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A SUSTAINABLE GLOBAL ENERGY OUTLOOK

GREENPEACE

Webinar September 2015

Dr. Sven Teske

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The E[R] Power Sector Logic

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FIGURE 3.3 | THE EVOLVING APPROACH TO GRIDS.

CURRENT SUPPLY SYSTEM:

- LOW SHARES OF FLUCTUATING RENEWABLE ENERGY
- THE 'BASE LOAD' POWER IS A SOLID BAR AT THE BOTTOM OF THE GRAPH.
- RENEWABLE ENERGY FORMS A 'VARIABLE' LAYER BECAUSE SUN AND WIND LEVELS CHANGES THROUGHOUT THE DAY.
- GAS AND HYDRO POWER CAN BE SWITCHED ON AND OFF IN RESPONSE TO DEMAND. THIS COMBINATION IS SUSTAINABLE USING WEATHER FORECASTING AND CLEVER GRID MANAGEMENT.
- WITH THIS ARRANGEMENT THERE IS ROOM FOR ABOUT 25 PERCENT VARIABLE RENEWABLE ENERGY.

TO COMBAT CLIMATE CHANGE MUCH MORE THAN 25 PERCENT RENEWABLE ELECTRICITY IS NEEDED.

source GREENPEACE ENERGY [R]EVOLUTION 2012.

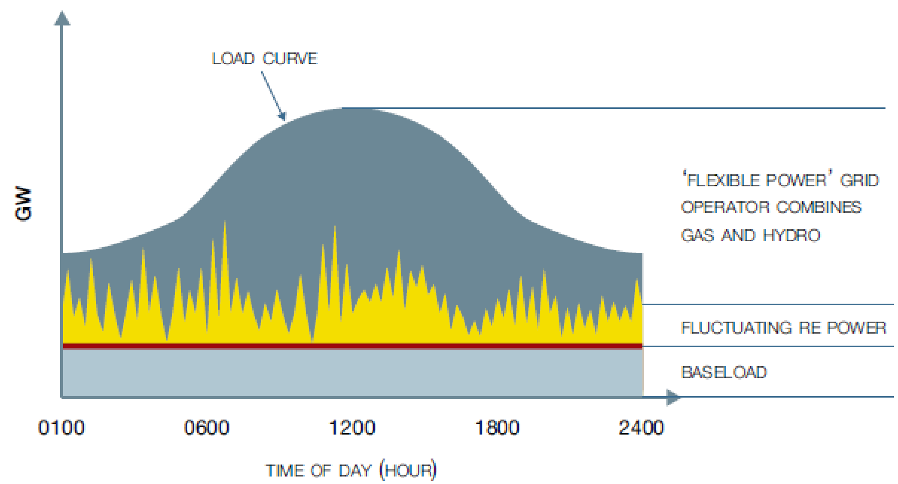

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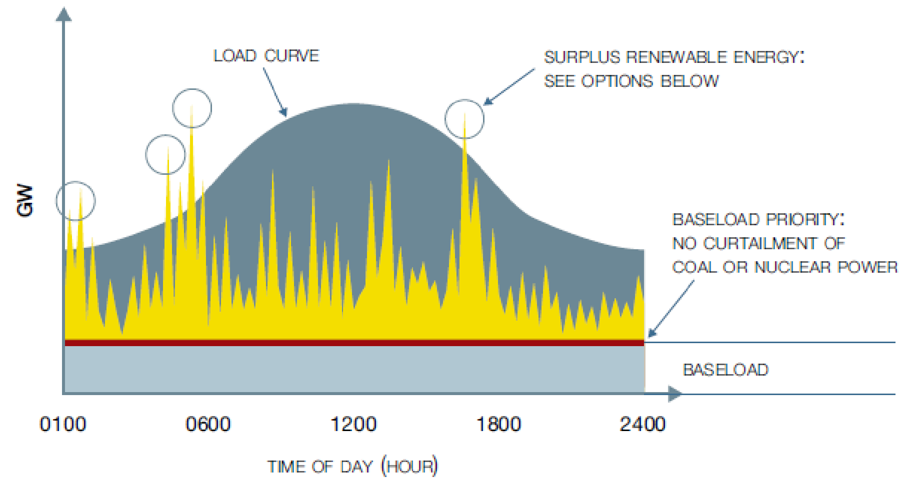
FIGURE 3.5 | **THE EVOLVING APPROACH TO GRIDS.** continued.

SUPPLY SYSTEM WITH MORE THAN 25 PERCENT FLUCTUATING RENEWABLE ENERGY > BASE LOAD PRIORITY:

- THIS APPROACH ADDS RENEWABLE ENERGY BUT GIVES PRIORITY TO BASE LOAD
- AS RENEWABLE ENERGY SUPPLIES GROW THEY WILL EXCEED THE DEMAND AT SOME TIMES OF THE DAY, CREATING SURPLUS POWER.
- TO A POINT, THIS CAN BE OVERCOME BY STORING POWER, MOVING POWER BETWEEN AREAS, SHIFTING DEMAND DURING THE DAY OR SHUTTING DOWN THE RENEWABLE GENERATORS AT PEAK TIMES.

THIS APPROACH DOES NOT WORK WHEN RENEWABLES EXCEED 50 PERCENT OF THE MIX, AND CANNOT PROVIDE RENEWABLE ENERGY AS 90- 100% OF THE MIX.



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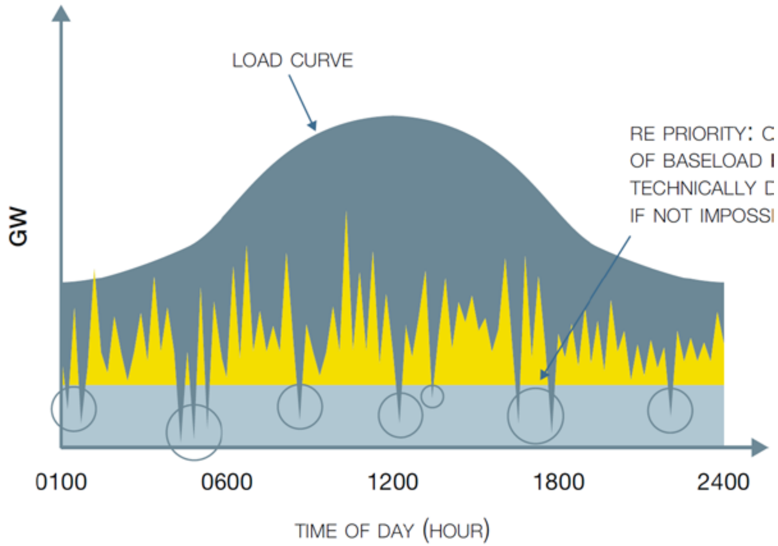
SUPPLY SYSTEM WITH MORE THAN 25 PERCENT FLUCTUATING RENEWABLE ENERGY – RENEWABLE ENERGY PRIORITY

- THIS APPROACH ADDS RENEWABLES BUT GIVES PRIORITY TO CLEAN ENERGY.
- IF RENEWABLE ENERGY IS GIVEN PRIORITY TO THE GRID, IT "CUTS INTO" THE BASE LOAD POWER.
- THEORETICALLY, NUCLEAR AND COAL NEED TO RUN AT REDUCED CAPACITY OR BE ENTIRELY TURNED OFF IN PEAK SUPPLY TIMES (VERY SUNNY OR WINDY).
- THERE ARE TECHNICAL AND SAFETY LIMITATIONS TO THE SPEED, SCALE AND FREQUENCY OF CHANGES IN POWER OUTPUT FOR NUCLEAR AND CCS COAL PLANTS.

TECHNICALLY DIFFICULT, NOT A SOLUTION.



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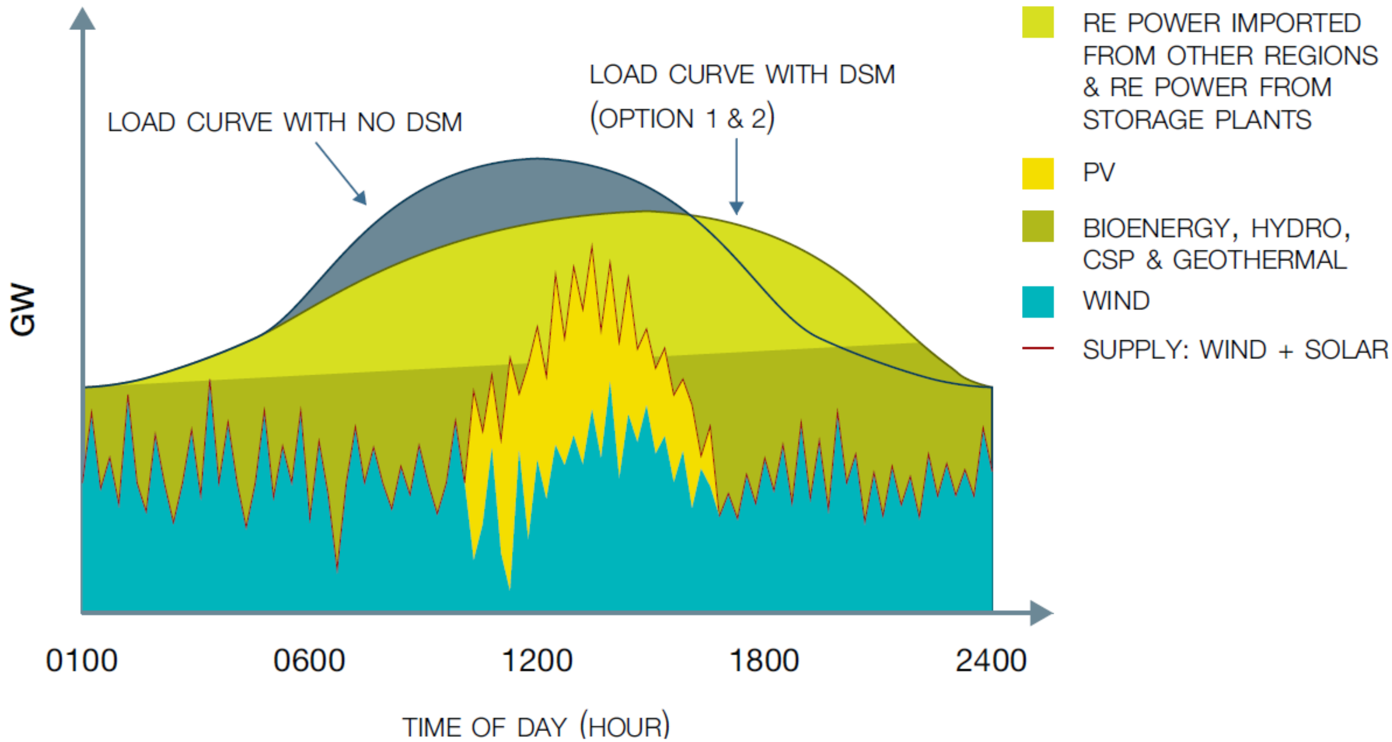

THE SOLUTION: AN OPTIMISED SYSTEM WITH OVER 90% RENEWABLE ENERGY SUPPLY

- A FULLY OPTIMISED GRID, WHERE 100 PERCENT RENEWABLES OPERATE WITH STORAGE, TRANSMISSION OF ELECTRICITY TO OTHER REGIONS, DEMAND MANAGEMENT AND CURTAILMENT ONLY WHEN REQUIRED.
- DEMAND MANAGEMENT EFFECTIVELY MOVES THE HIGHEST PEAK AND ‘FLATTENS OUT’ THE CURVE OF ELECTRICITY USE OVER A DAY.

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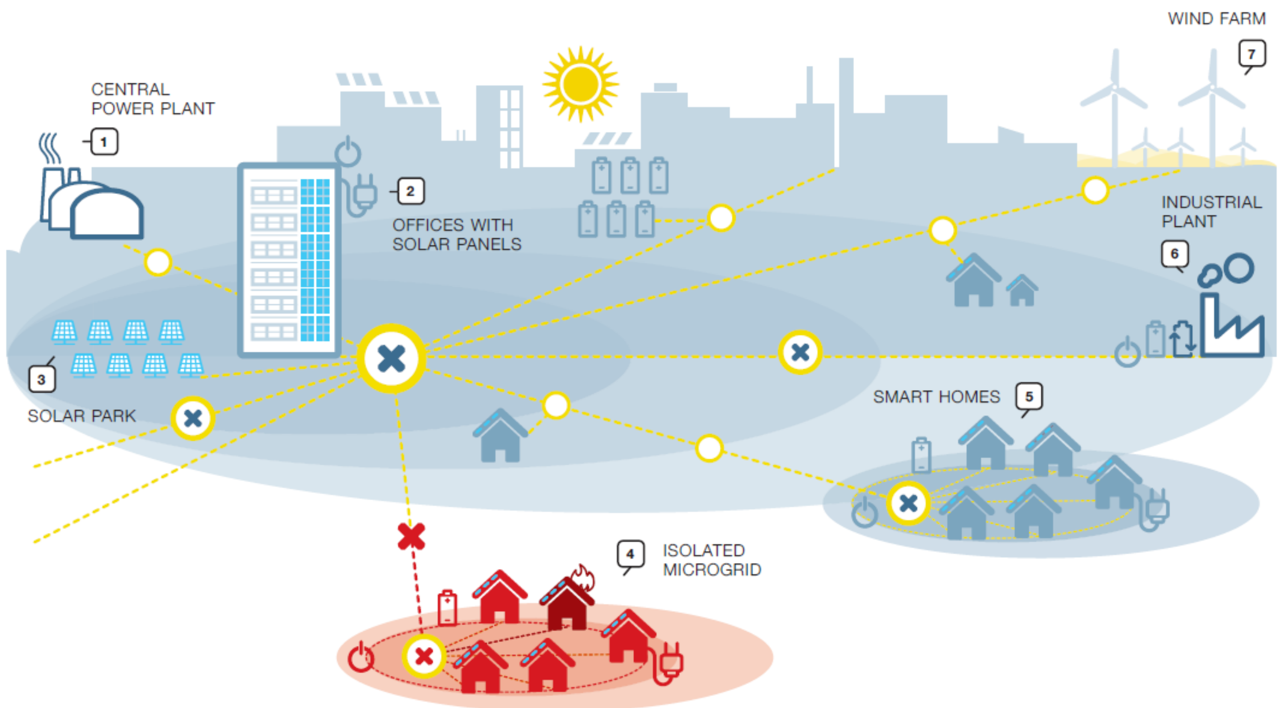
FIGURE 3.4 | **THE SMART-GRID VISION FOR THE ENERGY [R]EVOLUTION**

A VISION FOR THE FUTURE – A NETWORK OF INTEGRATED MICROGRIDS THAT CAN MONITOR AND HEAL ITSELF



PROCESSORS

EXECUTE SPECIAL PROTECTION SCHEMES IN MICROSECONDS

SENSORS (ON 'STANDBY')

DETECT FLUCTUATIONS AND DISTURBANCES, AND CAN SIGNAL FOR AREAS TO BE ISOLATED

SENSORS ('ACTIVATED')

DETECT FLUCTUATIONS AND DISTURBANCES, AND CAN SIGNAL FOR AREAS TO BE ISOLATED

DISTURBANCE

IN THE GRID

SMART APPLIANCES

CAN SHUT OFF IN RESPONSE TO FREQUENCY FLUCTUATIONS

DEMAND MANAGEMENT

USE CAN BE SHIFTED TO OFF PEAK TIMES TO SAVE MONEY

GENERATORS

ENERGY FROM SMALL GENERATORS AND SOLAR PANELS CAN REDUCE OVERALL DEMAND ON THE GRID

STORAGE ENERGY

GENERATED AT OFF-PEAK TIMES COULD BE STORED IN BATTERIES FOR LATER USE

source GREENPEACE ENERGY [R]EVOLUTION 2012.

report 2014

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poweE[R] 2030:

A European Grid for ¾ Renewable Electricity by 2030

Dr. Sven Teske

Background of the powE[R] 2030 study:

1. Report builds on two earlier analysis from 2009 and 2011 “[r]enewables 24/7”
   consulting company ENERGYNAUTICS and GREENPEACE INTERNATIONAL developed a European Grid Model

2. Grid Analysis “powE[R] 2030 compares 3 different cases to study:
   - requirements for grid integration of renewable power
   - requirements for grid expansion for 75% RE power by 2030

3. Challenge the current ENTSO-E Ten Year Development Plan (TYNDP)

Simulation of 3 cases:

1. **The Reference Case** is based on the ‘business as usual’ scenario of:
   - IEA Current Policies scenarios (WEO 2011)
   - power plant capacities for 2020 + 2030 are equal to ENTSO-E TYNDP

2. **The Greenpeace Energy [R]evolution Case for Europe** (published December 2012)
   - 75% renewable electricity by 2030
   - broken down to 30 countries (28 EU member states +Norway, Switzerland)

3. **The Conflict Case**
   - France, Czech Republic and Poland keep inflexible coal/lignite/nuclear power
   - E[R] case for all other European countries

Methodology: Installed capacity by case for Europe (EU 28 + 2)

table 1.4: installed capacities for reference, conflict and energy [r]evolution case (IN GW)

EUROPE	REF 2030	CONFLICT 2030	E[R] 2030
Coal	113,515	49,106	39,123
Lignite	45,004	18,758	15,119
Gas	282,090	230,163	239,363
Oil + Diesel	25,167	7,815	8,732
Nuclear	106,120	75,424	11,668
Renewable Total	**619,865**	**989,714**	**1,169,515**
Wind - Offshore	47,566	111,195	144,811
Wind - Onshore	227,630	292,409	348,797
Photovoltaic	125,322	302,189	369,878
Geothermal	2,365	10,852	12,896
Bioenergy	36,399	45,222	49,022
CSP	11,011	75,188	75,175
Hydro	169,572	152,659	168,936
Hydro Pump Storage	64,669	64,669	64,669

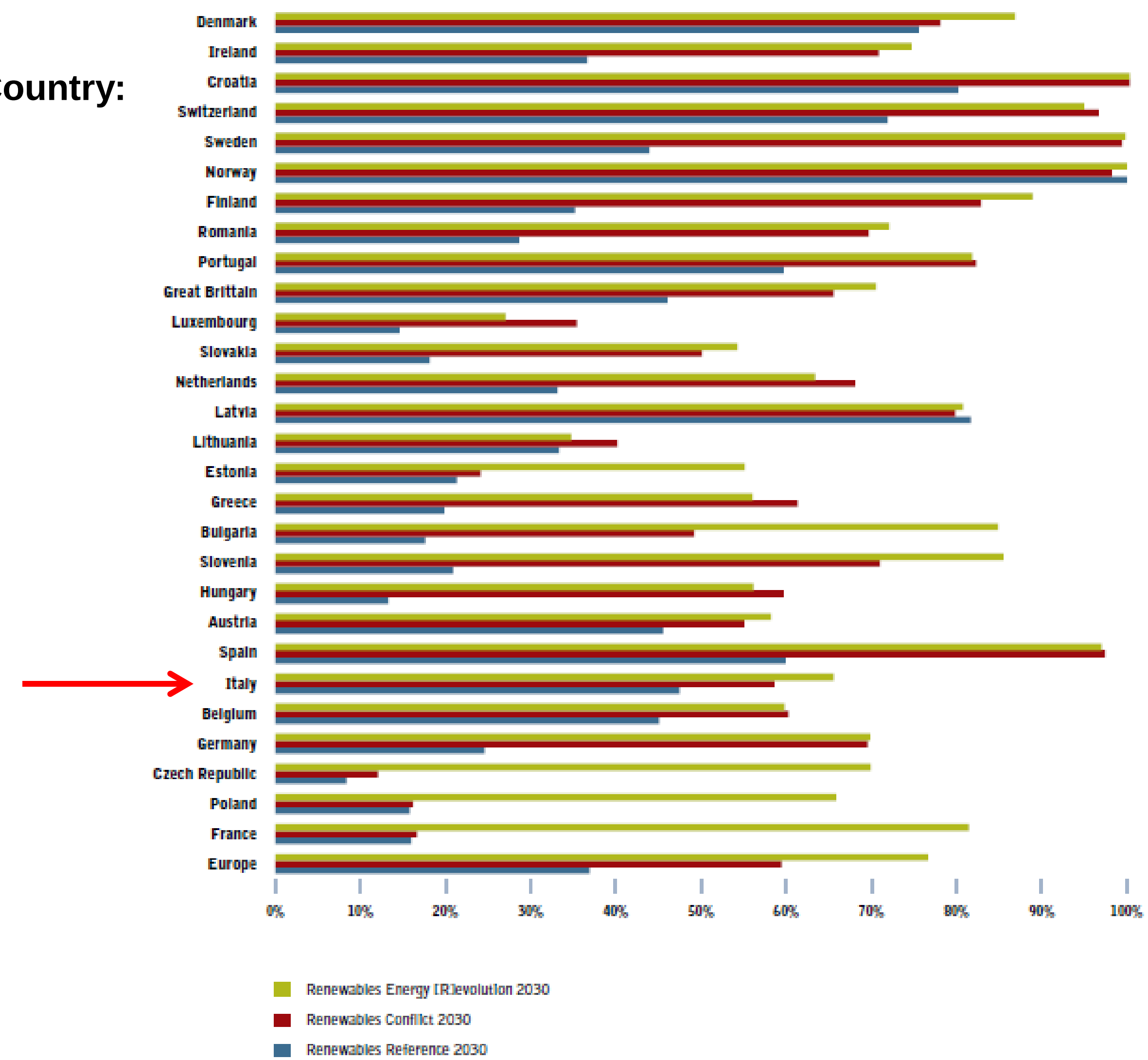
source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

RE electricty share: 37% 59% 77%

Methodology:

Renewable Electricity Share by Country:

figure 1.12: renewable electricity shares by country and scenario in 2030



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Methodology:

The network model:

• 200+ nodes representing major load and generation sites in ENTSO-E area

• 400+ AC lines for major transmission corridors with capacities [in MVA] and impedances

• All existing HVDC lines with capacities [in MW]

• ENTSO-E's Ten Year Network Development Plan (TYNDP) from 2012 split into mid- and long-term projects

• Network model built in *DIgSILENT PowerFactory*

source ENERGYNAUTICS 2014 - [illegible]

Methodology:

Inputs:

- Initial network topology
  - for High Voltage Alternating Current (HVAC)
  - and High Voltage Direct Current (HVDC)
  - with line capacities [MW] aggregated EU grid model

- Installed capacities
  - for all power plant technologies in Giga-Watt [GW]
  - yearly electrical load in Terawatt hours per year [TWh/a] for all European countries according to Greenpeace and/or IEA scenarios

- Energynautics' distribution key for how the technologies are distributed in each country
  - Wind and PV according to potential,
  - conventional generation sources according to existing capacity

- Time series for the weather year of 2011 to calculate the feed-in
  - for variable renewables, including wind and solar insolation;
  - the load profile for 2011 per country taken from ENTSO-E published profiles

Methodology:

Outputs:

- The necessary network extensions and costs

- Dispatch per node of technologies, including:
  - curtailment for variable renewables
  - load factors for controllable generators

- Network flows for AC and DC lines

Methodology: Costs taken from ENTSO-E

table 1.1: calculation of costs for the ENTSO-E TYNDP

(WITH ESTIMATED COST ASSUMPTION USED FOR ALL CASES IN THIS REPORT)

COUNTRY	LENGTH (KM)	ASSUMED CAPACITY (MVA)	TVAKM	COST (BILLION €)
DC subsea	9,000	2,000	18	19,800
DC underground	1,490	2,000	2.98	3,725
DC OHL	2,100	2,000	4.2	1,680
AC	36,700	1,500	55.05	24,497
AC cable	420	1,500	0.63	788
AC subsea	400	1,500	0.6	660
	Number of converter pairs		TW	
Converters for DC projects	22	2,000	0.044	6,600
Total	**50,110**			**57,750**

source VALUES TAKE FROM SECTION 7.2 OF TYNDP 2012 AT https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2012/

Methodology: Technologies Assumptions

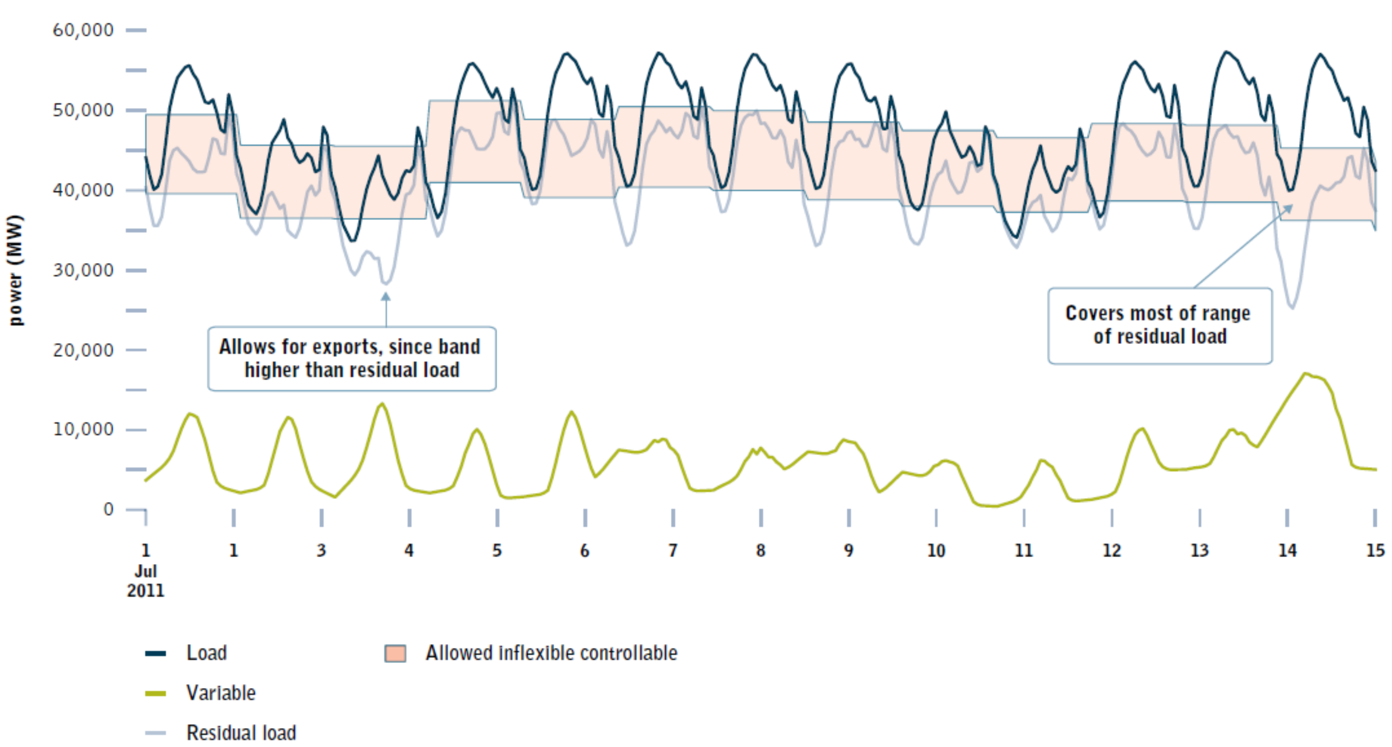
table 1.2: assignment of variable renewables and flexible/inflexible controllables to particular generation technologies

MODEL TYPE	TECHNOLOGIES	MODELLING PROPERTIES
Variable renewables	Wind onshore and offshore, PV	Weather dependent availability, curtailable to % of nominal power
Flexible controllables	Biomass, Hydro, Gas, Oil, Geothermal, CSP	Flexibly dispatchable
Inflexible controllables	Nuclear, lignite, coal	Can be inflexibly modelled
Pumped Hydro	Pumped Hydro	Storage flexibly dispatchable
PV batteries	PV batteries	Must-run profiles according to local self-consumption

source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

Methodology: Assumption for inflexible generation (coal and nuclear)

figure 1.8: example limited flexibility band (in pink) for two weeks in france in july



source ENERGYNAUTICS 2014 - POWE[R] 2030.

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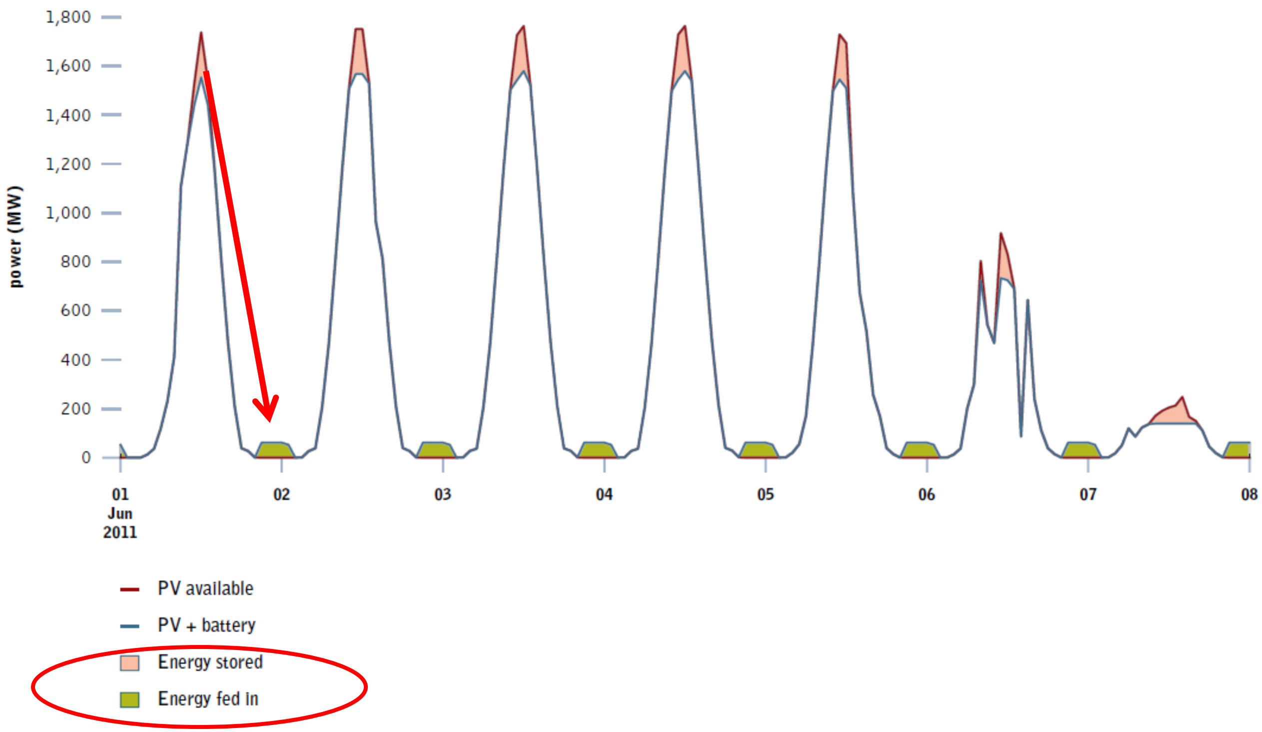
Methodology: Assumption for flexible generation e.g solar photovoltaics

figure 1.10: PV peak capping by battery with consumer-orientated operation at node DE02

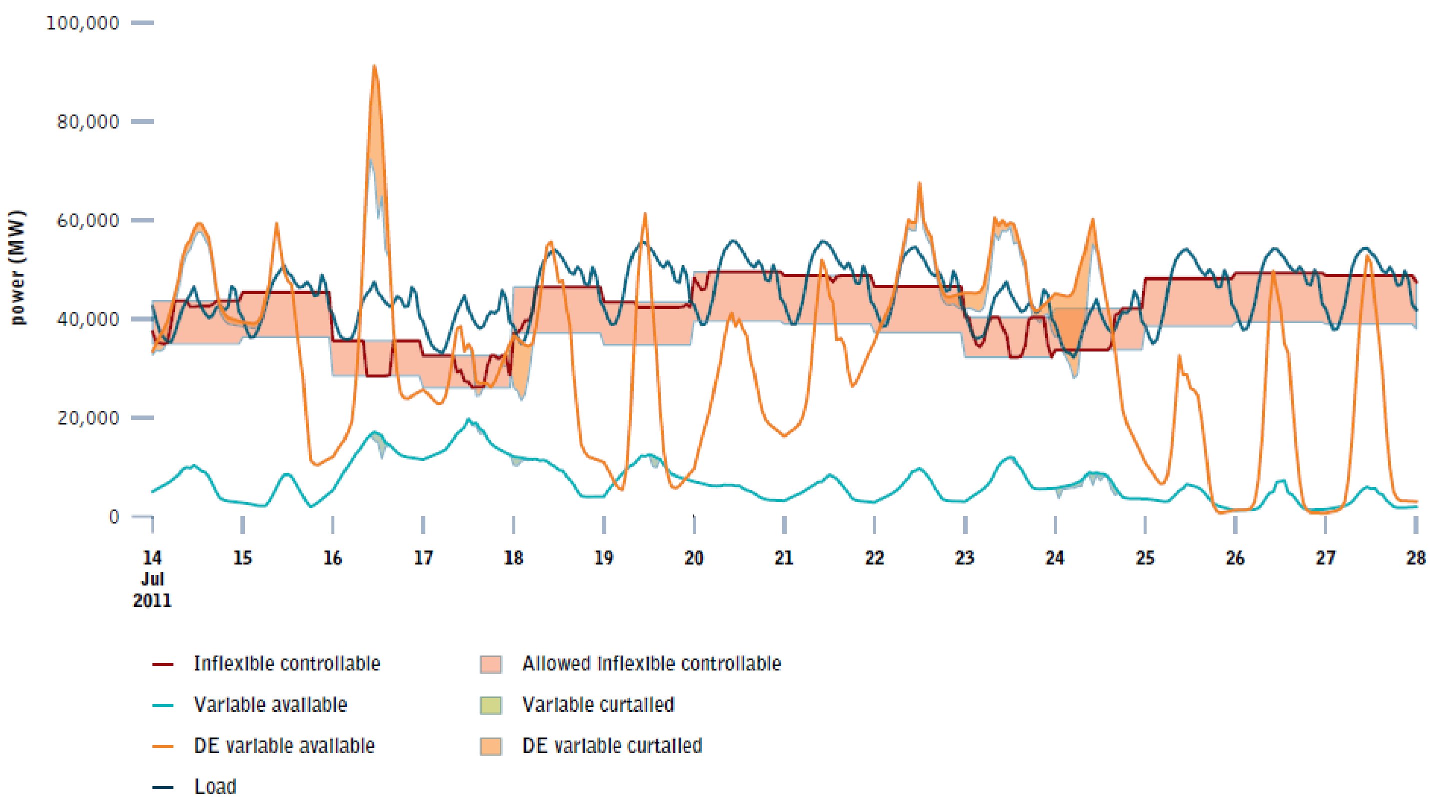


source ENERGYNAUTICS 2014 - POWE[R] 2030.

Example: **Cross Border System Conflict in the Grid - France versus Germany in the Summer**

- Inflexible controllables running flat out at 90% of nominal power the whole year - flexibility band 20%

figure 2.7: **generation in france plotted with variables in germany shows a system conflict: inflexible generation in france causes curtailment in germany**



Results: Capacity factor of conventional generation in selected countries in three scenarios

COUNTRY	COAL	LIGNITE	GAS	NUCLEAR
France - Conflict 2020	34%	0%	8%	70%
France - Conflict 2030	43%	0%	9%	75%
France - E[R] 2020	0%	0%	90%	18%
France - E[R] 2030	0%	0%	85%	0%
Poland - Conflict 2020	71%	0%	8%	90%
Poland - Conflict 2030	80%	11%	10%	90%
Poland - E[R] 2020	10%	1%	90%	0%
Poland - E[R] 2030	0%	0%	59%	0%
Czech Rep. - Conflict 2020	85%	67%	15%	86%
Czech Rep. - Conflict 2030	81%	68%	33%	82%
Czech Rep. - E[R] 2020	4%	2%	90%	14%
Czech Rep. - E[R] 2030	0%	0%	79%	0%
Germany - Conflict 2020	90%	80%	15%	89%
Germany - Conflict 2030	90%	83%	25%	0%
Germany - E[R] 2020	9%	3%	73%	14%
Germany - E[R] 2030	0%	0%	43%	0%

source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

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Results: Load coverage + load factors factor by technology/Imports in 2030 under the energy [r]evolution

(% COVERAGE OF LOAD)

COUNTRY	IMPORTS	VARIABLE DISPATCH	FLEXIBLE CONTROLLABLE	RENEWABLE	NON-RENEWABLE	GAS LOAD FACTOR	VARIABLE CURTAILMENT
Europe	0.0	52.9	47.3	76.7	23.3	34.1	2.8
France	-3.3	60.6	42.9	84.2	19.2	84.8	1.4
Poland	-14.7	57.4	57.3	75.6	39.1	58.7	3.7
Czech Republic	7.2	30.8	62.2	64.9	27.9	79.4	1.2
Germany	6.2	52.7	41.4	65.5	28.3	43.1	2.4
Belgium	9.0	47.2	44.0	54.4	36.6	35.5	0.9
Italy	12.6	32.6	55.0	57.3	30.1	33.4	0.7
Spain	-9.3	71.0	38.7	106.1	3.2	7.0	2.0

source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

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Main Expansion:

- AC inter-connection between countries
- DC over-lay
  - East-West
  - North-South

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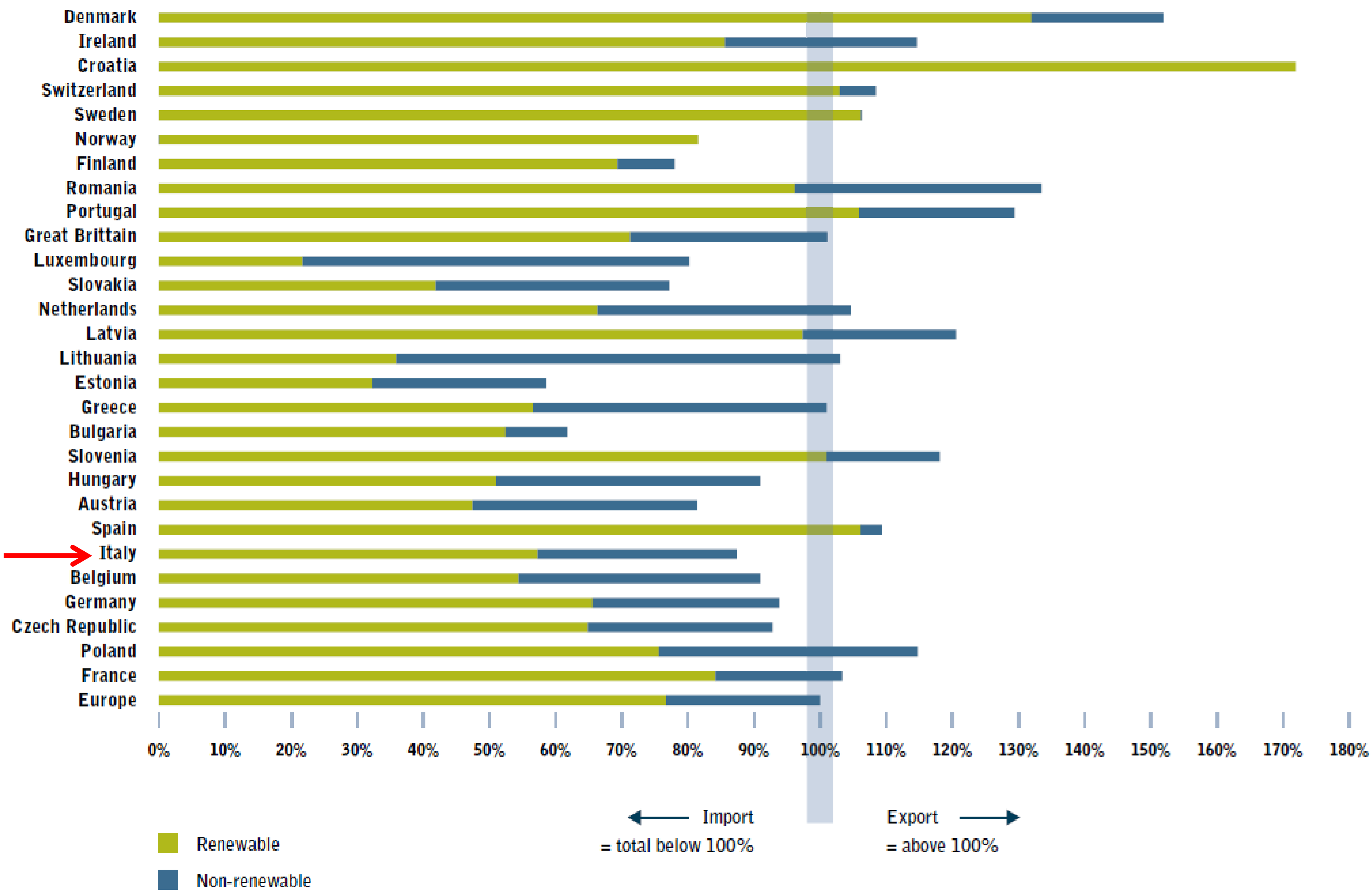
Load Coverage of the energy [r]evolution by country for 2030



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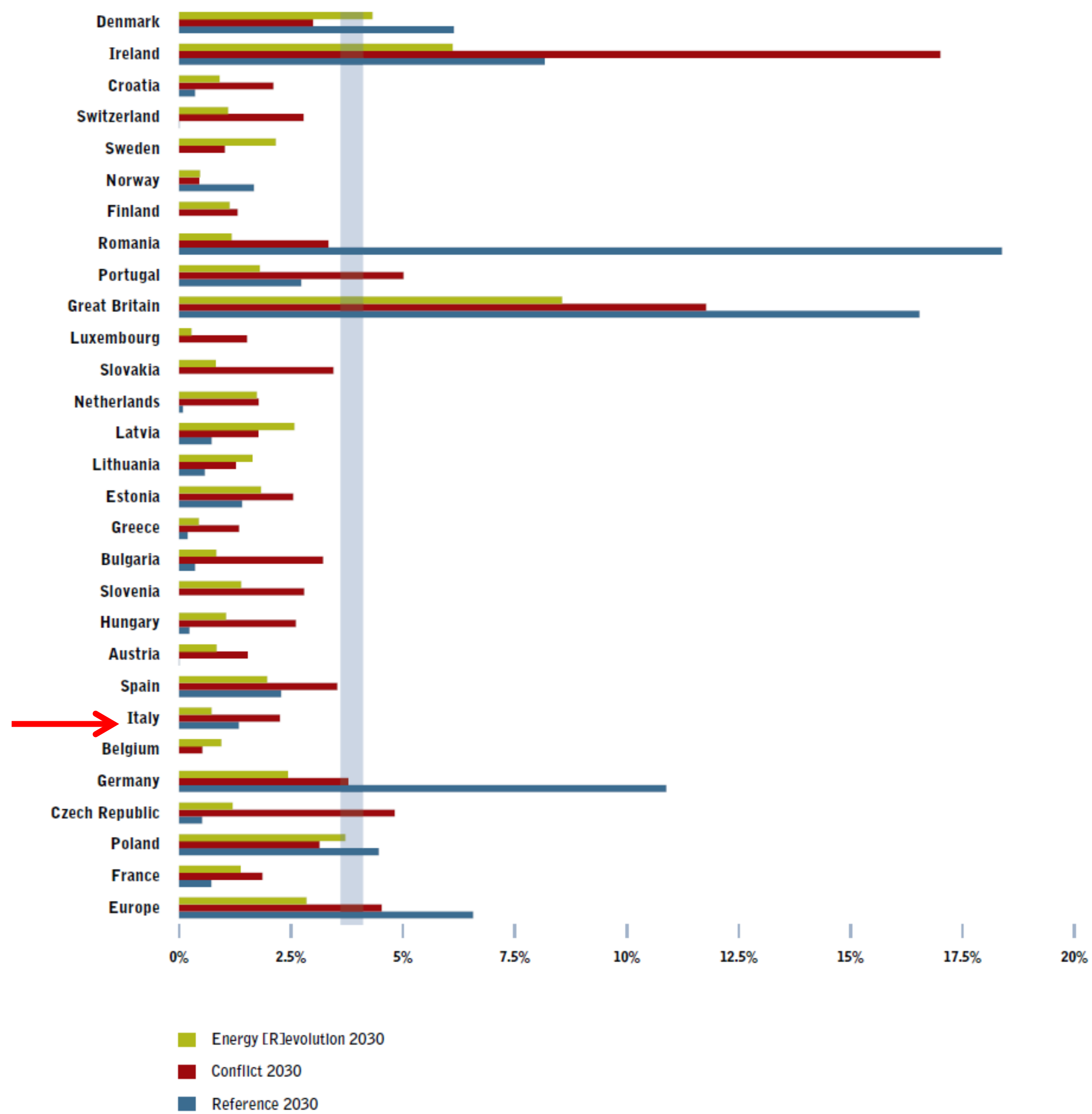
Curtailment rates of wind + solar by country and scenario for 2030



source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

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Key Results + Comparison with ENTSO-E

CASE	TECHNOLOGY	NETWORK EXTENSION (MVA)[a]	LENGTH (KM)[b]	EXTENSION IN (MVAkm)[c]	TRANSMISSION LINES (KM)[d]	NETWORK EXTENSION COSTS (MILLION €)
Reference 2020	AC	1,500	343	514,500	343	229
	DC	5,000	1,727	1,682,910	1,370	1,968
	AC+DC	6,500	2,070	2,197,410	1,713	2,197
Reference 2030	AC	3,000	562	842,489	562	375
	DC	20,000	2,425	8,145,934	3,101	7,773
	AC+DC	23,000	2,985	8,988,423	3,663	8,148
Conflict 2020	AC	4,500	731	1,095,796	731	530
	DC	16,000	2,895	7,909,550	2,895	6,702
	AC+DC	20,500	3,625	8,005,346	3,626	7,232
Conflict 2030	AC	84,700	8,224	15,188,762	8,779	7,089
	DC	91,000	7,055	39,110,736	10,002	33,563
	AC+DC	175,700	15,279	54,299,498	18,781	40,652
Energy [R]evolution in 2020	AC	4,500	731	1,096,796	731	530
	DC	15,000	2,634	7,648,550	2,634	6,254
	AC+DC	19,500	3,365	8,745,346	3,365	6,784
Energy [R]evolution in 2030	AC	112,200	22,489	22,168,854	11,719	10,314
	DC	148,000	10,738	52,390,238	14,556	50,859
	AC+DC	260,200	22,227	74,559,093	26,275	61,172
ENTSO-E TYNDP	AC		37,520	56,280,000	37,520	25,945
	DC		12,590	25,180,000	12,590	25,205
	AC+DC		50,110	81,460,000	50,110	51,150

notes

a MVA = SUM OF CAPACITY EXTENSION IN MVA FOR EACH LINE.

b MVAkm = CAPACITY EXTENSION IN MVA MULTIPLIED WITH THE LENGTH IN KM OF EACH LINE.

c LENGHT IN KM = LENGTH OF LINE AFFECTED.

d TRANSMISSION LINE LENGTH IN KM = LENGTH OF NEW BUILD TRANSMISSION LINES.

source ENERGYNAUTICS/GREENPEACE/TESKE 2014 - POWE[R] 2030.

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