The Green*Net* Project Idea: Cost-Efficient Integration of Renewable Energy

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Agenda

1. Overview of Model Green*Net-Europe*

2. Modelling Approach of Green*Net-Europe*

Definition of RES-E Potentials
Grid Connection Cost
Grid Reinforcement Cost
System Balancing Cost
Capacity Credit of Wind (System Adequacy)
Different Allocation Policies of RES-E Integration Cost

3. Selected Results based on Green*Net-Europe*

Examples on RES-E Deployment in the EU27 up to 2020
Corresponding Grid-related and System-related Cost
Scenarios on RES-E Deployment in Poland up to 2020

4. Lessons Learned

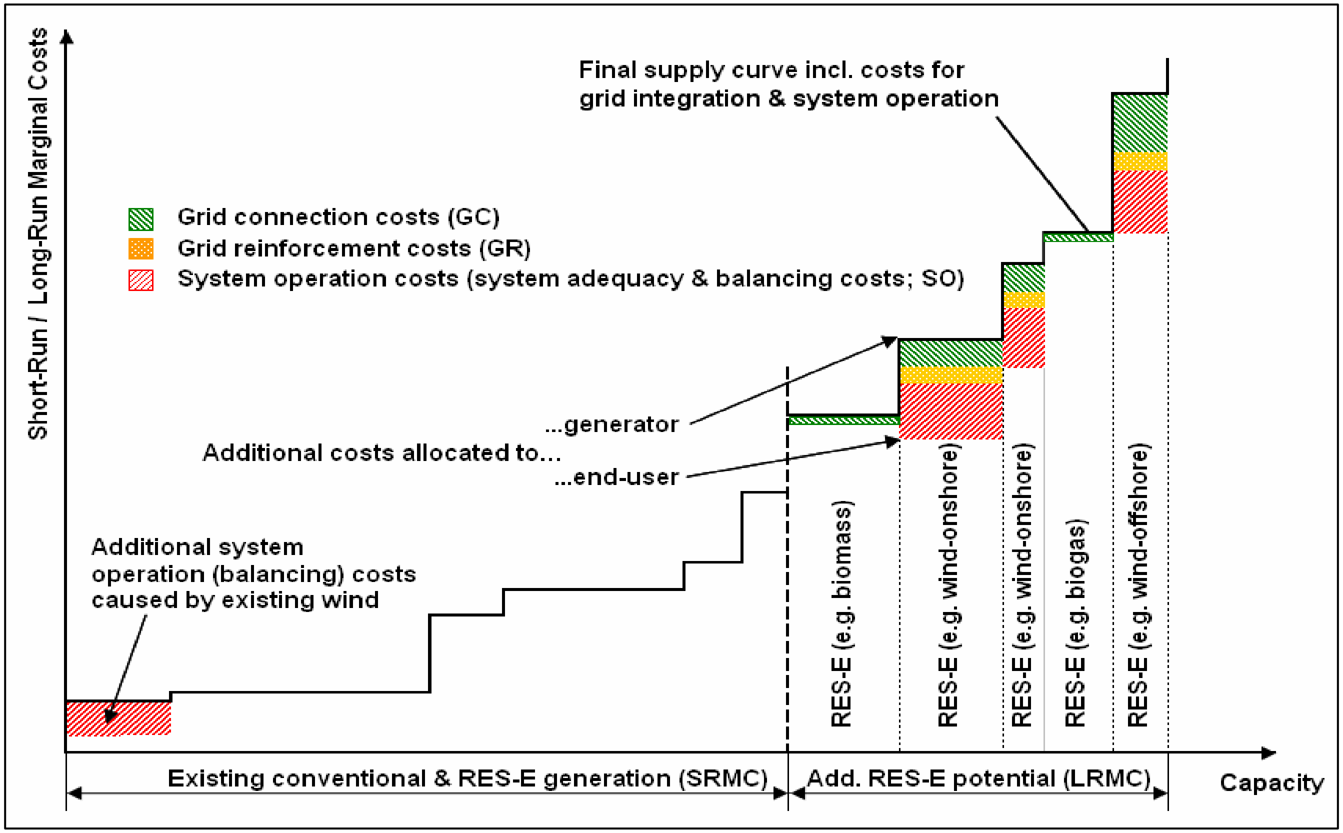
5. Policy Recommendations

1. Overview of Model Green*Net-Europe*

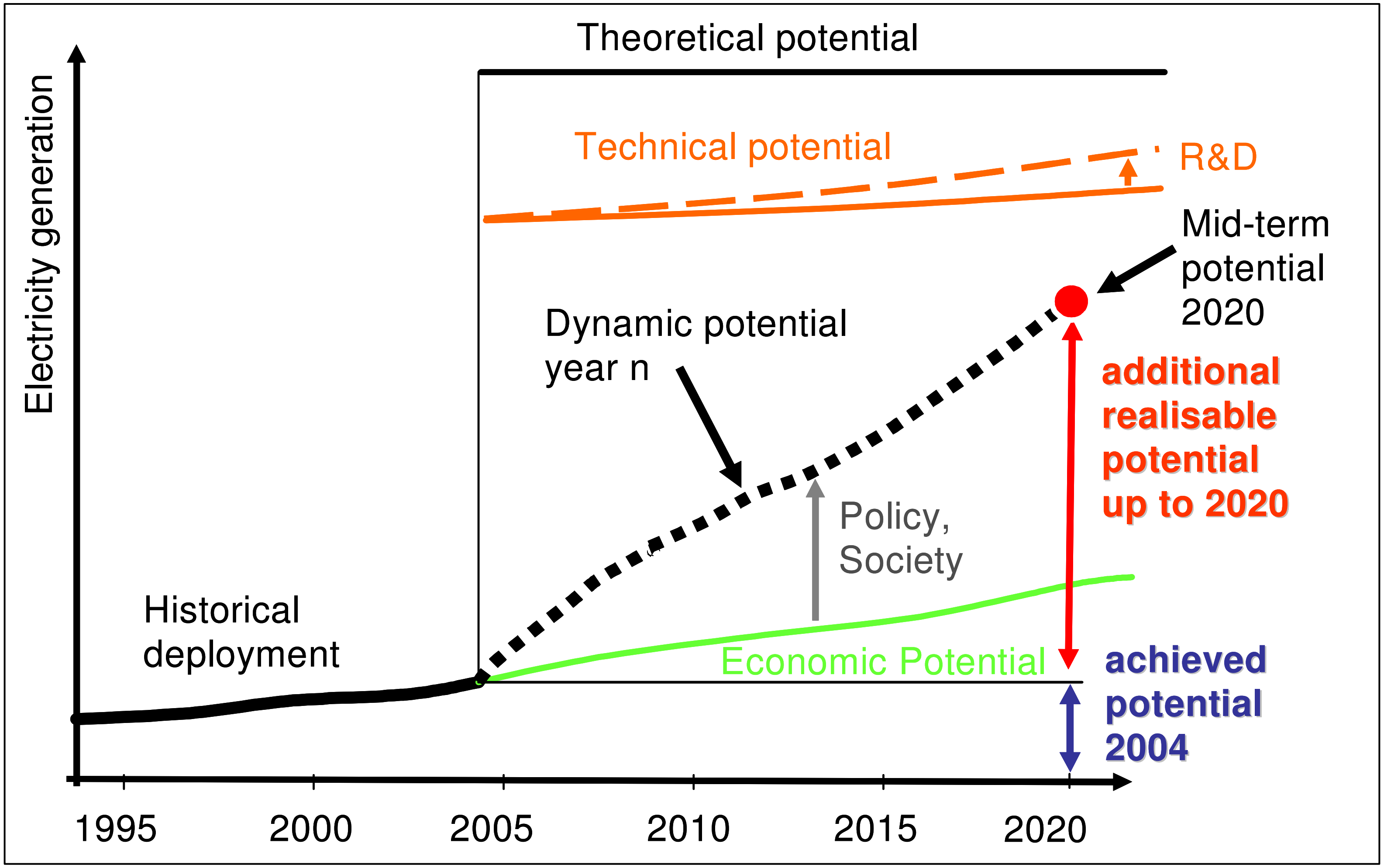
- Simulation software deriving scenarios on least cost RES-E deployment under a variety of different RES-E policy settings, cost allocation strategies, other policies and constraints
- Geographical coverage: Status quo: EU27+HR+CH+NO; 2009: incl. Western Balkan & Turkey
- Simulation period (results on annual basis): 2005 – 2020
- RES-E support instruments: implementation of currently existing policy in each country
- Examples of scenario settings:
  - Selection of a single country or any cluster of countries up to EU27
  - Selection of a single RES-E technology or any cluster of RES-E technologies
  - Entire portfolio of existing cost allocation policies (deep vs. shallow vs. super-shallow RES-E integration)
  - Parameter variation of key parameters like capacity credit of wind, specific cost of load response options, etc.
  - Creation and design of own RES-E support instruments (e.g. own TGC-system)
- Major results:
  - RES-E deployment under several different scenario settings and parameter variations on country-level as well as on EU27-level
  - Deployment of the different disaggregated grid-related and system-related cost of RES-E integration

2. Modelling Approach of Green*Net-Europe*

- Different strategies for implementation of grid-related and system-related cost of RES-E integration into the supply curve (existing power plants and additional RES-E potentials).
- Cost allocation of these cost (RES-E support instrument vs. grid tariff vs. balancing/ wholesale markets) affects overall generation cost of RES-E developer (and, therefore, investment decision).



2.1 Definition of RES-E Potentials

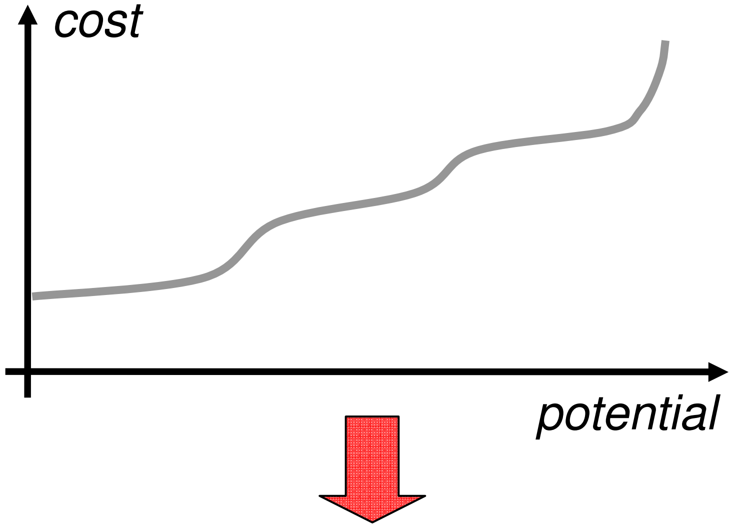


Static Cost-Resource Curves

- Combines information on the potentials and the corresponding cost
- All potential/cost-bands are sorted on least-cost basis (starting with cheapest one)
- For limited resources (like RES-E potentials) cost rise with increased utilization

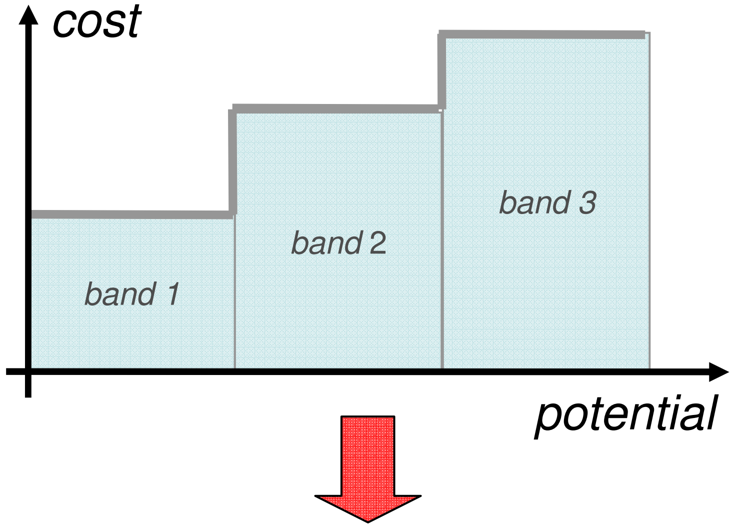
cost = f (potential); t = constant

continuous function



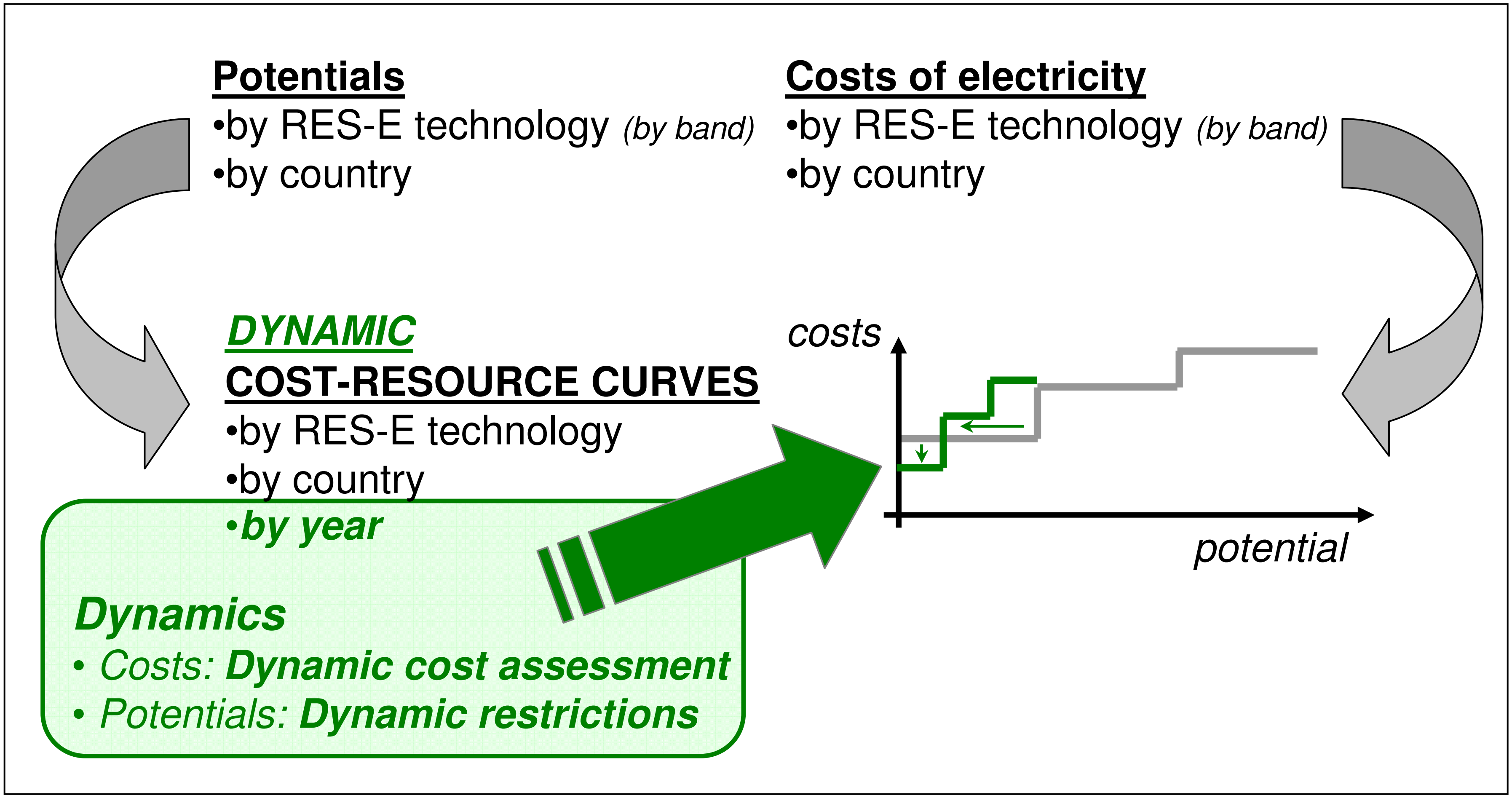
Reality: Each location is slightly different…

stepped (discrete) function



Modelling approach: Sites with similar characteristics are described by 1 band

Dynamic Cost-Resource Curves



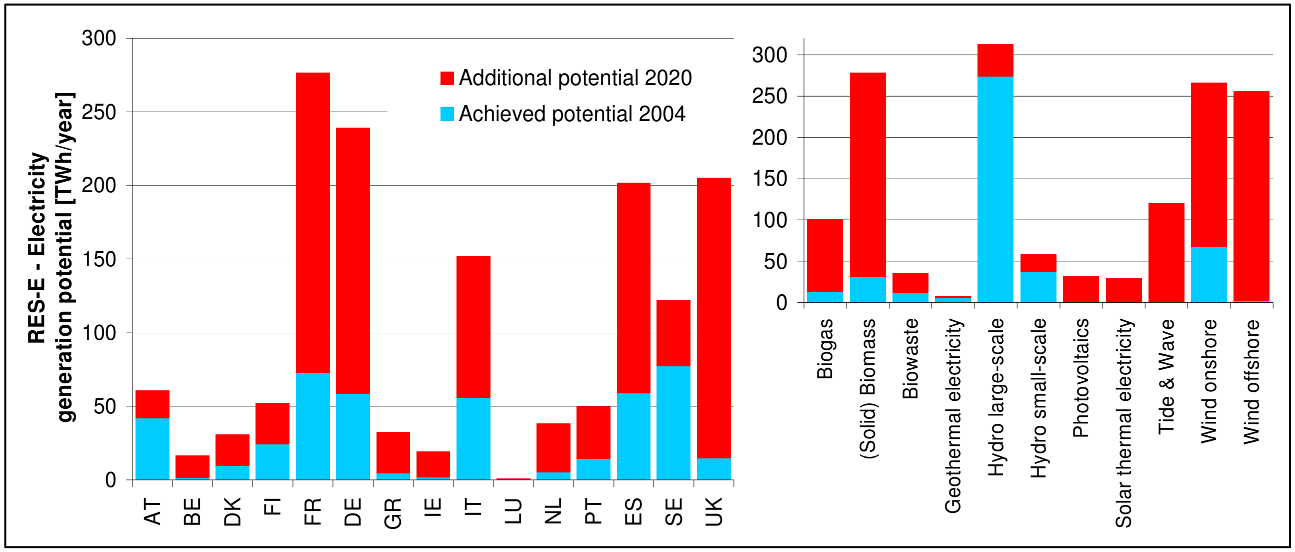
Potentials
- by RES-E technology *(by band)*
- by country

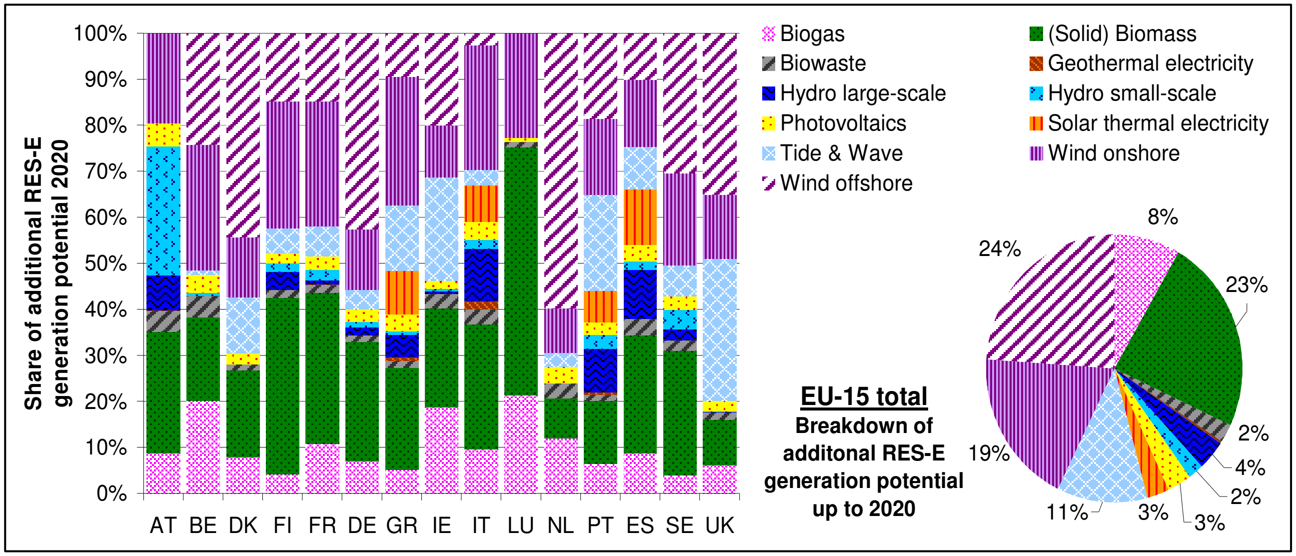
Costs of electricity
- by RES-E technology *(by band)*
- by country

DYNAMIC
COST-RESOURCE CURVES
- by RES-E technology
- by country
- ***by year***

Dynamics
- *Costs:* ***Dynamic cost assessment***
- *Potentials:* ***Dynamic restrictions***

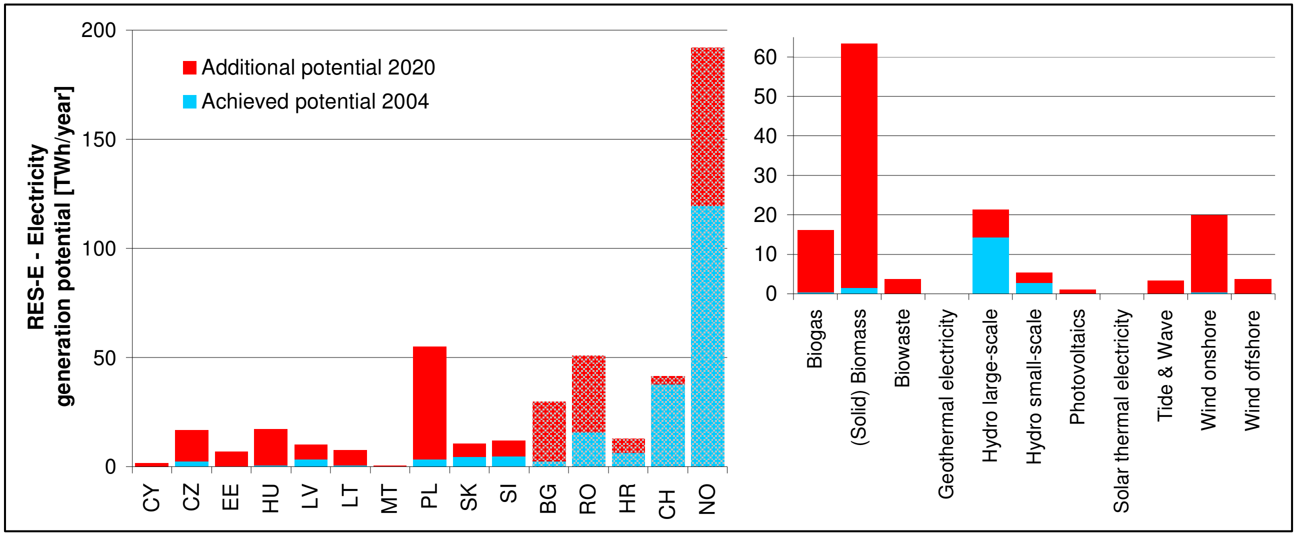
RES-E Generation Potentials in the EU15 up to 2020

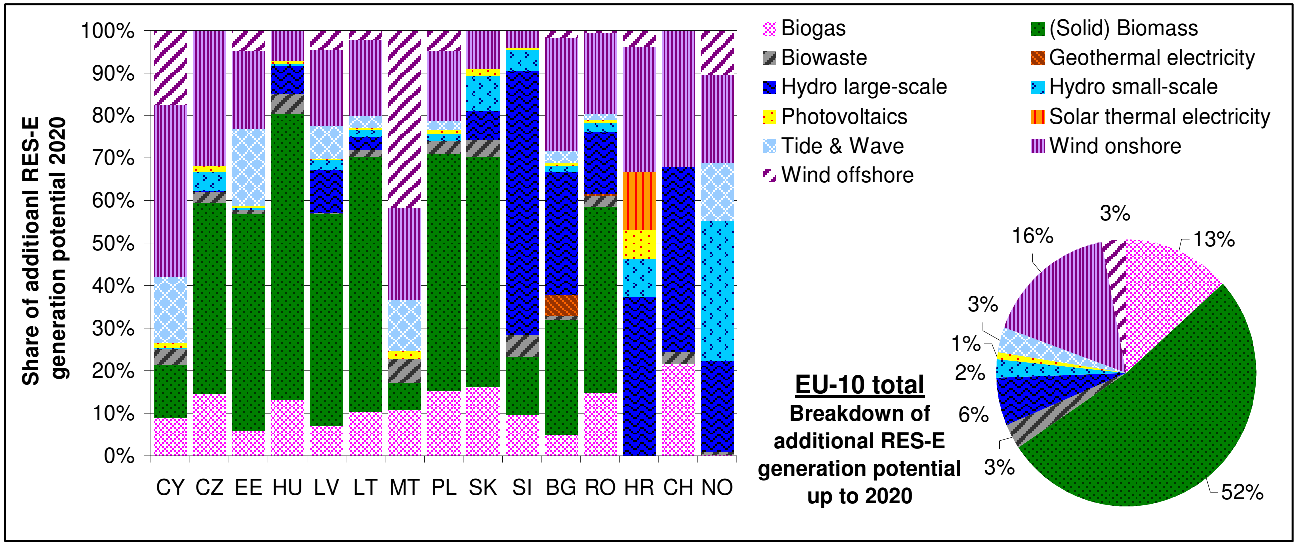




EU-15 total
Breakdown of additonal RES-E generation potential up to 2020

RES-E Generation Potentials in the EU12 up to 2020





EU-10 total
Breakdown of additional RES-E generation potential up to 2020

2.2 Modelling Grid Connection Cost

Results of RES-E case studies are the basis for model implementation

Wind onshore

- Grid connection cost: 8 % of total project investment

Wind offshore

- Grid connection cost depending on distance to shore

Zone 0 (near shore): 10% of total project investment
Zone 1 < 30 km: 15% of total project investment
Zone 2 30-50 km: 20% of total project investment
Zone 3 > 50 km: 25% of total project investment

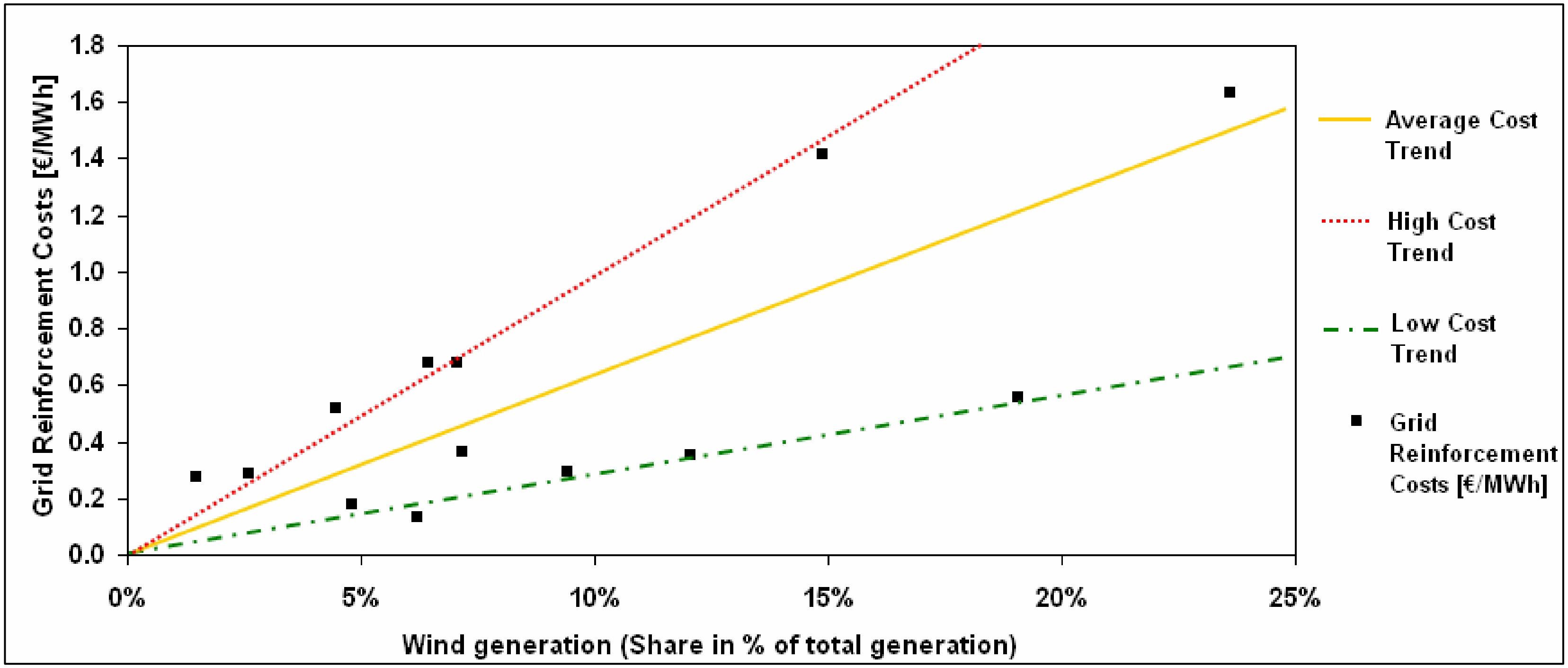
Model implementation enables separate application of learning rates for grid connection and the wind farm itself

2.3 Modelling Grid Reinforcement Cost

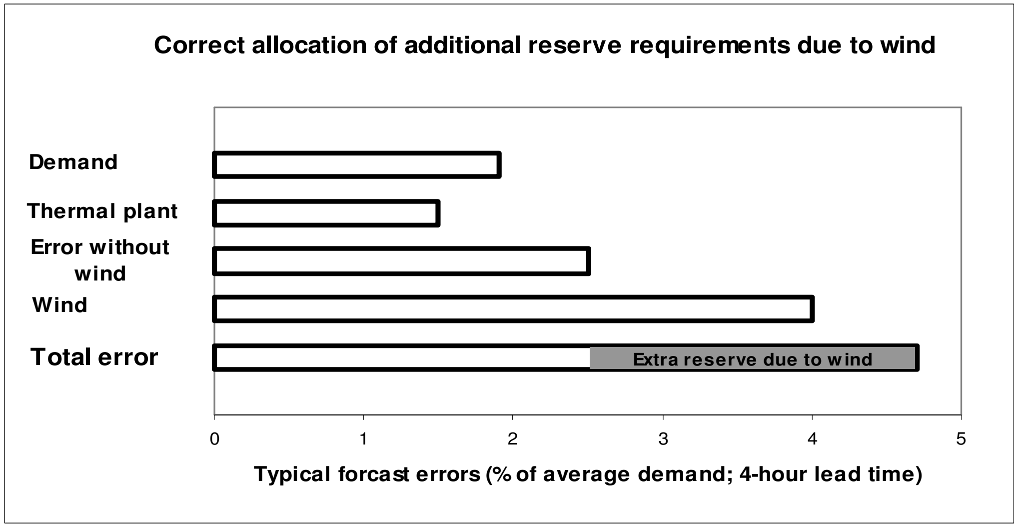
- Empirical data (transmission grid only) based on national load flow analyses
- Correlation between wind penetration and specific grid reinforcement cost
- Share of cost allocated to wind determined by the capacity factor:

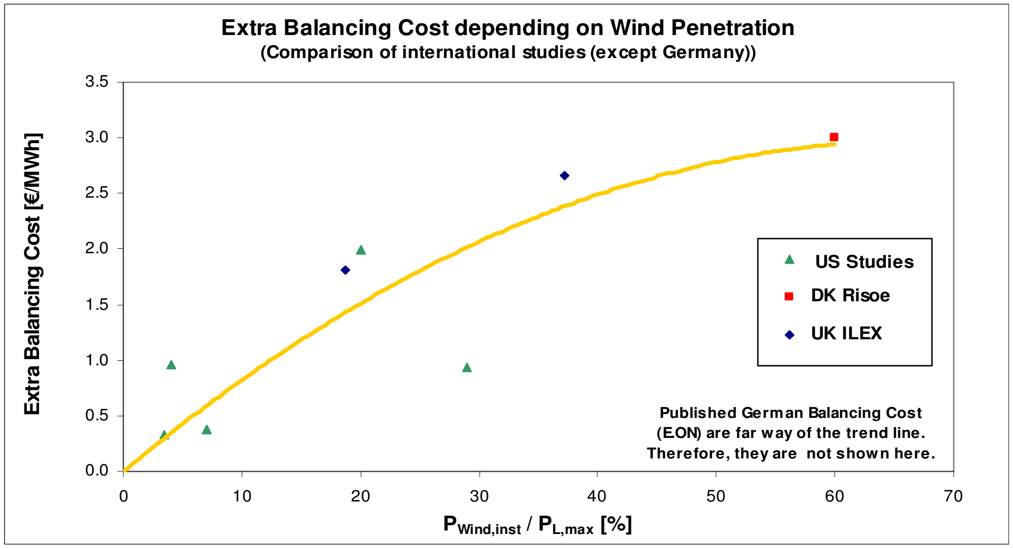
$$C_{GR,\,Wind} = CF_{Wind} * C_{GR,\,total}$$

- Due to bandwidth of grid reinforcement cost three scenarios are implemented



2.4 Modelling System Balancing Cost


Correct allocation of additional reserve requirements due to wind

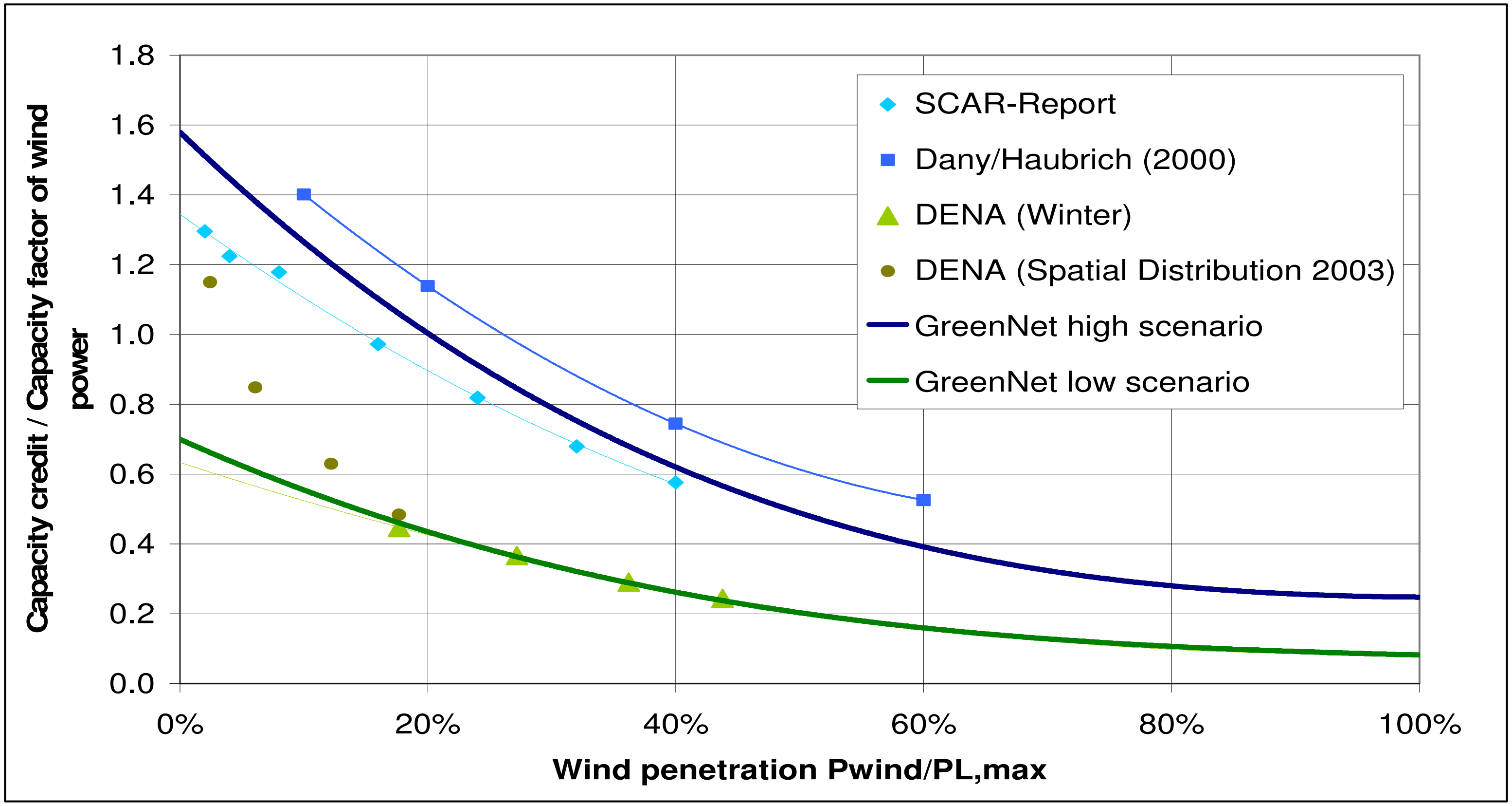

Extra Balancing Cost depending on Wind Penetration
(Comparison of international studies (except Germany))

Published German Balancing Cost (EON) are far way of the trend line. Therefore, they are not shown here.

- Driver for <u>short-term</u> system balancing requirements is the magnitude of random power fluctuations, caused by unpredictable changes in both generation and load
- At present, in different electricity systems a variety of different schemes exist for the allocation of corresponding extra balancing cost caused by large-scale intermittent wind generation

2.5 Modelling Capacity Credit of Wind (System Adequacy)

- **Conventional power plants provide both energy (kWh) and capacity (kW)**
- **Intermittent wind generation provides limited contribution to system capacity**
- **This is expressed in the capacity credit of wind power (take care of definition)**
- **Corresponding cost are estimated using the *"thermal equivalent approach"***



2.6 Modelling Different Allocation Policies of RES-E Integration Cost

Software Green*Net-Europe* **models several different grid integration policies**

- Reference scenario reflects the status quo of cost allocation policies in the EU-27

Deep grid integration

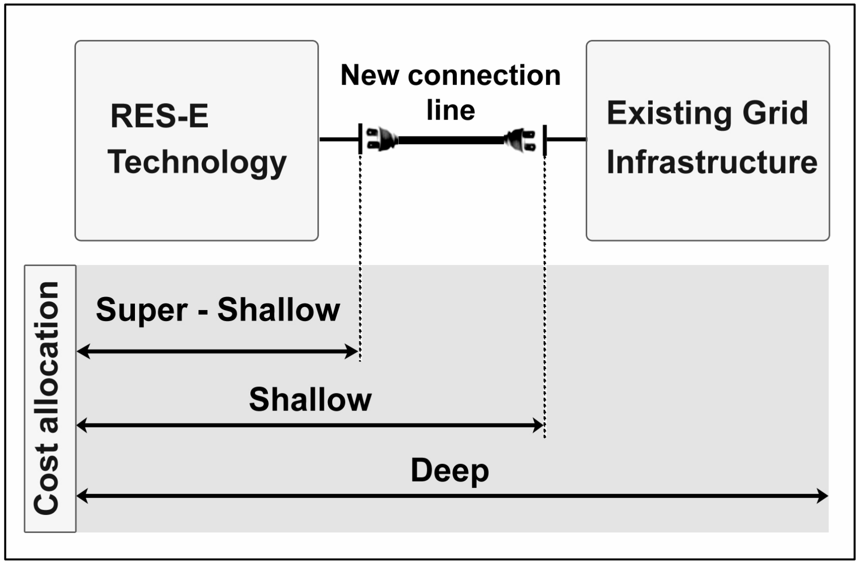
- Several disaggregated cost elements allocated to RES-E developer

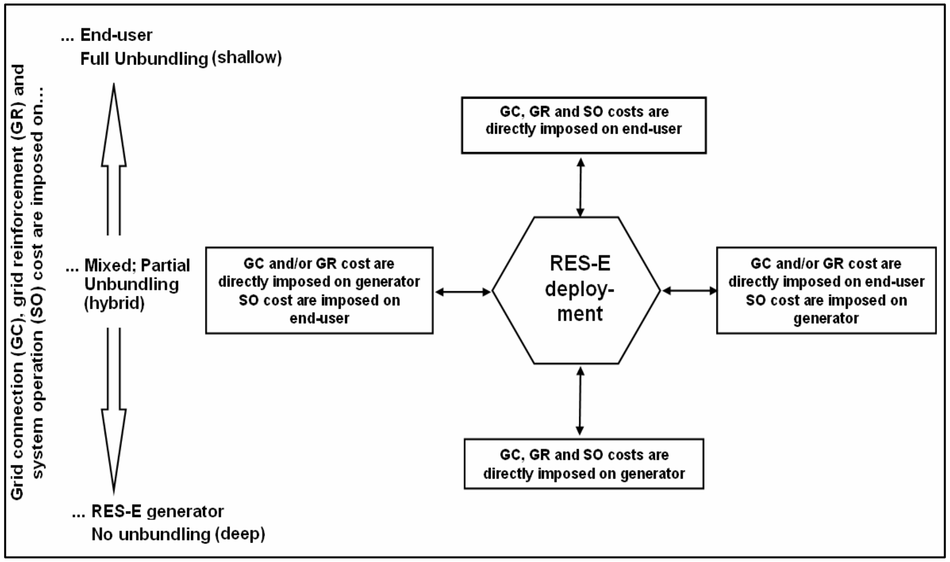
Shallow grid integration

- Only grid connection cost allocated to RES-E developer; remaining cost to end-user

Super-shallow grid integration

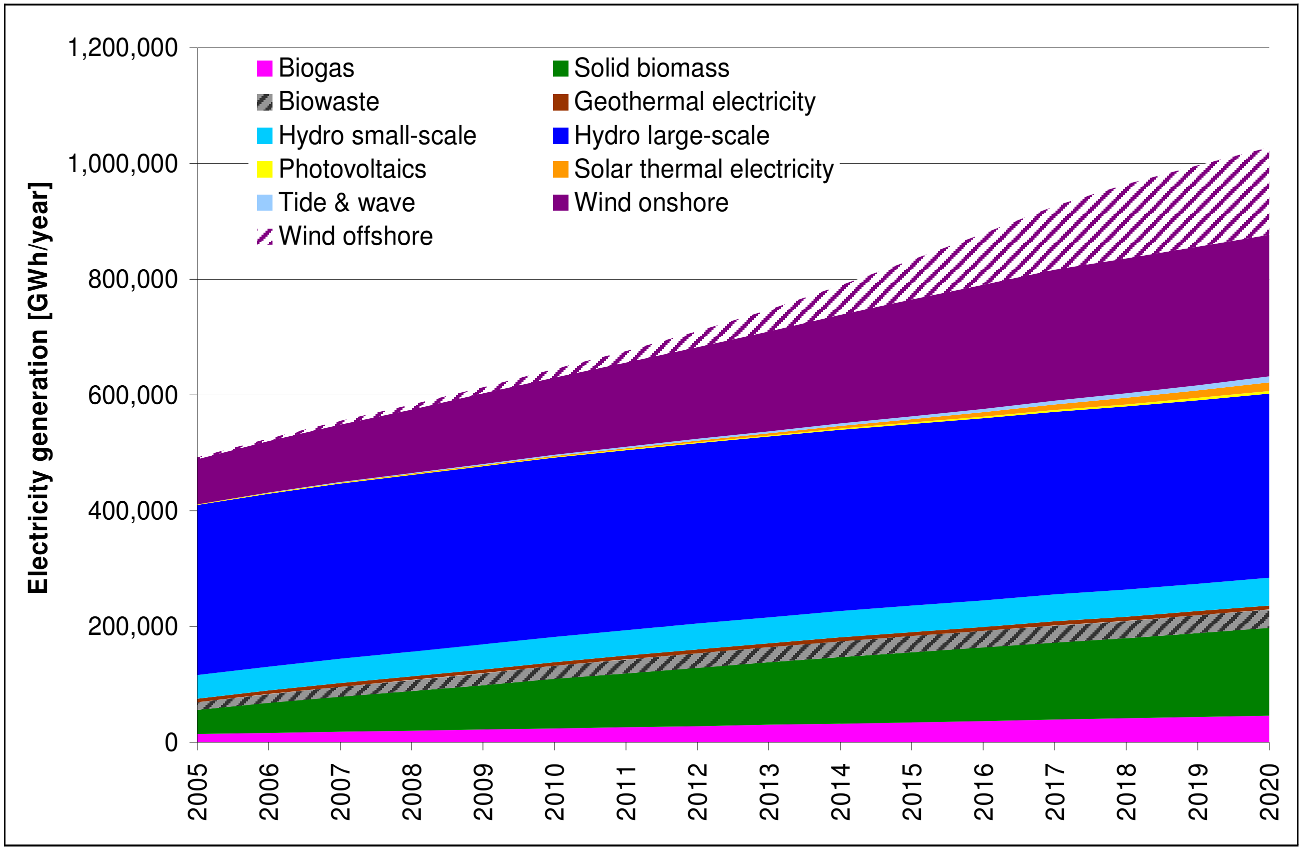
- Several disaggregated cost elements (incl. grid connection) are allocated to end-user





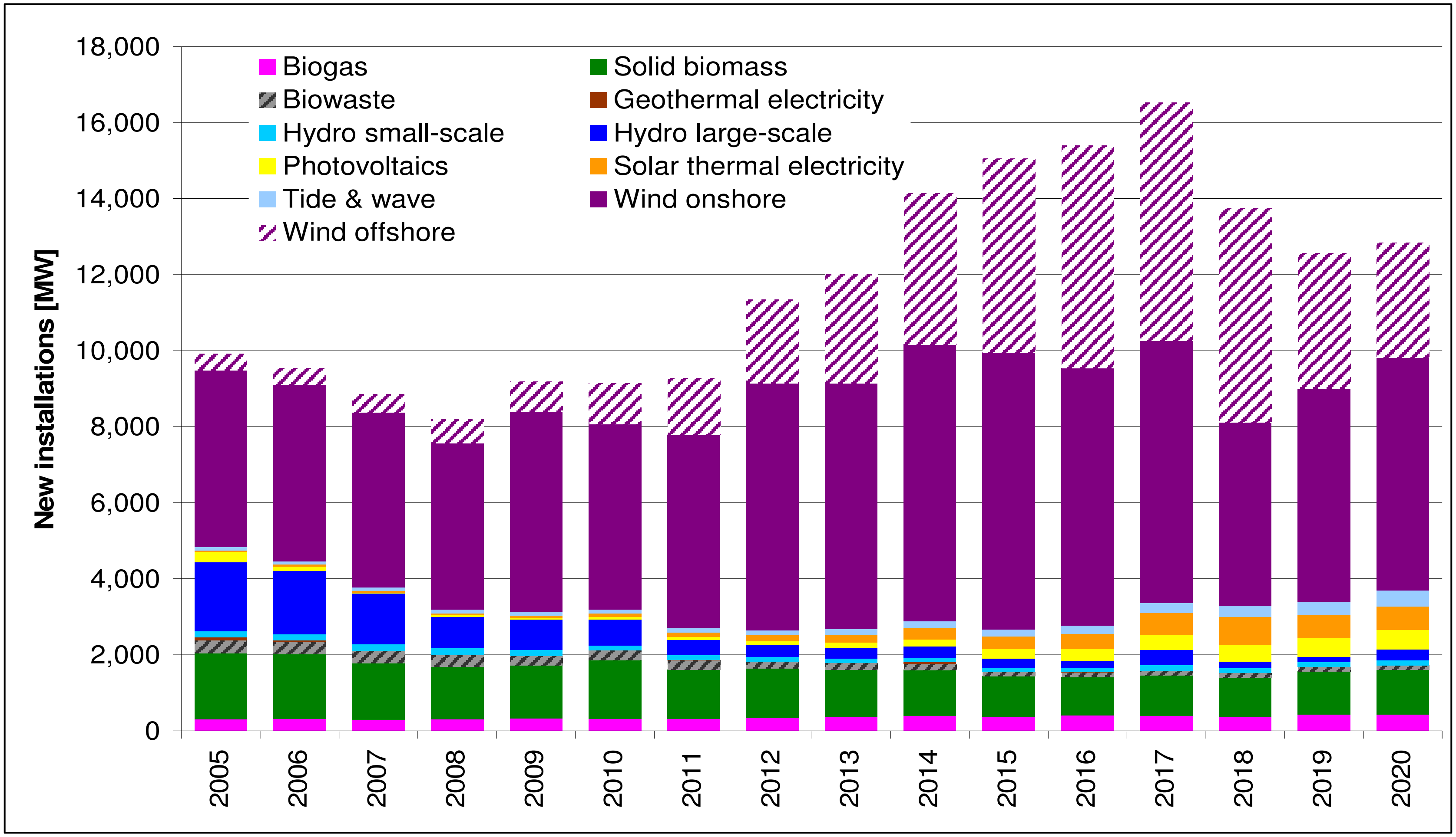
3. Selected Results based on Green*Net-Europe*

RES-E deployment in the EU27 up to 2020 according to the BAU scenario

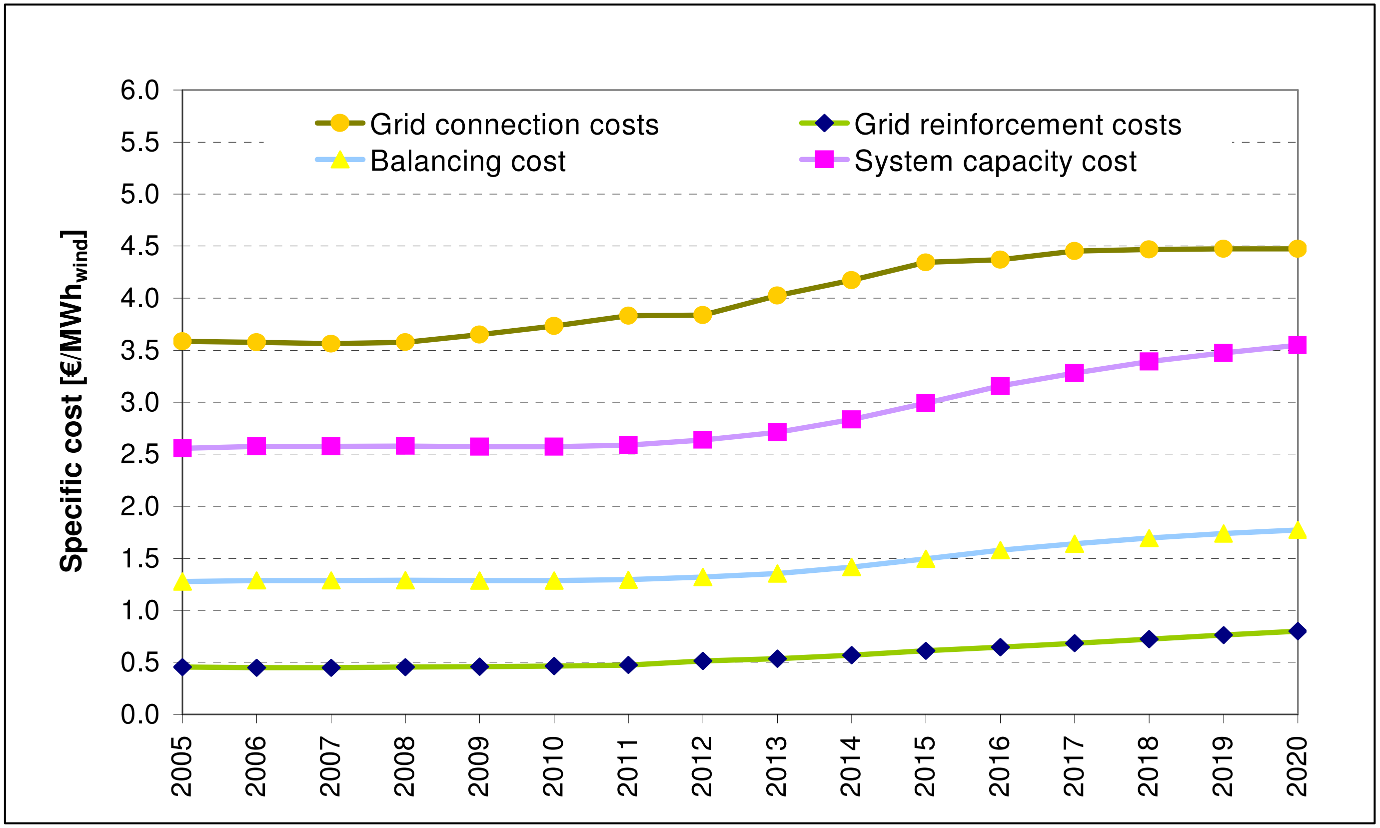


- Increase of RES-E generation from 492 TWh/yr in 2005 to 1028 TWh/yr in 2020
- Generation from “old” RES-E technologies remains stable
- Wind (onshore & offshore), biomass and biogas will increase considerably

RES-E installations in the EU27 up to 2020 according to the BAU scenario



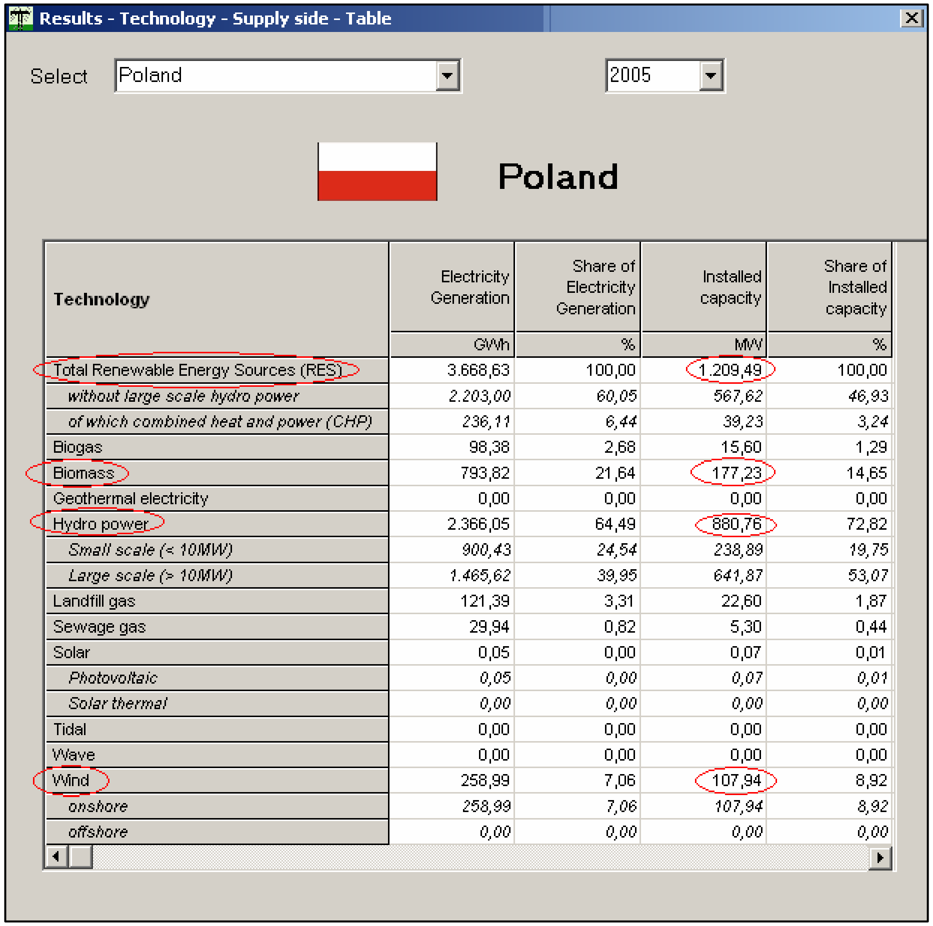
Development of specific grid-related and system-related cost of wind integration in the EU27 up to 2020



- Dominant cost element: grid connection cost
- Grid reinforcement cost are rather low
- Extra system operation cost between 4 - 5.5 €/MWh$_{wind}$

Poland:
RES-E deployment in the BAU scenario from 2005 - 2020

2005

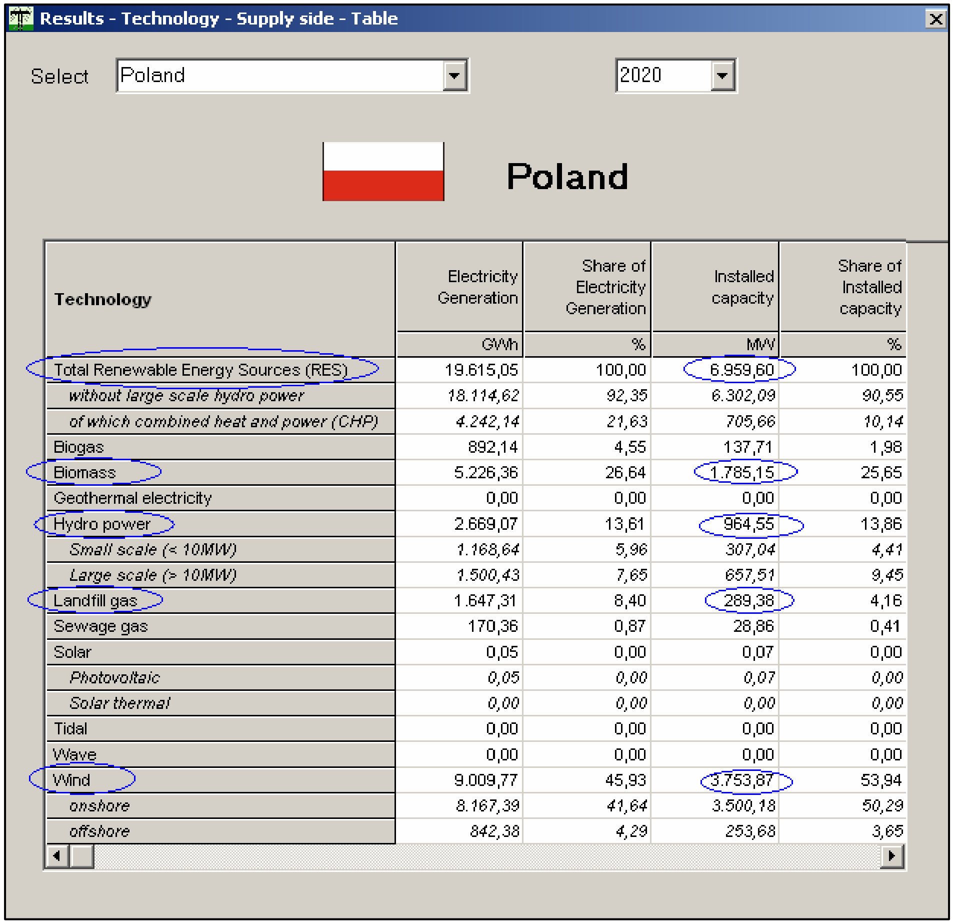

Results - Technology - Supply side - Table

Select: Poland, 2005

Poland

Technology	Electricity Generation	Share of Electricity Generation	Installed capacity	Share of Installed capacity
	GWh	%	MW	%
Total Renewable Energy Sources (RES)	3.668,63	100,00	1.209,49	100,00
without large scale hydro power	*2.203,00*	*60,05*	*567,62*	*46,93*
of which combined heat and power (CHP)	*236,11*	*6,44*	*39,23*	*3,24*
Biogas	98,38	2,68	15,60	1,29
Biomass	793,82	21,64	177,23	14,65
Geothermal electricity	0,00	0,00	0,00	0,00
Hydro power	2.366,05	64,49	880,76	72,82
Small scale (< 10MW)	*900,43*	*24,54*	*238,89*	*19,75*
Large scale (> 10MW)	*1.465,62*	*39,95*	*641,87*	*53,07*
Landfill gas	121,39	3,31	22,60	1,87
Sewage gas	29,94	0,82	5,30	0,44
Solar	0,05	0,00	0,07	0,01
Photovoltaic	*0,05*	*0,00*	*0,07*	*0,01*
Solar thermal	*0,00*	*0,00*	*0,00*	*0,00*
Tidal	0,00	0,00	0,00	0,00
Wave	0,00	0,00	0,00	0,00
Wind	258,99	7,06	107,94	8,92
onshore	*258,99*	*7,06*	*107,94*	*8,92*
offshore	*0,00*	*0,00*	*0,00*	*0,00*

2020

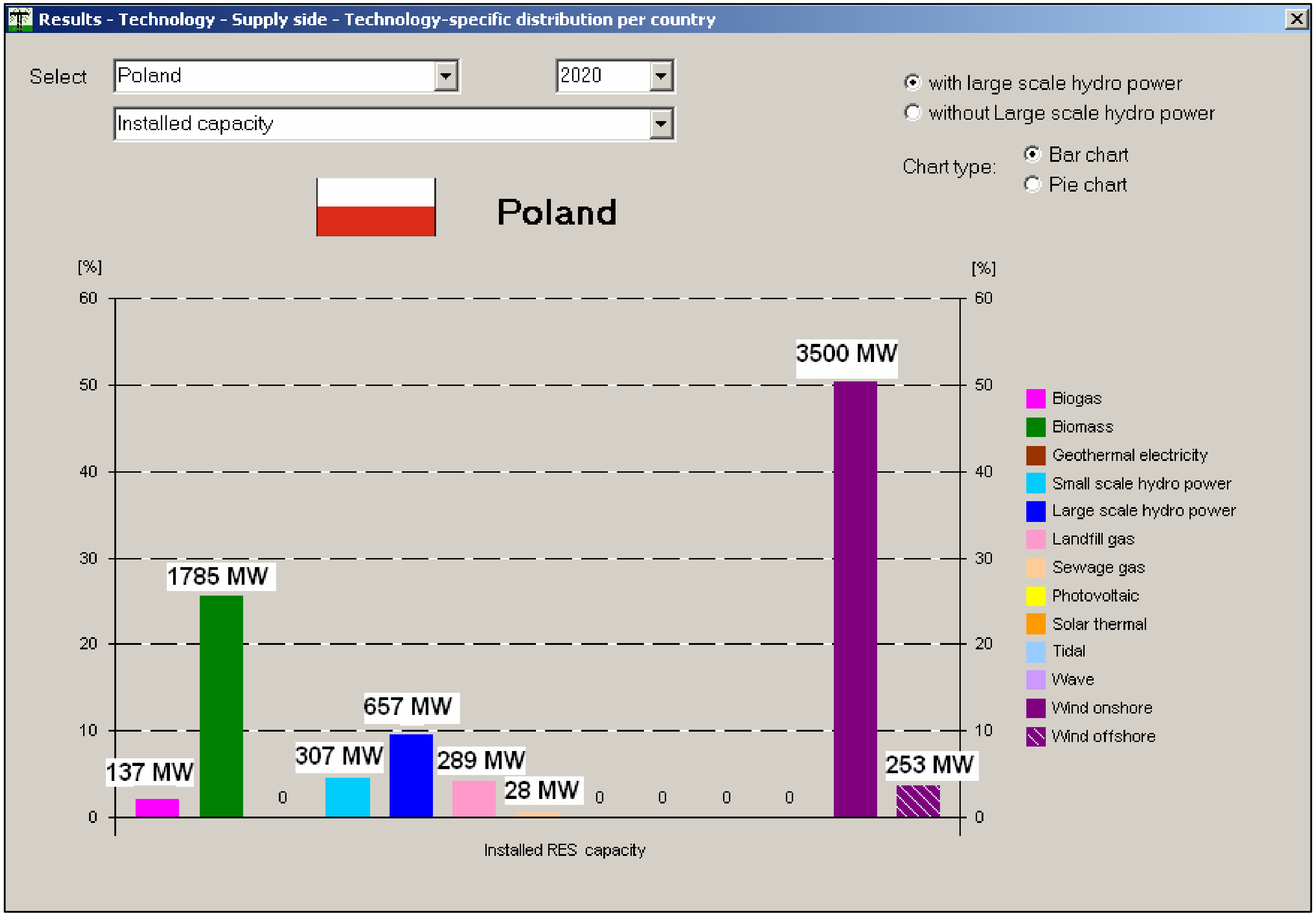

Results - Technology - Supply side - Table

Select: Poland, 2020

Poland

Technology	Electricity Generation	Share of Electricity Generation	Installed capacity	Share of Installed capacity
	GWh	%	MW	%
Total Renewable Energy Sources (RES)	19.615,05	100,00	6.959,60	100,00
without large scale hydro power	*18.114,62*	*92,35*	*6.302,09*	*90,55*
of which combined heat and power (CHP)	*4.242,14*	*21,63*	*705,66*	*10,14*
Biogas	892,14	4,55	137,71	1,98
Biomass	5.226,36	26,64	1.785,15	25,65
Geothermal electricity	0,00	0,00	0,00	0,00
Hydro power	2.669,07	13,61	964,55	13,86
Small scale (< 10MW)	*1.168,64*	*5,96*	*307,04*	*4,41*
Large scale (> 10MW)	*1.500,43*	*7,65*	*657,51*	*9,45*
Landfill gas	1.647,31	8,40	289,38	4,16
Sewage gas	170,36	0,87	28,86	0,41
Solar	0,05	0,00	0,07	0,00
Photovoltaic	*0,05*	*0,00*	*0,07*	*0,00*
Solar thermal	*0,00*	*0,00*	*0,00*	*0,00*
Tidal	0,00	0,00	0,00	0,00
Wave	0,00	0,00	0,00	0,00
Wind	9.009,77	45,93	3.753,87	53,94
onshore	*8.167,39*	*41,64*	*3.500,18*	*50,29*
offshore	*842,38*	*4,29*	*253,68*	*3,65*

Poland:
Installed RES-E capacities in the BAU scenario in 2020



Results - Technology - Supply side - Technology-specific distribution per country

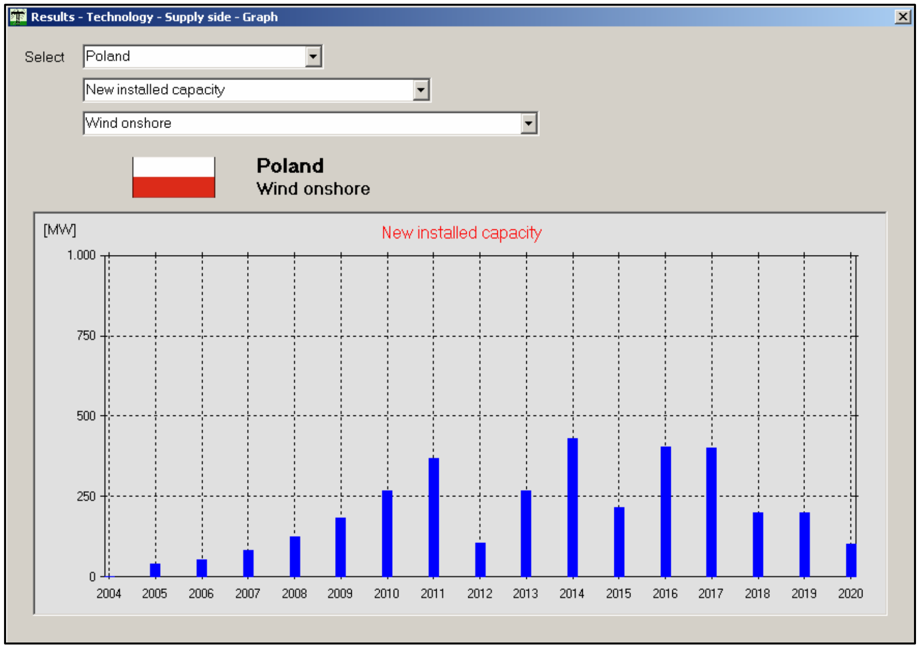
Select: Poland | 2020
Installed capacity

● with large scale hydro power
○ without Large scale hydro power

Chart type: ● Bar chart ○ Pie chart

Poland:
Annual installed capacities for wind-onshore and wind-offshore in the BAU scenario from 2005 - 2020

Wind-onshore



Results - Technology - Supply side - Graph

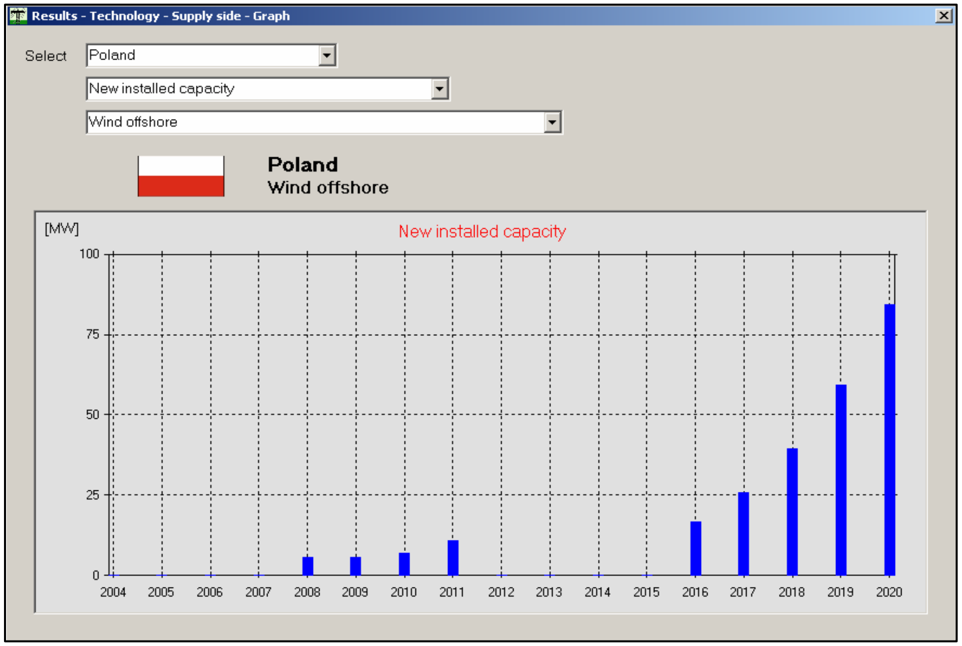
Select: Poland

New installed capacity

Wind onshore

Poland
Wind onshore

Wind-offshore



Results - Technology - Supply side - Graph

Select: Poland

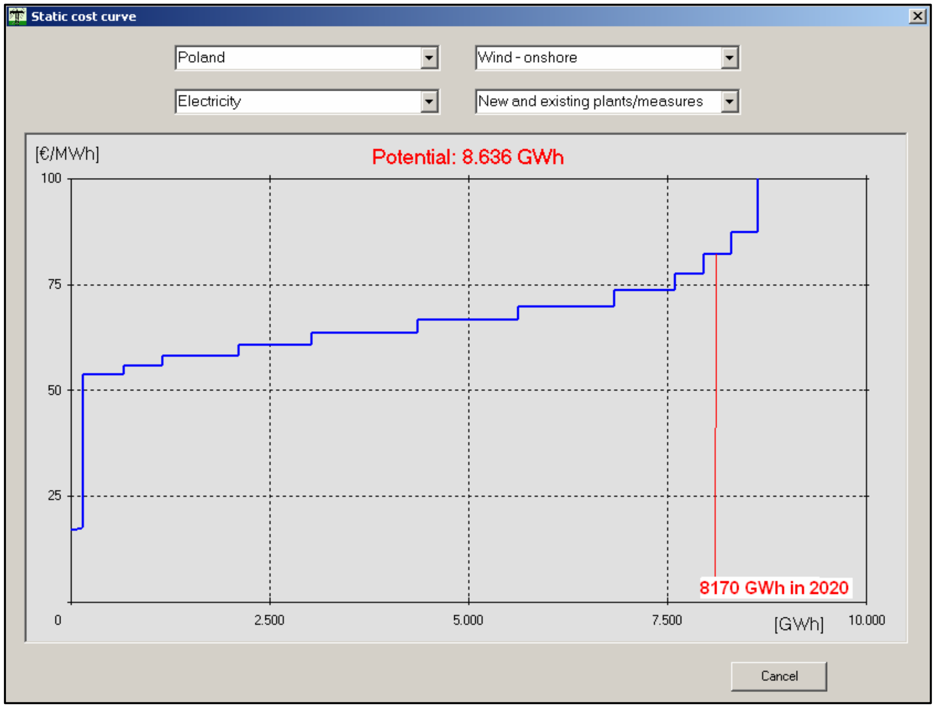
New installed capacity

Wind offshore

Poland
Wind offshore

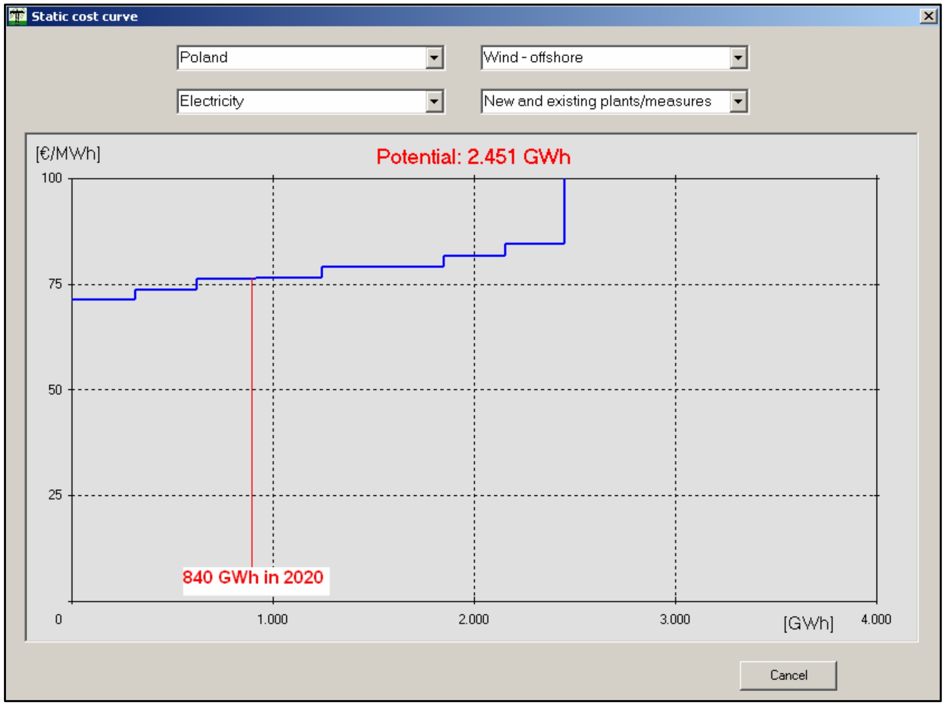
Poland:
Share of implemented potential for wind-onshore and wind-offshore in the BAU scenario in 2020

Wind-onshore



Poland
Wind - onshore
Electricity
New and existing plants/measures

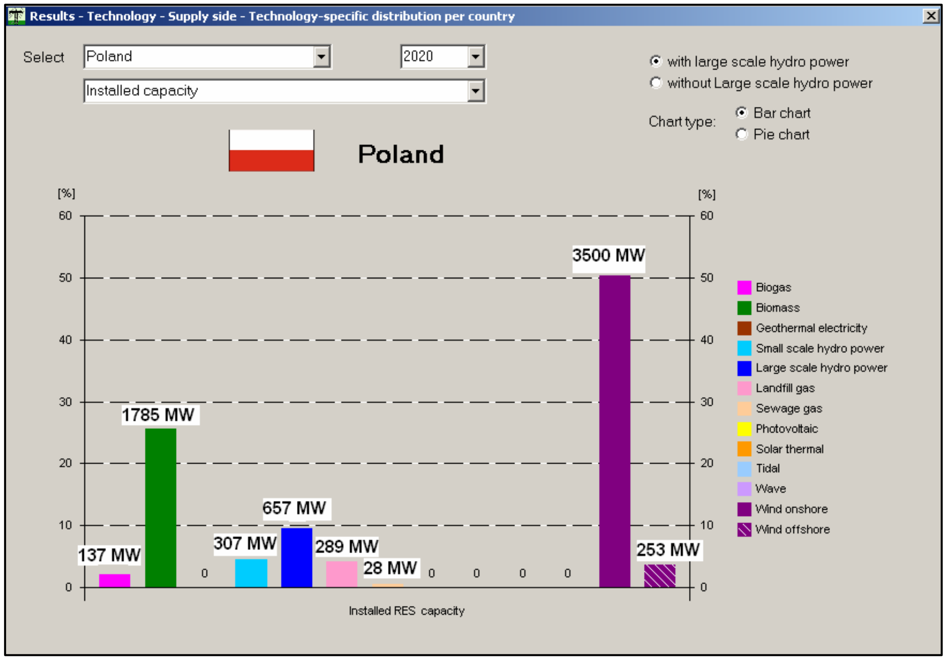
Wind-offshore



Poland
Wind - offshore
Electricity
New and existing plants/measures

Poland:
Comparison of installed RES-E capacities in the "Shallow" (=BAU scenario) and the "Super-shallow" scenario in 2020

„Shallow" (=BAU scenario)



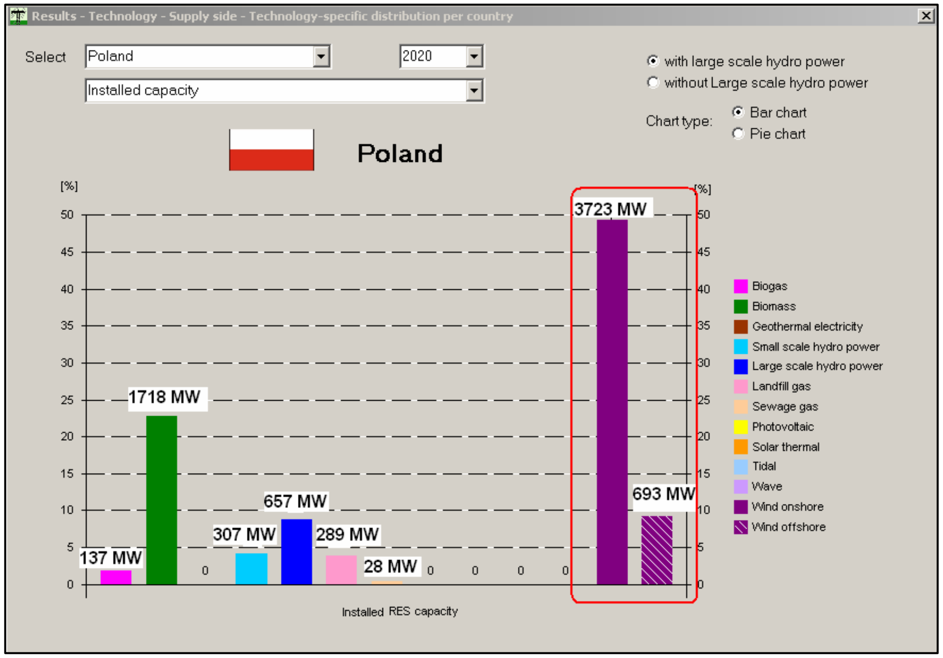
Results - Technology - Supply side - Technology-specific distribution per country

Select: Poland; 2020; Installed capacity

● with large scale hydro power
○ without Large scale hydro power

Chart type: ● Bar chart ○ Pie chart

„Super-Shallow"



Results - Technology - Supply side - Technology-specific distribution per country

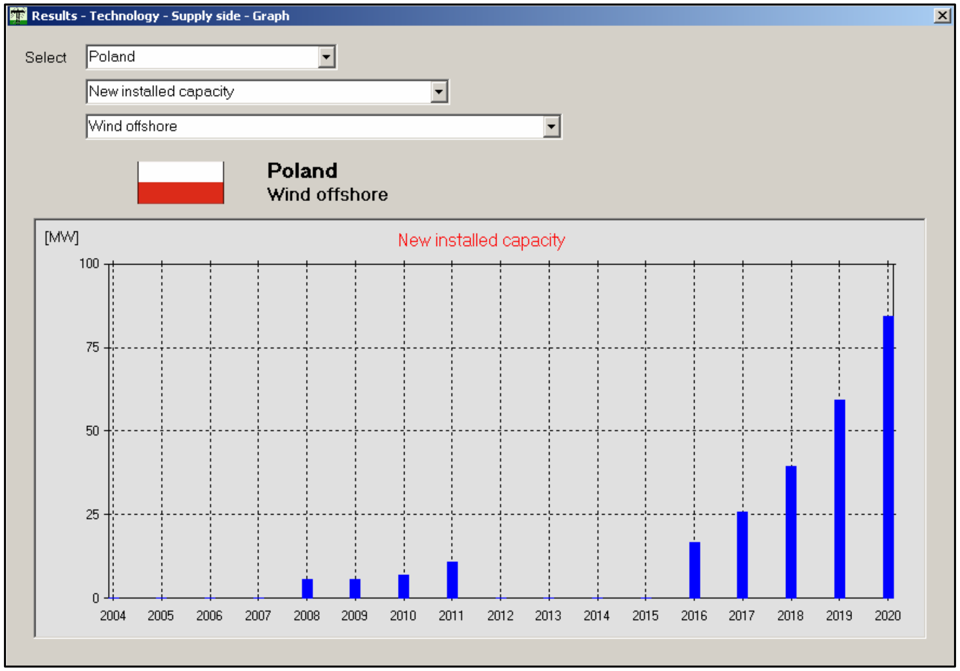
Select: Poland; 2020; Installed capacity

● with large scale hydro power
○ without Large scale hydro power

Chart type: ● Bar chart ○ Pie chart

Poland:
Annual installed capacities for wind-offshore in the "Shallow" (=BAU scenario) and the "Super-shallow" scenario from 2005 - 2020

„Shallow" (=BAU scenario)



Results - Technology - Supply side - Graph

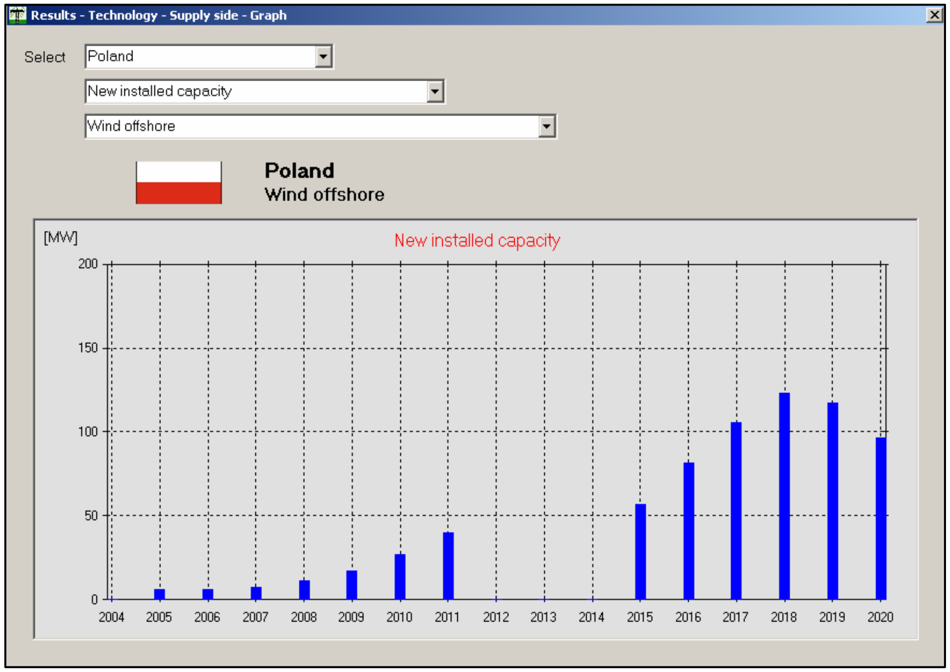
Select: Poland

New installed capacity

Wind offshore

Poland
Wind offshore

„Super-Shallow"



Results - Technology - Supply side - Graph

Select: Poland

New installed capacity

Wind offshore

Poland
Wind offshore

4. Lessons Learned

- **There exist different cost elements of RES-E integration: RES-E power plant, grid connection, grid reinforcement, system operation**

- **At present, cost allocation policies of RES-E integration are very heterogeneous in different EU Member States**
  - Grid infrastructure: “deep” vs. “shallow” vs. “super-shallow” approach
  - System operation: intermittency risk either socialized to end-user or fully covered by RES-E operator

- **Basic unbundling / market principles are still often violated in the context of RES-E integration (e.g. in the “deep” and “shallow” integration approach)**

- **Cost allocation policy significantly affects economics (generation cost) of RES-E technologies and, subsequently, RES-E deployment**
  - Grid connection often is a significant economic barrier for RES-E developers in dispersed locations
  - For the location selection of RES-E sites a trade-off is often necessary between best generation sites and conditions for grid access

- **Grid operators are facing two – unsolved – problems at the moment**
  - National regulators implement new grid regulation models, benchmark grid infrastructure and grid operation cost and expect “cost efficiency”
    - -> These uncertain constraints don’t trigger any investments into the grids
    - -> But increasing shares of RES-E integration expect investments into the grid infrastructure and investments into intelligent new technologies for grid operation (“Smart Grids”)
  - Cost recovery of RES-E related grid cost is essential for grid operators since investments into the capital intensive infrastructure are effectively sunk and vulnerable to regulatory changes

5. Policy Recommendations

Implement Unbundling !

- A clear definition of the boundary between RES-E power plant and the grid infrastructure is necessary
- Super-shallow or at least shallow RES-E integration approach (incl. transparent locational signals) is preferable compared to deep integration

Don't neglect grid operator's point of view !

- Large-scale RES-E grid integration can't take place on the expense of market actors like grid operators
- Ex-ante mechanism in the grid regulation for cost recovery provides incentives for grid operators to invest

Establish markets in system operation !

- Support technological development (e.g. wind forecasting), improve regulatory framework (e.g. shorter gate closure, continuous day-ahead markets) and increasingly implement market mechanisms in system operation (with an extended geographical coverage compared to the status quo) caused by intermittent RES-E generation

Then start RES-E policy / integration discussion again !