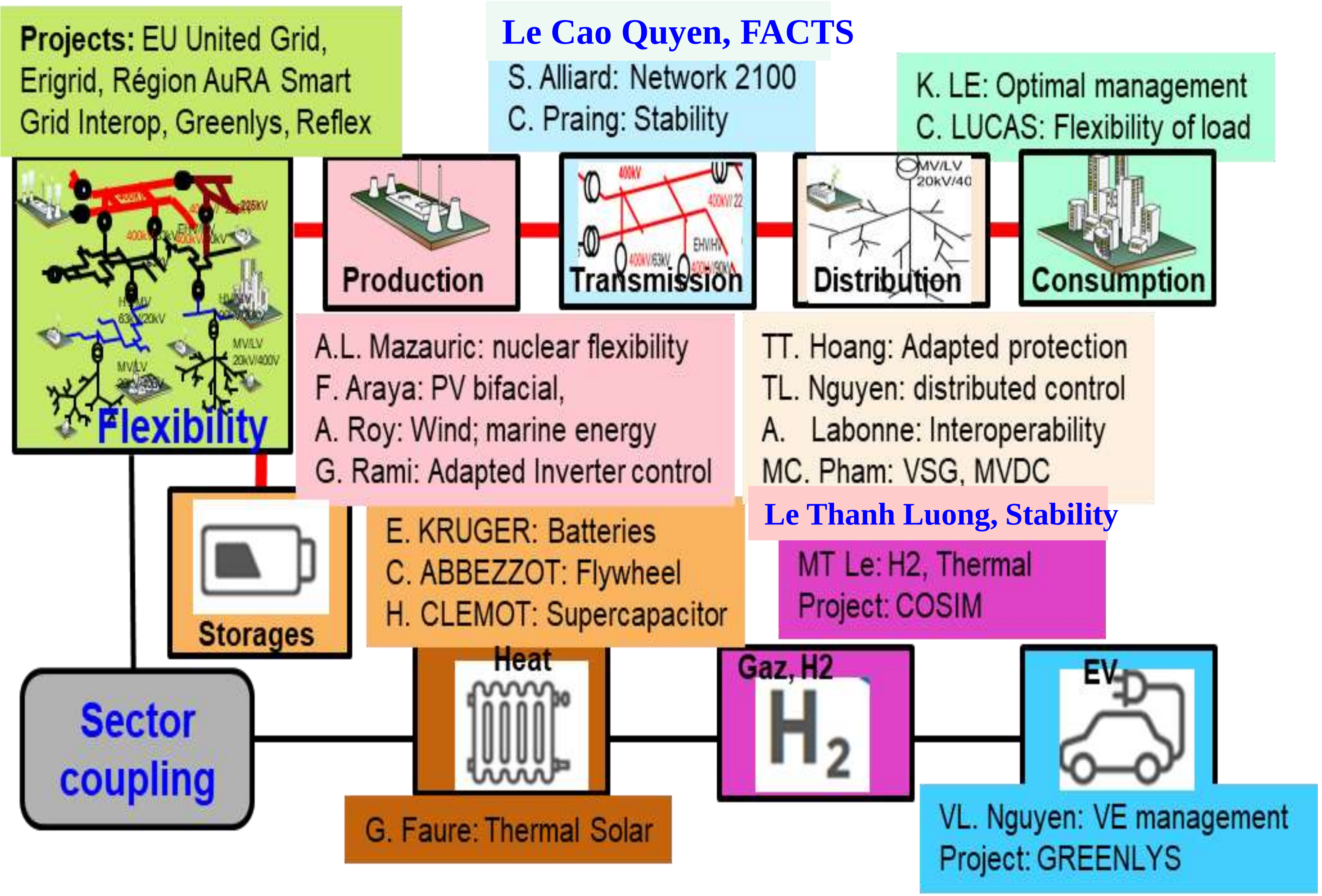
| Utility | Country/Market | Score | + / - (%) | Best Practices |
|---|---|---|---|---|
| Enedis | FRA | 98.2 | 1.8 | |
| TaiPower | TWN | 94.6 | 0.0 | |
| UKPN | GBR | 94.6 | 0.0 | |
| ConEd | USA | 92.9 | -1.8 | |
| WPD | GBR | 92.9 | 0.0 | |
| CitiPower | AUS | 91.1 | -1.8 | |
| DEWA | ARE | 89.3 | 0.0 | |
| SP Energy Networks | GBR | 89.3 | 1.8 | |
| SDGE | USA | 87.5 | 0.0 | |
| FPL | USA | 85.7 | 0.0 | |
| Northern Powergrid | GBR | 85.7 | 1.8 | |
| SCE | USA | 85.7 | 0.0 | |
| Stedin | NLD | 85.7 | 0.0 | |
| ComEd | USA | 83.9 | 0.0 | |
| PG&E | USA | 83.9 | -3.6 | |
| ENWL | GBR | 82.1 | -3.6 | |
| Jemena | AUS | 82.1 | 1.8 | |
| PEPCO | USA | 82.1 | 5.4 | |
| Powercor | AUS | 82.1 | - | |
| Radius | DNK | 82.1 | -3.6 | |
| United Energy | AUS | 82.1 | - | |
| Chubu | JPN | 80.4 | 8.9 | |
| Hydro Ottawa | CAN | 80.4 | 1.8 | |
| LADWP | USA | 80.4 | 0.0 | |
| SSEN | GBR | 80.4 | 0.0 | |
| State Grid Beijing | CHN | 80.4 | 0.0 | |
| Tata power-DDL | IND | 80.4 | 0.0 | |
| TEPCO | JPN | 80.4 | -1.8 | |
| APS | USA | 78.6 | 0.0 | |
| CLP | HKG | 78.6 | 3.6 | |
| State Grid Shanghai | CHN | 78.6 | 3.6 | |
| Westnetz | DEU | 78.6 | -1.8 | |
| Ausgrid | AUS | 76.8 | 5.4 | |
| BC Hydro | CAN | 76.8 | 0.0 | |
| BGE | USA | 76.8 | 1.8 | |
| e-distribuzione | ITA | 76.8 | -8.9 | |
| Guangzhou Power | CHN | 76.8 | 1.8 | |
| i-DE | ESP | 76.8 | 0.0 | |
| Ausnet | AUS | 75.0 | -3.6 | |
| Dominion Energy | USA | 75.0 | 7.1 | |
| Liander | NLD | 75.0 | 5.4 | |
| SP Group | SGP | 75.0 | 0.0 | |
| Fluvius | BEL | 73.2 | 3.6 | |
| Kansai | JPN | 73.2 | 0.0 | |
| KEPCO | KOR | 73.2 | 0.0 | |
| Duke Energy | USA | 71.4 | -1.8 | |
| EVN HCMC | VNM | 71.4 | 3.6 | |

| Utility | Country/Market | Score | + / - (%) | Best Practices |
|---|---|---|---|---|
| TNB | MYS | 71.4 | 3.6 | |
| Toronto Hydro | CAN | 71.4 | -1.8 | |
| Western Power | AUS | 71.4 | -3.6 | |
| CenterPoint Energy | USA | 69.6 | 0.0 | |
| PSE | USA | 69.6 | 0.0 | |
| State Grid Chongqing | CHN | 69.6 | -1.8 | |
| EDP | PRT | 67.9 | 0.0 | |
| Eversource | USA | 67.9 | 0.0 | |
| HK Electric | HKG | 67.9 | 5.4 | |
| MEA | THA | 67.9 | 0.0 | |
| NIEN | GBR | 67.9 | 3.6 | |
| Shenzhen Power | CHN | 67.9 | -8.9 | |
| State Grid Tianjin | CHN | 67.9 | 5.4 | |
| Vattenfall | SWE | 67.9 | 0.0 | |
| ESB | IRL | 66.1 | 0.0 | |
| EVN Hanoi | VNM | 66.1 | 5.4 | |
| Helen | FIN | 66.1 | 5.4 | |
| Kahramaa | QAT | 66.1 | 3.6 | |
| EVN CPC | VNM | 64.3 | 0.0 | |
| State Grid Hubei | CHN | 64.3 | 1.8 | |
| State Grid Nanjing | CHN | 64.3 | 1.8 | |
| Stromnetz Berlin | DEU | 64.3 | 1.8 | |
| ACEA | ITA | 62.5 | 10.7 | |
| Meralco | PHL | 62.5 | 3.6 | |
| PEA | THA | 62.5 | 3.6 | |
| State Grid Sichuan | CHN | 62.5 | -3.6 | |
| State Grid Changsha | CHN | 58.9 | 0.0 | |
| Tata power Ltd | IND | 58.9 | 7.1 | |
| Vector | NZL | 58.9 | -1.8 | |
| Wiener Netze | AUT | 58.9 | 3.6 | |
| CEM | MAC | 55.4 | 3.6 | |
| Enel Dist Sao Paulo | BRA | 55.4 | 17.9 | |
| Eskom | ZAF | 55.4 | 0.0 | |
| Rosseti | RUS | 50.0 | 1.8 | |
| Sarawak Energy | MYS | 50.0 | 3.6 | |
| Edenor | ARG | 48.2 | 3.6 | |
| Elektro Gorenjska | SLO | 46.4 | - | |
| Light | BRA | 44.6 | -3.6 | |
| PLN | IDN | 44.6 | 0.0 | |
| Enel Dist Chile | CHL | 41.1 | 5.4 | |
| E-distributie Banat | ROU | 39.3 | - | |
| E- distribución | ESP | 35.7 | - | |
| Edesur | ARG | 35.7 | 3.6 | |
| TasNetworks | AUS | 33.9 | - | |
| E-distributie Dobrogea | ROU | 26.8 | - | |
| E-distributie Muntenia | ROU | 26.8 | - | |
| City Power | ZAF | 25.0 | 3.6 | |

# Smart Grids & Flexibility via PhD theses

Energy Transition => **Flexibility:** maintain balance, stability, safety and integrate an increasing share of renewables into the network.


~50 theses




Flexibility & smartgrid via PhD theses (supervised by Tran Q. Tuan)

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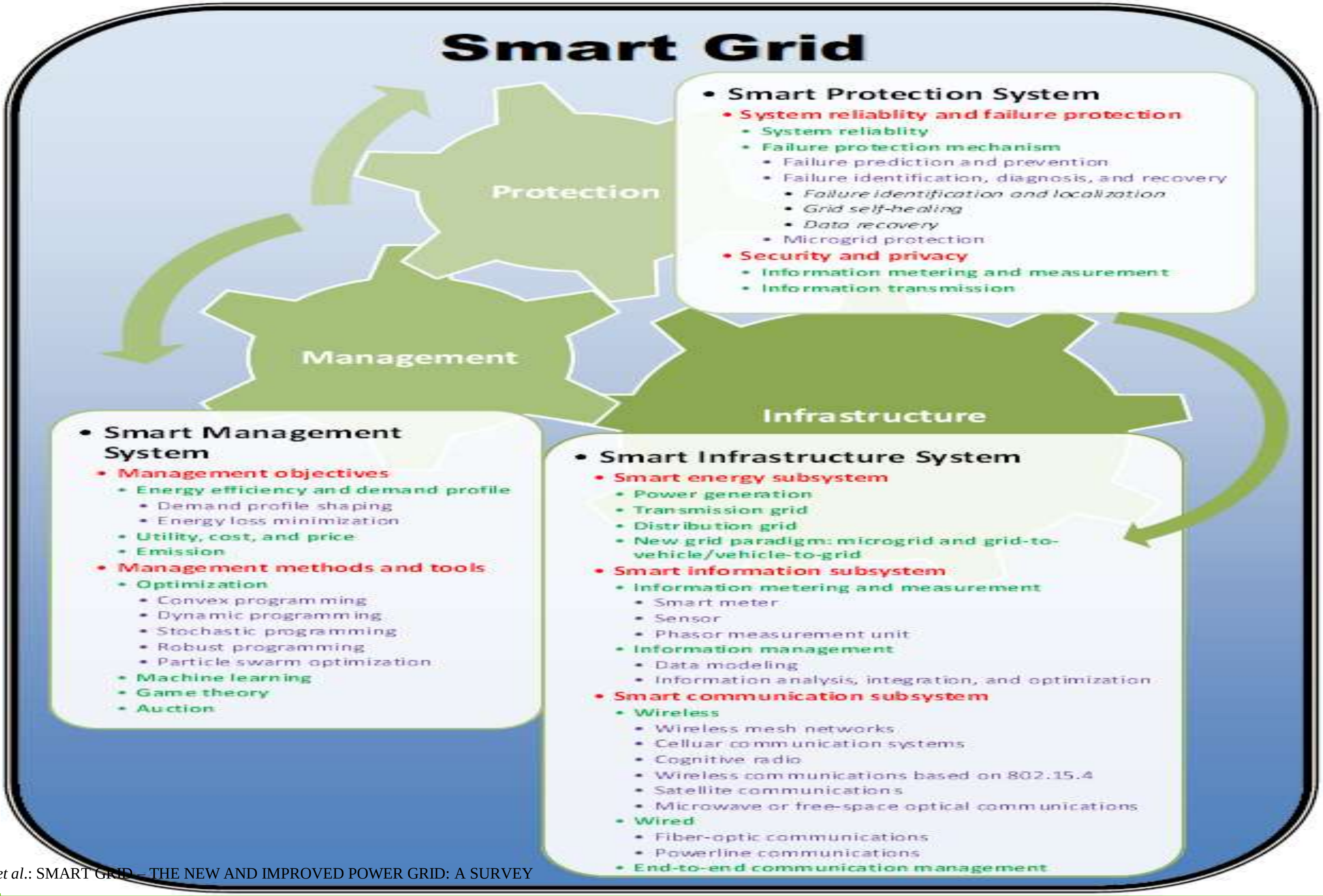


FANG *et al.*: SMART GRID – THE NEW AND IMPROVED POWER GRID: A SURVEY

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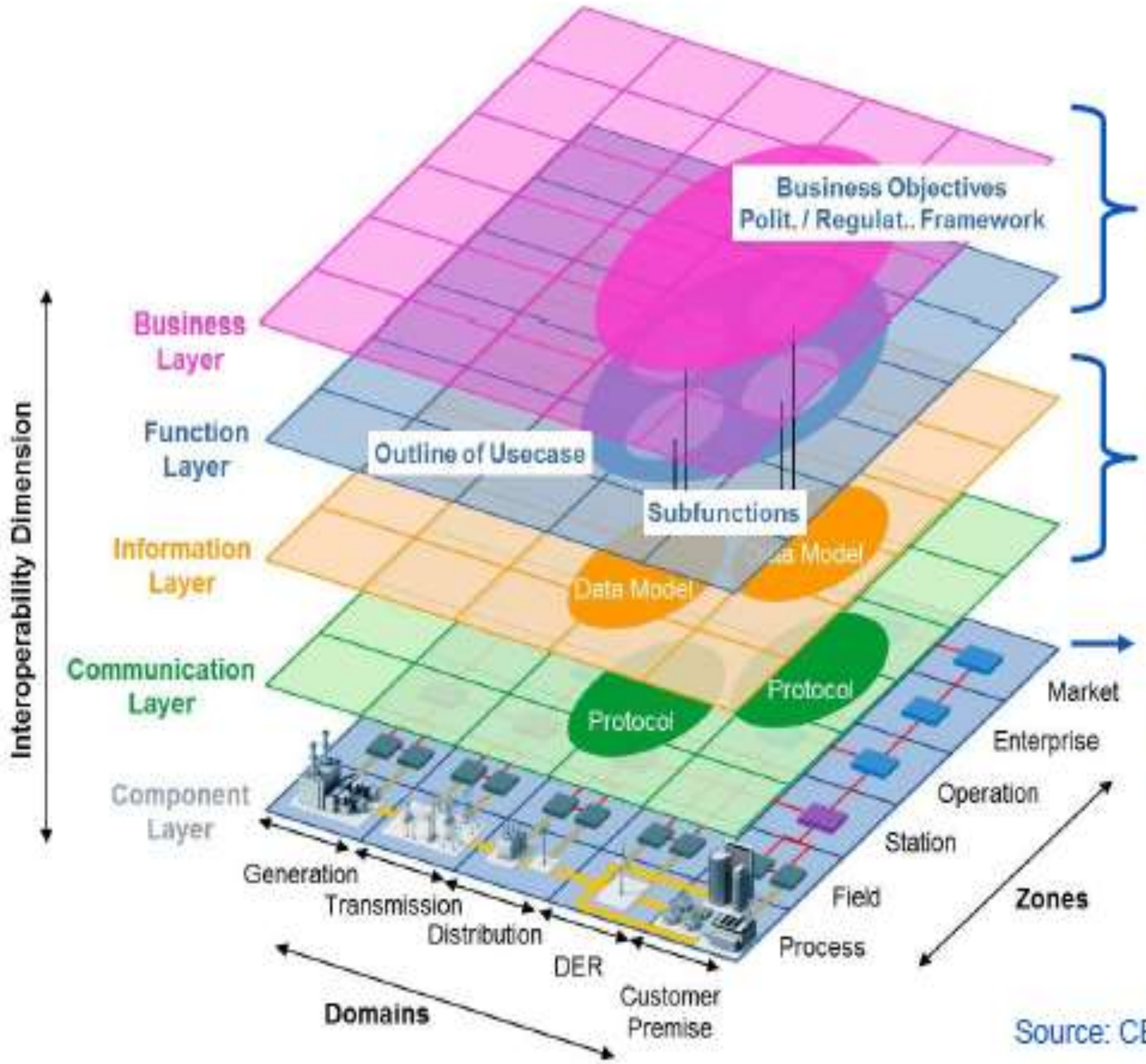
# Smart grid: Interoperability layers (SG Architecture Model - SGAM)




New business models related issues

Privacy and data management & protection related issues

Power system operation / asset management / security of supply related issues

Source: CEN-CENELEC-ETSI Smart Grid Coordination Group

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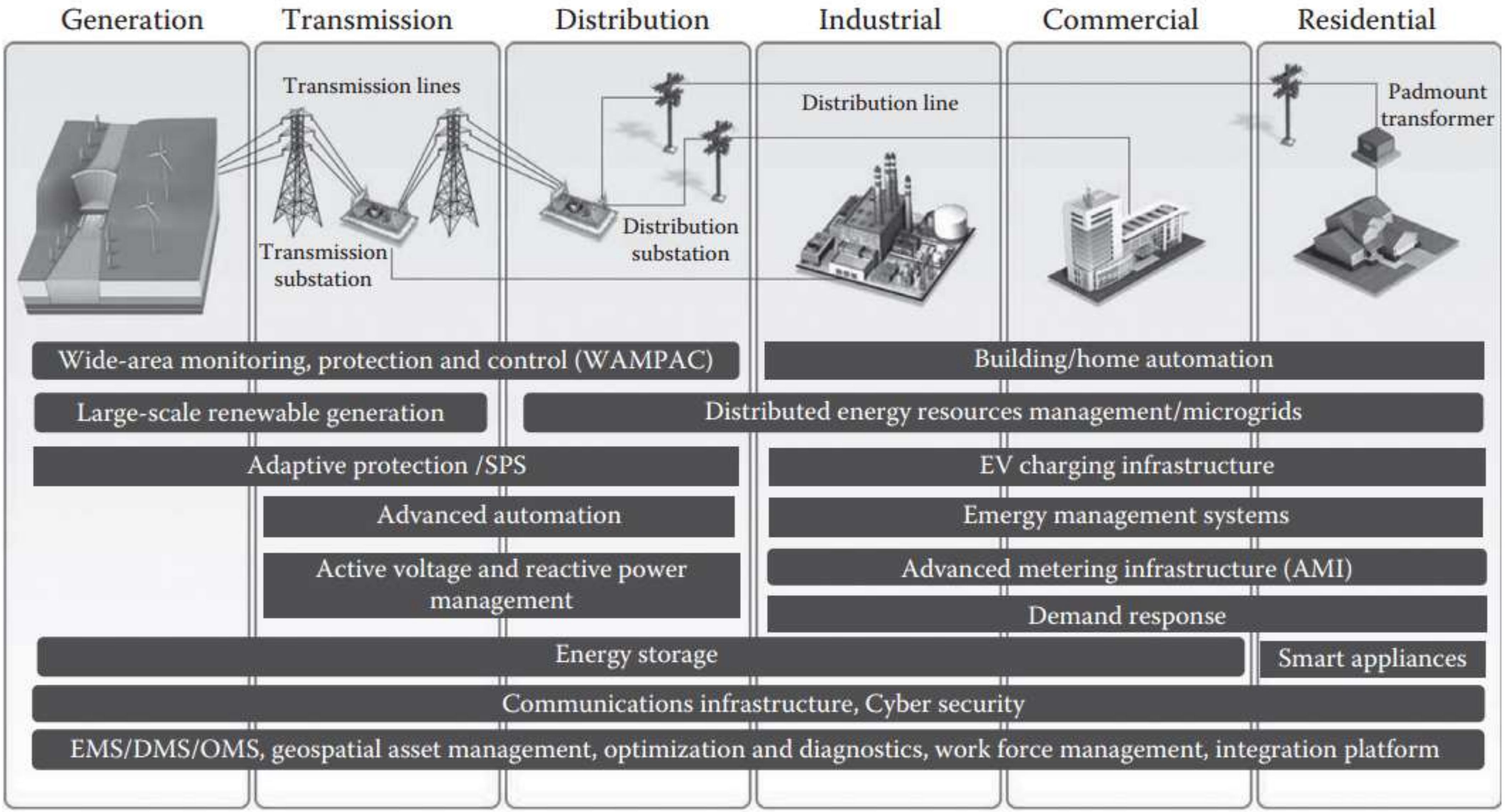
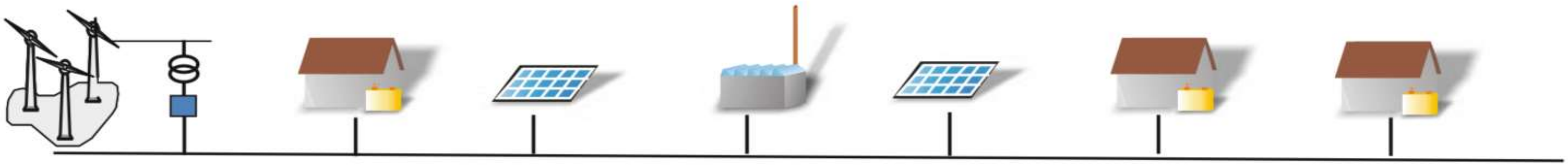
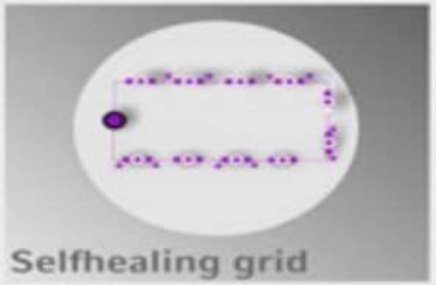
# Smart-Grid




Source GE Energy

# Three pillars of smart distribution



| Distribution Automation | Smart Aggregation | Smart Metering |
|---|---|---|
|   |   |   |
| **Main Tasks, Functions, Targets** | | |
| Voltage and load flow control, Remote control of switches Remote reading of fault indications, Automated elimination of faults **Improved quality of supply** | Aggregation of dispersed generators storage and loads for balancing and optimizing participation on prospective markets **Economic benefits** | Market integration of consumers by variable tariffs–Online visibility of demand , costs & savings **Energy efficiency and economic benefits** |

# Smart-grid Actors

| | |
|---|---|
| Grid operators | • Transmission system operator (TSO)<br>• Distribution system operator (DSO) |
| Grid users | • Generator<br>• Customer<br>• Electrical installer<br>• Supplier<br>• Retailer |
| Energy market place | • Balance responsible party<br>• Clearing & Settlement agent<br>• Trader<br>• Supplier<br>• Aggregator |
| Technology providers | • Electric power grid equipment vendor<br>• Ancillary service provider<br>• Metering operator<br>• ICT service provider<br>• Grid communications network provider<br>• Home appliances vendor<br>• Building Energy Management (BEM) system provider<br>• Electric transportation & Vechicle solutions provider |
| Influencers | • Regulator<br>• Standardization bodies<br>• EU and national legislation authorities<br>• Financial sector entities |

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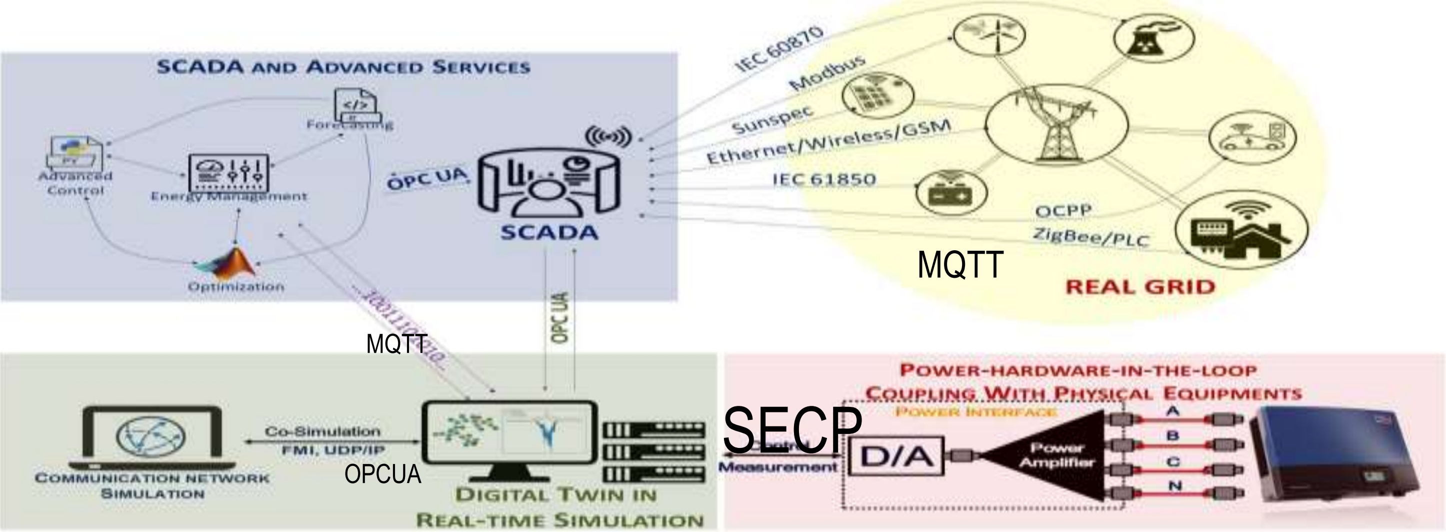
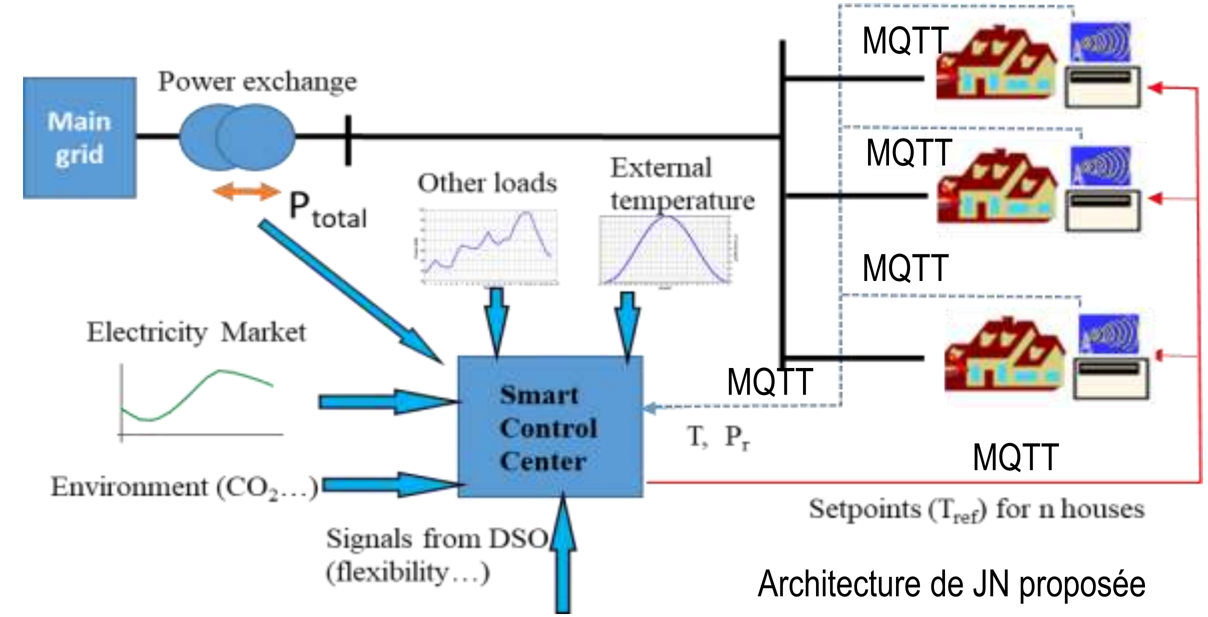
# DIGITAL TWIN of a cyber-physical energy system



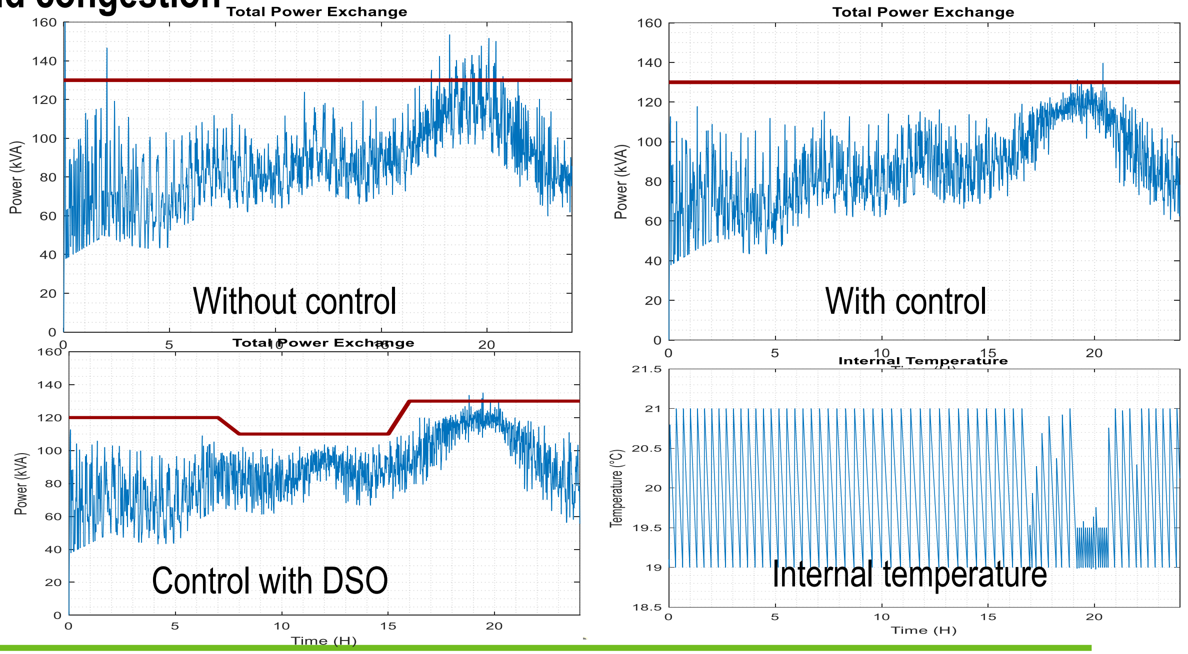
PhD Thesis, Tran Thien Phong




## Energy management for a district including heatings to reduce peak load and congestion




Architecture de JN proposée

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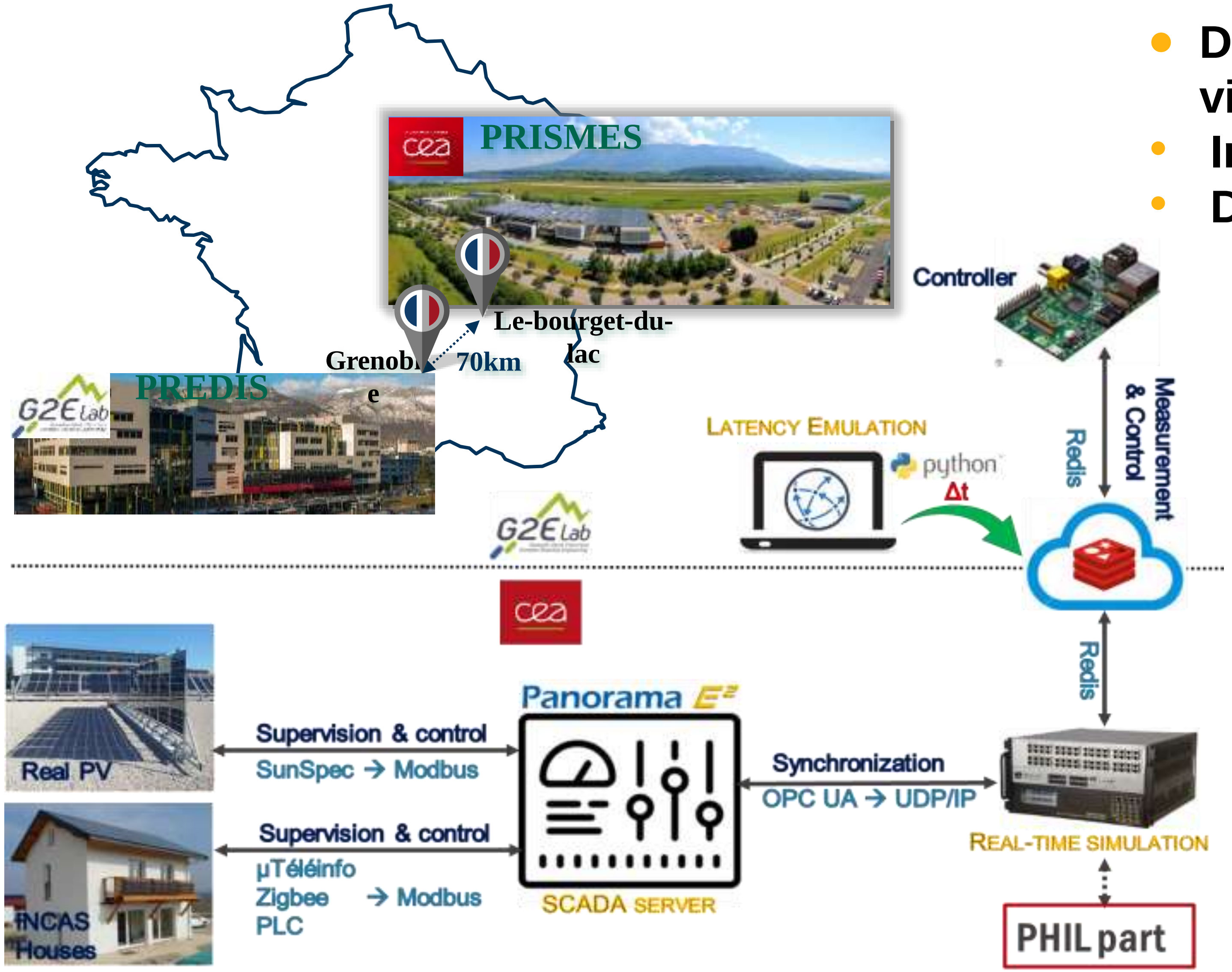
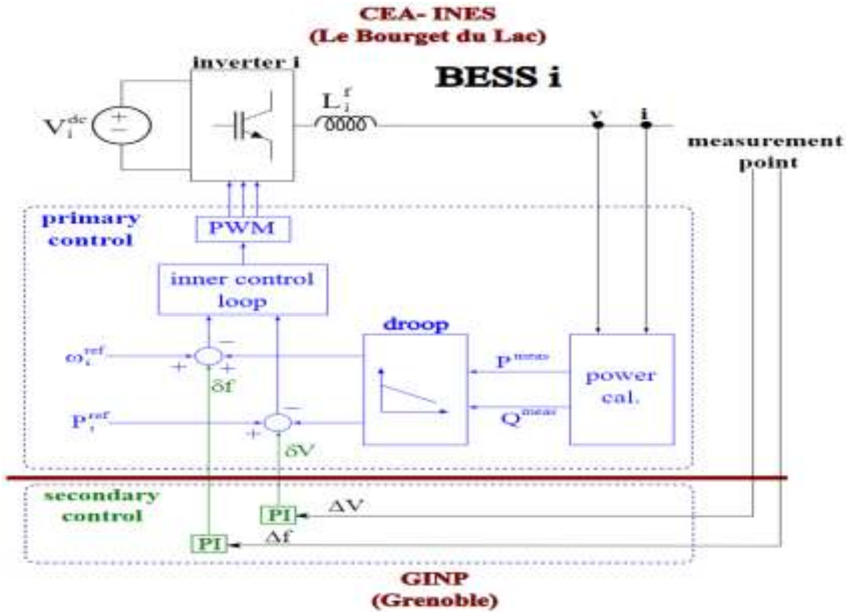
# Impacts of communication to distributed control in isolated microgrid

EU Erigrid project | PhD Thesis: Tung Lam NGUYEN



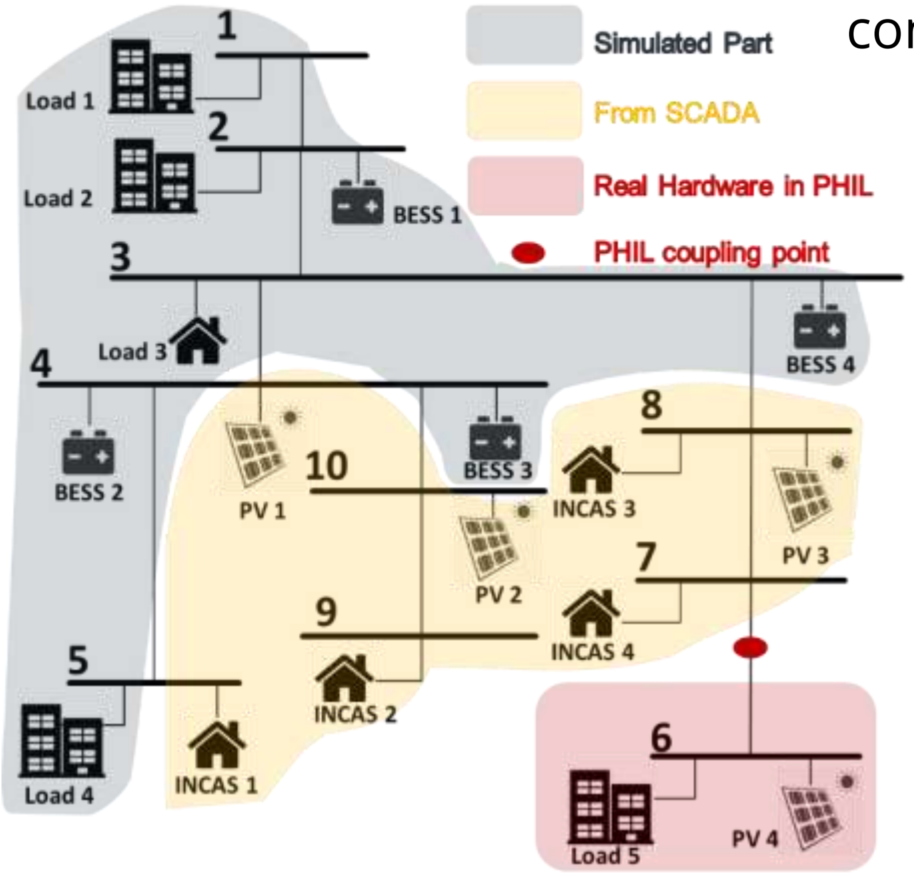

- Distributed Control Testing on a mixed virtual-physical microgrid
- Impact of communication
- DER integration via PHIL cluster

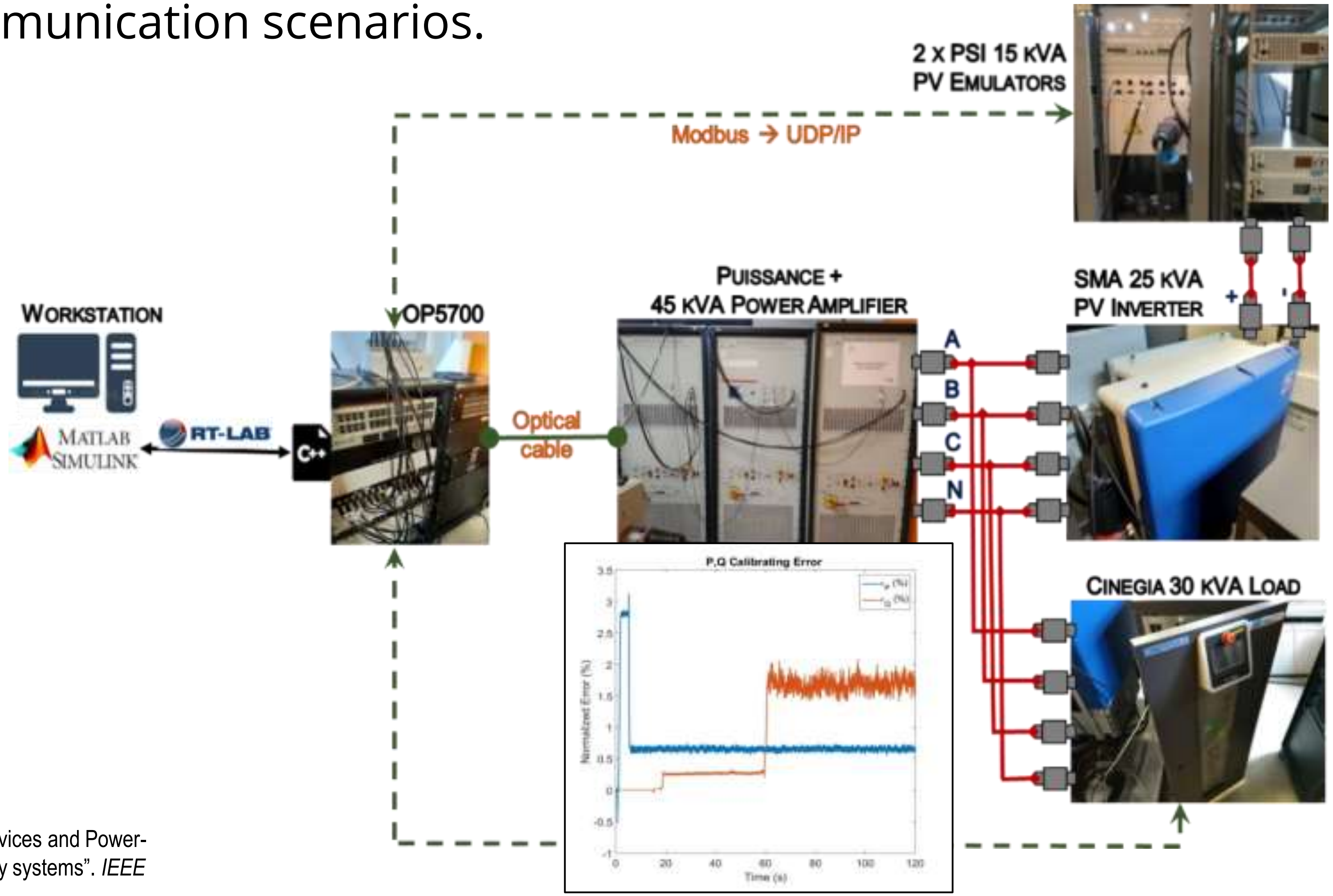



V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020*

*Tung Lam Nguyen; Yu Wang; Quoc Tuan Tran; Raphael Caire; Yan Xu; Catalin Gavriluta "A Distributed Hierarchical Control Framework in Islanded Microgrids and Its Agent-based Design for Cyber-Physical Implementations," IEEE Transactions on Industrial Electronics; September 2020*

Investigation of the DER integration at bus 6 and its response to the disturbance caused by the communication scenarios.




V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020.*

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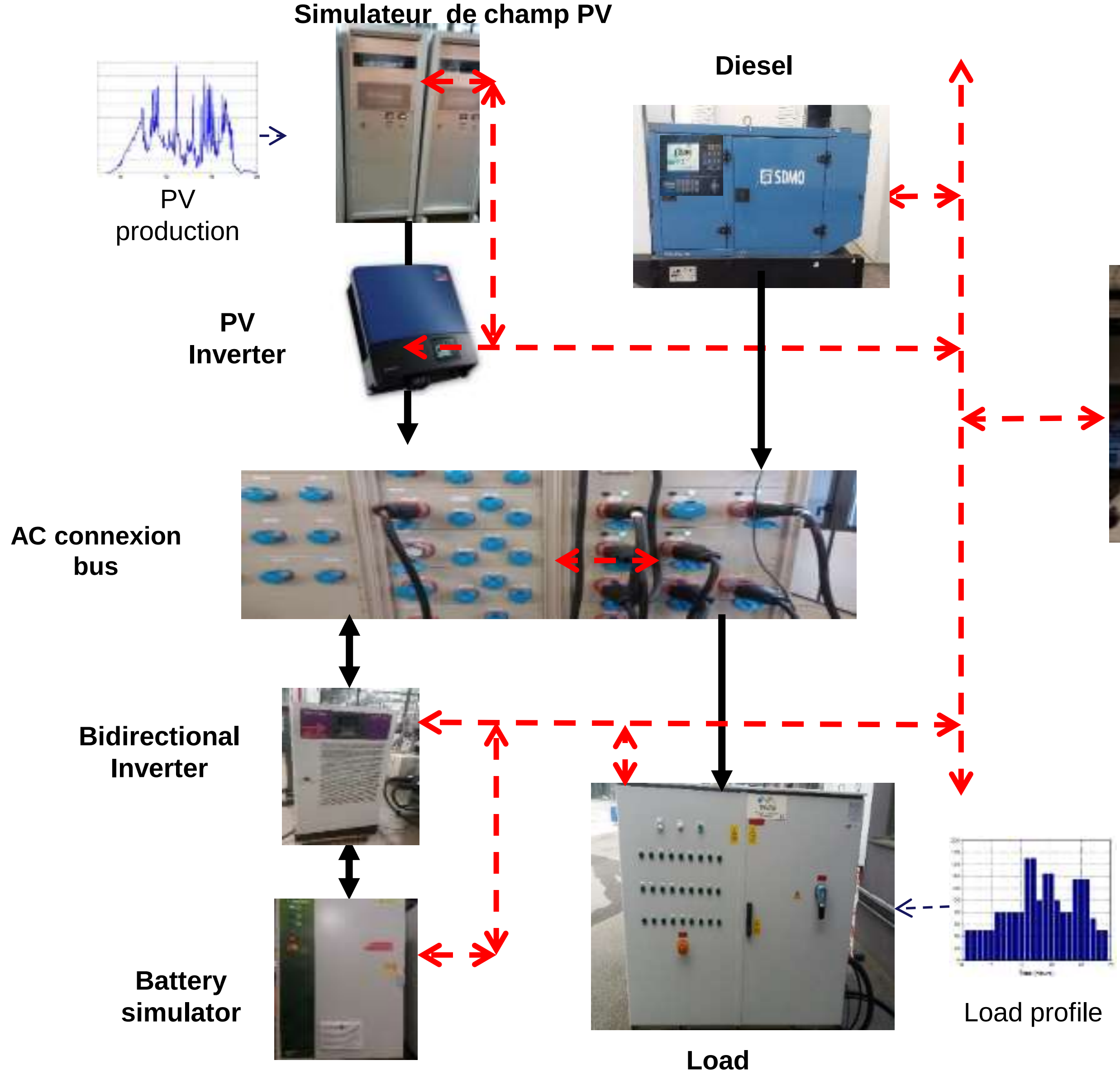
# RT Validation: EMS for an islanded microgrid




SCADA

| | Value |
|---|---|
| P_PV | 10 kWc |
| P_Diesel | 35 kW |
| Pmin_Diesel | 10 kW (30% of $P_{GD}^{max}$) |
| E_bat | 15 kWh |
| Pmax_Bat (discharge) | 6 kW |
| Pmax_Bat (charge) | -6 kW |
| Initial SOC (at the start of the day) | 50 % |
| Final SOC (at the end of the day) | 40 % |
| Test time (duration) | 2 H |

Gabin Koucoi, Daniel Yamegueu, Quoc-Tuan Tran, Yézouma Coulibaly, Hervé Buttin., "**Energy Management Strategies for Hybrid PV/Diesel Energy Systems: Simulation and Experimental Validation**", *International Journal of Energy and Power Engineering*. Vol. 5, No. 1, 2016, pp. 6-14.

Power

Communication (Modbus TCP/IP)

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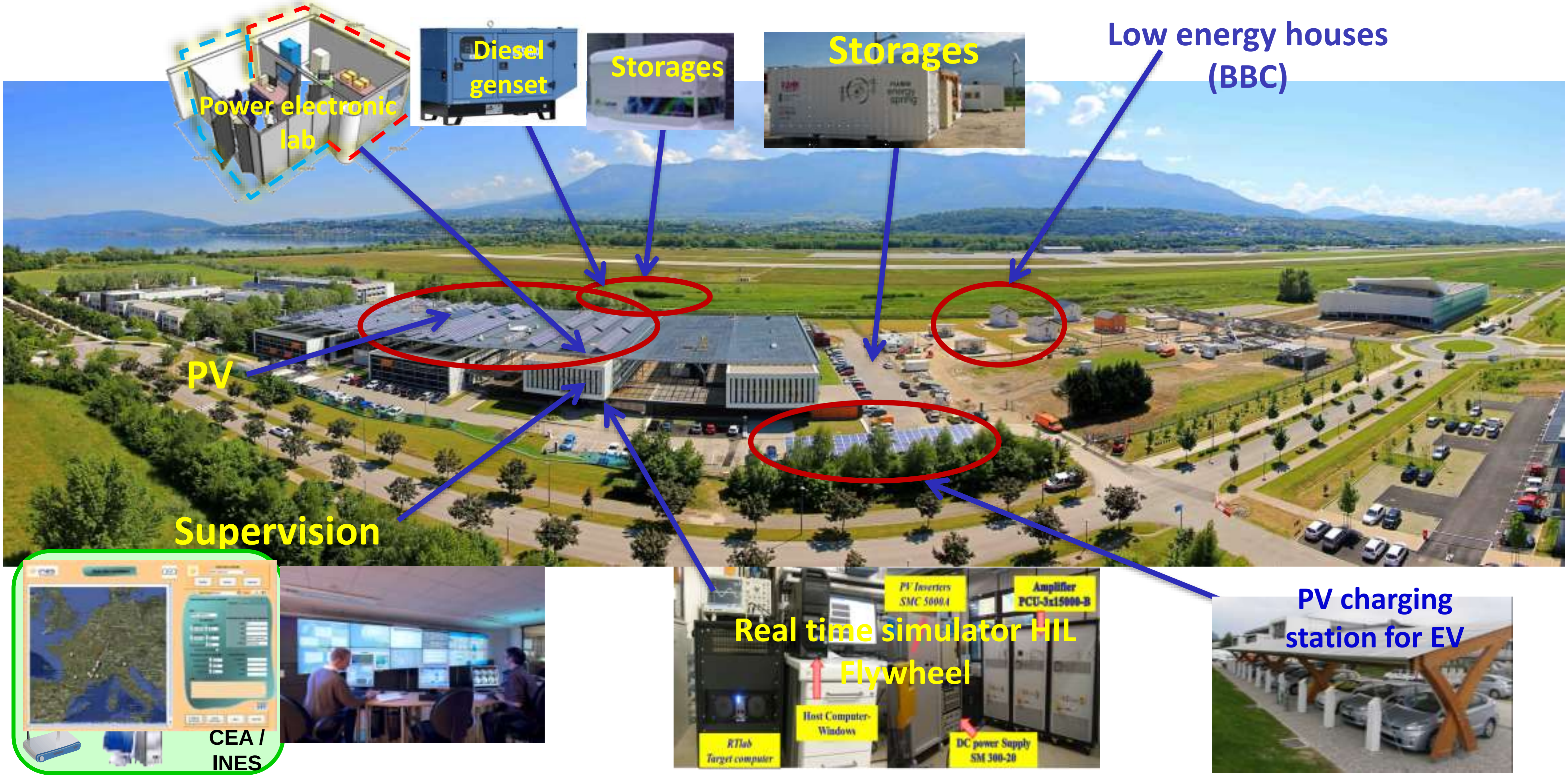
# Demonstrations: Micro Grid at CEA-INES

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# Demonstrators in CEA-INES and real applications

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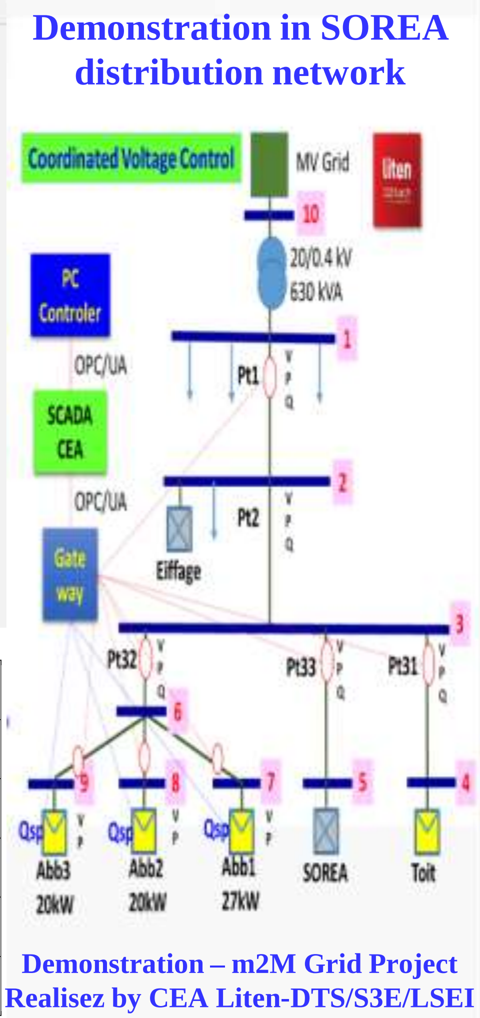
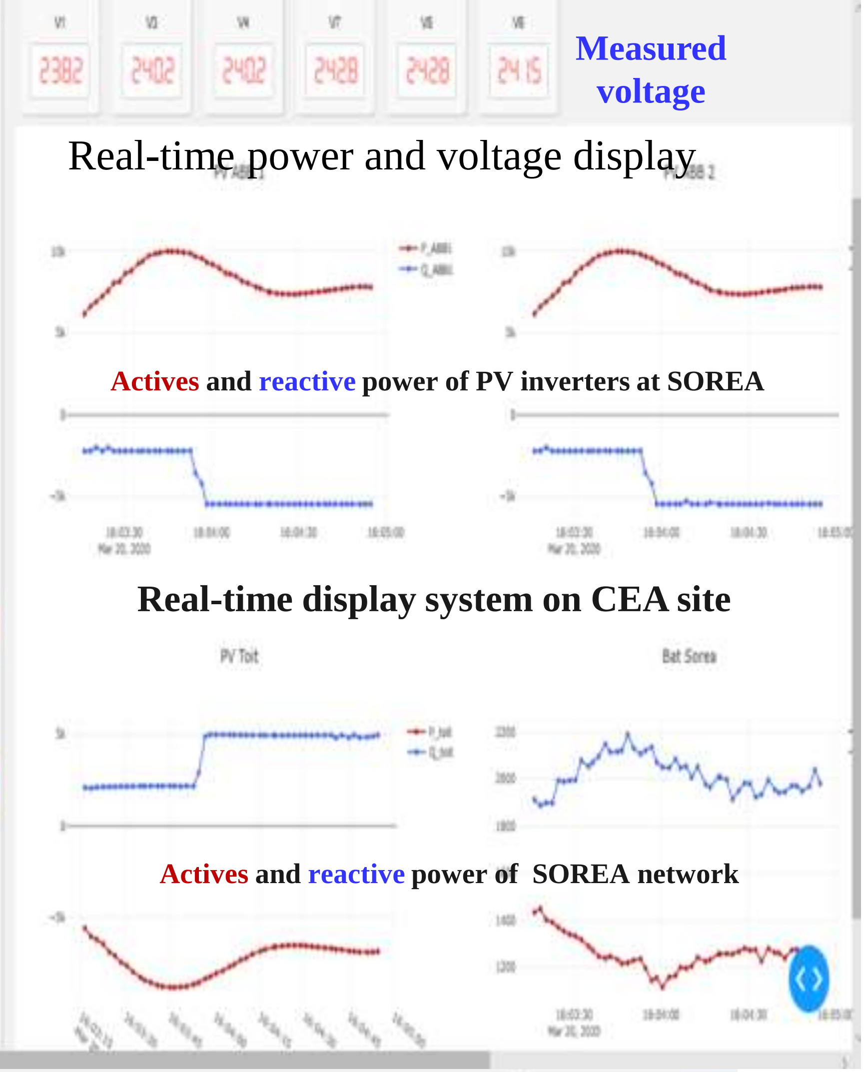
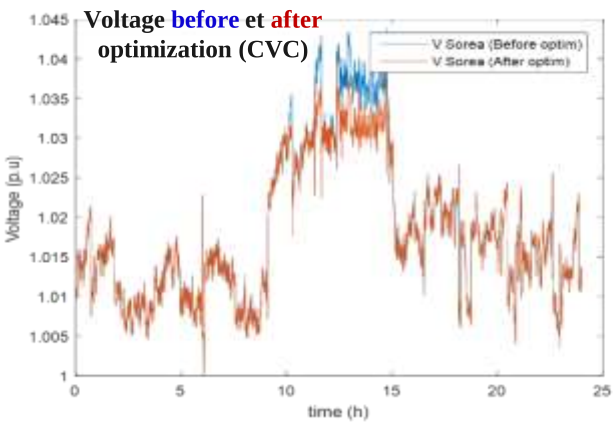
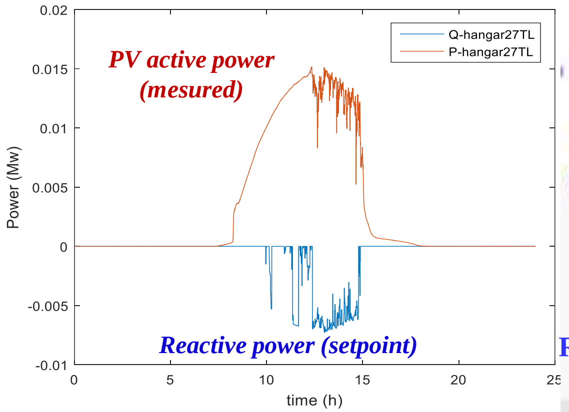
# DIGITAL TWIN - Demonstration and validation at SOREA

m2M & United grid projects


Van Hoa Nguyen, Quoc Tuan Tran, Hervé Buttin, Mouloud Guemri, "**Implementation of a coordinated voltage control algorithm for a microgrid via SCADA-as-a-service approach**", *Springer, Electrical Engineering*, March 2021

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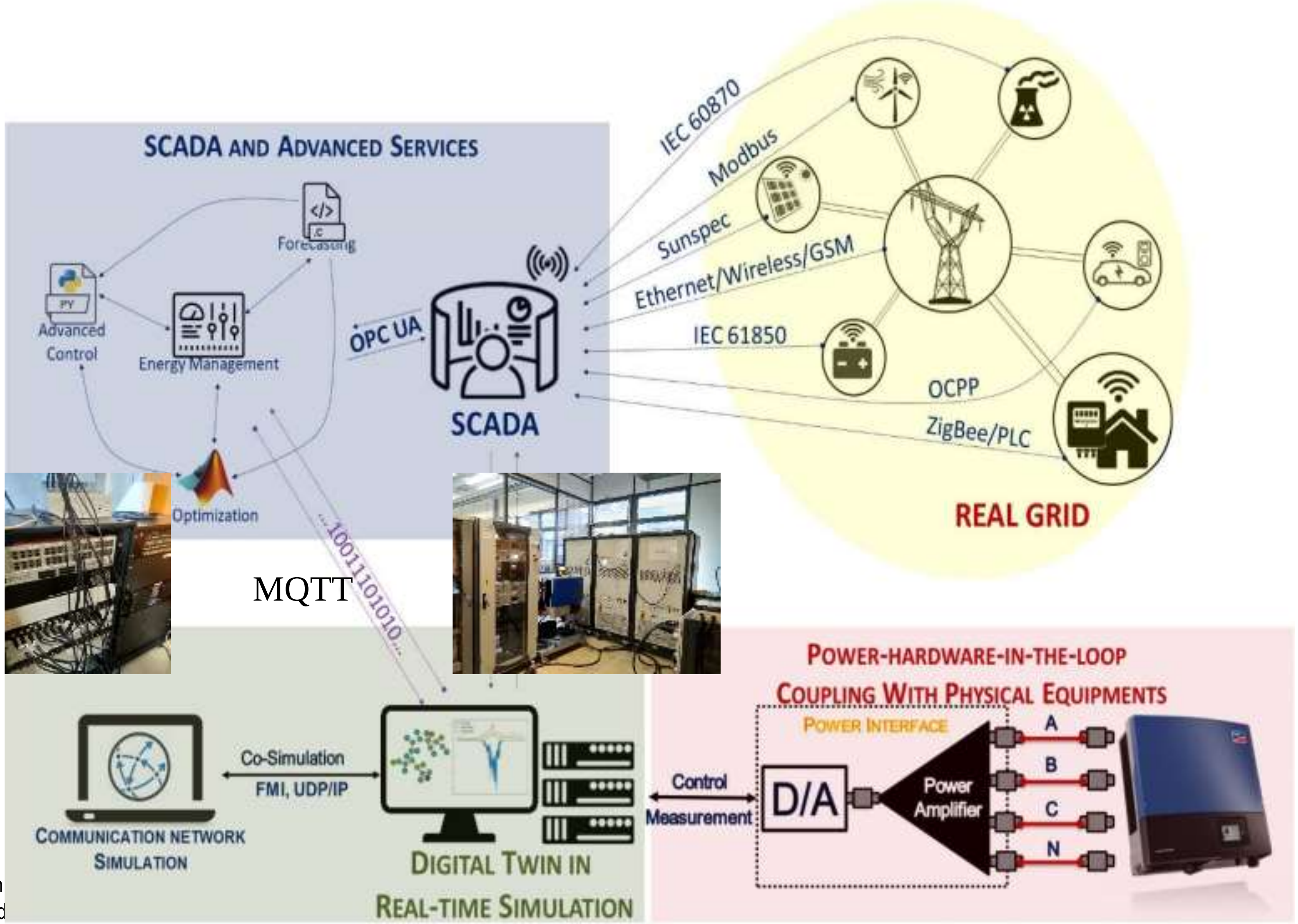
- CEA platform is capable of testing inverters, batteries, advanced control and management of renewables and storage, digital twin, protection, EV, microgrid, cyber-physical systems, SCADA, and communication integration...
- This seminar will introduce a review of these activities in RT simulations & demonstrations via several Ph.D. Thesis & Projects




Van Hoa Nguyen, Quoc Tuan Tran, Yvon Besanger, Marc Jung, Tung Lam Nguyen
"Digital twin integrated power-hardware-in-the-loop for the assessment of distributed renewable energy resources", Springer, Electrical Engineering, March 2021

# Plan



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# Digital transformation – Definition and necessary

Recently, the energy market is going through drastic changes with the launch of a new climate regime and the advent of the Fourth Industrial Revolution era. => many countries worldwide are strategically pushing for **digital transformation** (combines technology and ICT) to energy transition.

**Digital transformation (DX) or e-transformation, is the phenomenon of change linked to the rise of digital technology and the Internet.**

| Generation | Transmission and Distribution | Energy Management | Sales |
|---|---|---|---|
| · Deterioration of the thermal power generation plant<br>· Decrease in the utilization rate | · Increase of association with new renewable energy<br>· Deterioration of power grid | · Intensification of imbalance between supply and demand<br>· Expansion of distributed resources/EV<br>→ Necessity for the expansion of flexibility | · Decrease/stagnation of sales<br>· Deterioration of the decrease in customers<br>· Increase of demand for customer participation |
| → Increase of necessity for cost-cutting | | | |

* Source: Utility Digitalization: Tech, Strategies, and Progress, BNEF, April 2018

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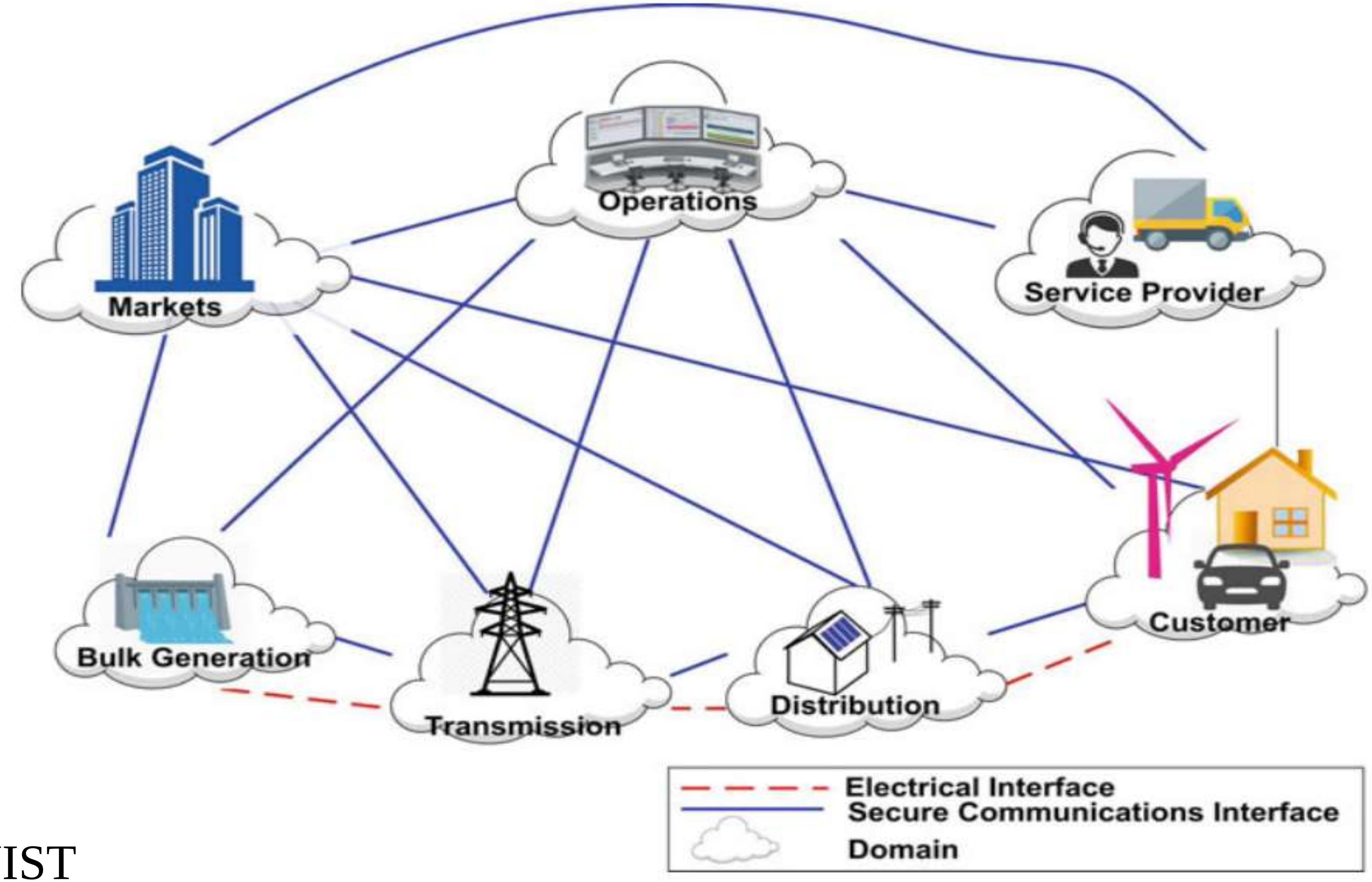
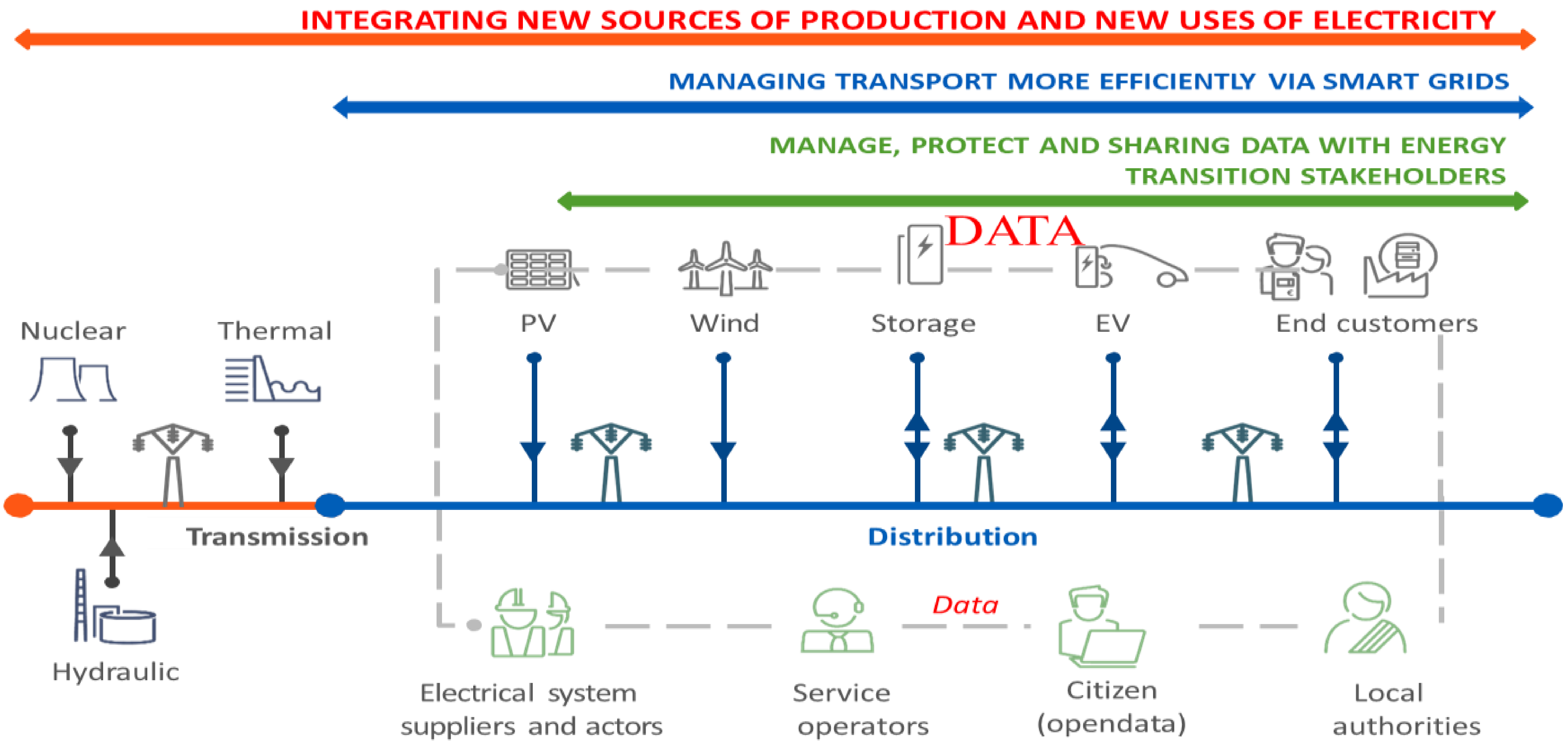
# Interaction of Actors in different Smart Grid Domains




Source: NIST

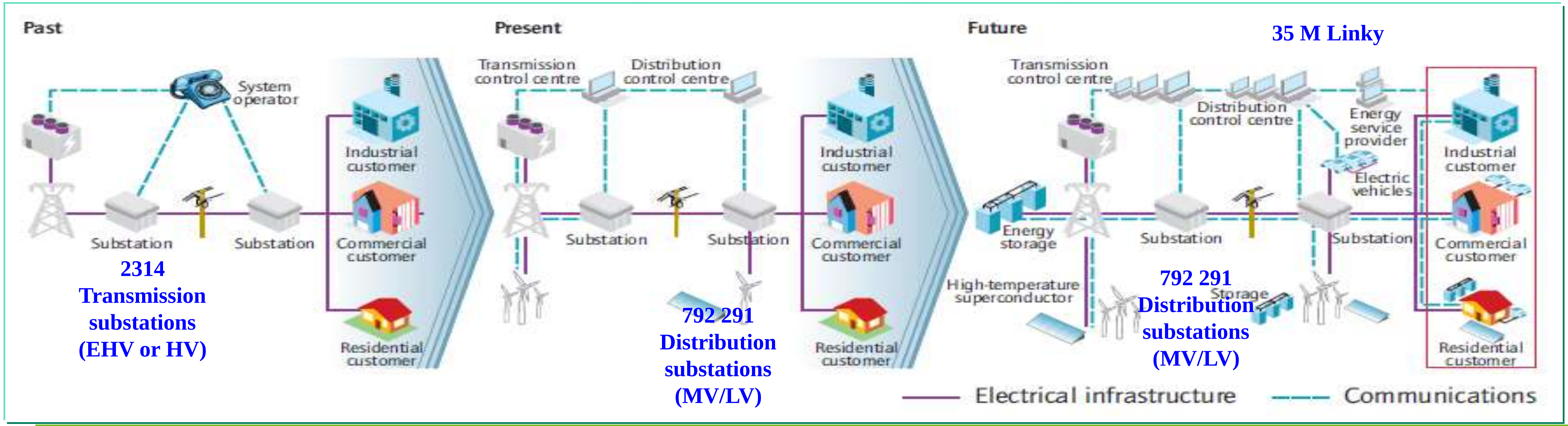
# DIGITAL INTEGRATION IN THE ENERGY TRANSITION: A SYSTEMIC APPROACH




Source: EDF

| | |
|---|---|
| **Organizational culture** | It lacks agility and innovation because of the utility's traditional organization culture to minimize risks and changes with a focus on the stable power supply. |
| **Digital talent** | It is difficult to attract digital specialists, such as data scientists, because of its corporate image associated with analog generation. |
| **IT system** | Operate IT systems, such as SCADA, DAS, etc., on a large scale and on a mutually separate basis. |

* Source: Accelerating digital transformations: A playbook for utilities, McKinsey, 2018

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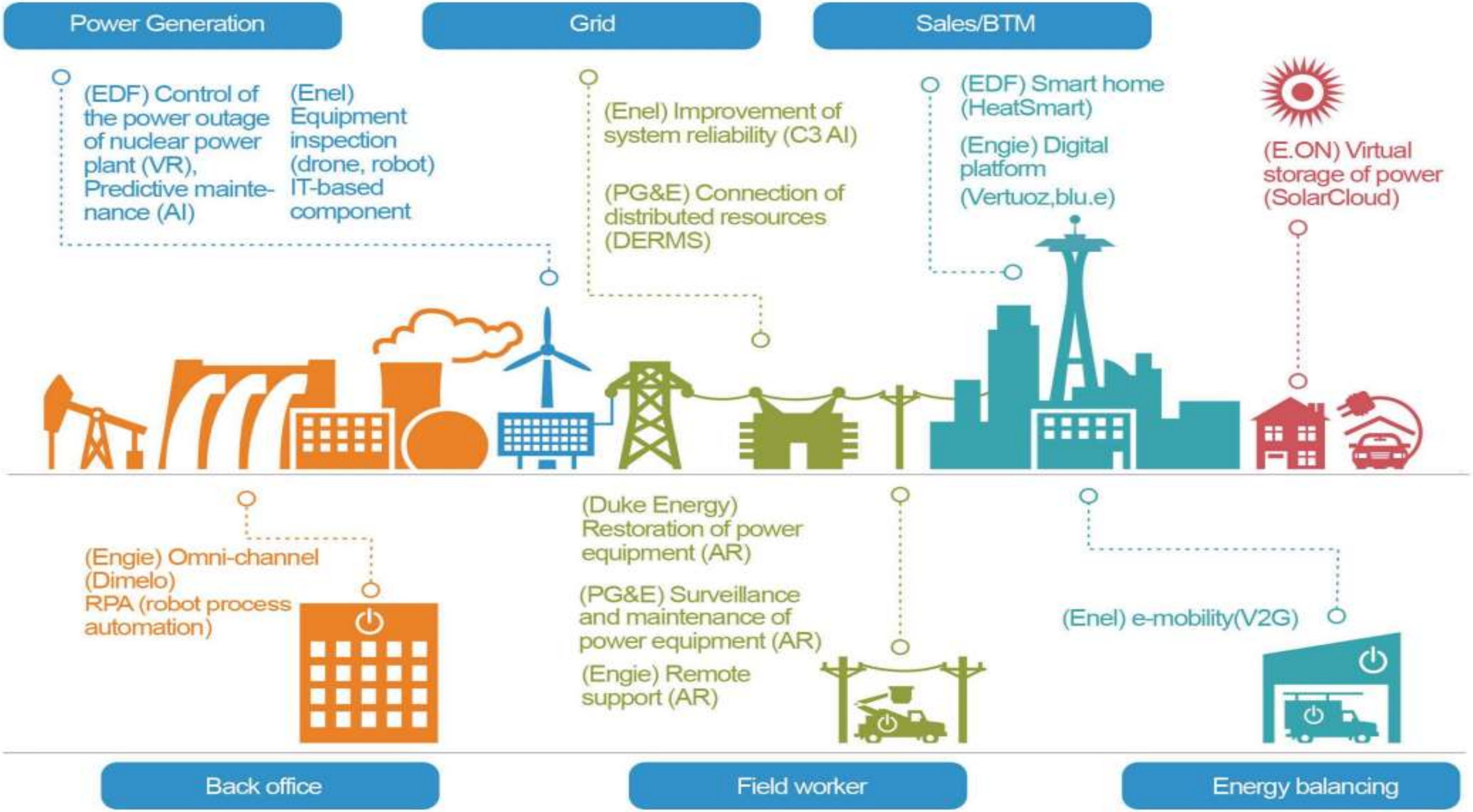
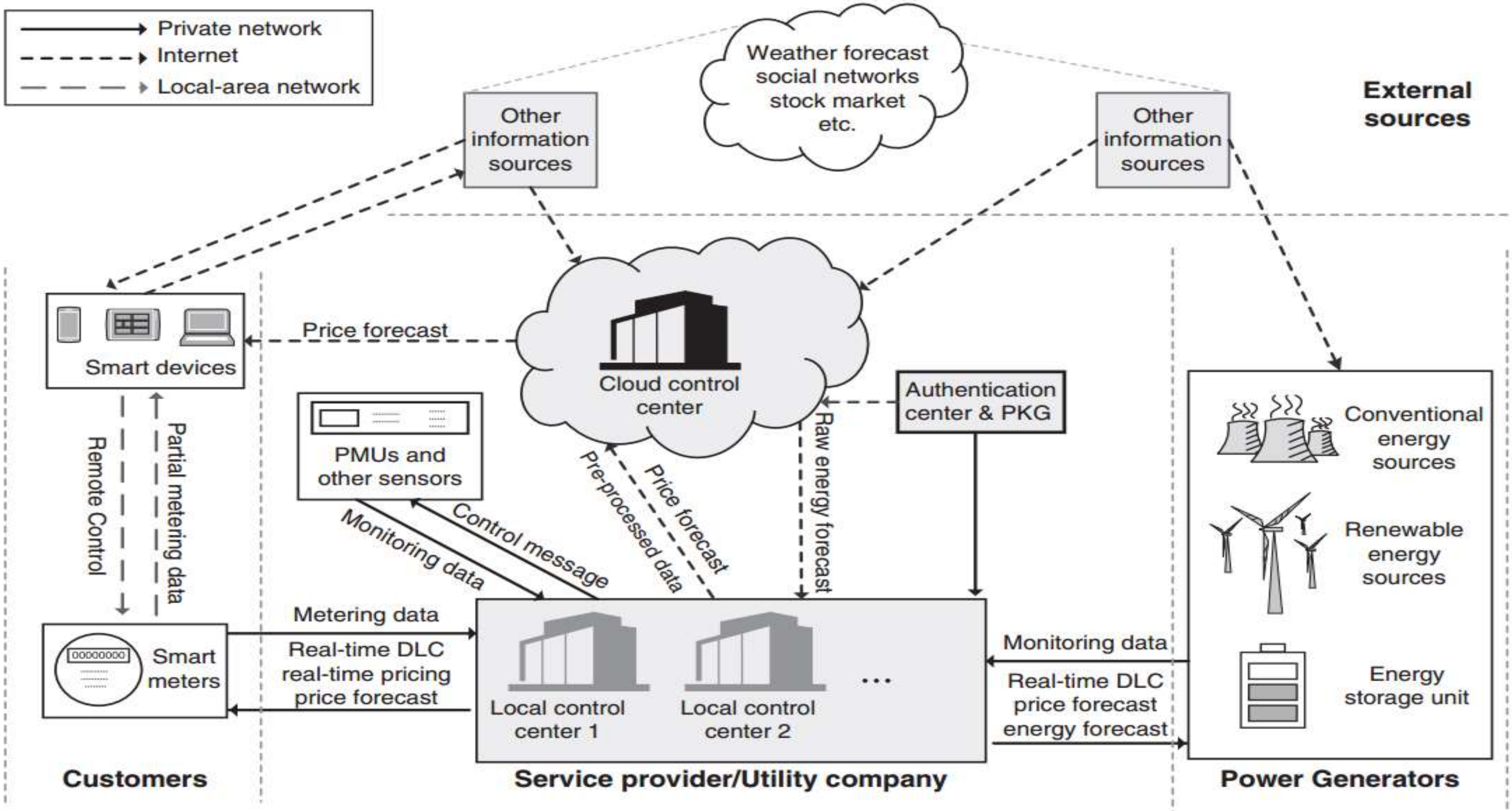
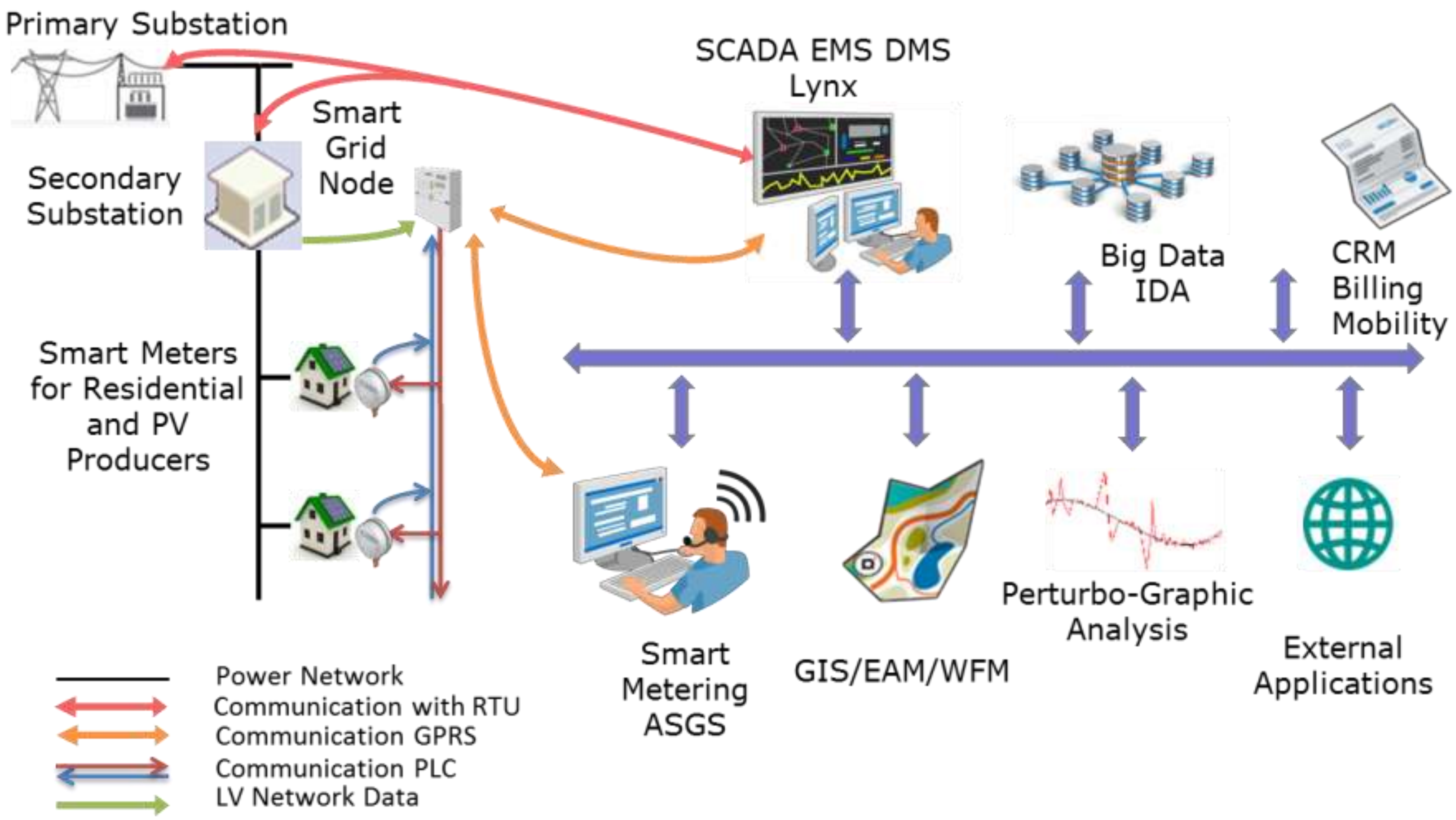

Power Generation
Grid
Sales/BTM
(EDF) Control of the power outage of nuclear power plant (VR), Predictive mainte-nance (AI)
(Enel) Equipment inspection (drone, robot) IT-based component
(Enel) Improvement of system reliability (C3 AI)
(PG&E) Connection of distributed resources (DERMS)
(EDF) Smart home (HeatSmart)
(Engie) Digital platform (Vertuoz,blu.e)
(E.ON) Virtual storage of power (SolarCloud)
(Engie) Omni-channel (Dimelo) RPA (robot process automation)
(Duke Energy) Restoration of power equipment (AR)
(PG&E) Surveillance and maintenance of power equipment (AR)
(Engie) Remote support (AR)
(Enel) e-mobility(V2G)
Back office
Field worker
Energy balancing

# Overview of ICT framework



# IT/OT integration for a DSO

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# Devices' Requirements

– *Low Power*: To reduce the cost of deployment or meet the portability requirements, many IoT devices are battery-operated with limited energy budget. Hence, low-power consumption is a major requirement.
– *Small Size*: Being integrated into other systems or being portable, IoT devices require a small form-factor.
– *Low Cost*
– *Durability*: To reduce the cost of maintenance, the IoT devices must be durable

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# Network Requirements

– *Latency*: Many IoT applications must have a determined and short response time, hence they are latency-sensitive with real-time demands. Therefore, short and deterministic latency is one of the network requirements in IoT.
– *Interoperability:* is the ability of two or more networks, systems, devices, applications, or components to communicate and operate together effectively and securely, without significant user intervention.
– *Bandwidth*: Especially inadvanced monitoring applications, IoTdevices require to transmit a large amount of data. With the increase in the number of IoT devices, the bandwidth of network may become a bottleneck in the IoT systems.
– *Resilience (Security)*: With the massive number of IoT devices, the wireless interference will be a challenge for the interconnection network. In addition, the concerns for security attacks such as Denial of Service (Dos) or Distributed DoS (DDoS) call for a network infrastructure that can be resilient against these threats.
– *Scalability*: The ever-increasing number of connected IoT devices necessitates the scalable network infrastructure.

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# Application Requirements

– *Security*: Many security concerns must be considered for IoT applications including malicious codes, key management, data integrity, access control, etc.

– *Privacy*: IoT applications will be deeply integrated with our daily lives, and hence, access to our sensitive information.

– *Dependability*: IoT applications will carry out many of our daily operations and required services. The applications must be dependable, available and reliable.

– *Response Time*: Some applications in the smartgrid (e.g.,self-recovery in renewable distributed energy resources), smart transportation, health-care, etc. require fast response time and have real-time constraints.

– *Service Quality*: It refers to the quality of application's output from user's perspective. The service quality is affected by the input quality (i.e., the resolution and sampling rate of captured data) as well as the data processing algorithm.

– *Fast deployment*.

– *Low Maintenance*: The applications must provide their service constantly over a long period with high availability. Maintenance of remote device's application (e.g., over-the-air firmware) may even open security surfaces.

– *Scalability*: IoT applications must scale up when the number of users, connected devices and service requests increase.

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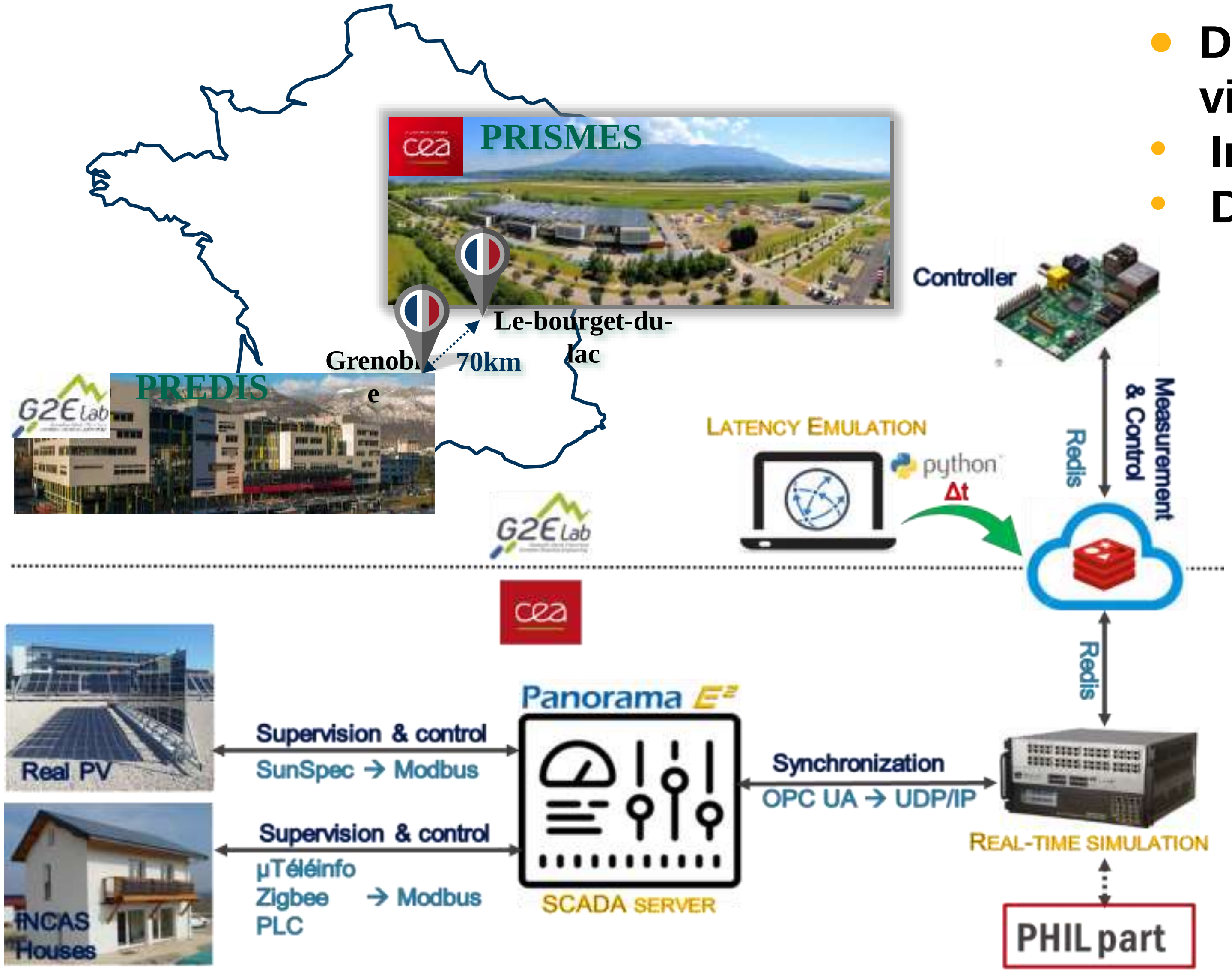
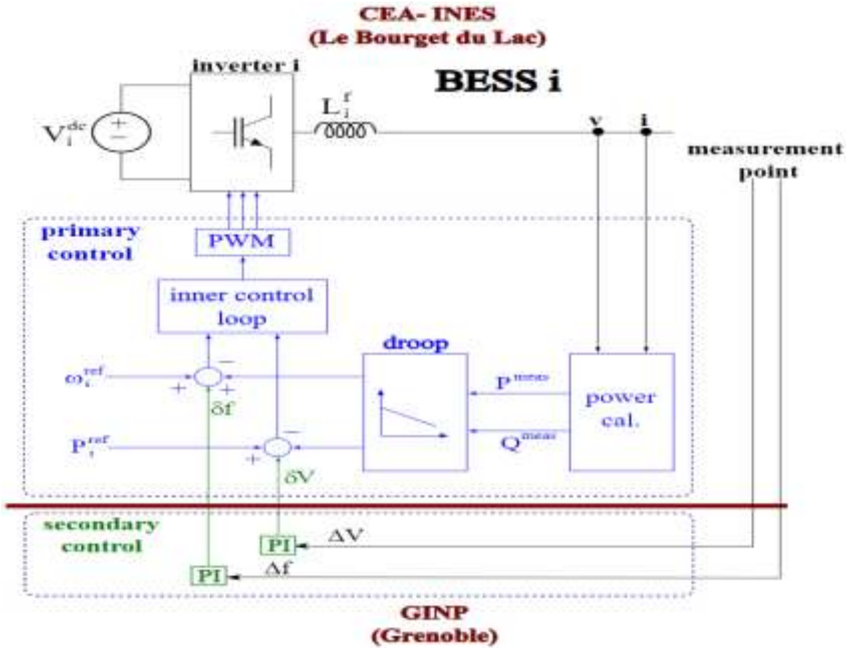
# Impacts of communication to distributed control in isolated microgrid

- Distributed Control Testing on a mixed virtual-physical microgrid
- Impact of communication
- DER integration via PHIL cluster



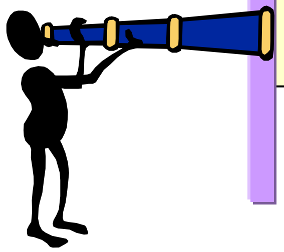




V.H. Nguyen, T.L. Nguyen, Q.T. Tran, Y. Besanger and R. Caire, "Integration of SCADA services and Power-hardware-in-the-loop technique in cross-infrastructure holistic tests of cyber-physical energy systems". *IEEE Transaction on Industry Applications, 2020*

*Tung Lam Nguyen; Yu Wang; Quoc Tuan Tran; Raphael Caire; Yan Xu; Catalin Gavriluta "A Distributed Hierarchical Control Framework in Islanded Microgrids and Its Agent-based Design for Cyber-Physical Implementations," IEEE Transactions on Industrial Electronics; September 2020*

# Plan





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# AI for smart grid

Some of the adapted AI techniques in the smart grid:
- Managing the grid users and controllers
- System based operation strategies for the grid
- Power supply optimization
- Consensus-based intelligent distribution techniques
- Machine learning and deep learning enabled costing mechanisms
- Intelligent energy storage systems
- Intelligent voltage profile regulation techniques using smart algorithms

The AI techniques in the smart grid can be classified into the following areas:
- Expert System: A human expert in loop technique used for certain problems
- Supervised learning: An AI paradigm in which the mapping of inputs and outputs has been studied to predict the outputs of new inputs.
- Unsupervised learning: An ML class in which the unlabeled data are used to capture the similarity and difference in the data.
- Reinforcement learning (RL): Differs from supervised and unsupervised learning, due to its intelligent agents strategy, which aims to maximize the notion of cumulative reward.
- Ensemble methods: Combine the results from several AI algorithms to overcome the limitations of one algorithm with better overall performance

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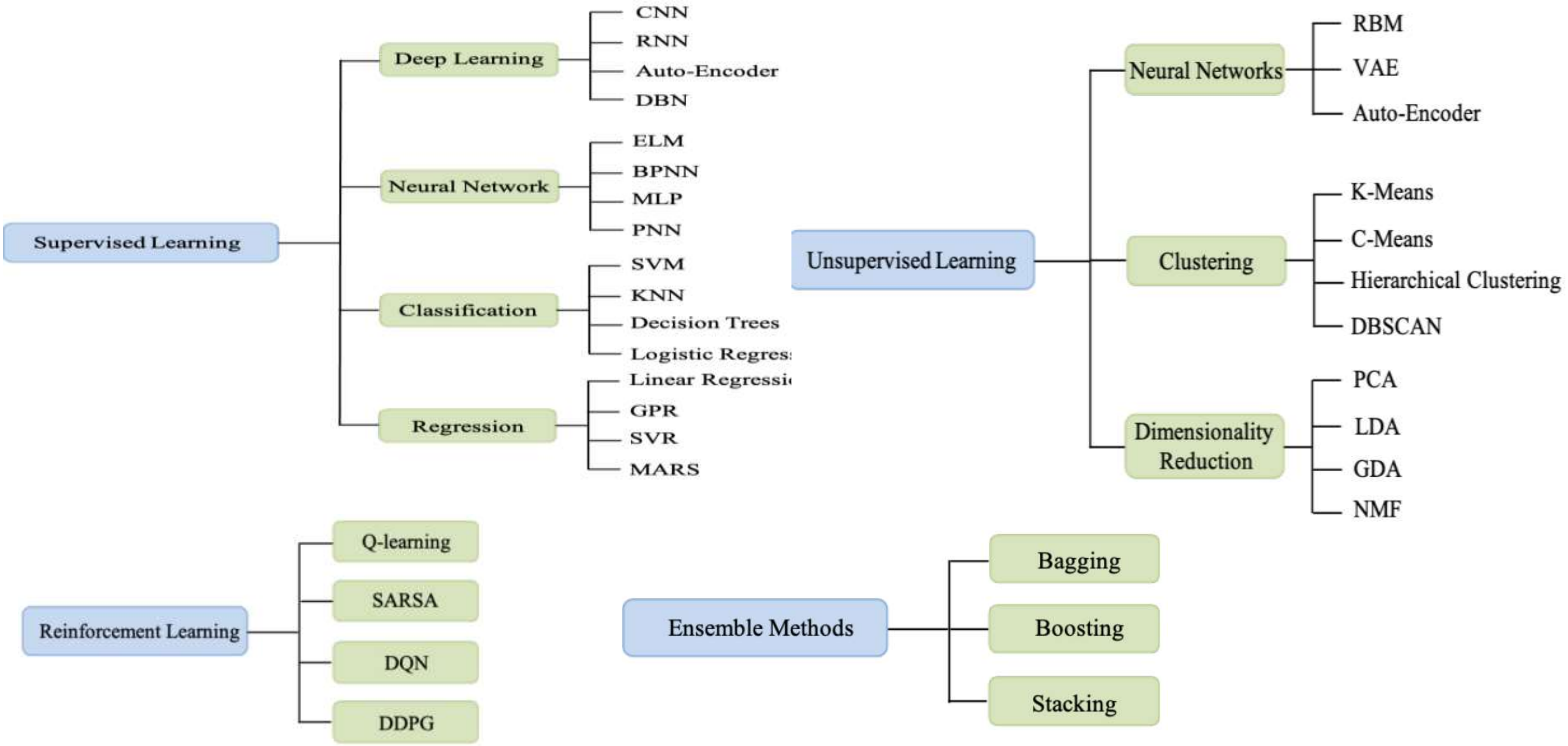
Supervised Learning
Deep Learning
CNN
RNN
Auto-Encoder
DBN
Neural Network
ELM
BPNN
MLP
PNN
Classification
SVM
KNN
Decision Trees
Logistic Regres
Regression
Linear Regressi
GPR
SVR
MARS
Unsupervised Learning
Neural Networks
RBM
VAE
Auto-Encoder
Clustering
K-Means
C-Means
Hierarchical Clustering
DBSCAN
Dimensionality Reduction
PCA
LDA
GDA
NMF
Reinforcement Learning
Q-learning
SARSA
DQN
DDPG
Ensemble Methods
Bagging
Boosting
Stacking

*1)* Forecasting

  *Load Forecasting*

  *PV Forecasting*

  Wind *Forecasting*

2) Power Grid Stability Assessment

  *Transient Stability Assessment*

  *Frequency Stability Assessment*

  *Small-Signal Stability Assessment*

  *Voltage Stability Assessment*

3) *Faults Detection*

4) *Smart Grid Security*

*5) Diagnostic*

*6) Control (ex: VoltVar Control)*

*7) Management*

…

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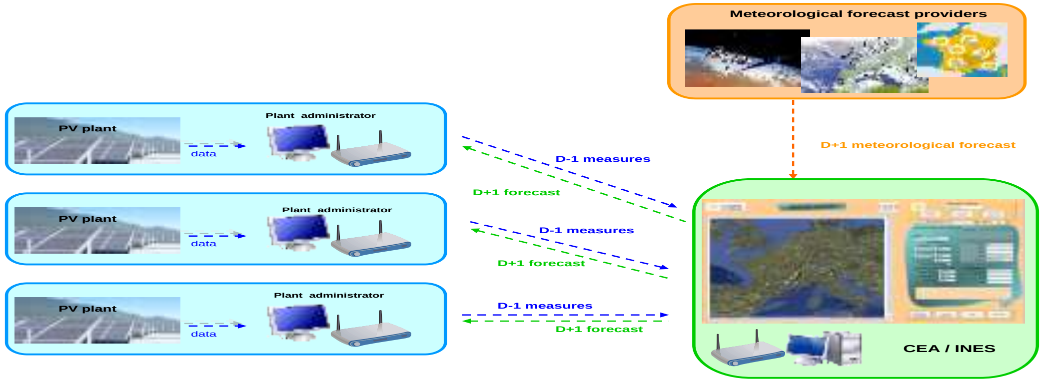
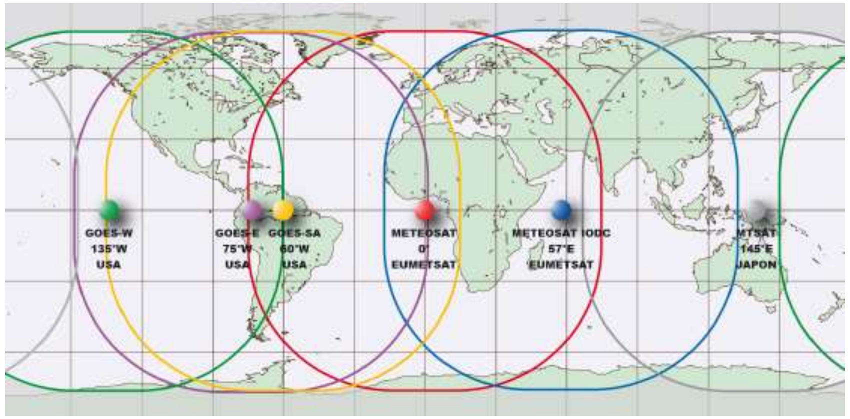
# PV forecasting (Developped by CEA INES)

1 Day-ahead forecasting based on meteorological data




2 Short-term forecasting based on satellite images (hourly)




3 Very short-term forecasting based on sky camera (a few minutes)



With funding from the European Community's Horizon 2020 Framework Programme under grant agreement 773717

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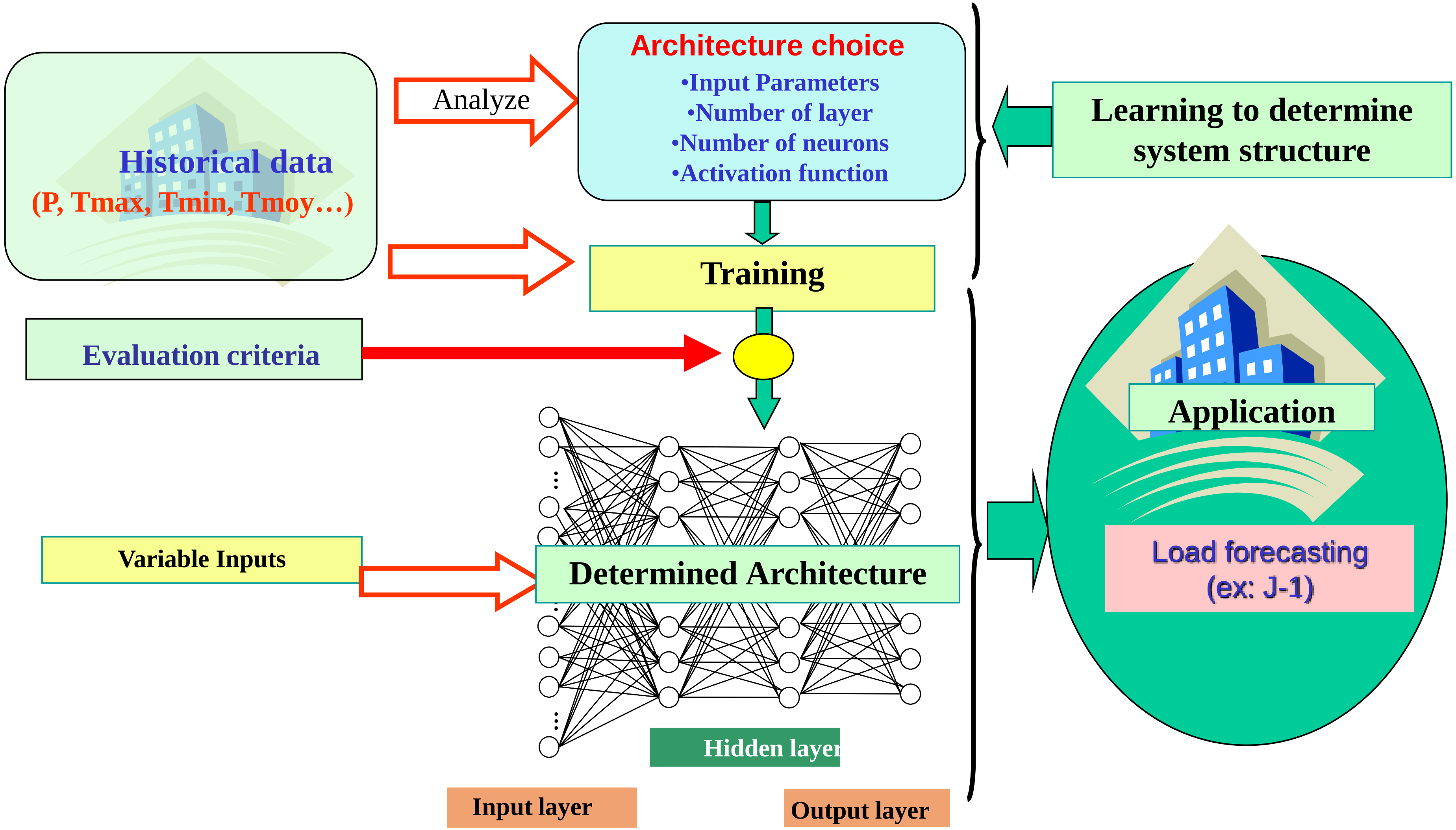
# Load forecasting: Neural networks

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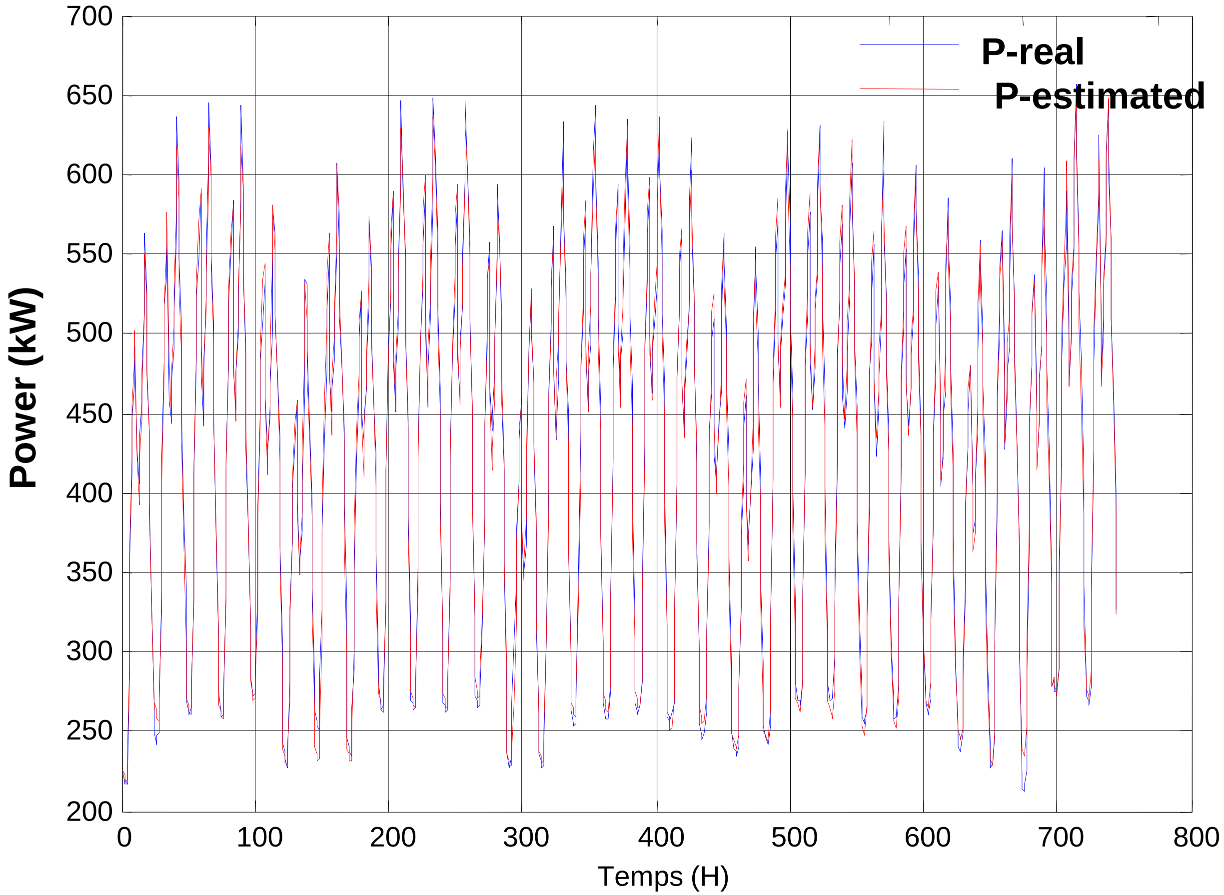
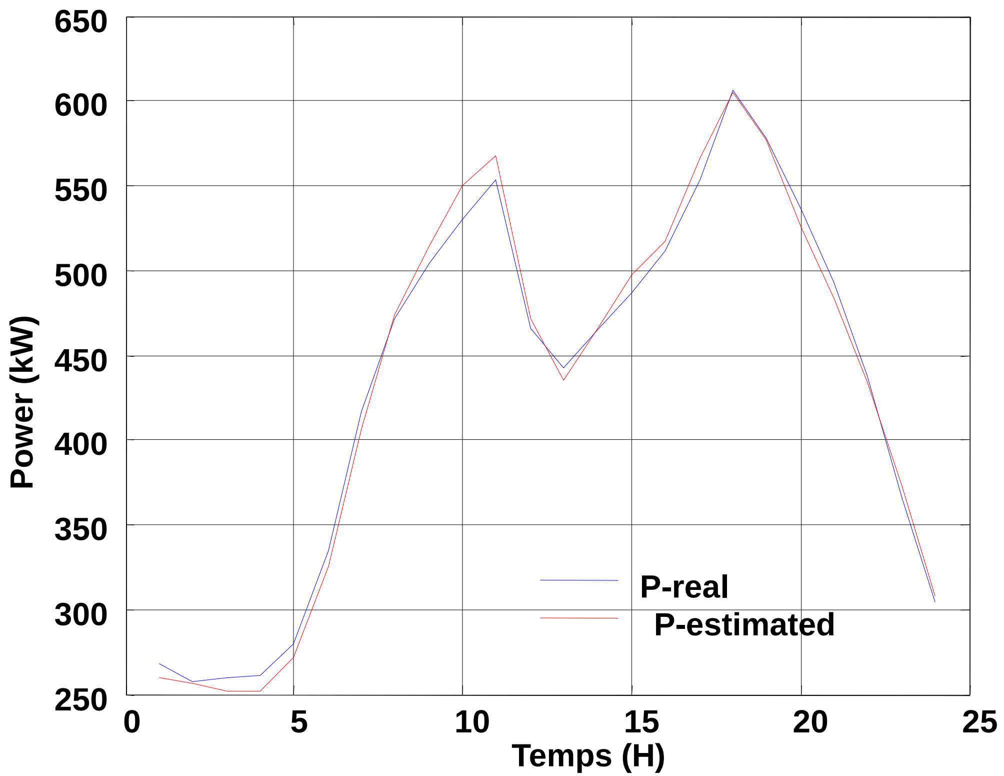
# Load forecasting: Neural network

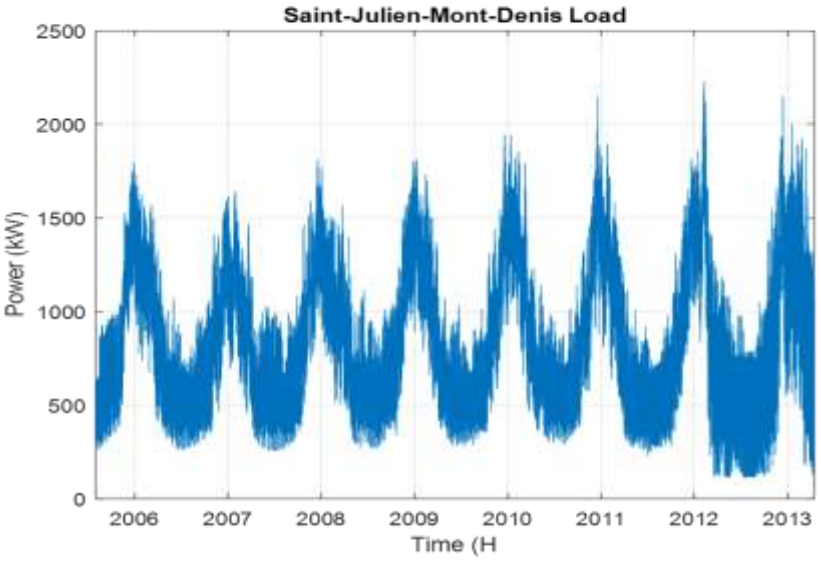


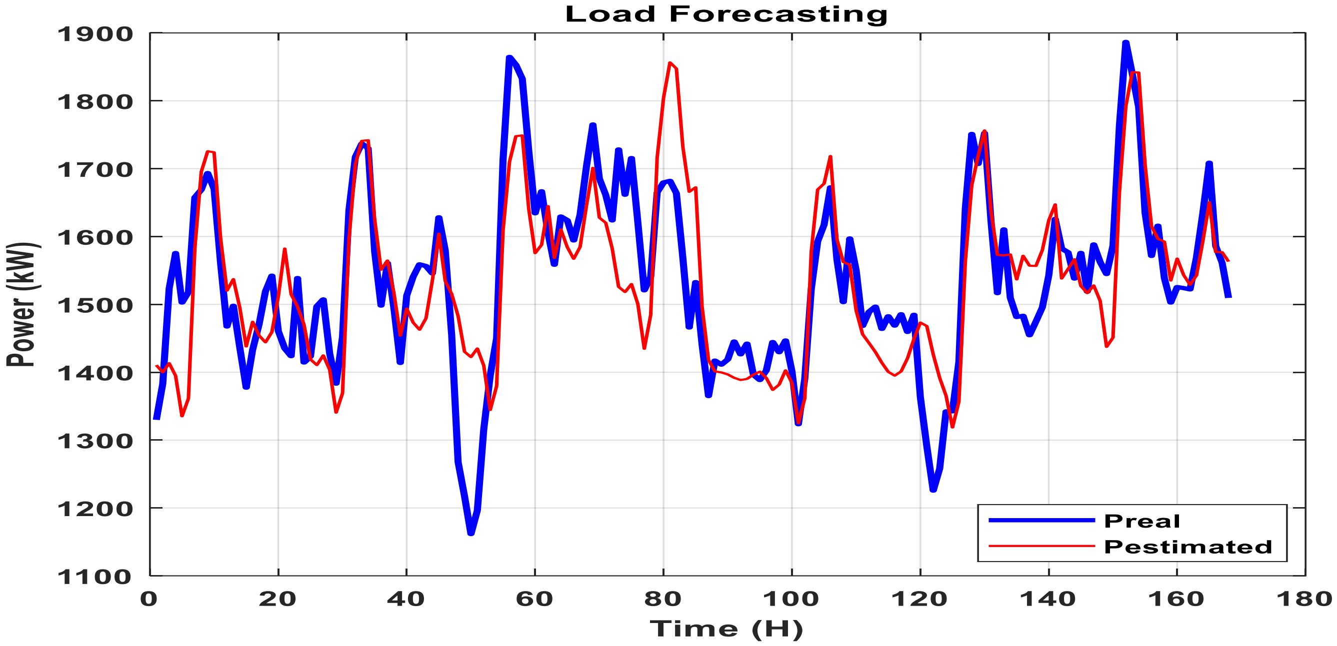



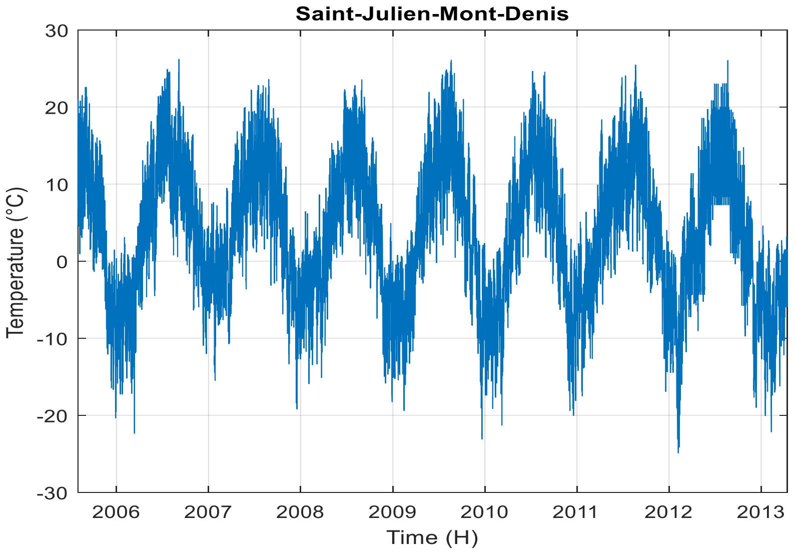

**Maximal absolute error = 13%**

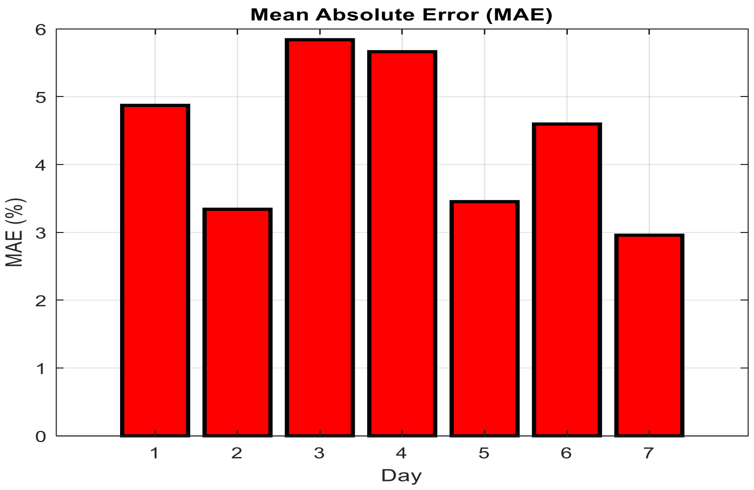
**RMSE < 6%.**

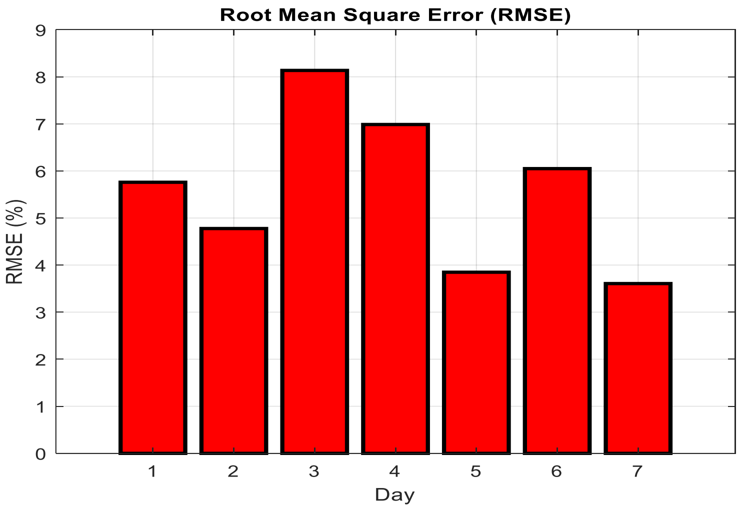
# Load forecasting: SOREA



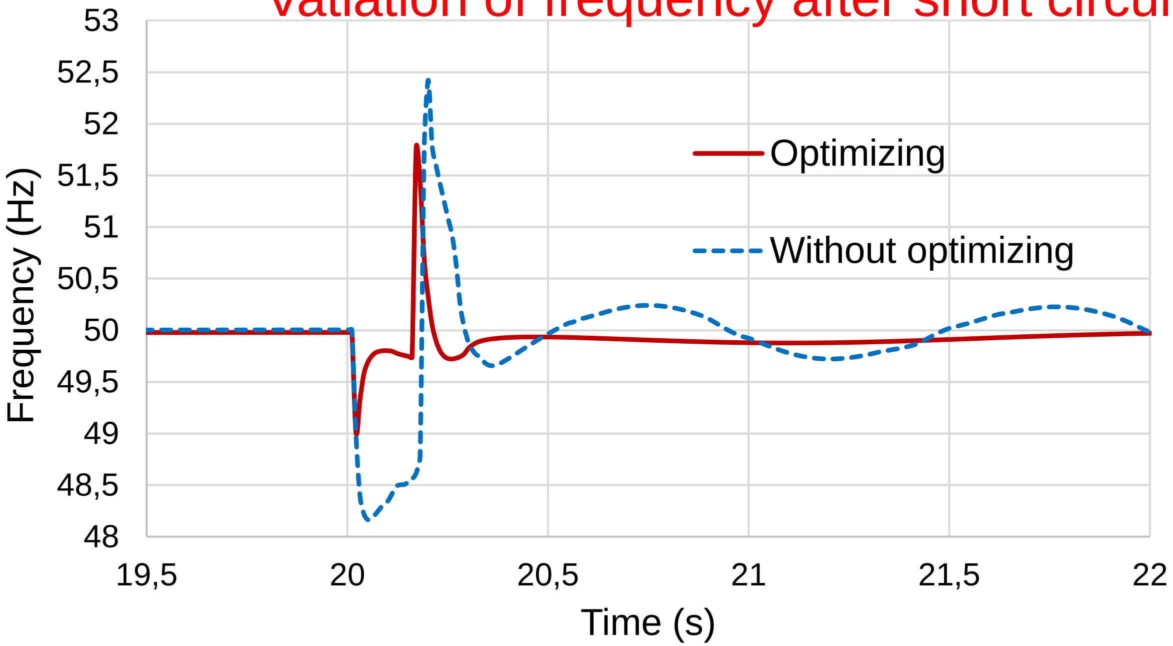



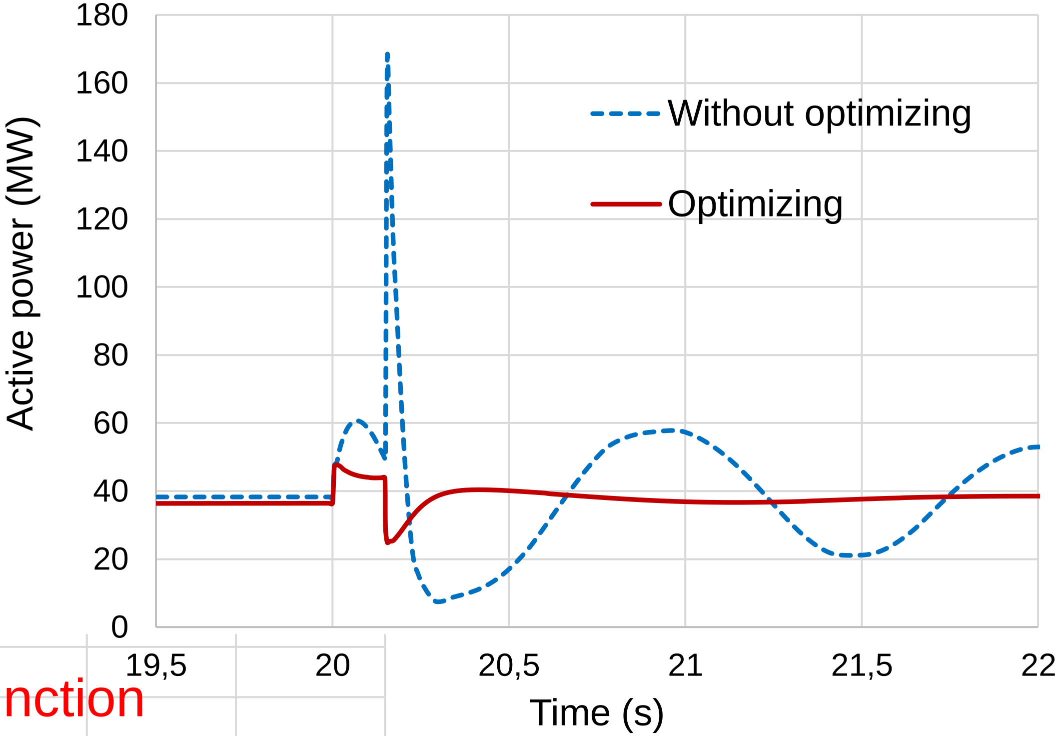



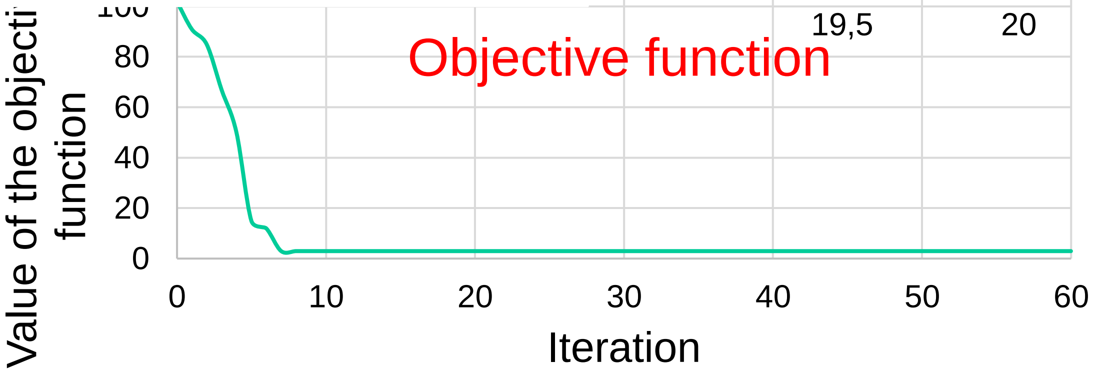
# Optimization for stability – Res 85%

Vatiation of frequency after short circuit




Power output of SG 31 after short circuit

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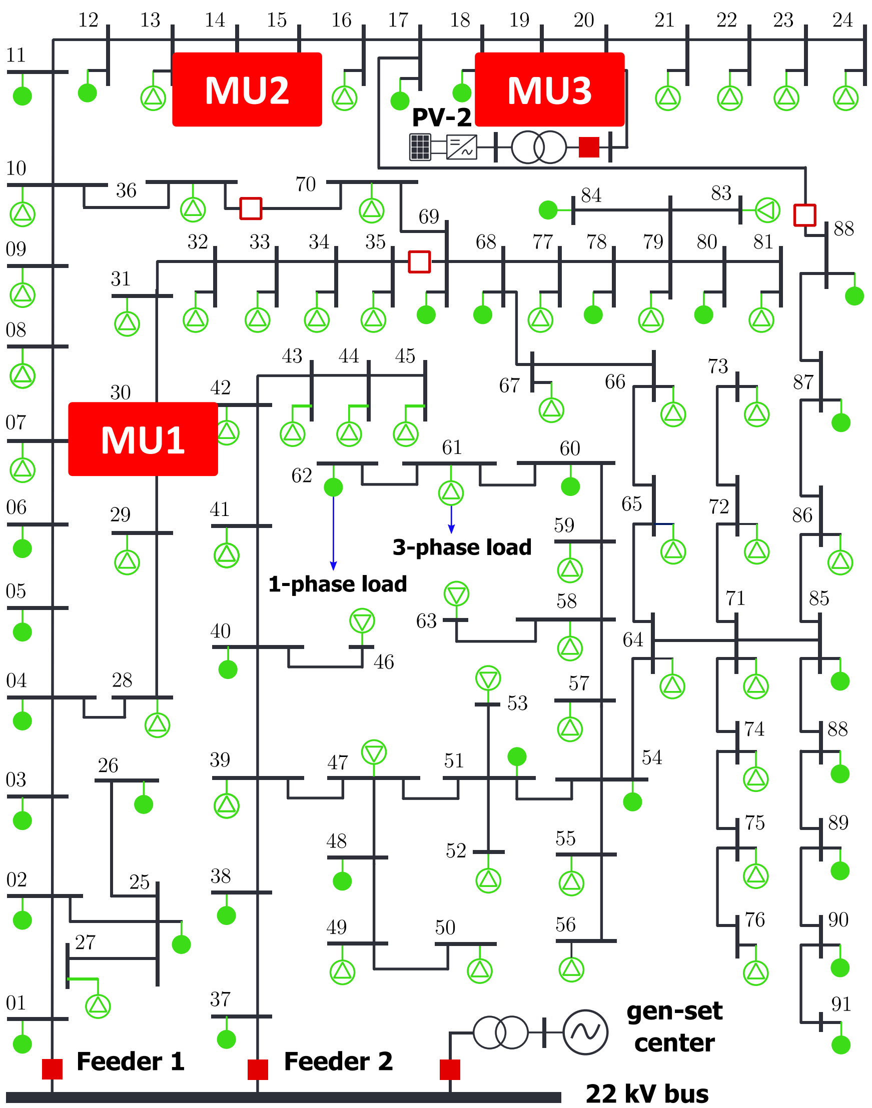
# Artificial Neural Network-based FLIS >> studied network

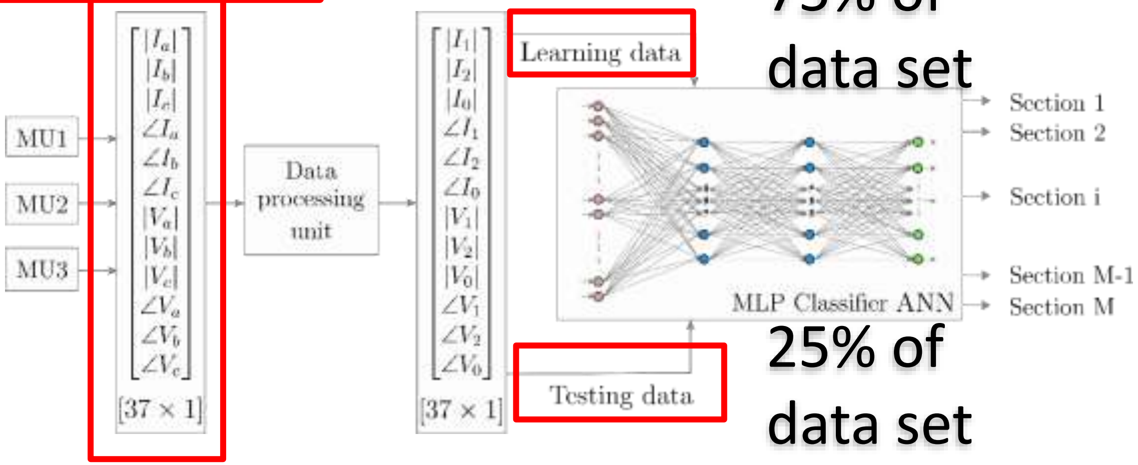



## ▶ Influencing factors:

- Fault type: three-phase, two-phase, two-phase-to-ground, single-phase-to-ground;
- Fault resistance: from 0 to 60 Ω by a step of 10 Ω;
- Fault location: 19 different sections;
- Simulation hours: from 0 to 20 hour by a step of 4 hours to consider solar variation.

**3192 data sets**

75% of data set




25% of data set

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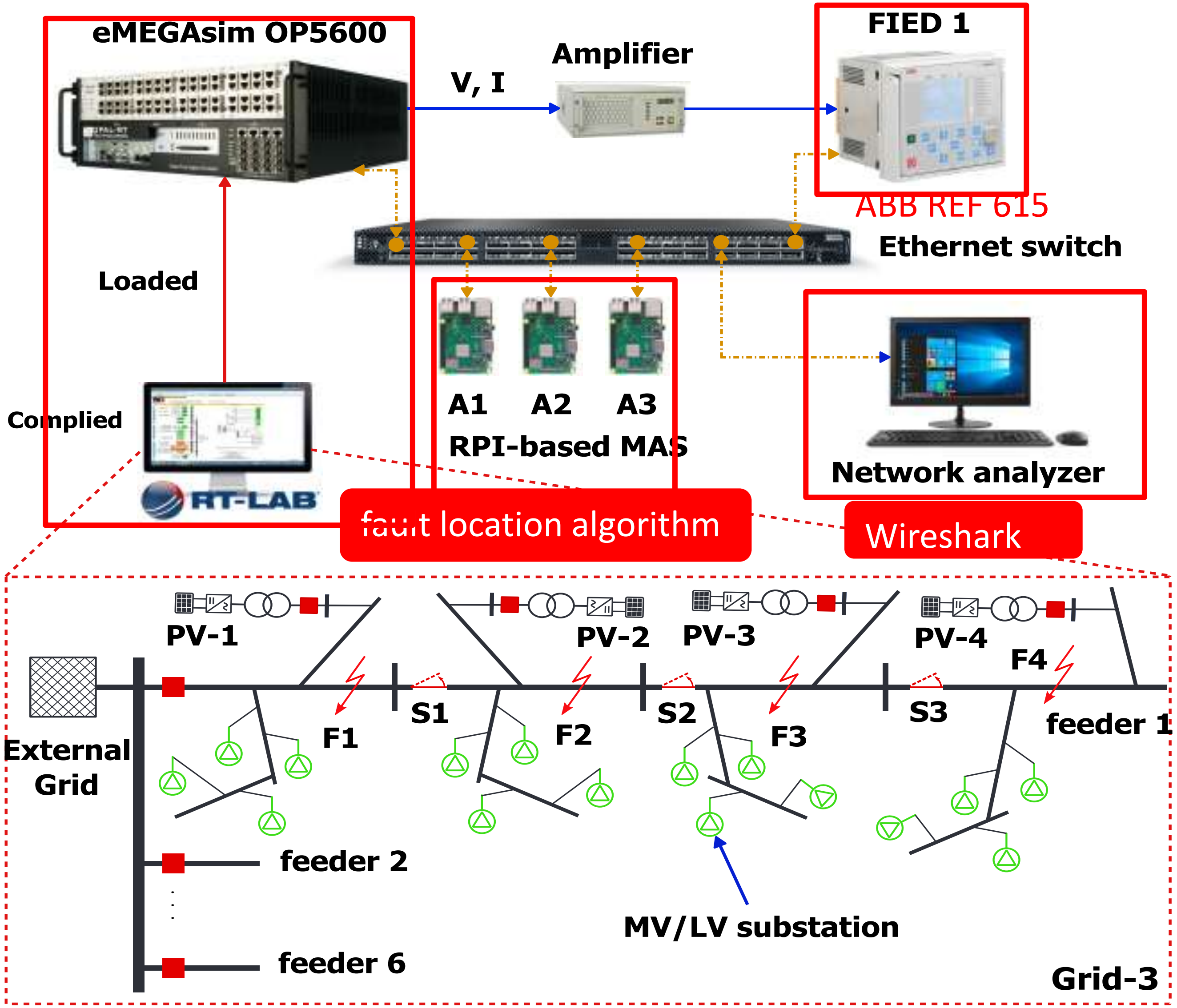
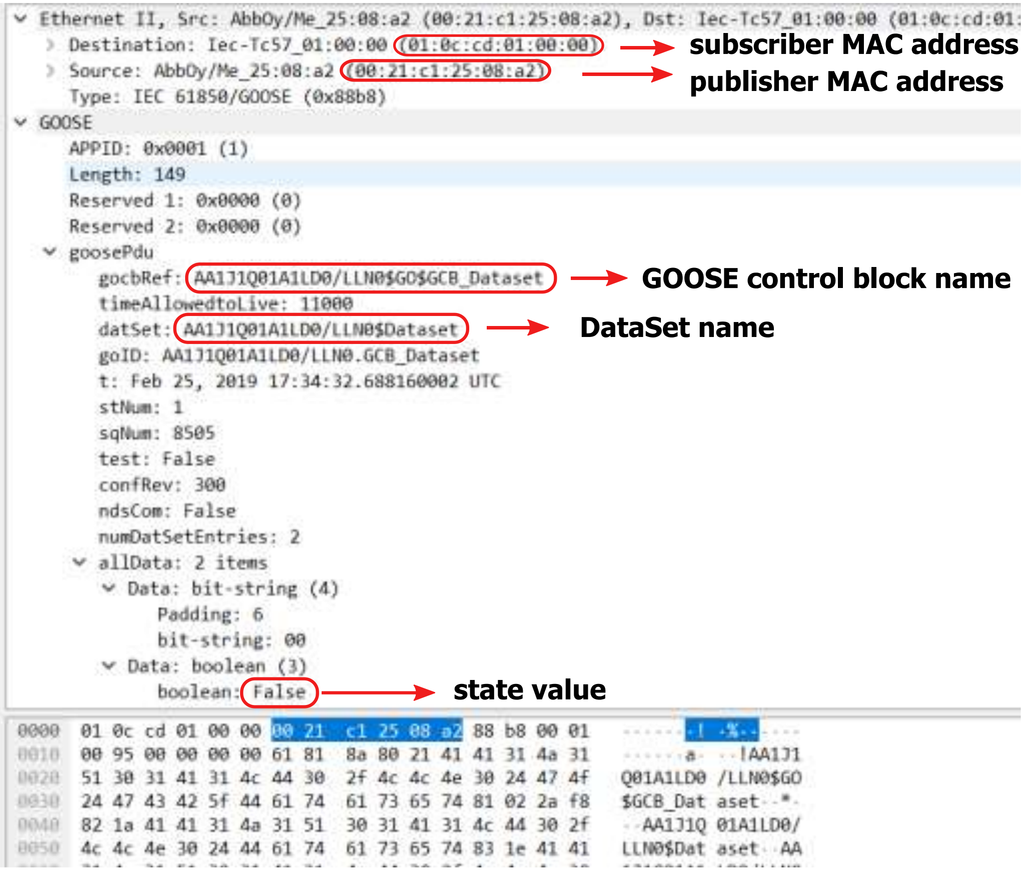
PhD Thesis: T. The HOANG

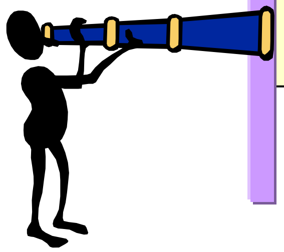



## ► GOOSE package published by REF 615 captured by WireShark




Tran The Hoang, Quoc Tuan Tran, Yvon Besanger, **"An advanced protection scheme for medium-voltage distribution networks containing low-voltage microgrids with high penetration of photovoltaic systems"**
*International Journal of Electrical Power & Energy Systems, Volume 139, July 2022, 107988,*

# Plan



**PRESENTATION**

**Context & Energy Transition**

**Solar Energy**

**Energy Transition in France and the World**

**Research and technology for Energy Transition**

**Smart Grid**

**Digital Transformation: Big data/Analytics**

**Conclusion**

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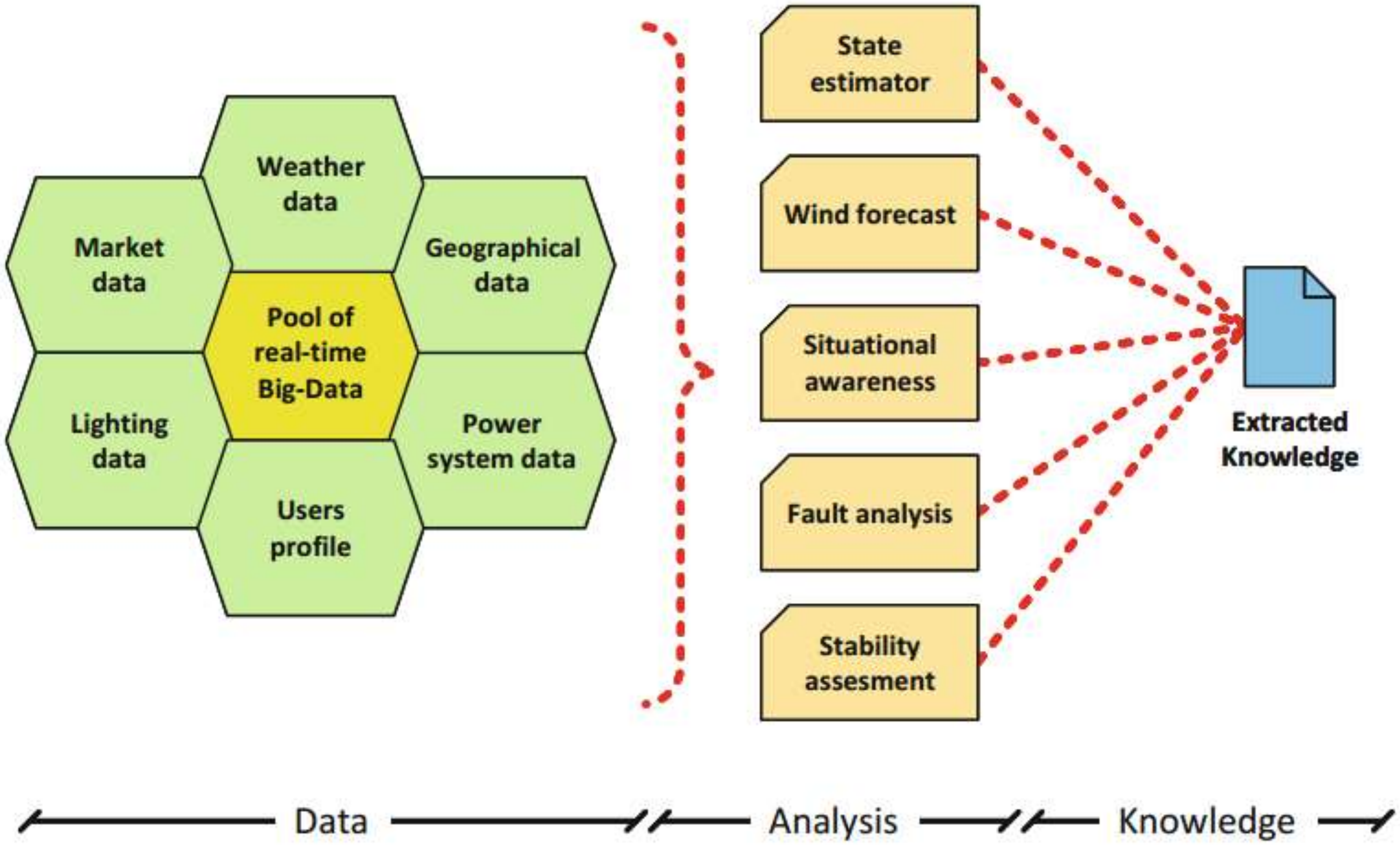
# Big data analytic



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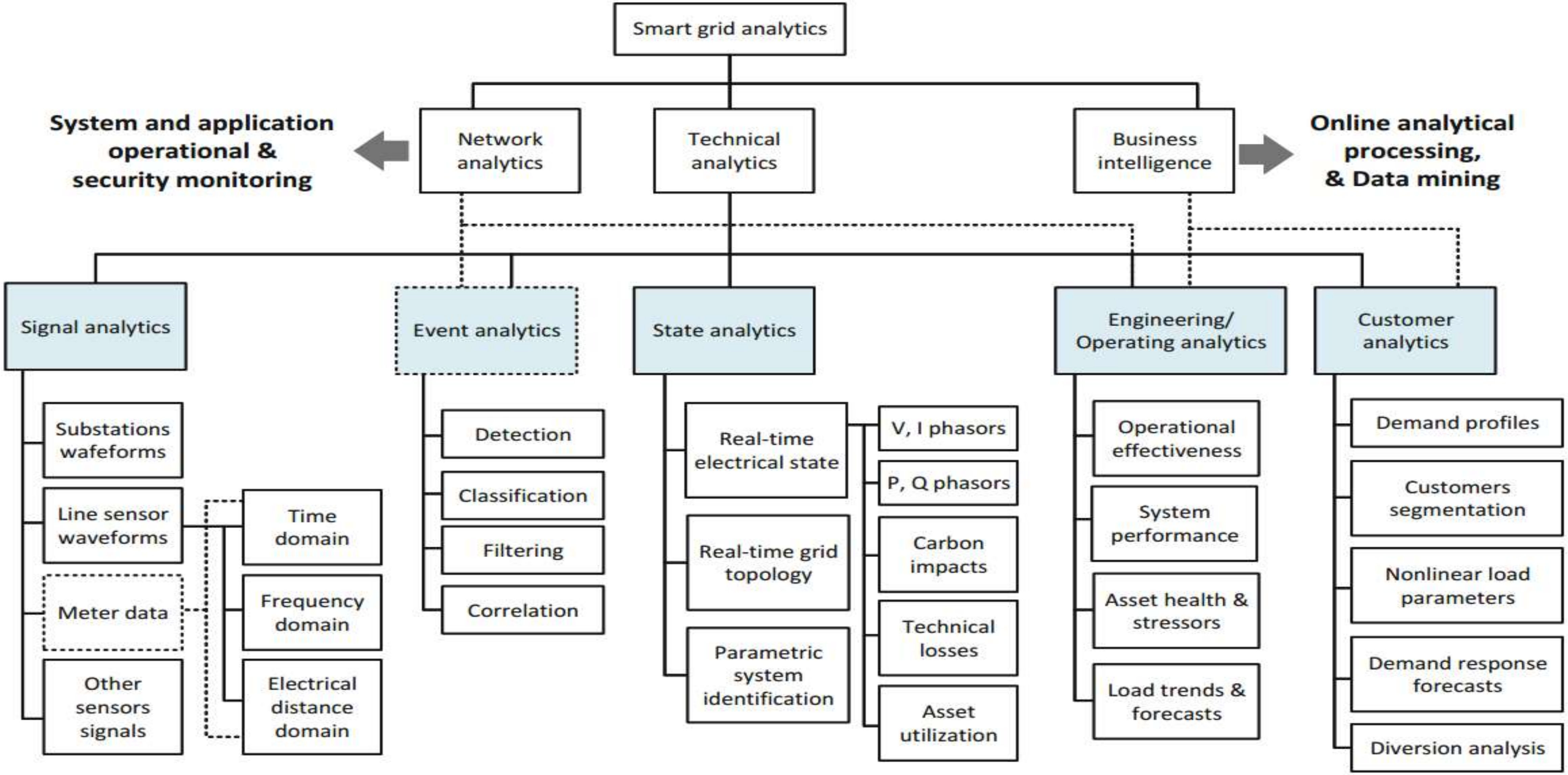
# Big data analytic

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# Plan

PRESENTATION

Context & Energy Transition

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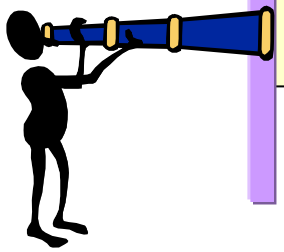
Smart Grid



**Digital Transformation: Cyber security**

Conclusion

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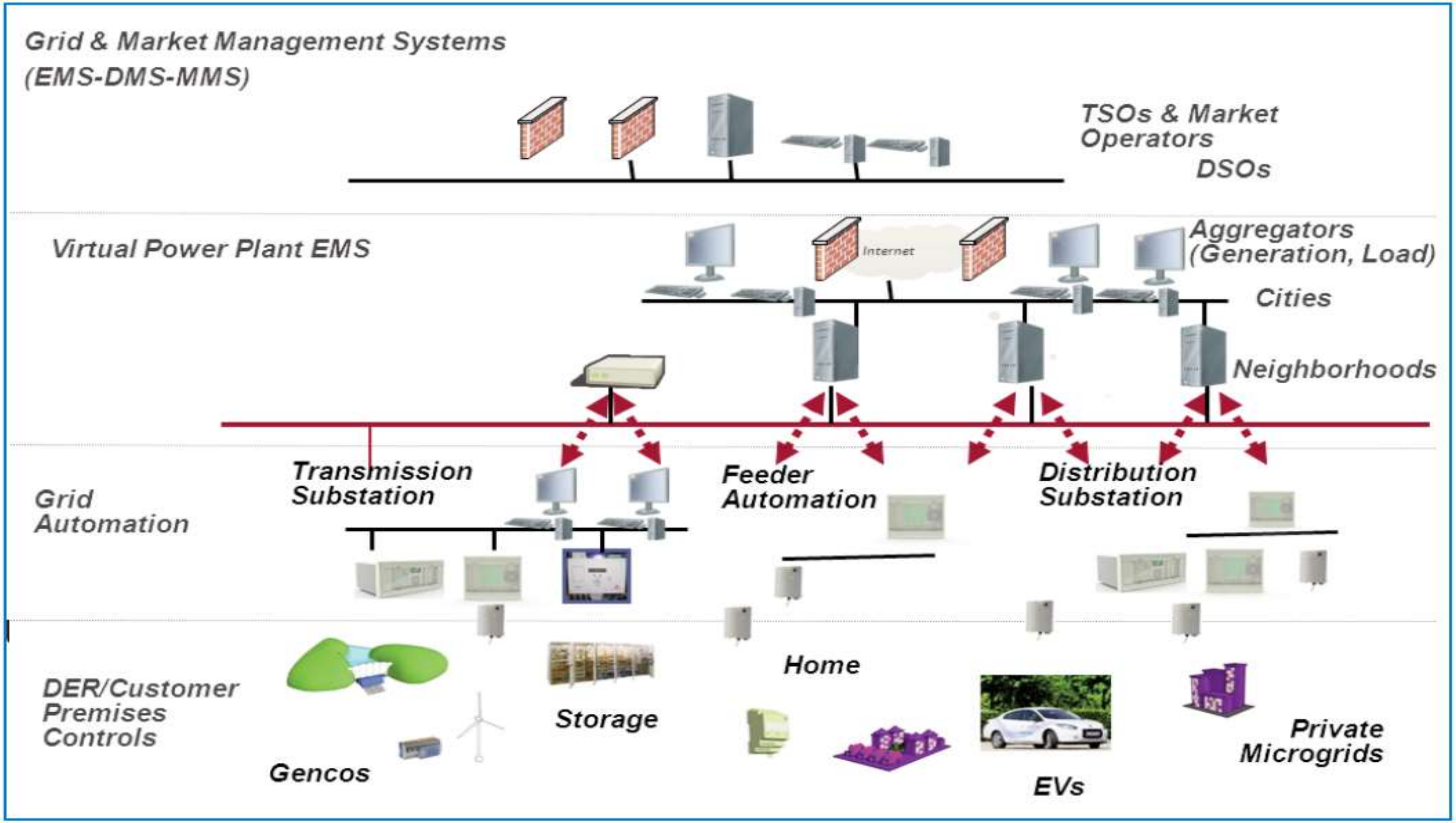


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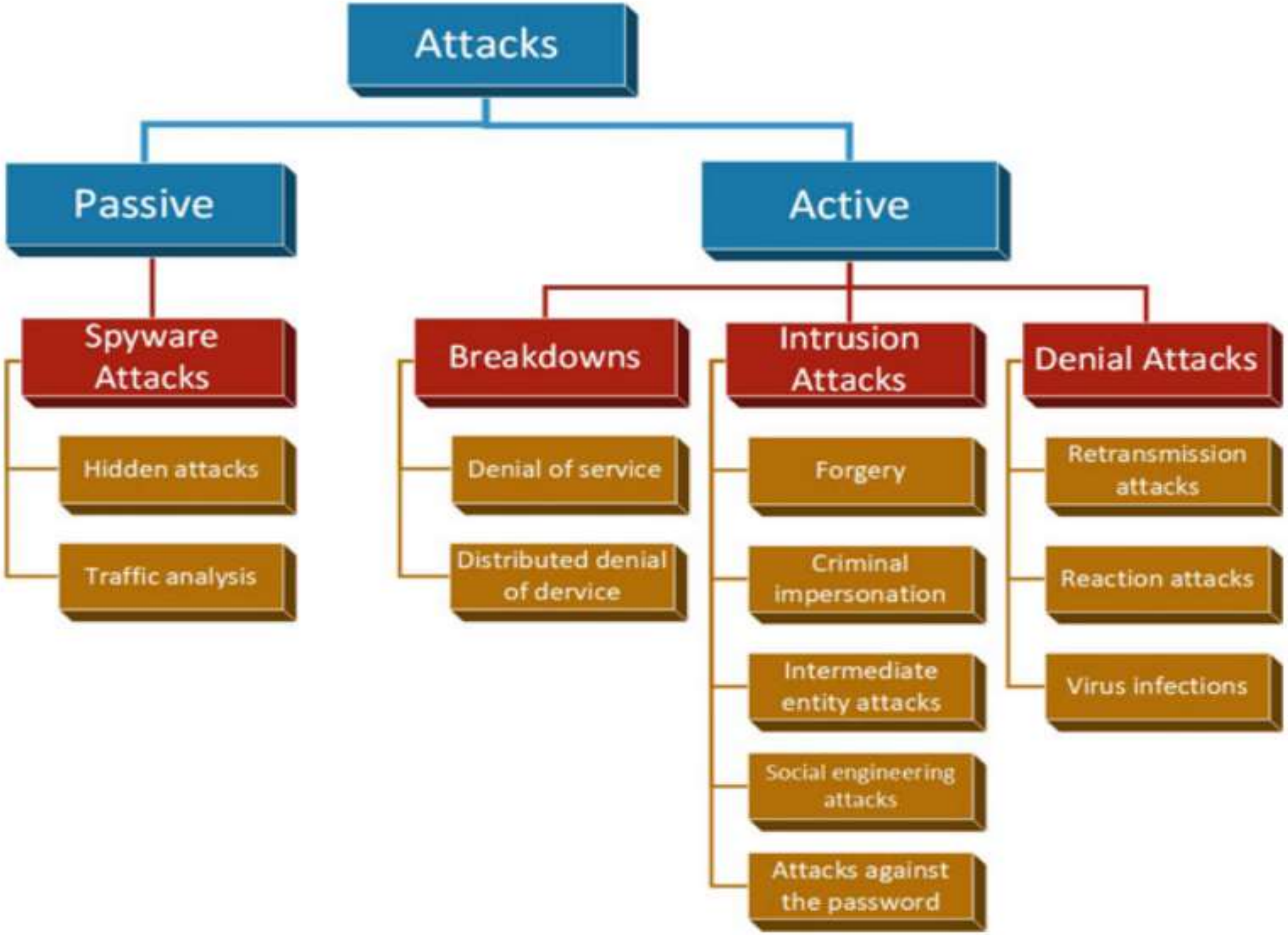
# Cyber Security




These aforementioned attackers can be broadly subdivided into the above categories:

- Terrorist attacks from other countries to deactivate the power grid.
- Deliberate false information trying to destabilize the country, manipulating the energy market.
- Violators, watching the energy consumption of smart meters, to find out when homeowners are missing.
- Individuals, violating the smart energy meter, for personal gain.
- Power suppliers or intermediaries involved in the smart grid, which have the potential to manipulate their competitor's pricing systems.

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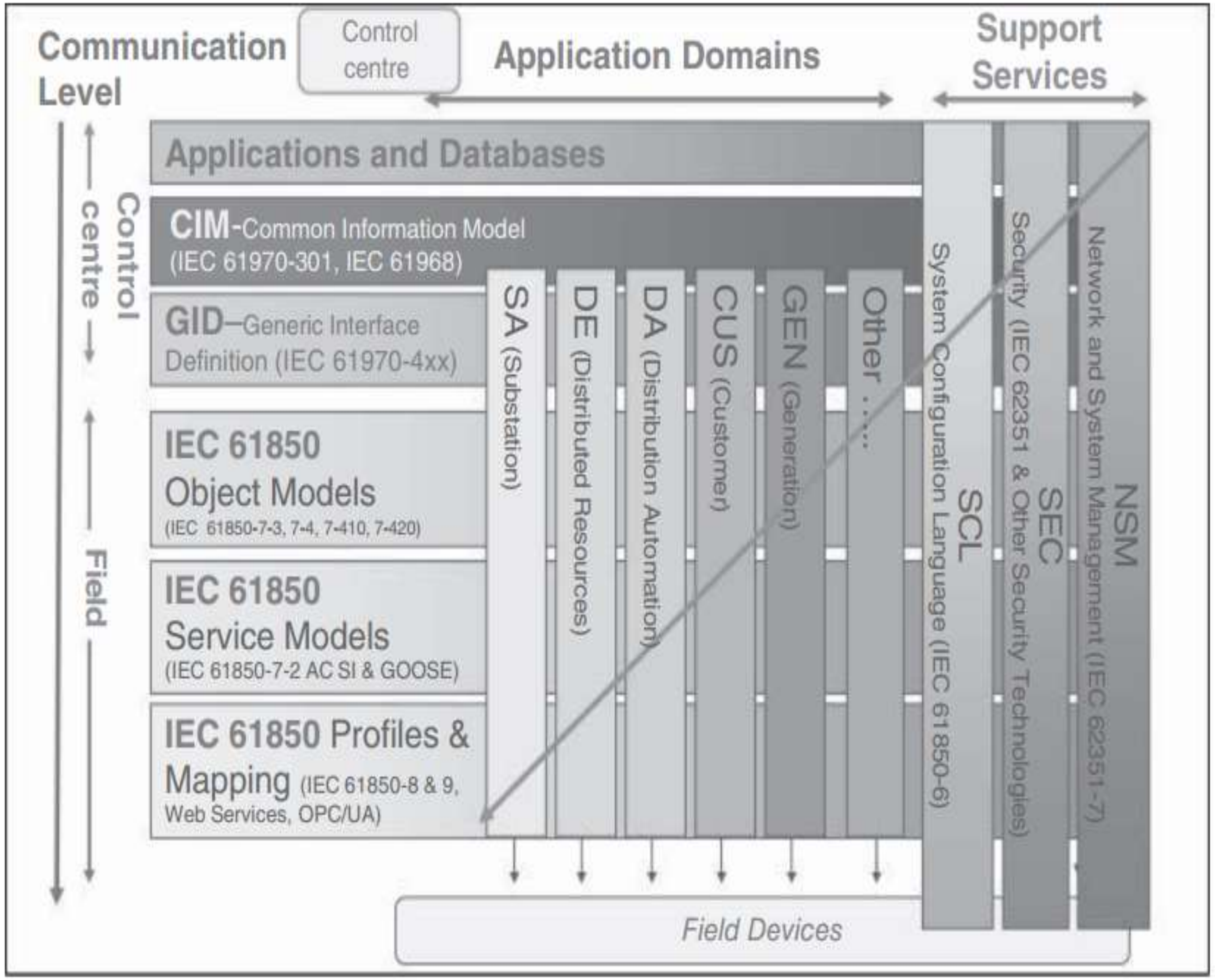
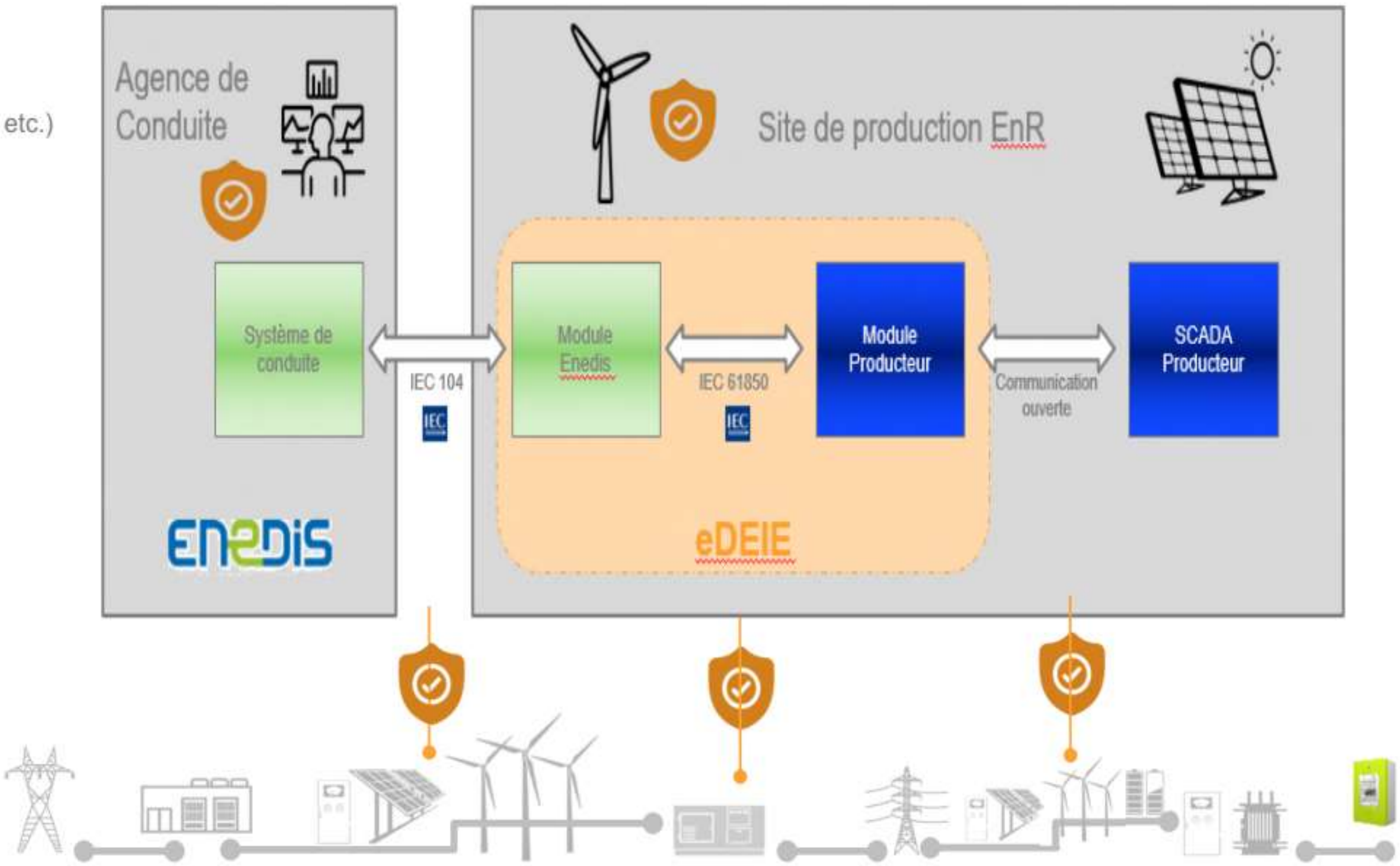
# Standards

| | |
|---|---|
| *Institute of Electrical and Electronics Engineers* | |
| IEEE Std 2030 | Power Engineering Technology<br>Information Technology<br>Communications Technology |
| *International Electrotechnical Commission* | |
| IEC 61968 | Distribution Management |
| IEC 61970 | Common Information Model |
| IEC 60870 | Intercontrol Center Communication Protocol |
| IEC 62351 | Data and Communication Security |
| IEC 62357 | Reference Architecture |
| IEC 61850 | Standard for Design of Substation Automation |
| IEC 61850-7-420 | Integration of Distributed Energy Resources |
| IEC 61850-7-410 | Integration of Hydro Resources |
| IEC 61400 | Integration of Wind Farms to Utility Communication Network |
| IEC 62056 | Communication |

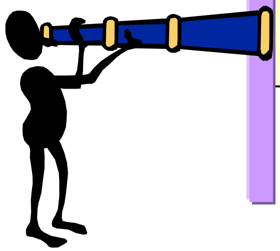


| | |
|---|---|
| IEC 62351 - 3 | Security for any profiles including TCP/IP |
| IEC 62351 - 4 | Security for any profiles including MMS (e.g., ICCP-based IEC 60870-6, IEC 61850, etc.) |
| IEC 62351 - 5 | Security for any profiles including IEC 60870-5 (e.g., DNP3 derivative) |
| IEC 62351 - 6 | Security for IEC 61850 profiles |
| IEC 62351 - 7 | Security through network and system management |
| IEC 62351 - 8 | Role-based access control |
| IEC 62351 - 9 | Key Management |
| IEC 62351 - 10 | Sécurité des profils de communication couches basses TLS / IP |
| IEC 62351 - 11 | Security for XML Files |




Source Enedis

# Plan



- **PRESENTATION**
- **Context & Energy Transition**
- **Solar Energy**
- **Energy Transition in France and the World**
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- **Digital Transformation: Cloud solution**
- **Conclusion**

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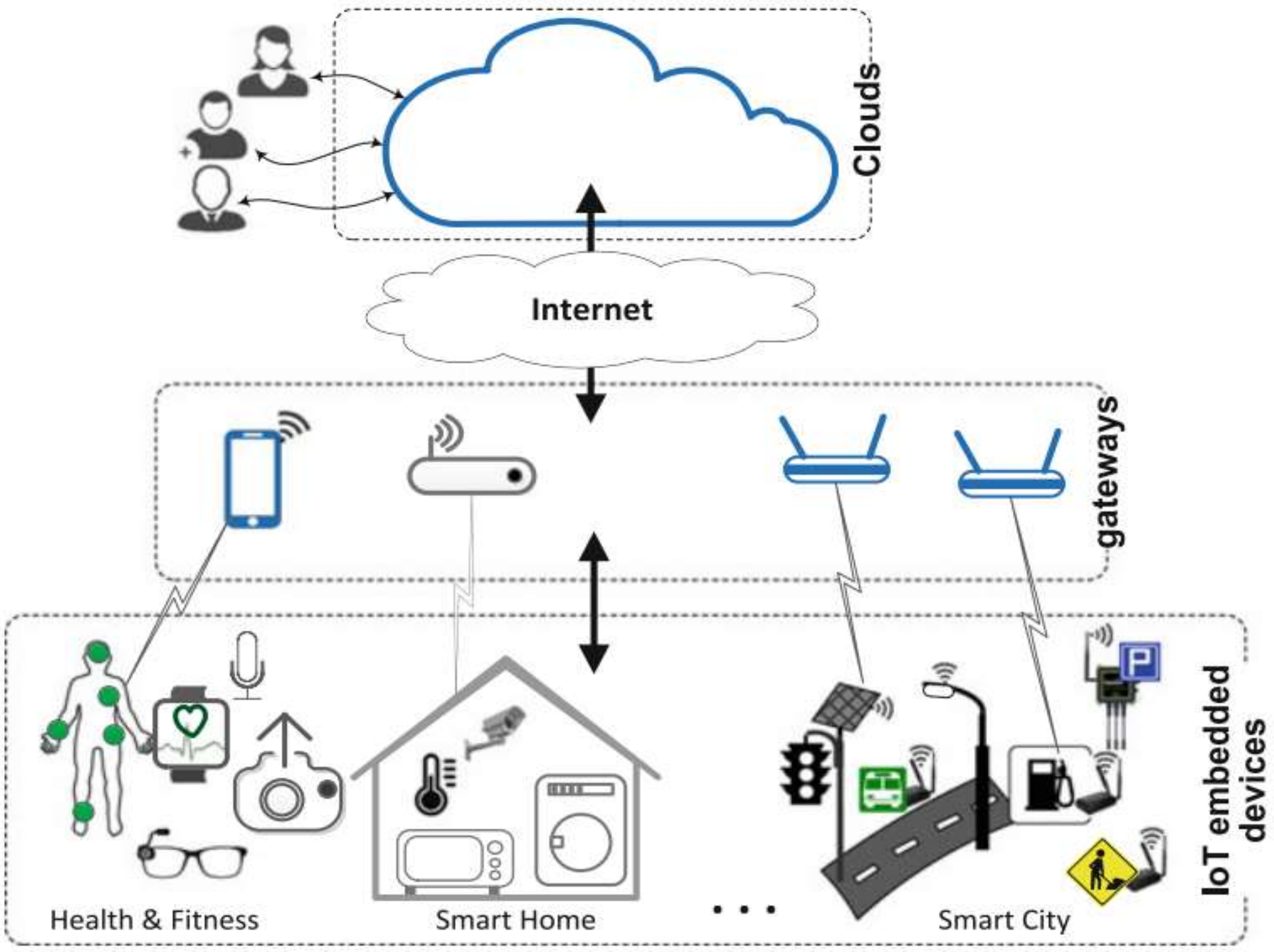
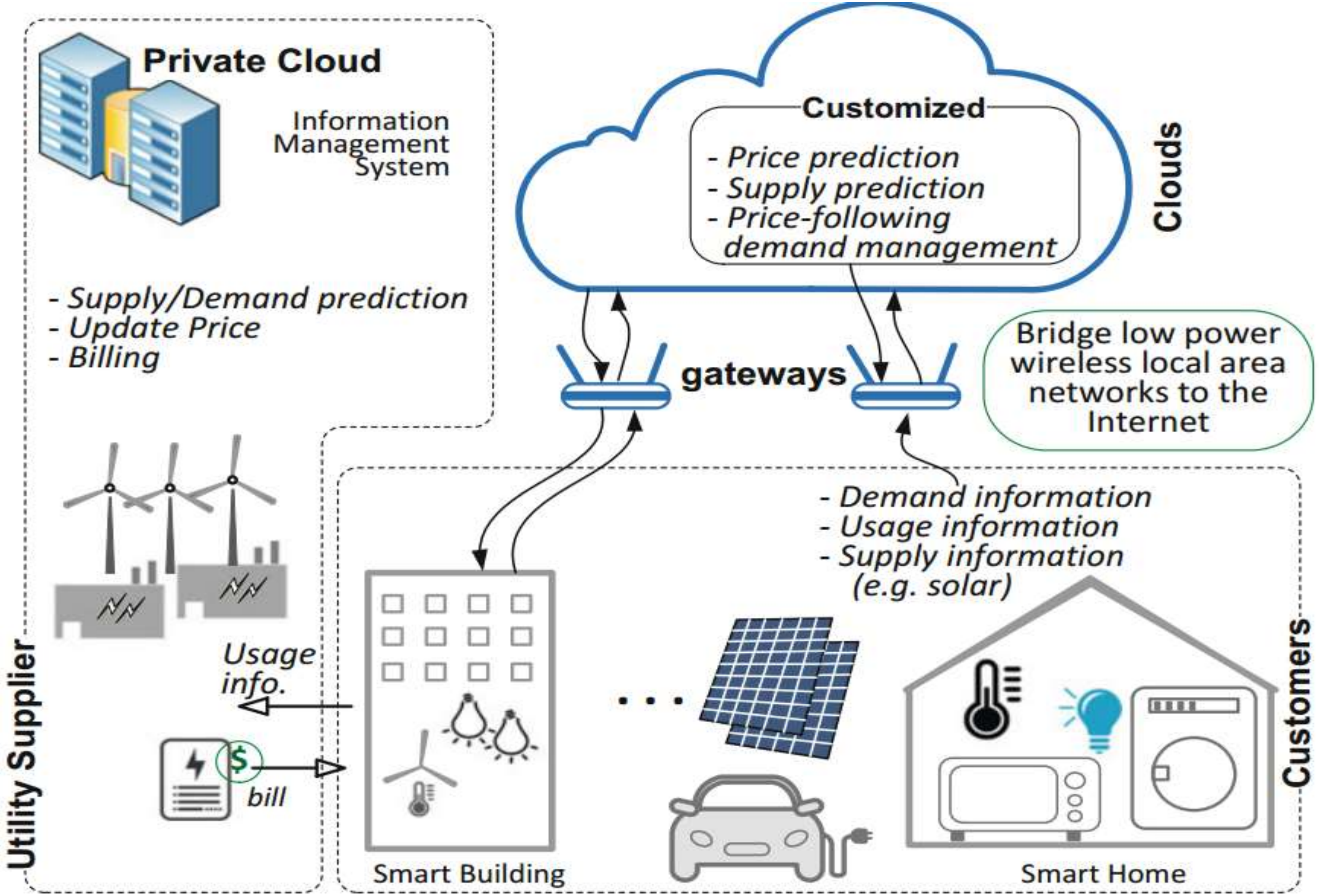
# Cloud-centric architecture



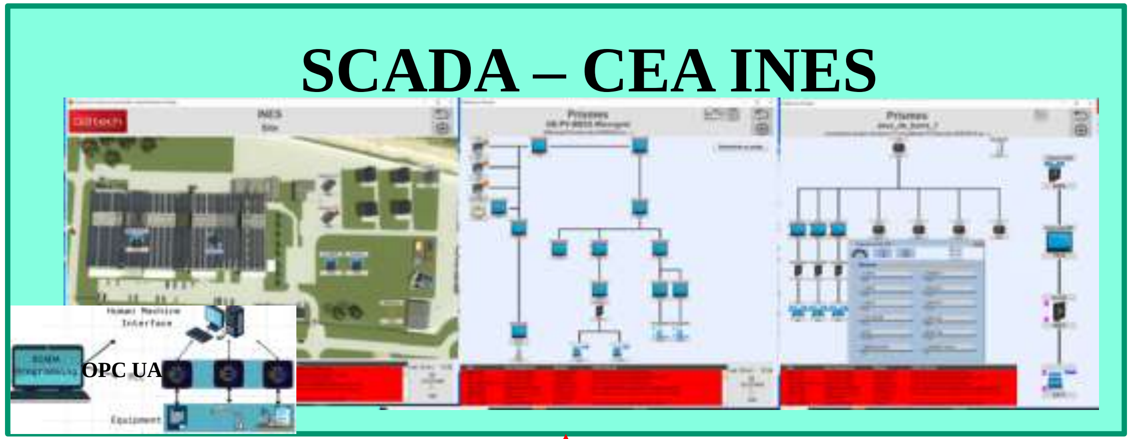
# Cloud service provider

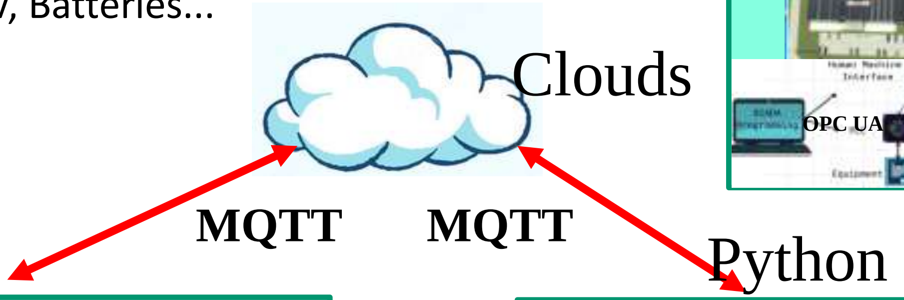


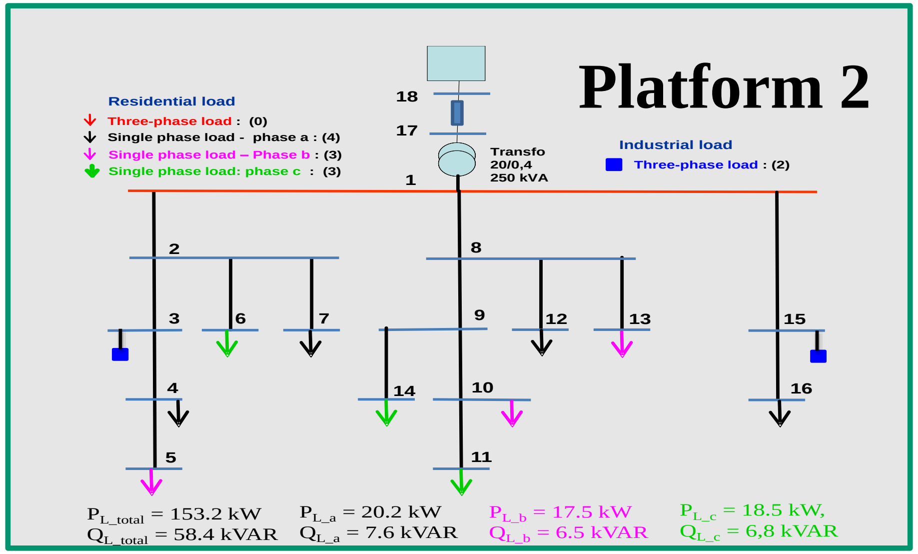
Post Doc Minh Cong Pham H2020 Erigrid 2.0 project

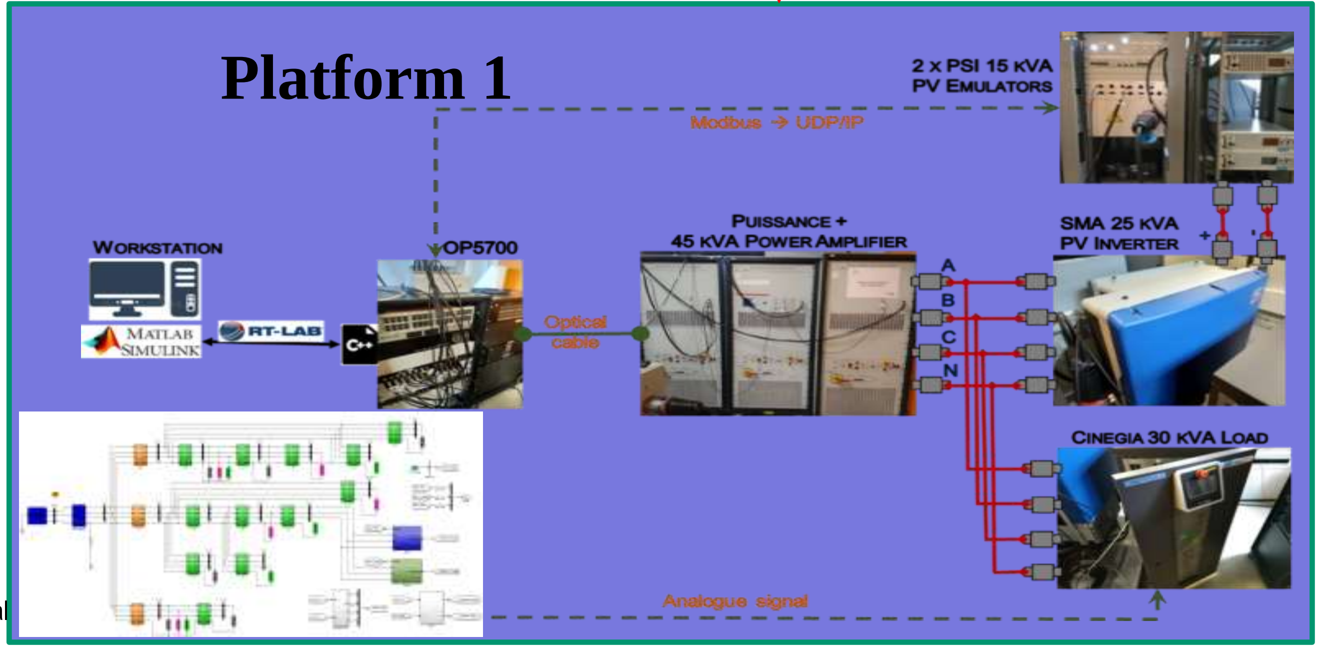
RT automation test between Prismes at CEA (Platform 1) and a distance platform (Platform 2)

- Platform 1 (CEA): OPAL-RT, SCADA system and HIL equipments such as inverters with FRT, load, PV, Batteries...
- Platform 2: microgrid




Minh Cong Pham, Quoc Tuan Tran, Hamad Hably, Seddik Bacha? **"Application of energy routers for frequency support in an AC/DC multi-microgrid system".** 21th IEEE International Conference on Environmental and Electrical Engineering – EEEIC, September 2021, Bari, Italy

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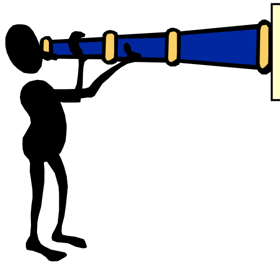
# Plan





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# Conclusion

- **Energy transition need:**
  - **Policies: Master plan, mechanism, development**
  - **Financial**
  - **Diversify energy sources**
  - **Markets**
  - **Research**
  - **Technology development**
  - **Digital transformation**
  - **Smart grid**
  - **Role of solar energy …**

**What do you do?**

- **Lead the energy transition by R+D+I**
- **Need the collaboration of all of you**

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## THANK YOU FOR YOUR ATTENTION

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**CEA – INES & INSTN**
**QuocTuan.Tran@cea.fr**
**TranQTuan09@gmail.com**
**Mob: +33 6 70 25 20 31**

**EEE-AM 2023**

**2023 IEEE Asia Meeting on Environment and Electrical Engineering**

**Accelerating the Energy Transition**

**National Convention Center, 57 Pham Hung Road, Me Tri, Nam Tu Liem, Hanoi - VIETNAM**

**From 13th to 15th November 2023**

**Conference Record Number #58328**

**Website** https://ieee_eeeam.epu.edu.vn/index.html **and** https://eeeam.net/eee-am-frontpage/eee-am-2023

**IMPORTANT DATES**

***Regular Papers***

| | |
|---|---|
| May 1st to **July 31th, 2023** | FULL PAPER Preliminary Submission |
| September 15th, 2023 | FULL PAPER Acceptance Notification |
| October 1st, 2023 | FULL PAPER Submission |

***Special Sessions***

| | |
|---|---|
| April 15th, 2023 | SESSION Proposal |
| May 31st, 2023 | SESSION Acceptance Notification |

***Registrations***

| | |
|---|---|
| September 1st, 2023 | Early-bird registration |
| October 1st, 2023 | Standard registration |

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