Towards a Global Electricity Grid

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CIGRE UK Study Committee C1 Technical Liaison Meeting

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Introduction to Global Electricity Grid

- **History: CIGRE WG C1.35 in 2019** performed the first known quantitative **feasibility study for the concept of a global electricity network**
- **Motivation of a Global Grid**: Among other advantages, interconnections help the power system to **take advantage of diversity from different timezones, seasons, load patterns and renewable energy availability**, thus supporting a balanced coordination of power supply of all interconnected countries.
- **The objective of WG C1.44:** extend the results of **WG C1.35** and make them more robust, by considering different **storage options**, **demand response**, transmission within continental regions, and **trading rule and governance** of a global grid.

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Introduction to Global Electricity Grid

- **TB for WG C1.44 published in 2024**
- The **two main data sources** were the International Energy Agency (**IEA**), and the World Energy Council (**WEC**).
- The geographic model used with **C1.44** increased the **granularity of grid architecture** from the previous **C1.35** study, from **13 to 22** regions
- Climatological data at a **0.5°x 0.625°** (latitude x longitude) **spatial resolution**

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TECHNICAL BROCHURE

Global Interconnected and sustainable electricity system

Effects of storage, demand response and trading rules

WG C1.44

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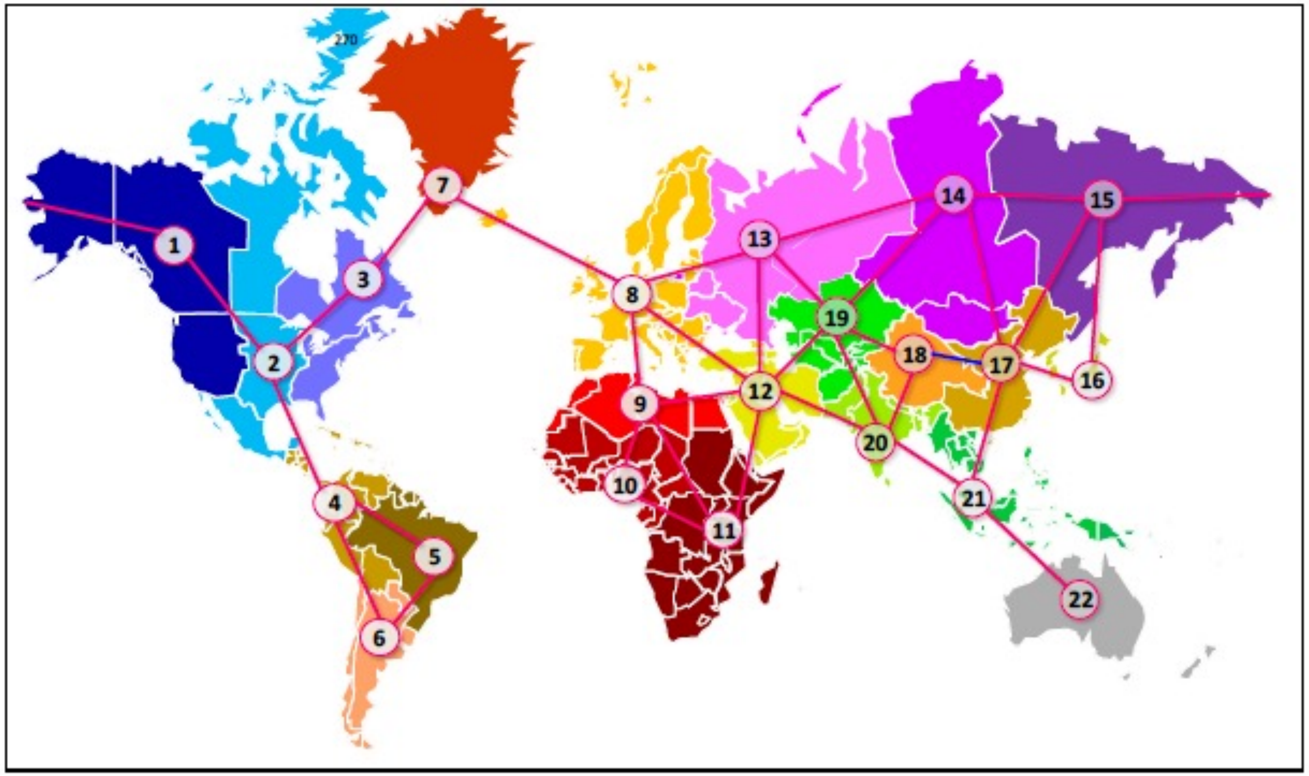
22-Region Global Electricity Grid Model with 35 Interconnectors



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Methodology for Analysis of Global Electricity Grid

- In an hourly optimisation algorithm, a transmission expansion approach based on linear (DC model) zonal optimisation.
- Correlating **internal continental grid analysis with global grid developments** needs a multiple loop procedure.
  - Stage 1: initial intercontinental/**global grid analysis without transmission expansion**
  - Stage 2: initial pan-continental/**regional analysis without transmission expansion**, keeping frozen the external flows
  - Stage 3: updated pan-continental/**regional analysis with transmission expansion**
  - Stage 4: updated intercontinental/**global grid analysis with transmission expansion**, keeping frozen the external flows
  - Stage 5: further updated intercontinental/**global grid analysis (with transmission expansion)** and **pan continental analysis (with internal transmission expansion) are jointly performed,** keeping frozen the external flows.

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Impact of DR, STORAGE and INTERCONNECTION

CS #	Variables					Results			
	Grid Configuration	Demand Response	Storage	CO2 Cost	Grid Cost	Cost (€/MWh)	CO2 (Mt/yr)	Cost evolution (%)	CO2 evolution (%)
1	Isolated	No DR	No ST	mid	-	49.0	453	Reference	
2	Isolated	No DR	ST	mid	-	48.6	316	-1%	-30%
3	Isolated	DR	No ST	mid	-	49.0	457	0%	+1%
4	Isolated	DR	ST	mid	-	48.7	330	-1%	-27%
10	Interconnected	No DR	No ST	mid	mid	46.5	242	-5%	-47%

- Regarding COST:
  - DR has **no impact** on the COST
  - STORAGE have a moderate impact on the COST which decrease only by **less than 1%**
  - INTERCONNECTION falls the COST by **-5%**
- Regarding CO2 emission:
  - Globally, DR slightly increase the CO2 emission level by **+1%**
  - STORAGE decrease CO2 emission by **-30%**
  - INTERCONNECTION with a fall of **-47%**

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Impact of STORAGE, DEMAND RESPONSE in INTERCONNECTION configuration

CS #	Variables					Results			
	Grid Configuration	Demand Response	Storage	CO_2 Cost	Grid Cost	Cost (€/MWh)	CO_2 (Mt/yr)	Cost evolution (%)	CO_2 evolution (%)
10	Interconnected	No DR	No ST	mid	mid	47,1	309	Reference	
11	Interconnected	No DR	ST	mid	mid	46,9	230	-0,5%	-26%
12	Interconnected	DR	No ST	mid	mid	47,2	294	+0,4%	-5%
13	Interconnected	DR	ST	mid	mid	47,1	239	0,0%	-23%

- Impact on COST: Globally in interconnected configuration
  - ➢ STORAGE slightly decrease the cost
  - ➢ DR has a negative impact on the yearly average COST which slightly increase
- Impact on CO_2 emission:
  - ➢ With STORAGE, CO_2 emissions fall by -26%
  - ➢ With DR, CO_2 emissions slightly decrease by -5%

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Trading rules on global interconnections

- The case of Europe with ENTSO-E can be taken as reference for its evolution to a regional/multilateral up to continental power pool for common electricity market and trading
- A gradual approach for trading – from bilateral to multilateral, regional, continental up to global level – is necessary and should be followed
- Commercial transactions are to be covered/hedged from external risks: geopolitical risk, environmental risk, climate change adverse impacts risk, legal/investment risks, financial/bankability risks, technical/operational risk
- Long-term power purchase agreements (PPA) should be considered as means for viability of new RES investments
- Regional institutions should be promoted and created, in the form of Regional Energy Committees or Regional Coordination Forums
- Bilateral energy trading — The market model for energy trading and using transmission capacity should be as simple as possible

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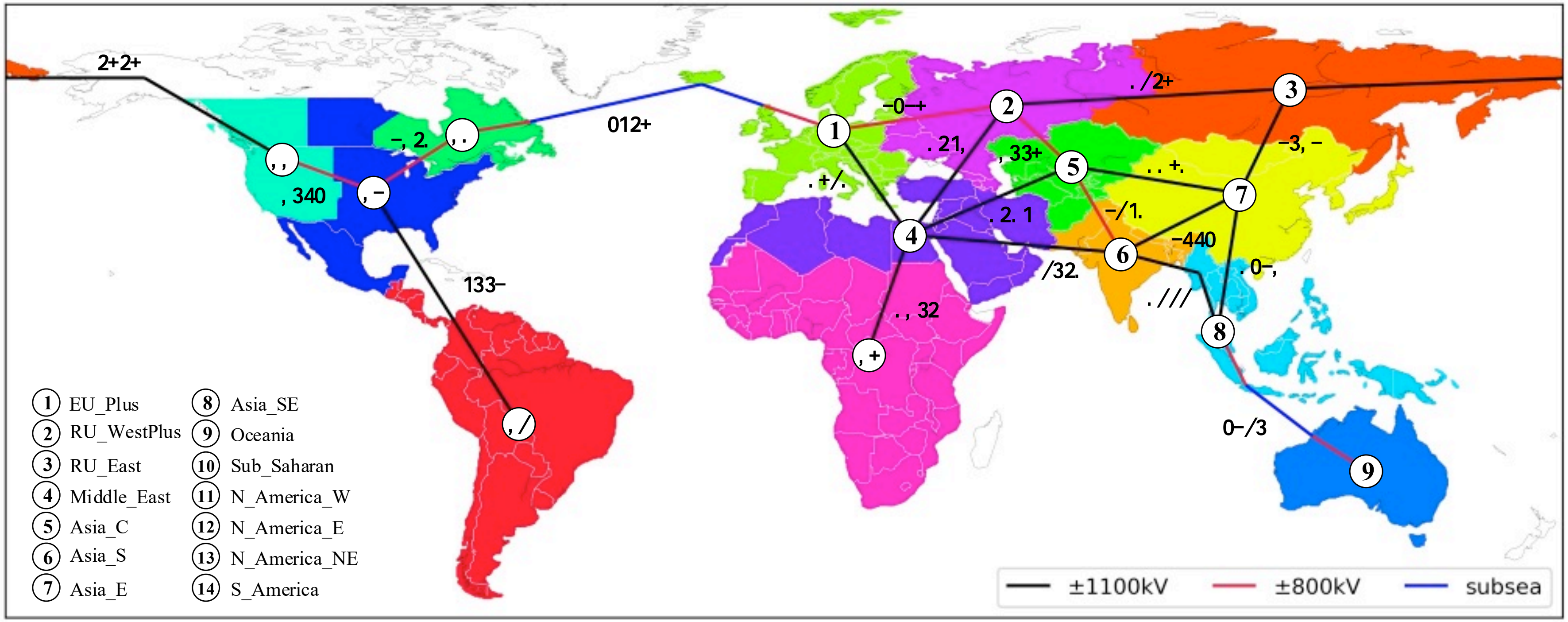
Global electricity grid with 100% renewable energy: 14-regions

Global 14 regions and 20 potential interconnection routes



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Global electricity grid with 100% renewable energy: Data resolution and model

- Detailed hourly demand and generation data series for 14-region global electricity grid for 12 months: Global hourly meteorological re-analysis data of up to seven years with **spatial resolution of $0.25^{\circ} \times 0.25^{\circ}$** is converted into solar, onshore, and offshore wind power series respectively, leading to a total of 224,750 grid cells for land areas and 19,958 grid cells for marine areas.
- **Hourly generation** within those cells are selected, aggregated, and further clustered into one year regional series based on weight-based aggregation rules and density-based cluster algorithms.
- With minimum annual system cost of the whole **14-region global grid** whose demands in 2050 are expected to be met by **100% RE, i.e., wind, solar, hydropower**, energy storage to determine the additional capacities of RE technologies, electricity storage systems, and the interconnectors since 2030.
- Load curtailment and **'*N*-1' security of interconnectors** are considered.

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Global electricity grid with 100% renewable energy: Interconnector capacity

Route NO.	Capacity (GW)	Annual cost (billion $)		
		Capital	O&M	*Sum*
1	409	14.0	2.9	*17*
2	138	6.8	1.3	*8*
3	169	5.0	1.0	*6*
4	564	24.4	5.0	*29*
5	218	10.4	2.1	*12*
6	151	5.0	1.0	*6*
7	74	3.2	0.6	*4*
8	94	4.2	0.8	*5*
9	84	5.3	1.0	*6*
10	46	2.0	0.3	*2*
11	18	0.8	0.1	*1*
12	24	4.1	0.6	*5*
13	0	0.0	0.0	*0*
14	245	7.8	1.6	*9*
15	412	13.9	2.8	*17*
16	545	47.5	9.7	*57*
17	136	11.5	2.2	*14*
18	62	3.1	0.6	*4*
19	0	0.0	0.0	*0*
20	179	8.8	1.7	*11*
Sum	*3,568*	*178*	*35*	*213*

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Global electricity grid with 100% renewable energy: Regional additional annual cost and its breakdowns (billion $)

- 1892 billion USD ($) of the Base Reference Case
- 1519 billion USD ($) of the Optimal Case
- The interconnectors accounting for 14.0% of the overall cost

Region	Without interconnection							With interconnection						
	On-shore	Off-shore	Solar	Hydro	Storage	Load Curtailment	*Sum*	On-shore	Off-shore	Solar	Hydro	Storage	Load Curtailment	*Sum*
EU_Plus	117.8	13.4	22.9	30.1	22.0	4.2	210	0.0	0.0	11.7	0.4	6.6	0.5	19
RU_WestPlus	28.3	0.0	0.2	22.2	6.1	0.7	58	123.3	0.0	0.0	0.0	0.0	0.0	123
RU_East	8.5	0.0	0.7	0.2	1.2	0.2	11	57.1	0.0	0.0	0.1	2.8	0.0	60
Middle_East	19.9	0.0	40.6	0.0	75.6	2.0	138	44.8	0.0	31.2	0.1	39.0	0.4	116
Asia_C	3.7	0.0	4.4	0.0	5.2	0.3	14	57.5	0.0	0.0	0.0	0.2	0.0	58
Asia_S	0.0	0.0	97.4	17.7	165.4	5.3	286	0.0	0.0	70.2	0.6	122.1	0.3	193
Asia_E	25.6	0.0	244.5	0.5	315.4	18.7	605	51.0	0.0	154.6	2.2	132.6	0.0	340
Asia_SE	0.0	0.0	62.4	0.3	85.3	0.4	148	0.0	0.0	54.7	0.6	68.7	0.1	124
Oceania	3.0	0.0	1.7	3.4	4.4	0.2	13	6.9	0.0	0.5	0.0	1.1	0.1	9
Sub_Saharan	0.0	0.0	31.2	0.5	54.1	0.6	86	18.9	0.0	23.2	0.5	36.1	0.1	79
N_America_W	0.0	0.7	9.2	8.9	11.8	0.8	31	0.0	0.0	29.2	0.3	5.1	0.0	35
N_America_E	54.5	0.0	65.6	8.1	84.8	3.8	217	4.4	0.0	36.9	0.3	28.3	0.0	70
N_America_NE	2.1	0.0	2.7	1.9	2.1	0.6	9	44.1	0.0	0.0	0.2	0.0	0.0	44
S_America	0.0	0.0	25.0	2.2	37.8	1.2	66	0.0	0.0	19.2	1.9	15.5	0.0	37
Sum	*264*	*14*	*608*	*96*	*871*	*39*	*1,892*	*408*	*0*	*431*	*7*	*458*	*1*	*1,306*

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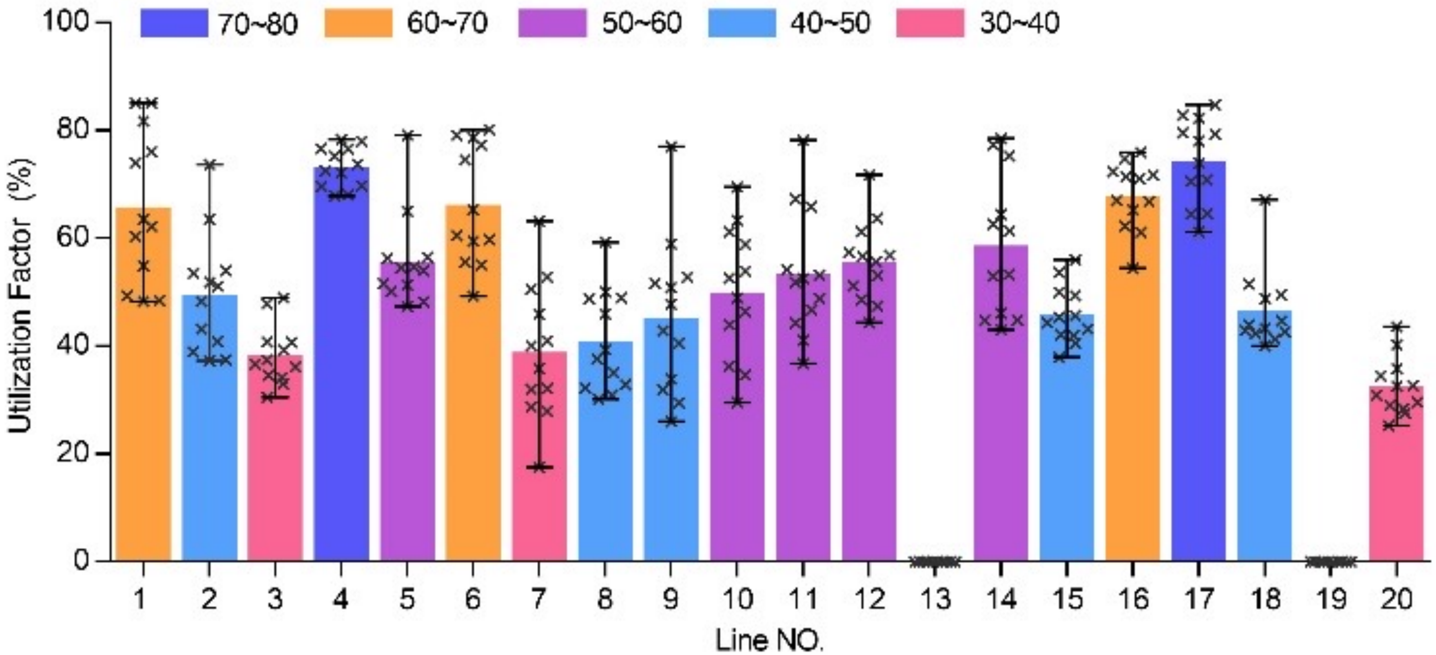
Global electricity grid with 100% renewable energy: Utilization factor of interconnectors

- all the deployed interconnectors have a higher annual UF than 30%
- annual UFs of 15 interconnectors and 5 interconnectors are higher than 40% and 60%, respectively



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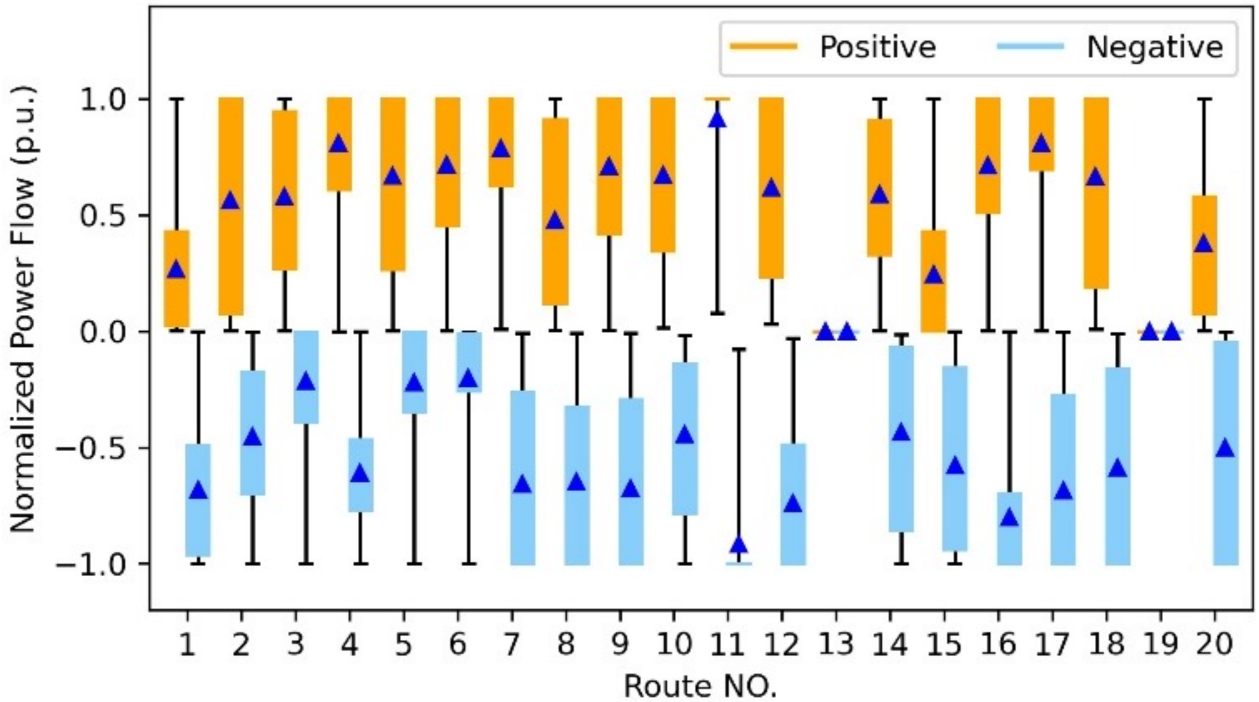
Global electricity grid with 100% renewable energy: Power flow patterns

- power flows of the interconnectors are changing dynamically over a wide range during a week, which indicates the value of interconnectors bring their market value into the real time balancing between demand and generation.



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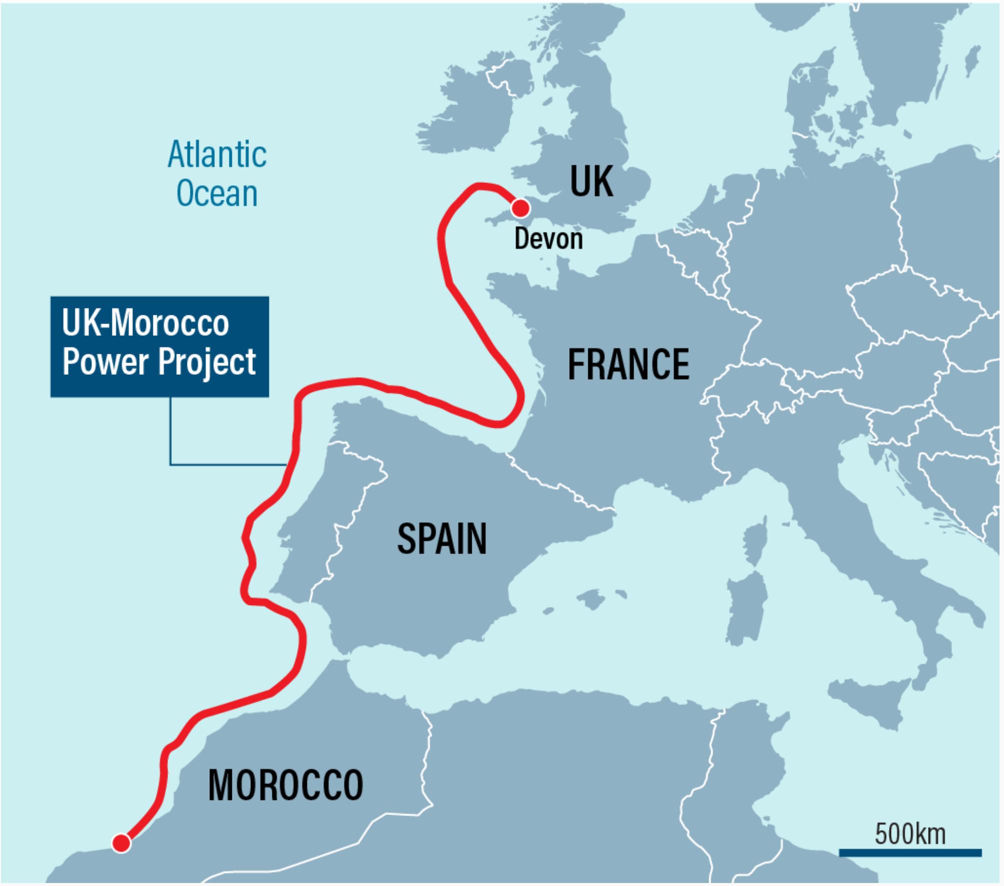
Xlinks Project – UK-Morocco HVDC Interconnector: The Beginning of a Global Grid

- **11.5 GW** of renewable generation, **22.5 GWh** of battery storage and a **3.6 GW** HVDC interconnector to carry solar and wind-generated electricity from Morocco to the UK
- **3800km**



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Global electricity grid with 100% renewable energy: Governance

- There are **political, economic and technical challenges for Global Electricity Grid.** These can be resolved by proper organizational arrangements.
- The **concept of 'Energy Union' for the Global Grid governance** was proposed at the workshop "The transmission grid that Europe needs - Strengthening cross-border interconnections within Europe and across the Mediterranean" at the EU Sustainable Energy Week hosted in the European Parliament, Tuesday, 25 June 2013
- **In 2015**, European Commission subsequently **established the Energy Union** to lead the energy transition in Europe
- Globally we **may need a World Energy Organisation (WEO)!**

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- Due to the time differences and availability of renewable energy sources, it would be desirable to build a **24-hour interruptible global electricity grid** to tackle the availability and uncertainties of renewable energy and hence reduce the energy storage costs and hence the total investment costs.
- Global HVDC interconnectors for **Global Grid with 100% renewable energy** become attractive for people to work towards net-zero transition with **20% investment savings**
- **Xlinks Project** – UK-Morocco HVDC Interconnector: **The Beginning of a Global Grid**
- Global organisations like **Energy Union or World Energy Organisation** are needed to **provide the leadership**
- There are also needs to educate the **next generation engineers** to develop and implement such initiatives

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Further reading

- **CIGRE WG C1.44 TB**: Global Interconnected and sustainable electricity system Effects of storage, demand response and trading rules, September 2024 - Reference 938

- **"Global Electricity Interconnection with 100% Renewable Energy Generation,"** IEEE Access, vol. 9, pp. 113169-113186, 2021, doi: 10.1109/ACCESS.2021.3104167.

  https://ieeexplore.ieee.org/document/9511456

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