A Work Project, presented as part of the requirements for the Award of a Master's degree in Economics / Finance / Management from the Nova School of Business and Economics.

Market research on energy transmission regarding sustainable energy transition

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NOVA SCHOOL OF BUSINESS & ECONOMICS

In light of a sustainable energy transition, what are the key changes across the multiple sectors and what opportunities will emerge?

Abstract

1 Demand

Demand for energy and renewable sources is increasing. The buildings segment has the potential to have the largest share of renewable-produced energy followed by industry, yet transport can face the highest growth. Greater investment opportunities will emerge in buildings and transport with new technology and low-carbon policies unlocking new business models in areas like demand flexibility, efficiency and e-mobility

2 Transmission

Transmission development comes as a result of the rise in demand, generation capacity and the distance that separates these two. These constraints can be addressed through a set of solutions which complemented, meet the requirements of a flexible integrated transmission

3 Generation

The generation energy market once dominated by massive oil companies is experiencing changes that allow new types of players. The 2050 scenarios show large increases in renewable technologies total installation capacities and power generation mainly in wind and solar power as well as a great investment opportunity in wind power

4 Investment Opportunities

A cleaner energy market will diversify the ecosystem and change the nature of factors to succeed across demand, transmission and generation. Investment opportunities will be greater in energy demand and the total investment of the three areas combined represents 3.1% of the World GDP. This new ecosystem will allow new players to emerge and fragment a former highly concentrated market with increased uncertainty, encouraging partnerships

Keywords: interconnection, geography expansion, co-location, energy storage

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Executive Summary: Transmission

2.1 Intro

It is impossible to separate intermittency from RE but there are useful techniques that minimize its impact

2.1.1 Demand is increasing and we are confronted with intermittency as a consequence of RE

2.1.2 The 'Duck Curve' represents a challenge of solar energy as it creates grid flexibility problems and leads to waste

2.2 Prominent Solutions

Interconnection is the main solution for intermittency which must be complemented with solid investments in diversification and storage

- Exploiting the fact the levels of irradiation are stronger near the equator and when it is summer in the North Hemisphere it is winter in the South
- Diversification could be deployed through the connection of geographies and sources

2.2.1 Interconnection

- As RE share increases, ensuring cost-effective and reliable integration changes flexibility requirements
- Transmission capacity in EU has the potential to increase fourfold, with year 2025 possibly being a critical year regarding investment
- China has achieved significant progress in reducing curtailment rates and is set to improve even more with the new additions
- To achieve higher proportions, actions in system operation, RE deployment and flexible resource planning are required

2.2.2 Diversification

- There is huge potential for wind diversification in Norway and for co-location, particularly in Germany, UK and Ireland
- Geography expansion and co-location are effective in reducing intermittency's impact and in delivering cost savings
- Complement scalability with spatial planning, promote joint ventures and pursuit the optimal mix in order to reduce intermittency's impact

2.2.3 Storage

- Pumped Storage Plant represents 94% of global capacity, stationary storage is gaining share and EVs are becoming a flexibility tool
- Prosumers with batteries demand less from a centralized grid potential for 59% decrease in ramp rate and a 14% peak load reduction
- Combining RE and storage through the investment in policies, regulation and education is the obvious solution to minimize curtailment

2.3 Investment

Market still dominated by big players but as the generation capacity increases new players and ambitious projects can arise

2.3.1 Desertec dreams about supplying the world's energy demand through Africa's desert

2.3.2 Supernode's technology can cut in half the transmission costs with twice the power and the cable distance with only 25% of the cables

2.3.3 Battery saved consumers $34m in its first year of operation and those savings will grow when the 50% expansion is completed in 2020

2.3.4 Investments can potentially increase 100% in EU and storage's share is perceived to grow significantly in the optimistic

Demand is increasing and we are confronted with intermittency as a consequence of RE

Energy transmission's drivers

Global **population** and **new consumers** growth (EVs) increase demand for energy

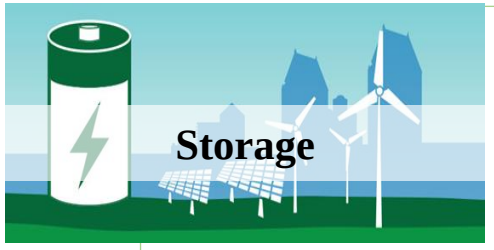
Low cost of RE, intermittency and increasing distances between generation and consumption

Creates need for **infrastructure** that delivers

Solutions

Connect countries

Connect resources



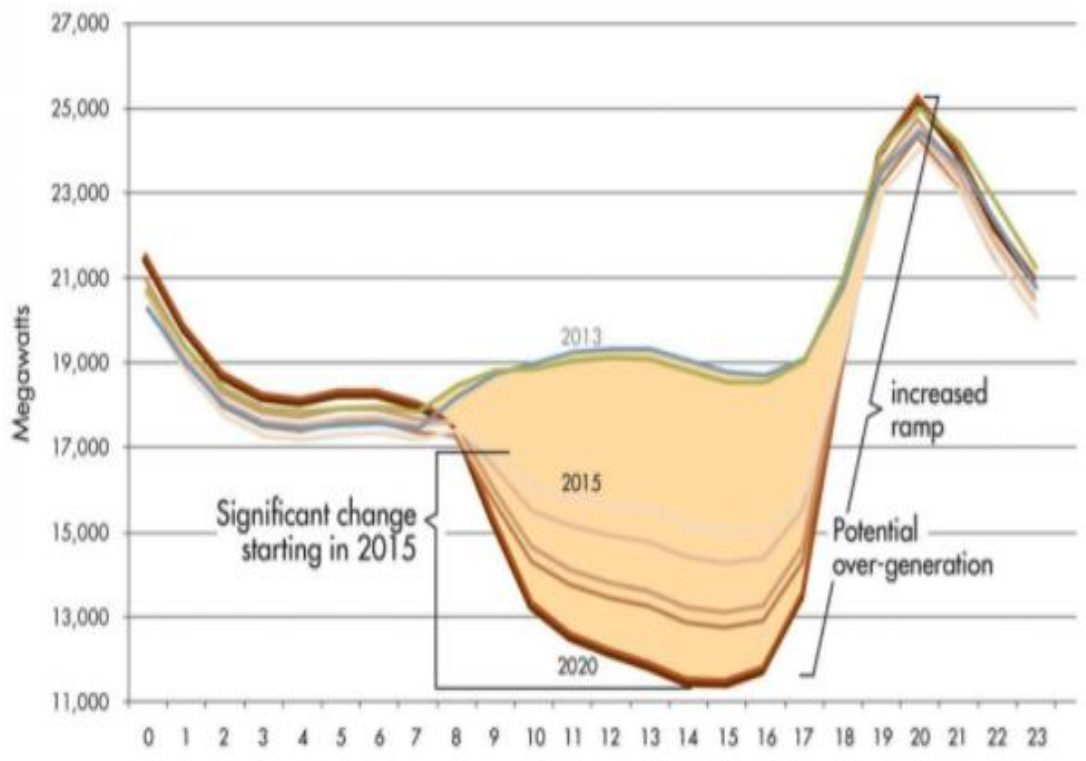
Store surplus

1. Source: Siemes 2019
2. Source: Liu 2015

The ‘Duck Curve’ represents a challenge of solar energy as it creates grid flexibility problems and leads to waste

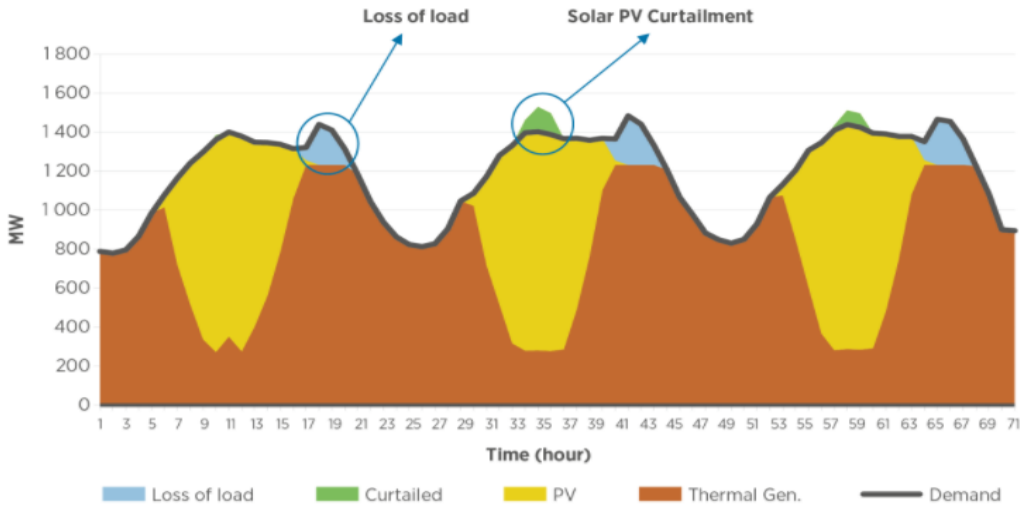
Output ends just as demand peaks leading to ramp up

1. Energy load throughout the day, (2013-20;MW; 24h)



Solar curtailment at mid-day and loss of load destabilize S/D

2. Energy Supply and demand throughout the day, (MW; 24h)

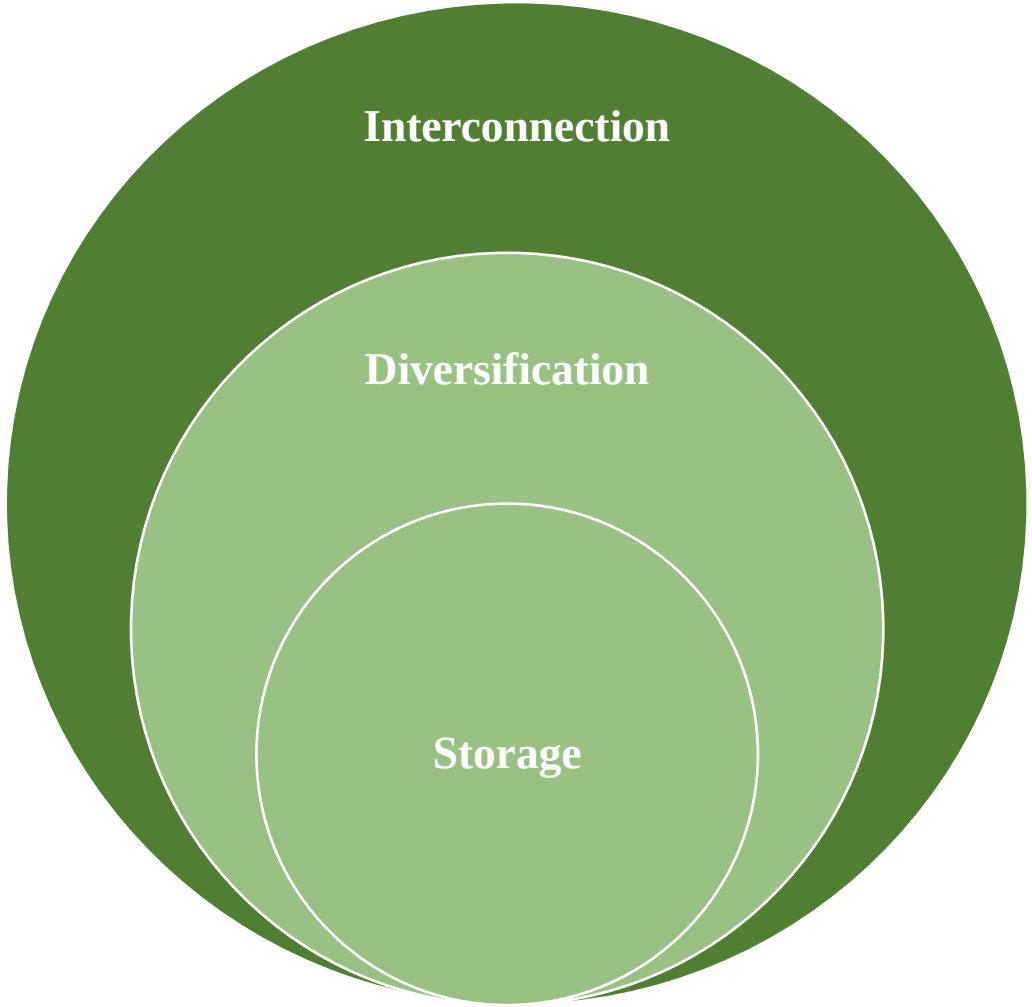


Hidden costs

- Power plant capacity on stand by (typically natural gas)
- Economic Profitability: nuclear and power plants must run around the clock
- Wind and solar energy curtailment

3. Source: Energy Institute Blog 2019
4. Source: IRENA 2018

Interconnection is the main solution for intermittency which must be complemented with solid investments in diversification and storage



Flexible Integrated Transmission

- Investments in interconnecting transmission systems increased significantly in 2017, as annual **line-kms tripled from 2016**
- **High-voltage** permits energy to travel **longer distances** at low losses and connection of remote energy sources
- **Digital smart-control** allow technologies to operate at **higher capacity and improve management of interconnection** among regions and countries

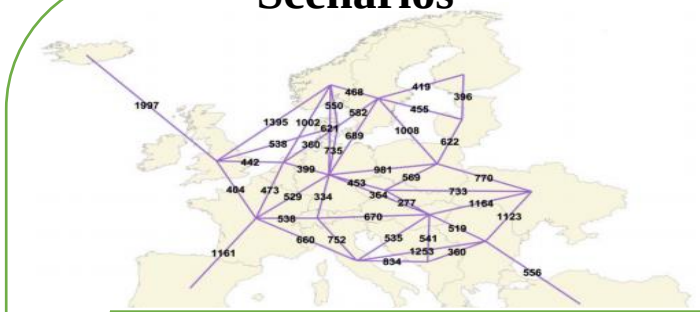
5. Source: IEA 2019

Exploiting the fact the levels of irradiation are stronger near the equator and when it is summer in the North Hemisphere is winter in the South

Geographic complementarity

Seasonality

Scenarios

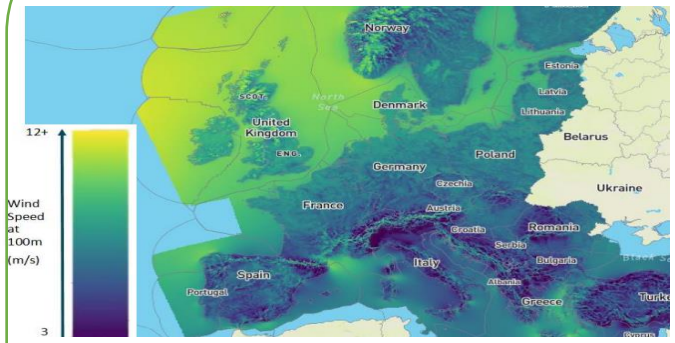


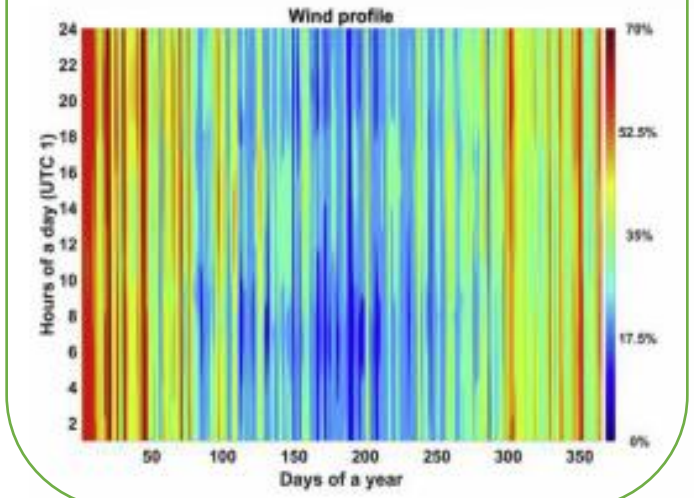
Pan European Transmission grids

Global interconnection

3. Illustration of interconnection's dynamic both geographically and seasonally

Wind resource

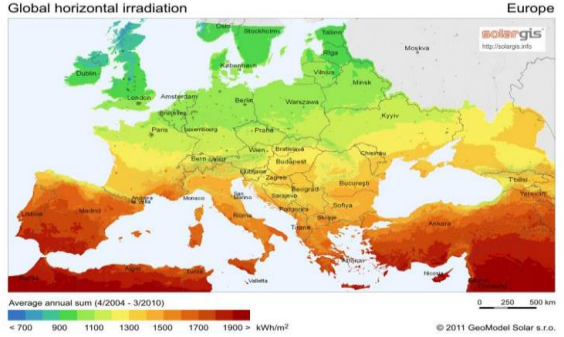


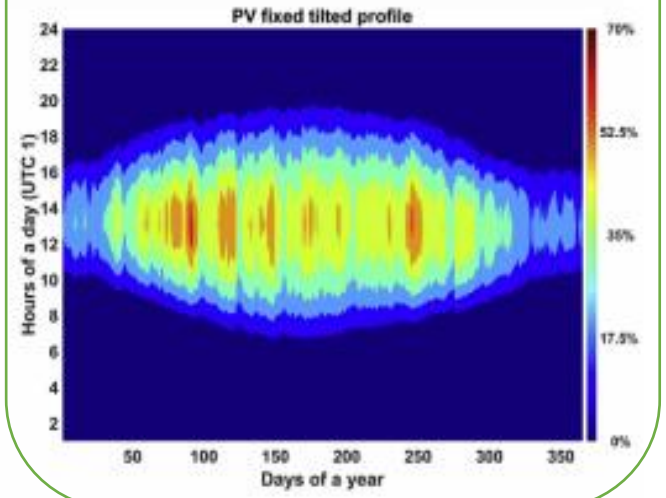


Low generation in the summer (Blue)

4. Energy Load of Wind energy

Solar resource





Generation in summer around mid day

5. Energy load of Solar energy

5. Source: Child et al. 2019

Diversification could be deployed through the connection of geographies and sources

Strategy	Geography Expansion	Co-location
Premise	Do not put your all your eggs in the same basket	Better together: Combine wind with solar
Argument	• Wind speed correlation among sites decreases • Probability that all sites experience the same wind regime drops	• Wind is consistent at night and sun is consistent during the day • Re-utilization of existing infrastructure (foundations, roads)
Result	Behavior similar to a single farm, with steady wind speed and thus, steady delivery of wind	Power generation around the clock and amortization of fixed costs

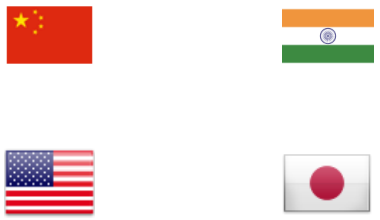
6. Image of geography expansion and supernode connection

6. Source: Delucchi and Jacobson 2011
7. Source: Supernode Energy 2019

As RE share increases, ensuring cost-effective and reliable integration changes flexibility requirements such as transmission assets, storage and synthetic fuels

1- RE has no noticeable impact on the system

2- Minor to moderate impact



3- Greater swings in the S/D balance create the need to increase system flexibility

4- The system experiences periods where RE makes up almost all generation

5- RE generation > demand which leads to increased risk of curtailment (days to weeks)

No countries

6- Seasonal/inter-annual surplus or deficit of RE supply

Potential need for seasonal storage and use of hydrogen

No countries

1 2 3 4 5 6 Fully integrated

7. Diagram Phases of RE integration until Fully integration

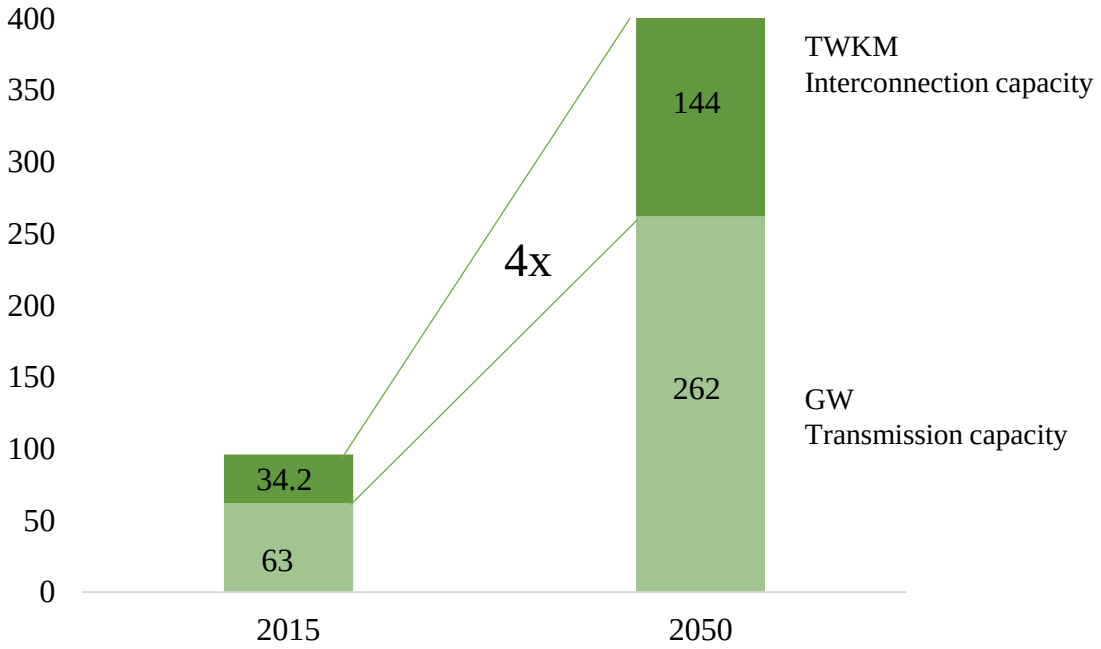
8. Source: IEA 2019
9. Source: Expresso 2019

* Only Chinese provinces Gansu and Qinghai

Transmission capacity in EU has the potential to increase fourfold, with year 2025 possibly being a critical year regarding investment

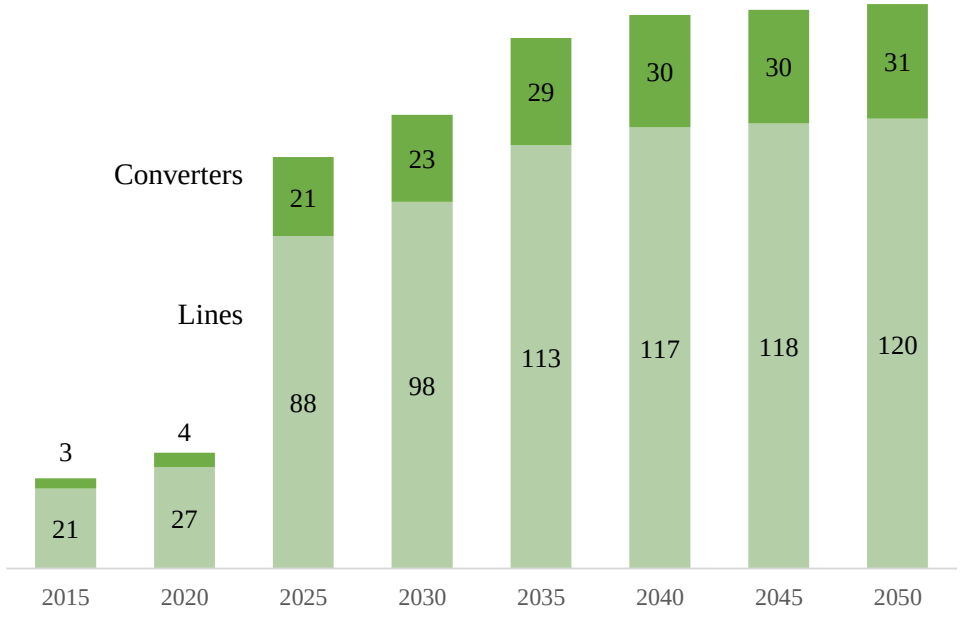
Transmission Capacity in Europe could increase 4x

8. Europe's transmission capacity [2015-2050; GW ; TWkm]



The year 2025 is perceived to be critical in investments

9. Capex divided into cables and converters, [2015-50; €Billion]



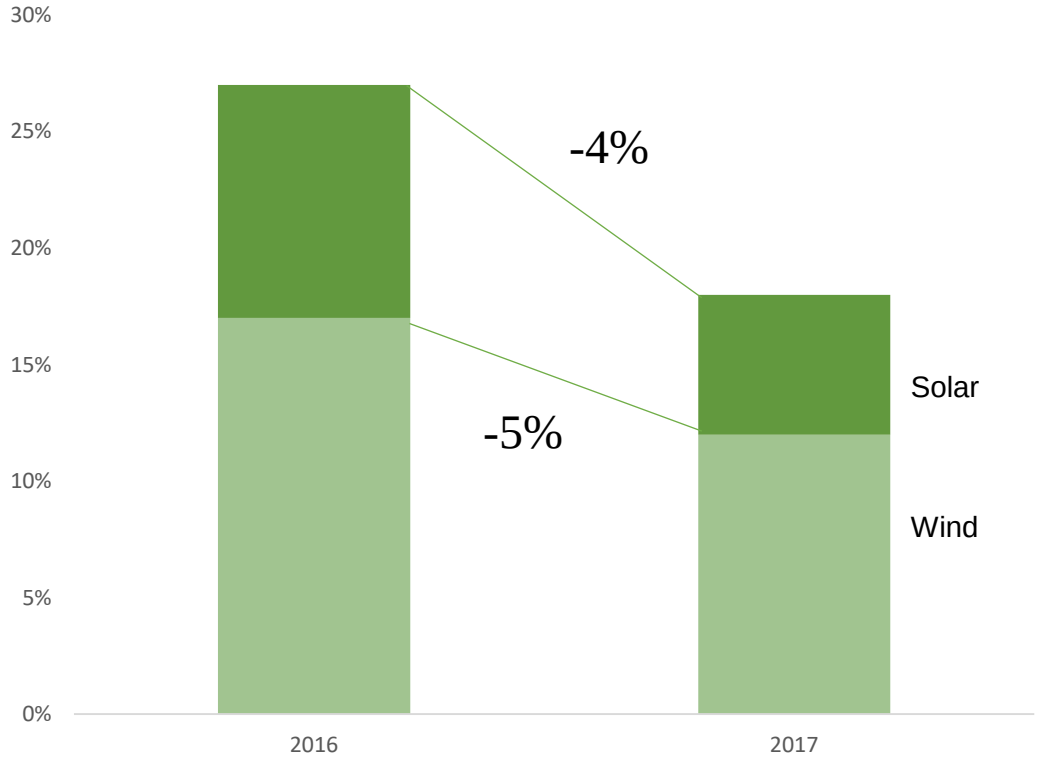
In 2025, the expectation is that a significant increase in new solar and wind capacity will create excess electricity, hence the big jump in transmission capacity in that year

5. Source: Child. et al. 2019

China has achieved significant progress in reducing curtailment rates due to transmission enhancement and is set to improve even more with the new additions

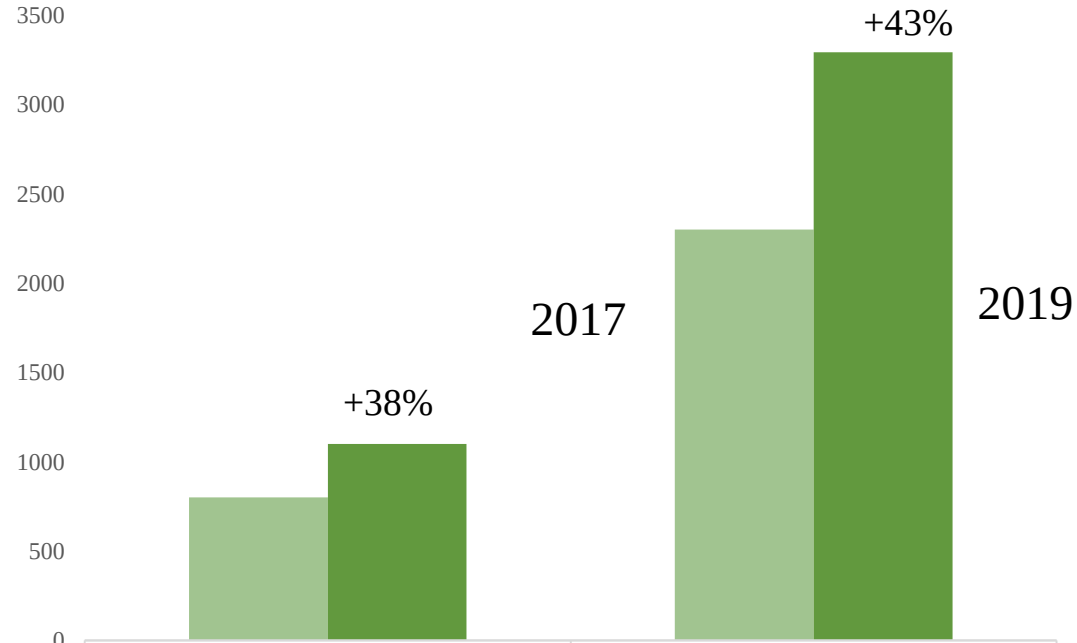
Curtailment rates have dropped in solar and wind have dropped 4% and 5%

10. Curtailment rates, Wind and solar



World record grid line has 38% more voltage going through a distance 43% longer than the Gansu – Hunan

11. Chinese Grid milestones, kv and Km



	Kilovolts	Distance (KM)
2017	800	2300
2019	1100	3293

4. Source: IRENA 2018

10. Source: IEEE Spectrum 2019

In order for interconnection to achieve higher proportions, actions in system operation, VRE deployment and flexible resource planning are required

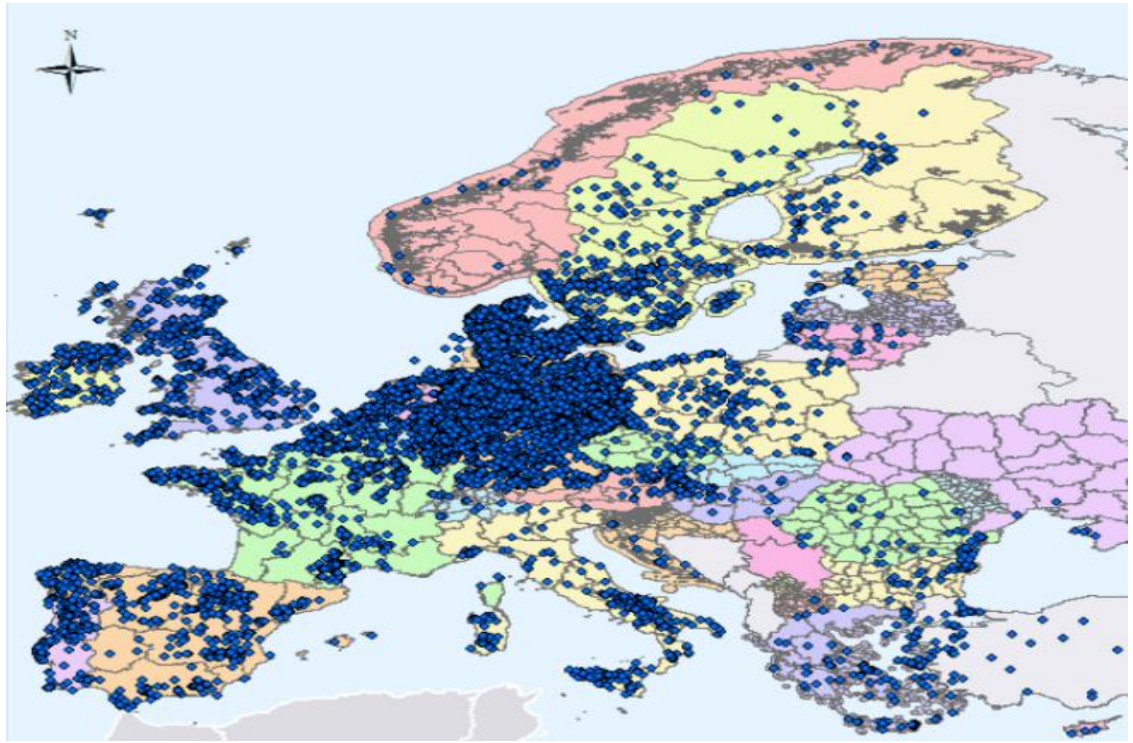
Maximize Asset contribution	• Advanced RE forecasting • Dynamic spot electricity market • Elaborate policies to establish friendly cross border energy trade
System-friendly VRE deployment	• Ensure full system services capabilities for large renewable energy plants • **Expansion of geographical areas** in which S/D are balanced
Flexible resources deployment	• Digitalization and DER (EVs and **storage**) constitute new options to balance S/D • Large scale networks to smooth seasonal variability

11. Source: IEA 2019

There is huge potential for wind geographic expansion in Norway and for co-location, particularly in Germany, UK and Ireland

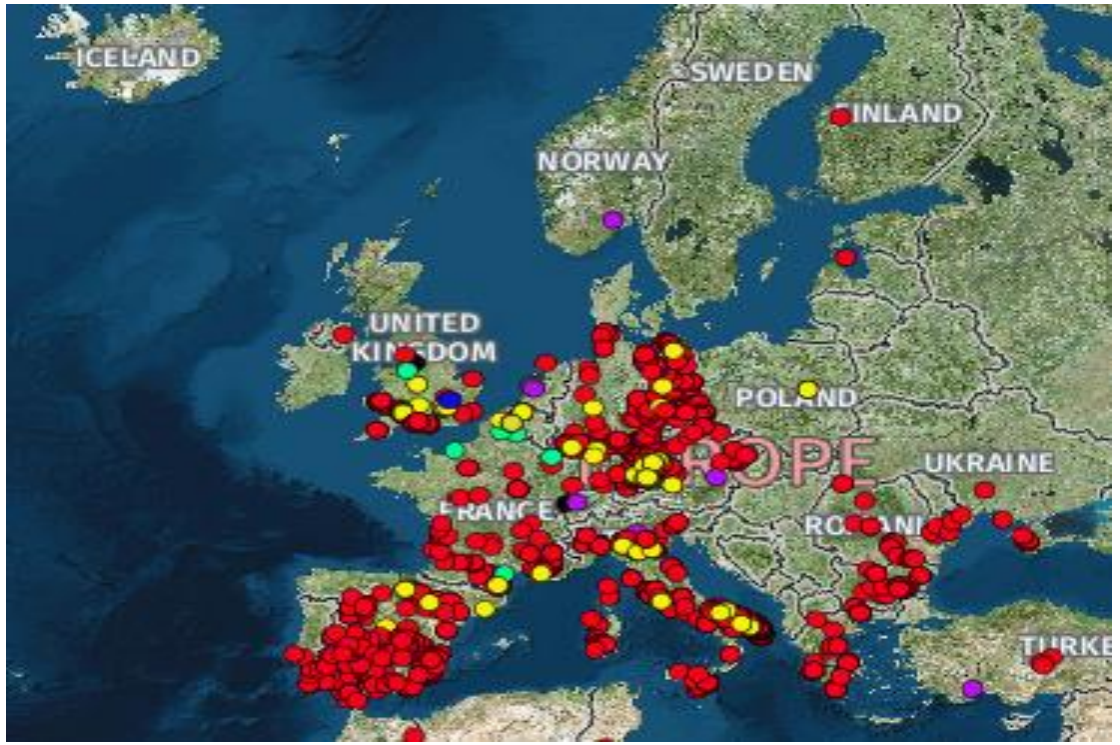
Germany and Denmark are fully exploit

12. European wind farms map in 2016



South is significantly populated with solar

13. European solar farms map in 2016



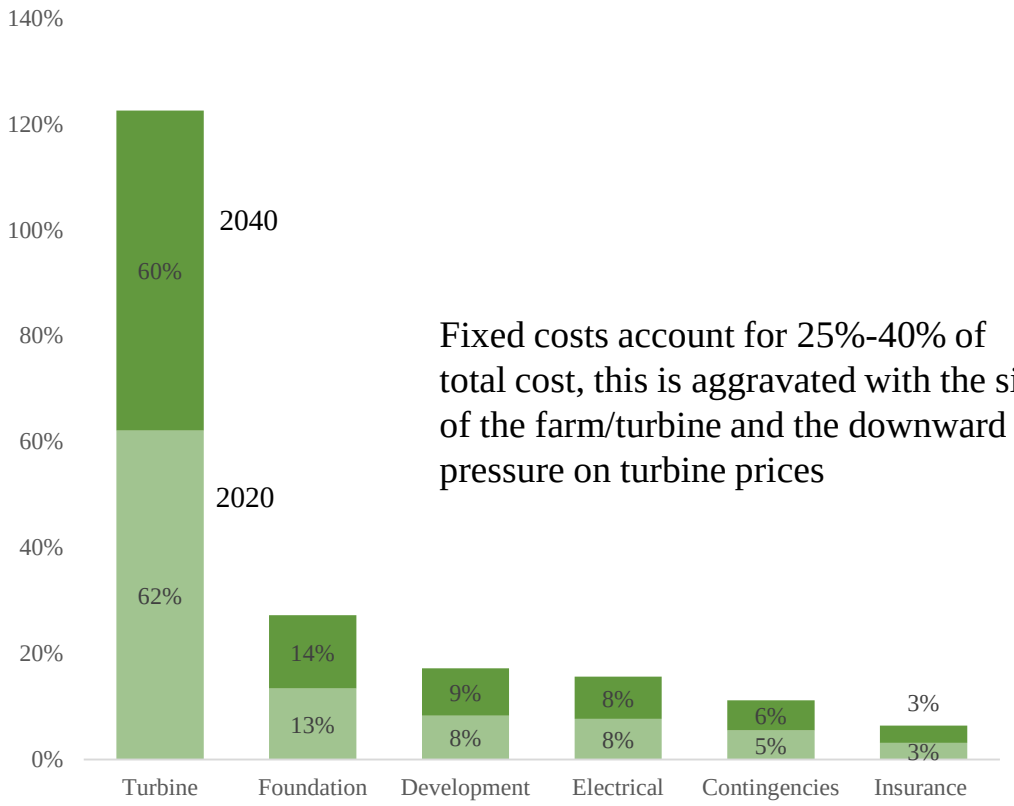
Countries with smaller concentration of wind farms such as Norway, Sweden and Finland have potential to diversify spatially whereas France, Iberia and the UK could diversify through co-location

12. Source: Solar Energy maps 2019

Geography Expansion (1) and Co-location (2) are effective in reducing intermittency's impact and in delivering cost savings

Set-up and fixed costs account for ~40% which makes it difficult to dilute

14. Installations costs of a small wind farm (16MW)

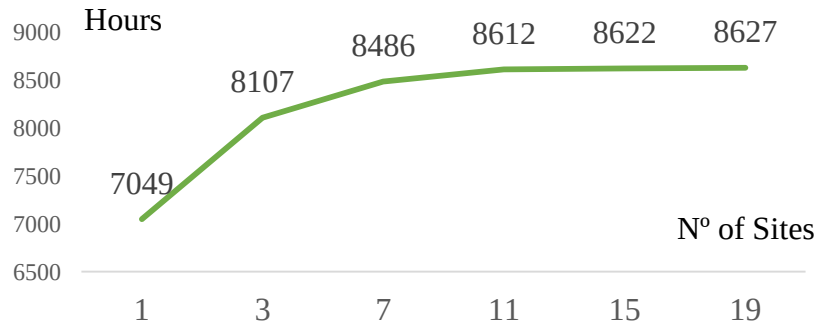


Fixed costs account for 25%-40% of total cost, this is aggravated with the size of the farm/turbine and the downward pressure on turbine prices

Generation hours increase with the number of sites

15. Nº hours of wind energy production in function of nº farms

1- Geography expansion



Variance of the Supply side decreases as probability of all sites experience the same wind regime drops

2- Co-location: Better together

Pairing 2 sources can deliver significant investment and operating savings of up to 16% (AECOM 2016)

13. Source:Archer and Jacobson 2007
14. Source: Supernode Energy 2019
15. Source: AECOM 2016

Complement scalability with spatial planning, promote joint ventures and pursuit the optimal mix of technologies and size in order to reduce intermittency's impact

 Scale Economies	• **Scalability:** Large rotor diameters and higher hub heights have higher yields • Promote **joint ventures** to reduce O&M inefficiencies (E.g EDP and Engie) • Exploit hub grid connections
 Scope Economies	• Utilization of existing infrastructure • Retrofit existing wind farms with solar capacity • Opportunities to **shared infrastructure**: Storage facilities and water treatment plants
 Mix optimization	• Spatial planning to ensure ROE • Optimal combination of technologies and size • Smart Grids: Improve interoperability and interaction with different geographies

14. Source: Supernode Energy 2019
16. Source: Financial Times 2019

Pumped Storage Plant is very much embedded globally, small scale stationary storage is gaining share and EVs are becoming a flexibility tool

Pumped Storage Plants

- Use surplus of wind energy at night to refill the upper reservoir
- Accounts for **over 94% of installed** global energy storage **capacity**
- China, Japan and USA hold the majority of its capacity
- **9000 GWh globally**
- Great degree of flexibility
- Constrained by Geophysical features

Prosumers and utility scale storage

- **Li-ion batteries represent 90%** of total capacity of large scale storage
- BTM battery with rooftop is expected to match utility scale as **costs fell by 80%** between 2010-17
- Record deployment in 2018 of 8GWh

Vehicle to Grid (V2G)

- **EV as decentralised storage**
- Current ratio of EVs to fuel is 1/250
- **Highly segmented (wealthy owners)**
- **EVs' price expected to match fuel cars by 2023**

Hydrogen

- Water electrolysis deployment: valued at $20-$30M/ year
- Last project installed was 10 MW in 2018 **(need to scale up)**
- **Larger projects** of 100 MW **announced** in Europe
- 20 MW under construction

Demand response from EVs

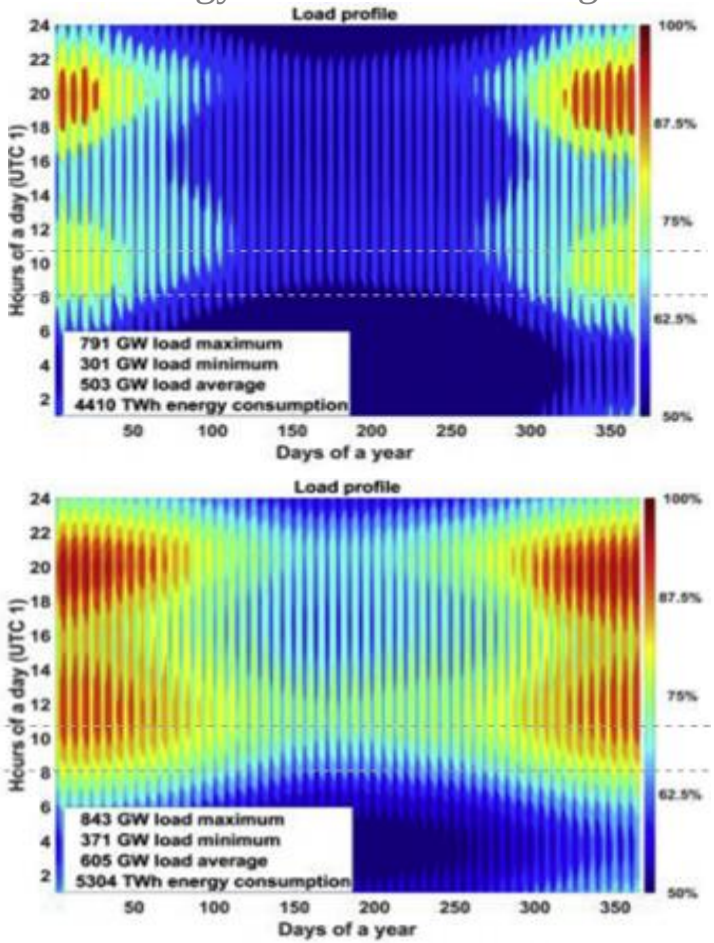
- Smart charging strategies that shift the time of day that EVs draw electricity from the grid
- Leading pilots in Netherlands, Germany and California
- If demand response for the full EV fleet today, **2 GW of flexibility would be immediately available**

Tracking Clean Energy Progress Scale (2019): On Track | More efforts needed | Not On Track

17. Source: IHA 2019
18. Source: IRENA 2019
19. Source: IEA 2019
20. Source: Negócios 2019

Prosumers could reduce load by 6% and energy flow by 17% while storage solutions could mean a 59% decrease in ramp rate and a 14% peak load reduction

16. Energy load of centralized grid



With impact of prosumers

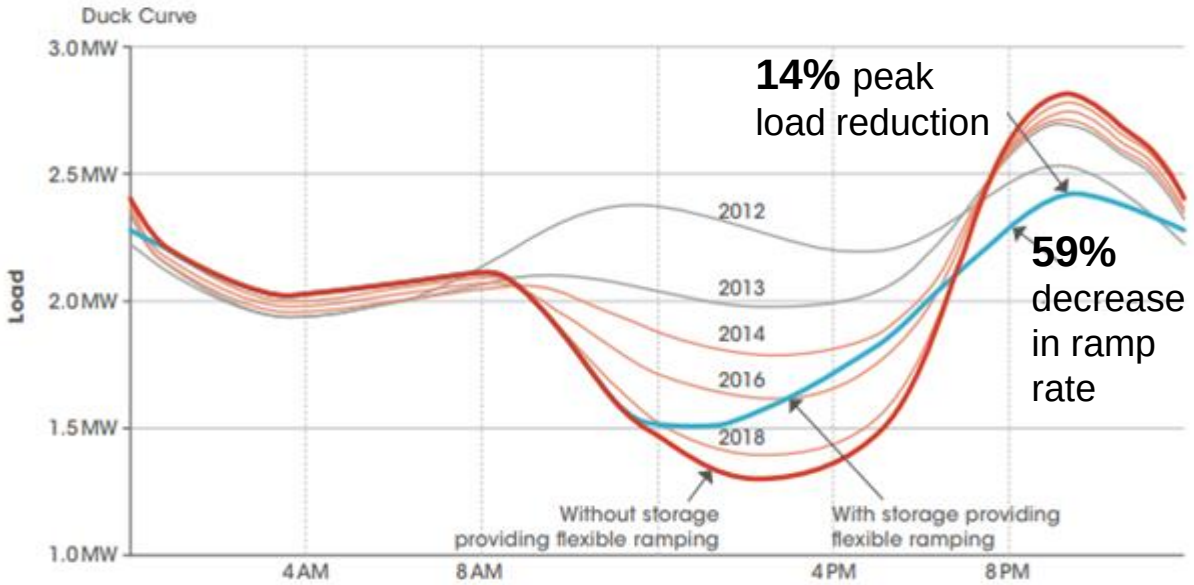
Without impact of prosumers

PV prosumers with batteries demand less from the grid.
Effect could reduce:

- max. load by **-6%**= $\frac{791\ GW}{843\ GW} - 1$
- Total energy flow by **-17%**=$\frac{4410 TWh}{5304 TWh} - 1$

Blue line shows that storage smooths energy load

17.Energy load throughout the day taking storage into account



5. Source: Child et al. 2019
21. Source: Sunverge 2019

Combining RE and storage is the obvious solution to minimize curtailment and smooth the duck curve through the investment in policies, regulation and education

 Prosumers/Utility scale storage	• Reducing upfront costs and the economic viability gap (subsidies) • Regulation that enable revenue streams for storage providers • Deploy storage as a solution to reduce overall investments in network reinforcement
 Hydrogen	• Path to cost reductions and competitiveness is unclear, governments play crucial role • Multilateral initiatives can help share knowledge and leverage spillovers benefits • Hydrogen in the gas grid (re-use already built infrastructure)
 V2G	• Allow discharge power back to the grid (bidirectional flow) • Demand response: Automatic regulation and efficient planning based on routine • Establish funding for pilot projects and disseminating knowledge

11. Source: IEA 2019
19. Source: IEA 2019

Market still dominated by big players but as the generation capacity increases new players and ambitious projects can arise as long as the Trilemma is satisfied

- Most countries have a **single Transmission System operator (TSO) in charge** of the transport of energy
- High capital intensive business requirements promotes industrial conglomerates (e.g Siemens)
- Increase in generation capacity, creates the need for expansion and interconnection of remote areas

Rules of the game: must fulfill one of the aspects of the trilemma

Affordability	• Bulk transfer and high-voltages minimizes costs and losses within long distances — DESERTEC FOUNDATION
Sustainability:	• Curtailment reduction through path creation towards demand and storage — SUPERNODE
Reliability:	• Decentralized storage increases flexibility — TESLA

18. Dynamic between players

Manufacturer

Supply and install networks

TSO

Manage network and deliver the commodity

edp

Utilities

Distribute to end user

22. Source: Entsoe.eu 2019
2. Source: Liu 2015

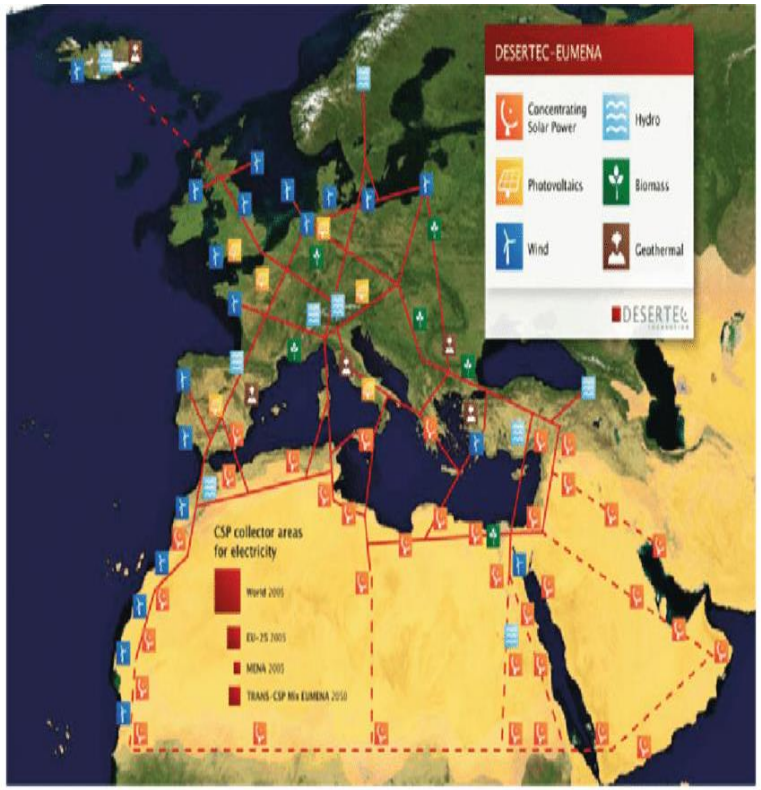
Desertec dreams about supplying the world's energy demand through Africa's desert

Case In Point

DESERTEC FOUNDATION

Large Scale production of solar power in North Africa and Middle East combined with renewable energy sources to Central Europe

Concept	• Large-scale solar and wind energy can be developed in the deserts of North Africa and Middle East • Cheap energy source outweighs the tranmission costs
How it works	• **Solar energy is concentrated by means of mirrors to heat water** • Steam is used to drive generation turbines • **HVDC lines up to 3000 km** (2-3% losses / 1000km)
Pros	• Heat is easily stored without losses • Response to fluctuations allows greater use of intermittent resources
Investment	• Total investment would range between **€400B- €480B** • Transmission costs could account for 11**% of total cost** • 20 or more HVDC cables (€1B each)



19.Illustration of the ideal Desertec set-up

23. Source: DESERTEC Foundation 2019
24. Source: New Internationalist 2019
25. Source: Hirschhausen et al. 2019

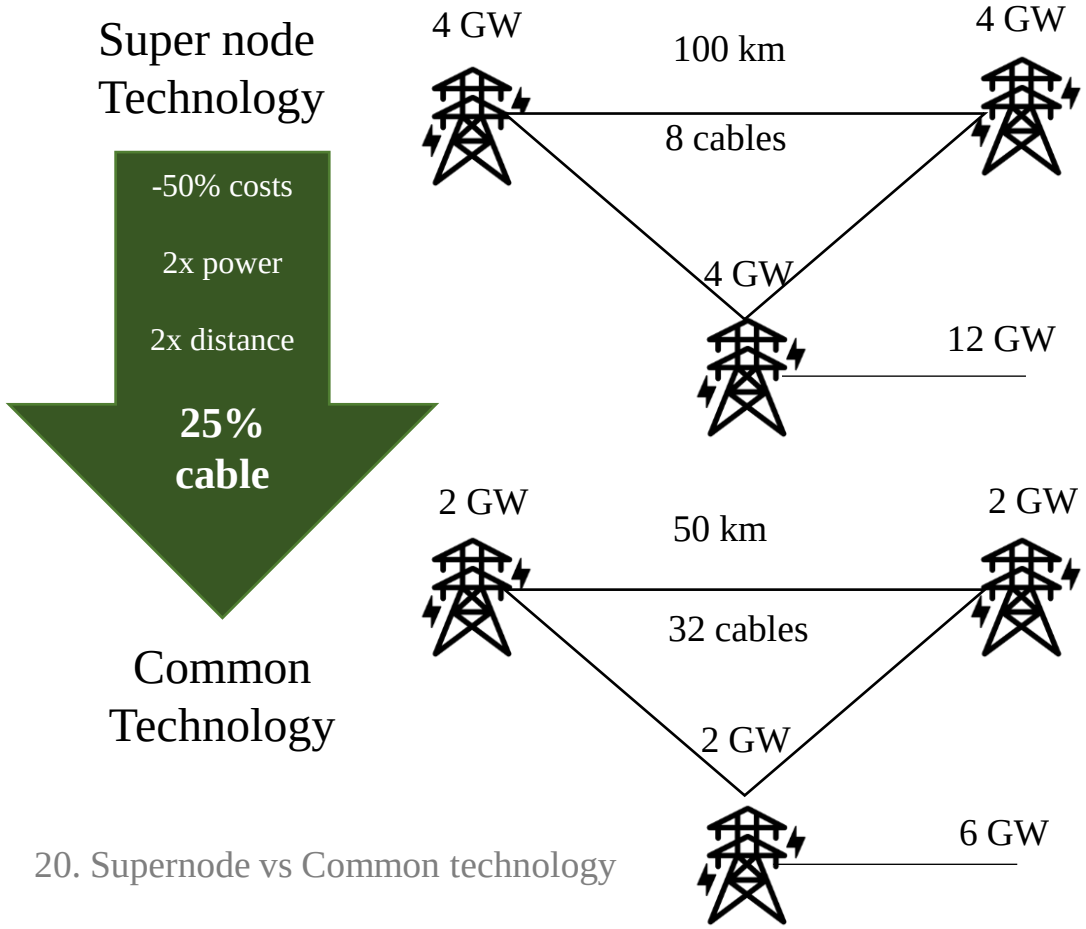
Supernode's technology can cut in half the transmission costs with twice the power and the cable distance with only 25% of the cables

Case In Point

SUPERNODE™

Collect the local renewable energy and route it across the Super Grid to where it is needed

Concept	• RE costs are dropping but not the cost of interconnecting • Scalability: increase the amount of renewables that can be connected to reduce fixed cost
How it works	• Superconductivity: less cable distance and higher power density of the system reduces the cost significantly
Pros	• Operates at higher current (10kA vs 2kA) • Zero resistivity = zero losses versus conventional tech
Investment	• **€20.5 B vs €44.4 B** to build 24 GW transmission capacity • Transmission costs: **6.50 €/MWh vs 14.07 €/MWh**



20. Supernode vs Common technology

7. Source: Supernode Energy 2019

Battery saved consumers $34m in its first year of operation and those savings will grow when the 50% expansion is completed in 2020

Case In Point

TESLA

Electric car manufacturer which developed a battery that stabilizes the Australian grid

Concept	• Australia has been deploying wind and solar generation at a record pace • Led to exposure of grid destabilization and need for a storage solution
How it works	• Battery is paired to the Hornsdale windfarm • 100 MW capacity and plan to expand 50% • 129 MWh which is enough to supply about 30k homes for 1 hour and **$34m in savings** in the 1st year
Pros	• Provided grid reliability • Rapid and precise frequency regulation • Reduced energy costs • Successful integration of RE into the grid
Investment	• **Intention to expand the battery by 50% to 150 MW** • Australian Federal Government of RE commited **$8 m** • South Australian government will commit **$3m / year for 5 years**

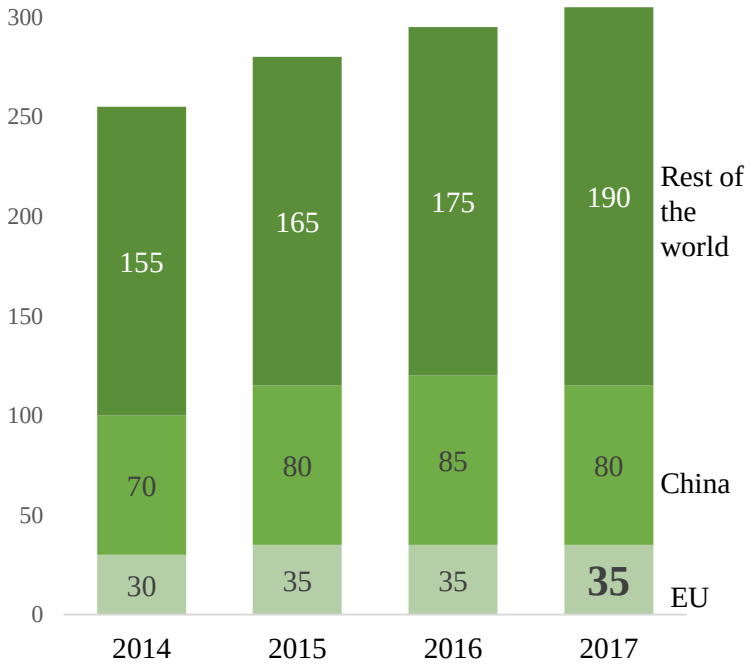
21. 100 MW battery in Hornsdale Site

26. Source: Financial Times 2019
27. Source: Toscano 2019

Investments can potentially twofold in EU and storage's share is perceived to grow significantly in the optimistic

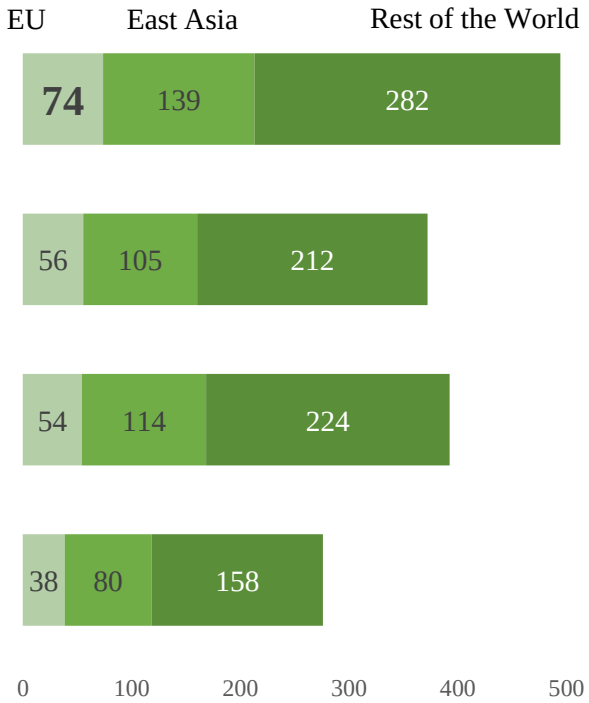
Investments have grown modestly

22.Annual investments in electricity networks [2014-2017, $B]



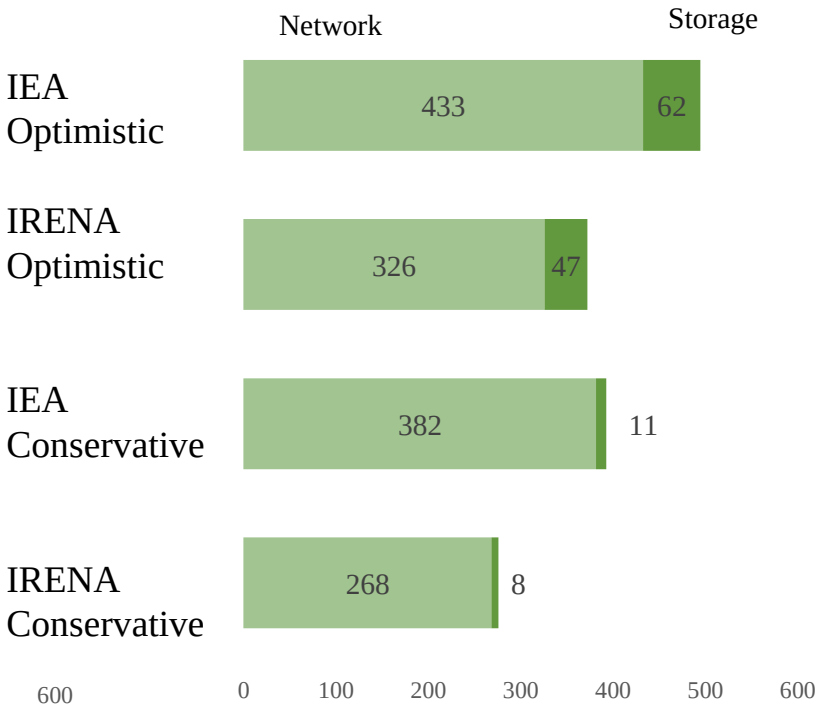
EU is roughly half of East Asia

23.Average yearly investments by **Region** [2050, $B]



Storage changes drastically

24.Average yearly investments by **Scope** [2050;$B]



In the optimistic scenario there is a greater need to have EU balanced with China in terms of infrastructure, ergo a higher growth level in investments is predicted as EU is currently falling behind

28. Source: IRENA 2019
29. Source: IEA 2018

A Work Project, presented as part of the requirements for the Award of a Master's degree in Economics / Finance / Management from the Nova School of Business and Economics.

Investment Opportunities

33135 – Pedro Miguel Galhano da Cruz

33257 – José Miguel Alves Sabino De Carvalho Farinha

33878 – Bruno Alexandre Link

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In light of a sustainable energy transition, what are the key changes across the multiple sectors and what opportunities will emerge?

Abstract

1 Demand

Demand for energy and renewable sources is increasing. The buildings segment has the potential to have the largest share of renewable-produced energy followed by industry, yet transport can face the highest growth. Greater investment opportunities will emerge in buildings and transport with new technology and low-carbon policies unlocking new business models in areas like demand flexibility, efficiency and e-mobility

2 Transmission

Transmission development comes as a result of the rise in demand, generation capacity and the distance that separates these two. These constraints can be addressed through a set of solutions which complemented, meet the requirements of a flexible integrated transmission

3 Generation

The generation energy market once dominated by massive oil companies is experiencing changes that allow new types of players. The 2050 scenarios show large increases in renewable technologies total installation capacities and power generation mainly in wind and solar power as well as a great investment opportunity in wind power

4 Investment Opportunities

A cleaner energy market will diversify the ecosystem and change the nature of factors to succeed across demand, transmission and generation. Investment opportunities will be greater in energy demand and the total investment of the three areas combined represents 3.1% of the World GDP. This new ecosystem will allow new players to emerge and fragment a former highly concentrated market with increased uncertainty, encouraging partnerships

Keywords: diversify, demand, ecosystem, fragmentation

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A cleaner energy market will diversify the energy ecosystem and change the nature of plays and factors to succeed across the three main stages of the energy market

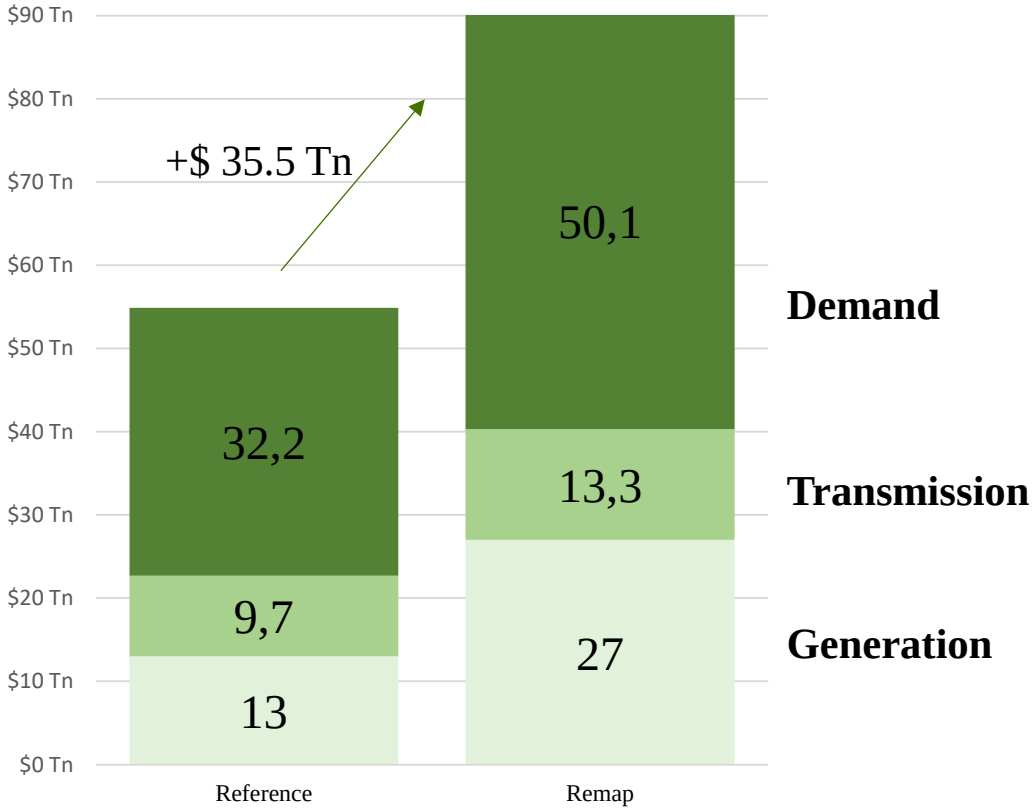
	Energy Demand	Transmission	Generation
Nature	• Virtual Power Plants • Efficiency Energetic Consultancy • E-Mobility Services	• Grid connection • Connect farms • Storage	• New plays/players • Innovative Technologies • Hybrid Systems
KSFs	• (F) High initial investments incentivise partnerships to lower costs down the line • (T) Rapid deployment of smart meters, smart grids and electric mobility technology • **(R) Subsidies to electric mobility and incentives for buildings to adopt efficiency standards**	• (F) Public private partnership to finance the high costs of projects such as power storage batteries • (T) Reduce CSP installation costs • **(R) International and intercontinental cooperation**	• (F) Pay-as-you-go: reducing upfront costs for the consumers • (T) Smarter Balance-of-System technologies • **(R) Support regulatory and pricing policies to allow consumers to become prosumers and sell electricity**

(F) Financial (T) Technological (R) Regulatory

Investment opportunities will be greater in energy demand, meanwhile total investment per year in the three areas combined represents 3.1% of the World GDP

Regardless from the scenario, **demand** investments will be far superior than the other two and the REmap scenario will require almost $35.5 Trillion more

Total investment in USD Trillion from 2016-2050 in 2 Scenarios



- **Demand**

Includes efficiency measures deployed across the end-use sectors – buildings, transport and industry

Investment per year (Remap): $**1.47 Trillion**

- **Transmission**

Includes investments made for transmission and distribution grid extensions as well as storage

Investment per year (Remap): **$391 Billion**

- **Generation**

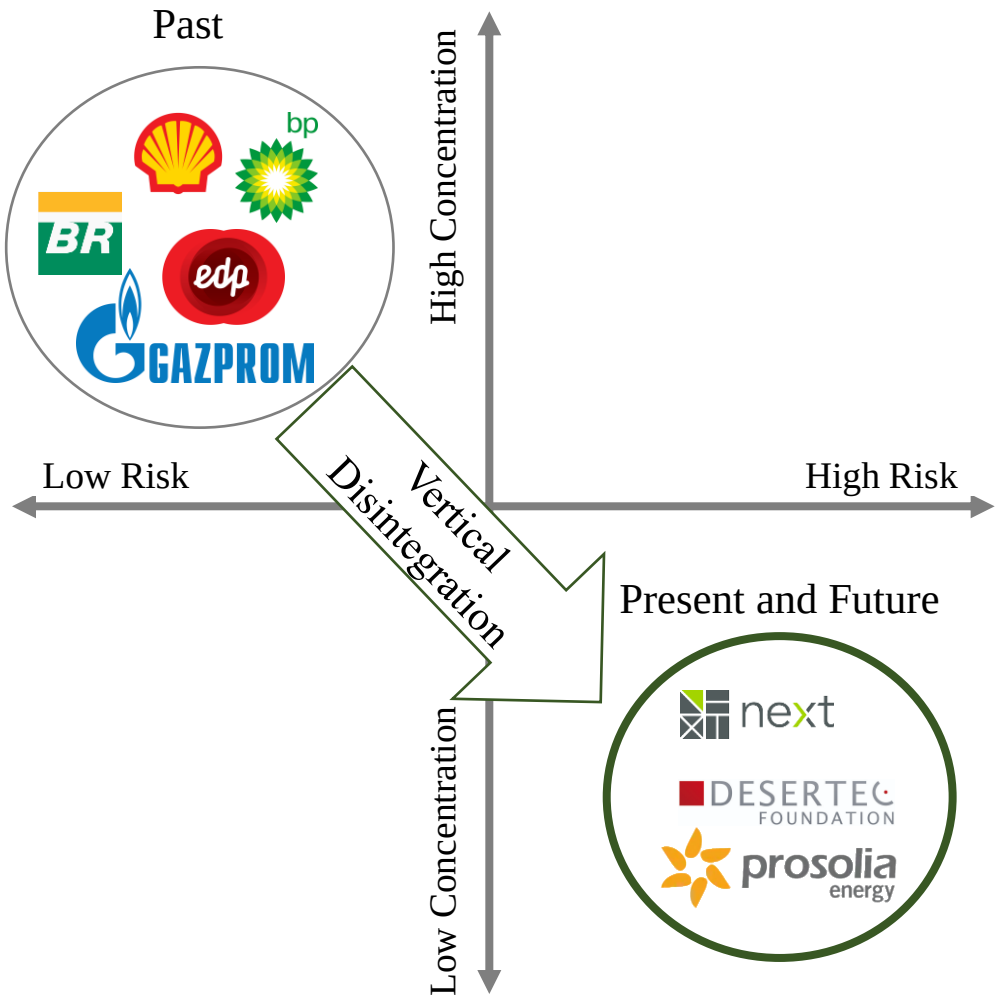
Includes investments for the deployment of renewable technologies for power generation such as capacity construction, operation and management

Investment per year (Remap): **$794 Billion**

Total combined investment per year = **$2.655 Trillion** which represents **3.1%** of the **World GDP** ($85.909 Trillion in 2018)

1. Source: IRENA 2019
2. Source: World Bank 2019

The new ecosystem will allow new players to emerge and fragment the former highly concentrated market encouraging partnerships to split risks and costs due to uncertainty



1. For the past century, **large players have dominated the energy ecosystem**, funded solely by public markets and governments

2. Technology and sustainability concerns are spawning **new business models and types of players** funded by pension funds and private-equity firms

3. This **fragmentation** is diminishing the power of scale to shape markets

4. With so many players interacting in different ways and locations, **uncertainty and risk** are higher than ever

Recommended Strategy

- Companies should make smaller initial investments and be flexible in adjusting strategies as circumstances change
- Partnerships can help companies splitting the cost and risk of large capital projects under high risk and uncertainty

3. Source: McKinsey & Company 2017

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Investment Opportunities

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