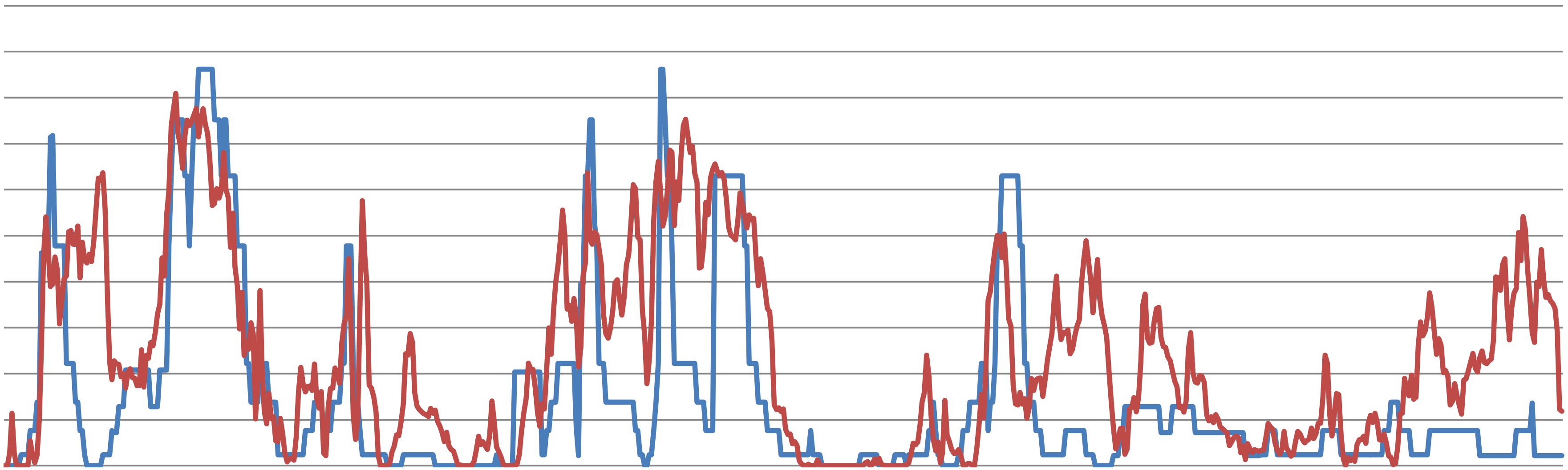
Wind energy overview



Lauri Ulm

14.08.2014

About me

- Name: Lauri Ulm
- Work
  - Currently: Renewable energy development manager
  - Past:
    - Asset Management Department network analyst
    - Eletricity network designer
- Education
  - Currently: PhD studies
  - Past:
    - 2013 – Master in Business Administration,
    - 2012 – Exchange studies in Aalto University School of Science
    - 2010 – Master in Electrical Power Engineering
    - 2008 – Bachelor in Electrical Power Engineering

Eesti Energia AS Wind farms

Virtsu WPP

Plant description

- Total installed capacity 1,4 MW
- Built in 2002/2008
- Investment: 1,3 MEUR, 0,9 MEUR/MW

Sjustaka WPP

Plant description

- Total installed capacity 0,15 MW
- Built in 2007
- Investment: 0,6 MEUR, 4,3 MEUR/MW

Eesti Energia AS Wind farms

Aulepa I WPP

Plant description

- Total installed capacity 39 MW
- Built in 2009
- Investment: 54,6 MEUR; 1,4 MEUR/MW

Aulepa II WPP

Plant description

- Total installed capacity 9 MW
- Built in 2012
- Investment: 11,3 MEUR, 1,3 MEUR/MW

Eesti Energia AS Wind farms

Narva WPP

Plant description

- Total installed capacity 39 MW
- Built in 2012
- Investment: 59,6 MEUR, 1,5 MEUR/MW

Paldiski WPP

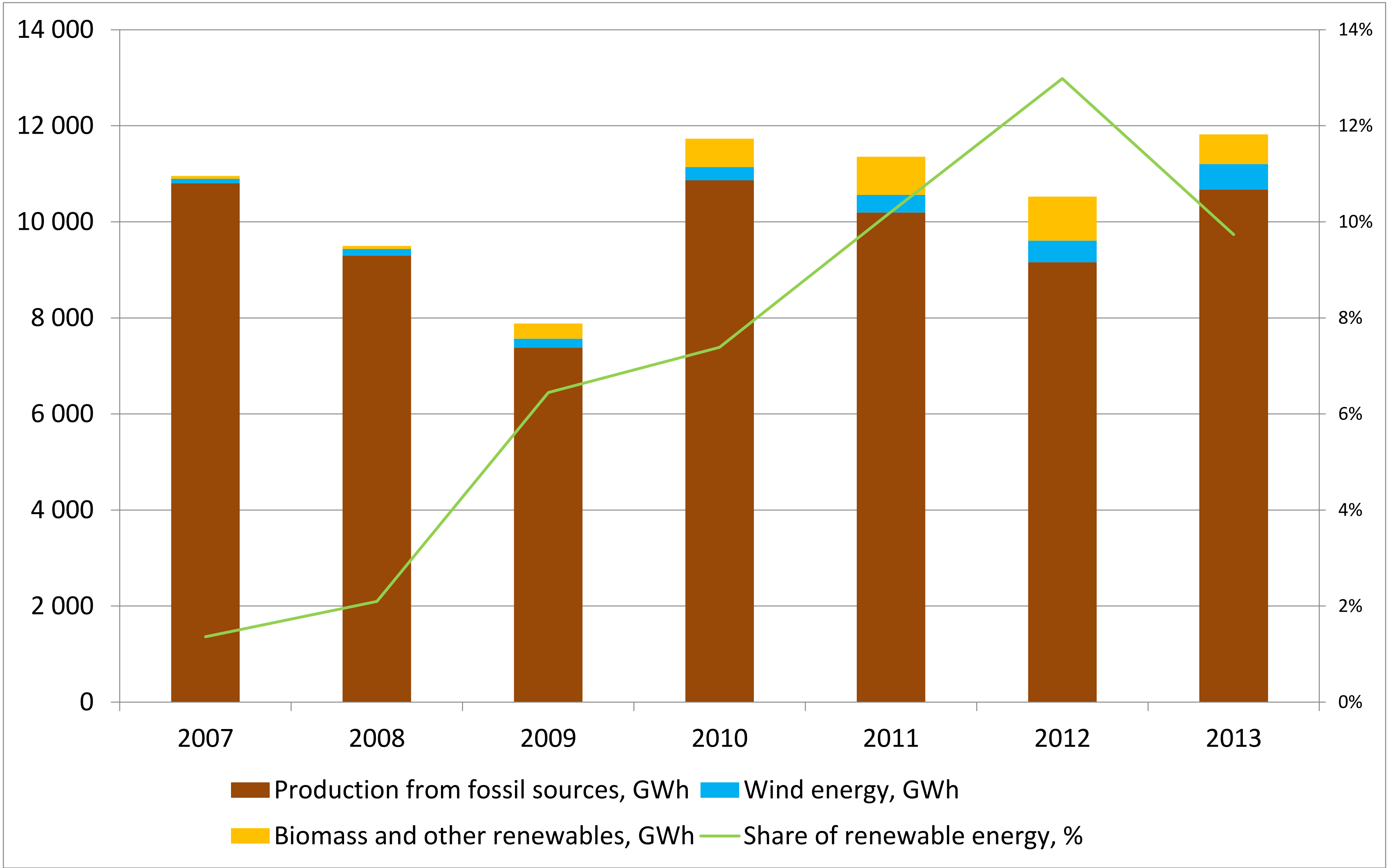
Plant description

- Total installed capacity 22,5 MW
- Built in 2012
- Investment: 30,8 MEUR, 1,4 MEUR/MW

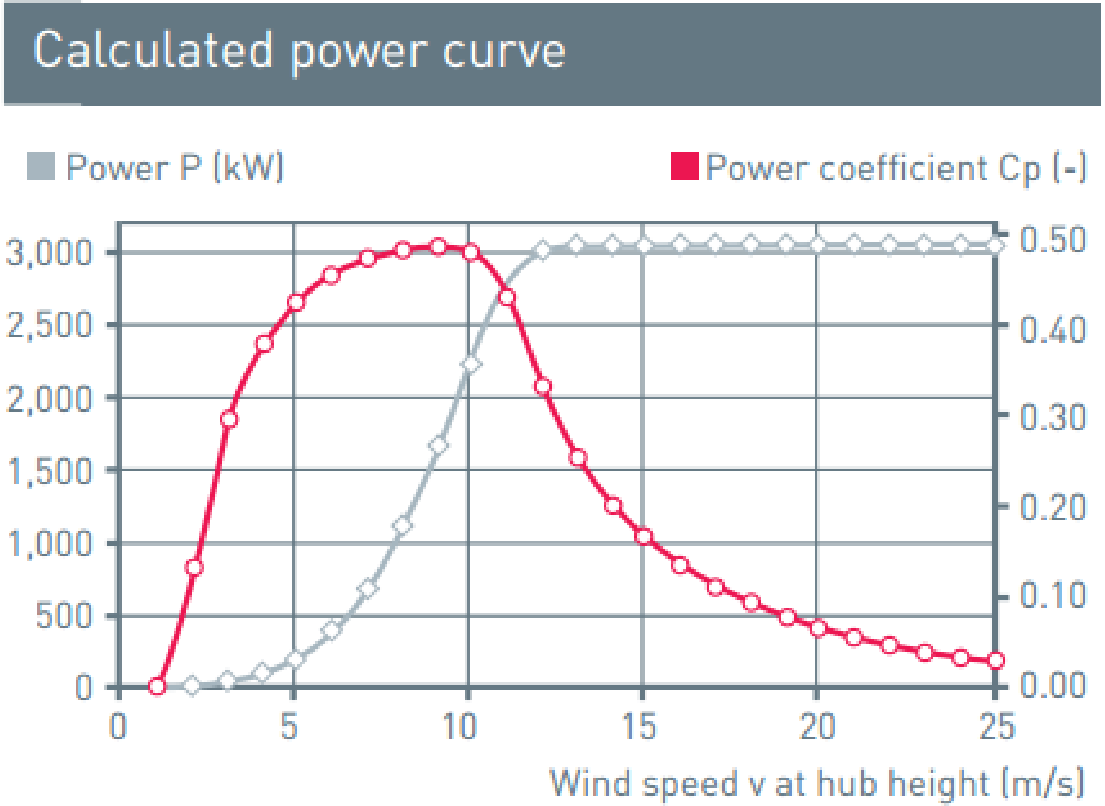
Eesti Energia AS Wind farms

- Total installed capacity: ca 110 MW
- Total yearly production: ca 215 000 000 kWh
- Average home consumes 2 500-5 000 kWh/year
- Renewable energy for 43 000 – 86 000 homes.

Renewable energy in Estonia



How wind turbine works?



$$P_1 = {}^1/_2\, m v_1^2 / t = {}^1/_2\, \gamma A v_1^3$$

How much energy from the wind can be used?

Betz's law

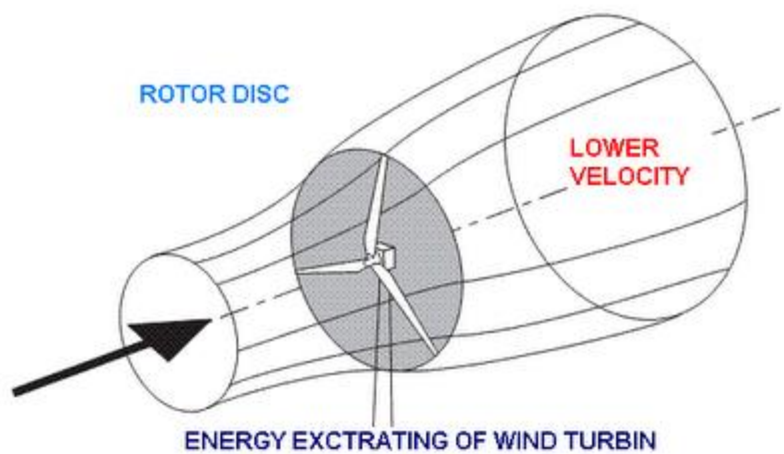
German physicist Albert Betz published it 1919

According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind.

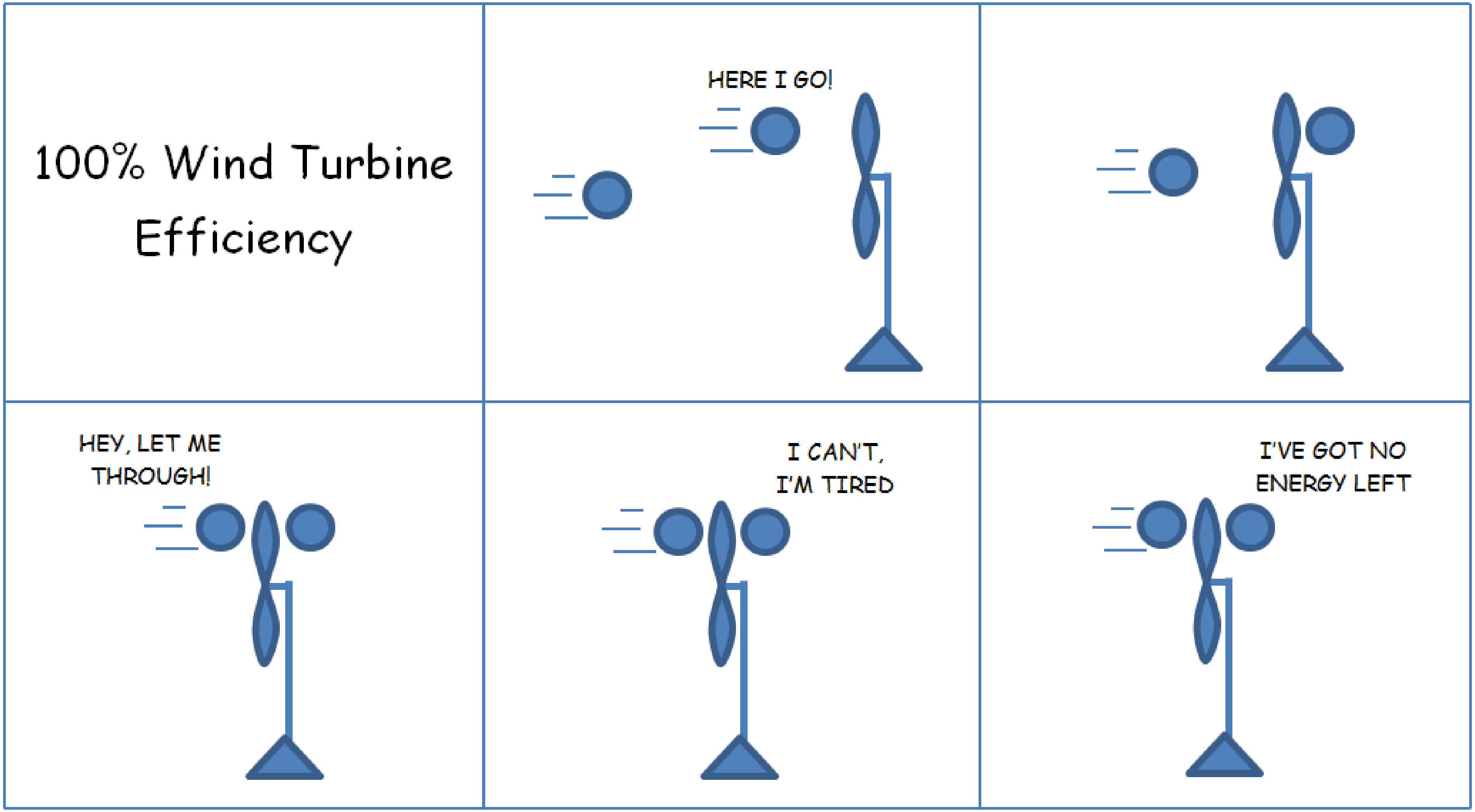
The factor 16/27 (0.593) is known as Betz's coefficient.

Wind is considered to be like fluid.

The law applies to all Newtonian fluids.

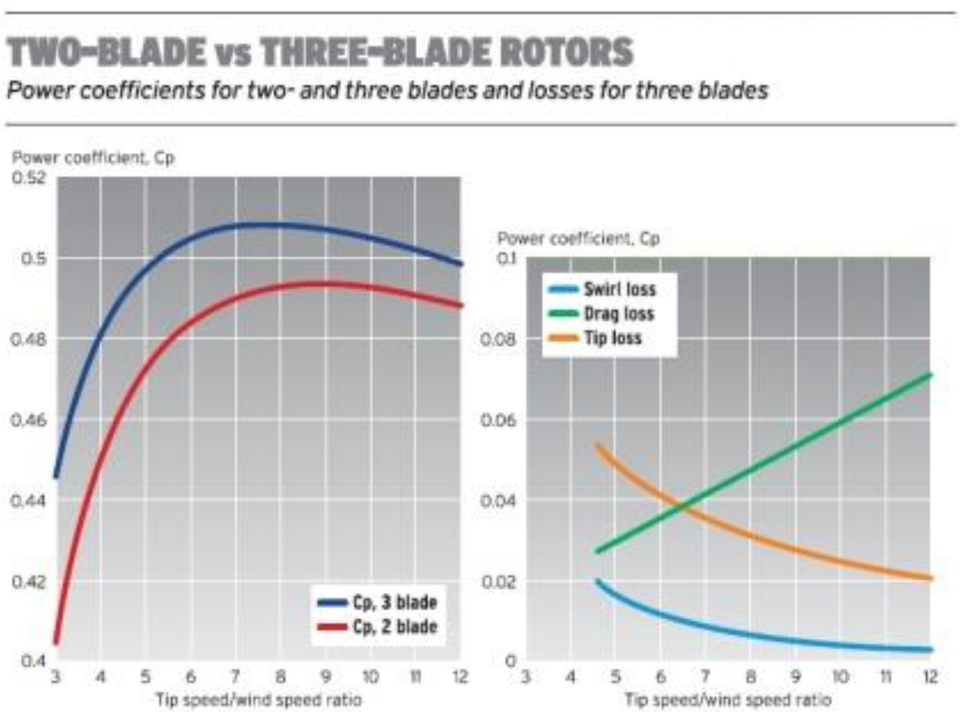


Two air molecules



Why three blades?

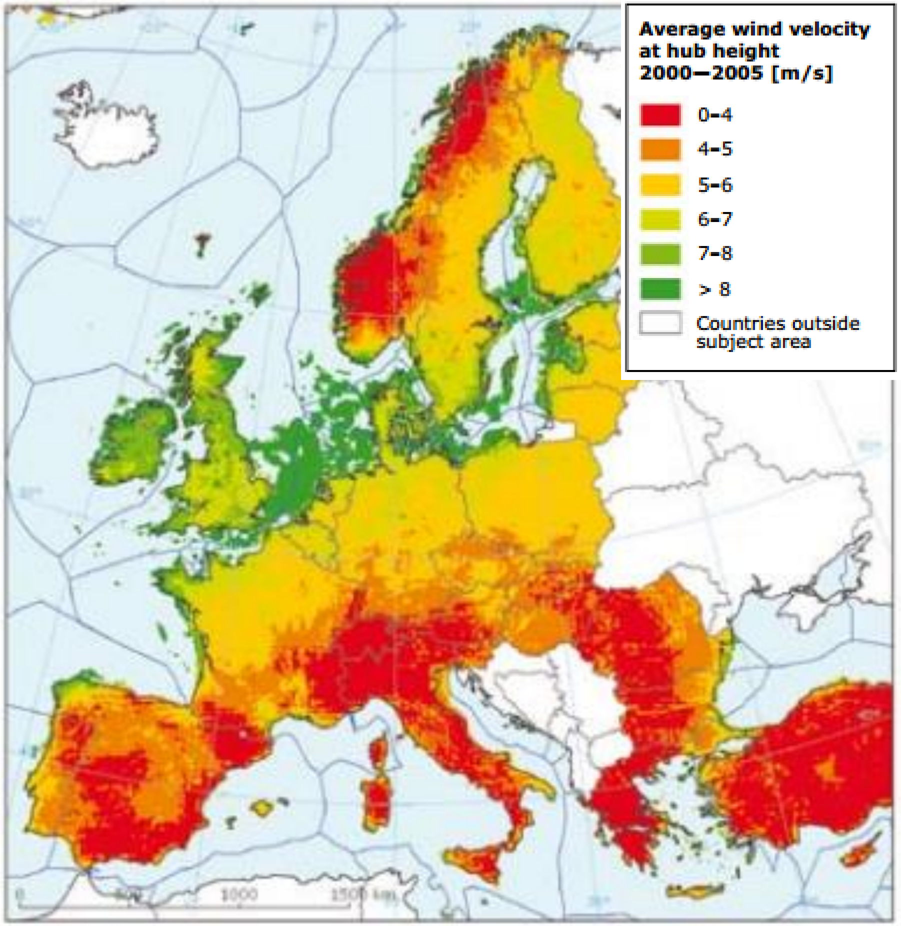
- Three blades – 0.51
- Two blades – 0.49
- Despite that several companies are testing two blade versions.

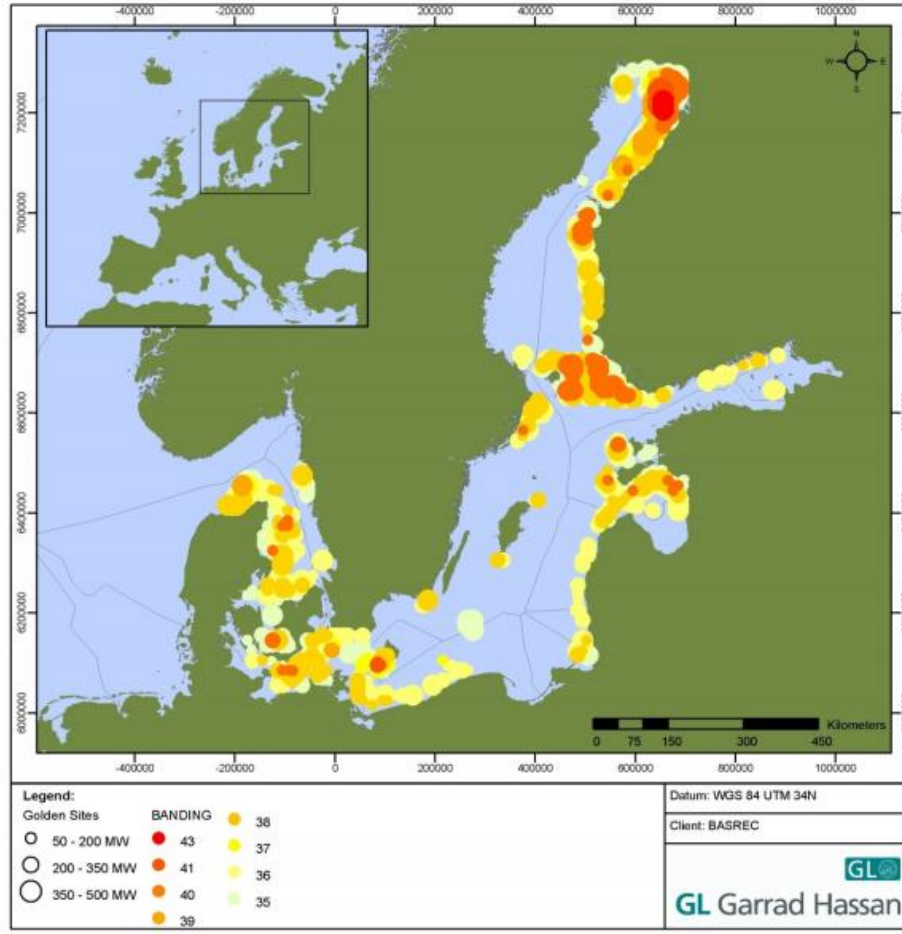


1 Recap

- The generated wind power depends of wind speed (**power of 3**), area of the blades and air density.
- According to Albert Betz it’s possible ideally to use 59,3% of energy from the wind.
- Mostly three blades are used to get most energy from the wind. Two blades are tested for offshore.

Is wind blowing in the Northern Baltic Sea region?





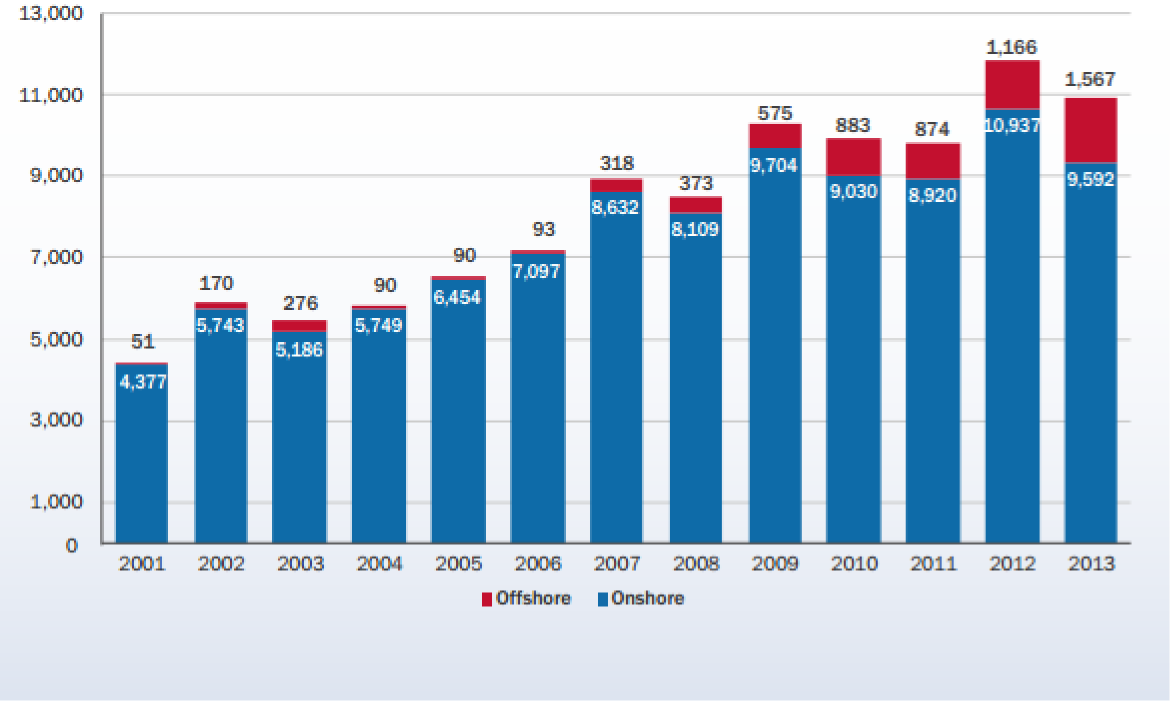
Northern Baltic Sea

Northern Baltic Sea vs North Sea

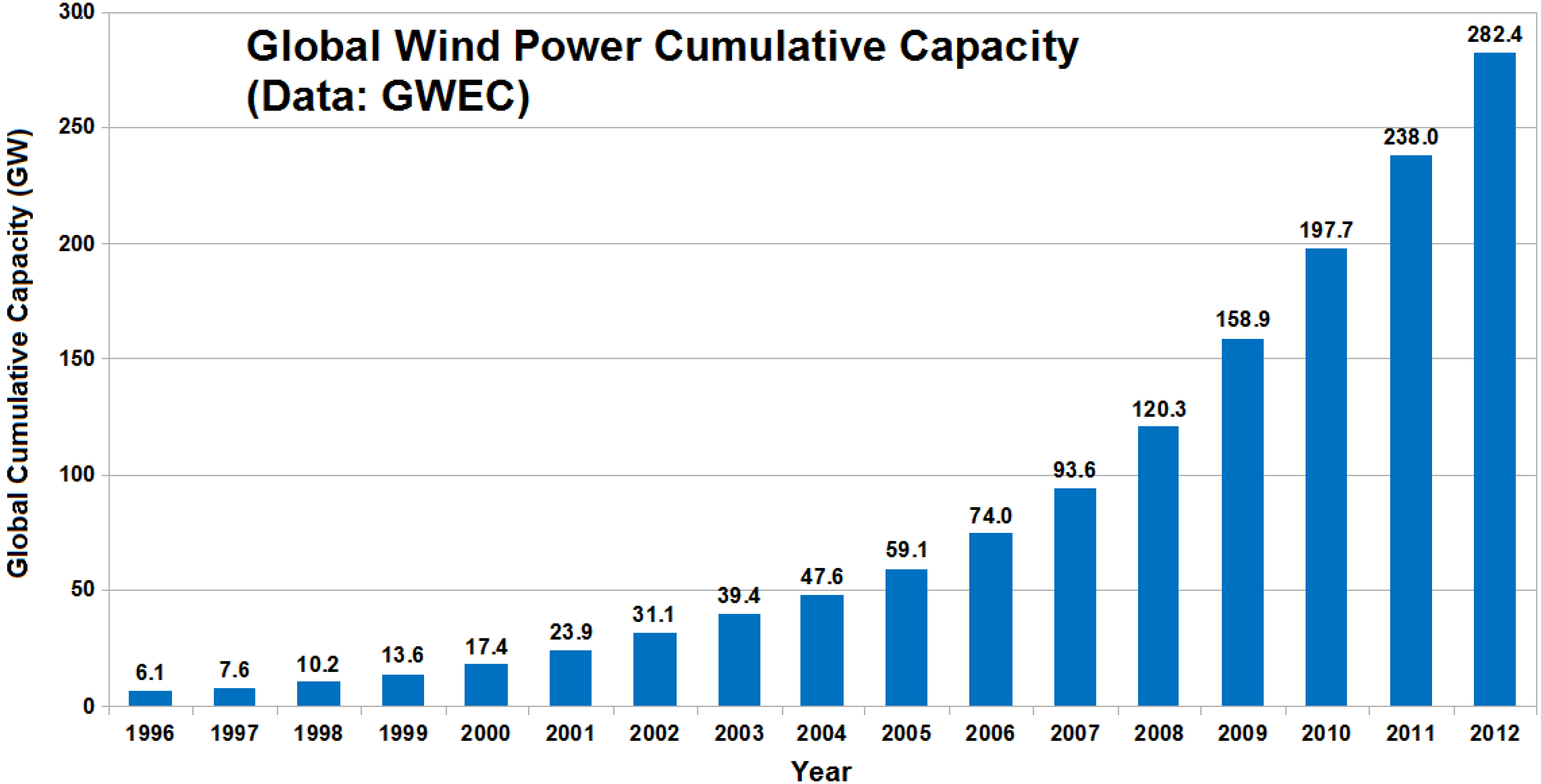
Region	**North Sea**	**Northern Baltic Sea**
Distance to coast	Long	Moderate/short
Water depth range	20…40	5…25
Tide	Yes	No
Swell	Yes	No / insignificant
Max wave	High	Moderate
Mean wind	IEC I	IEC I/II
Extreme wind	IEC I	IEC I/II
Water salinity	High	Low
Salt spray	Yes	Insignificant
Corroding air	Yes	Insignificant?
Operating temp. range	-10…+30 C	**-30…+30 C**
Drift ice	No	**Yes**
Pack ice	No	**Yes**
Turbine design	Offshore	Onshore/ semi-offshore Cold Climate Version
Remuneration offshore	> 150 €/MWh	No offshore-specific remuneration system

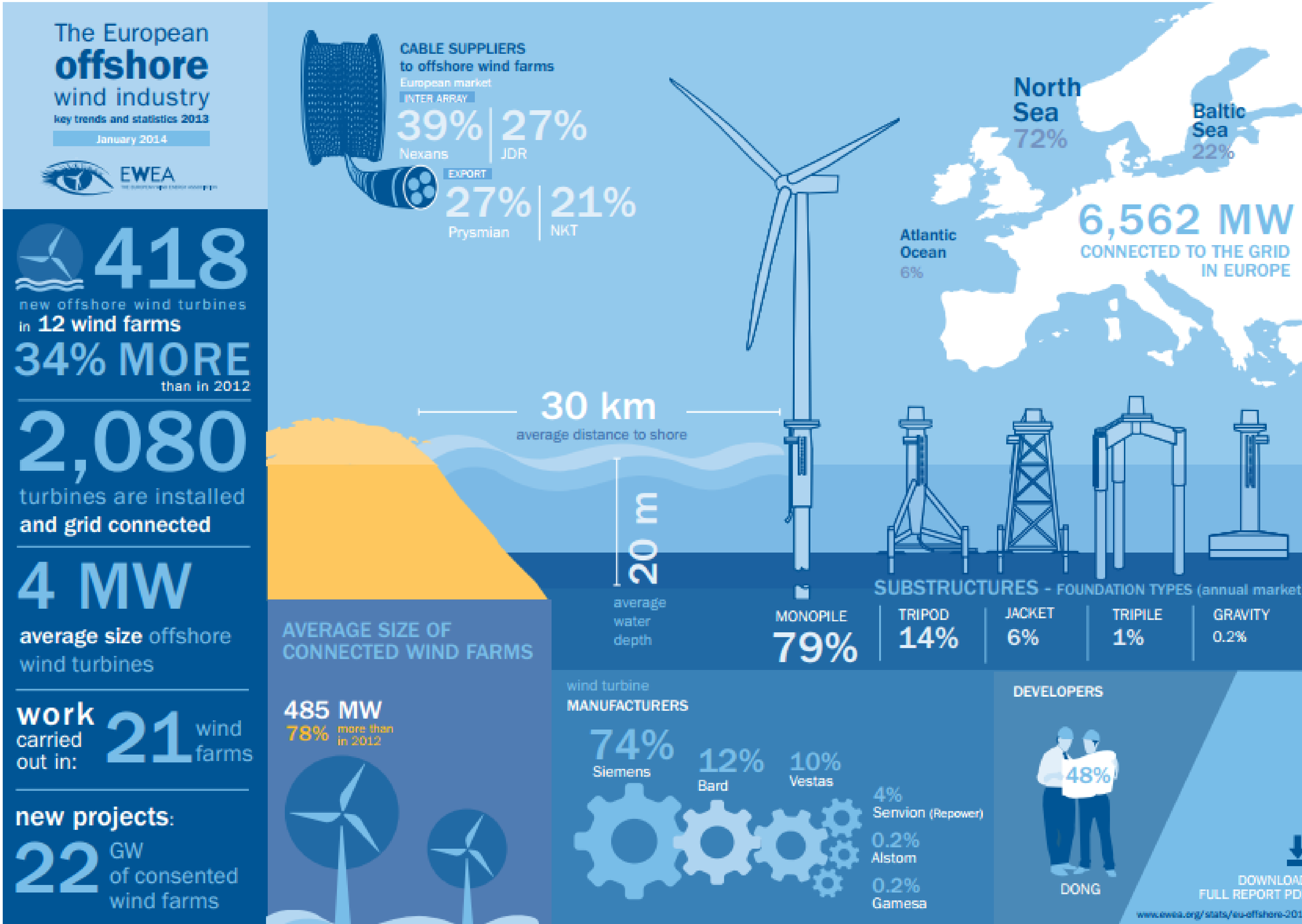
Statistics – installed capacity

Annual EU onshore and offshore installations (MW):



Installed wind power capacity

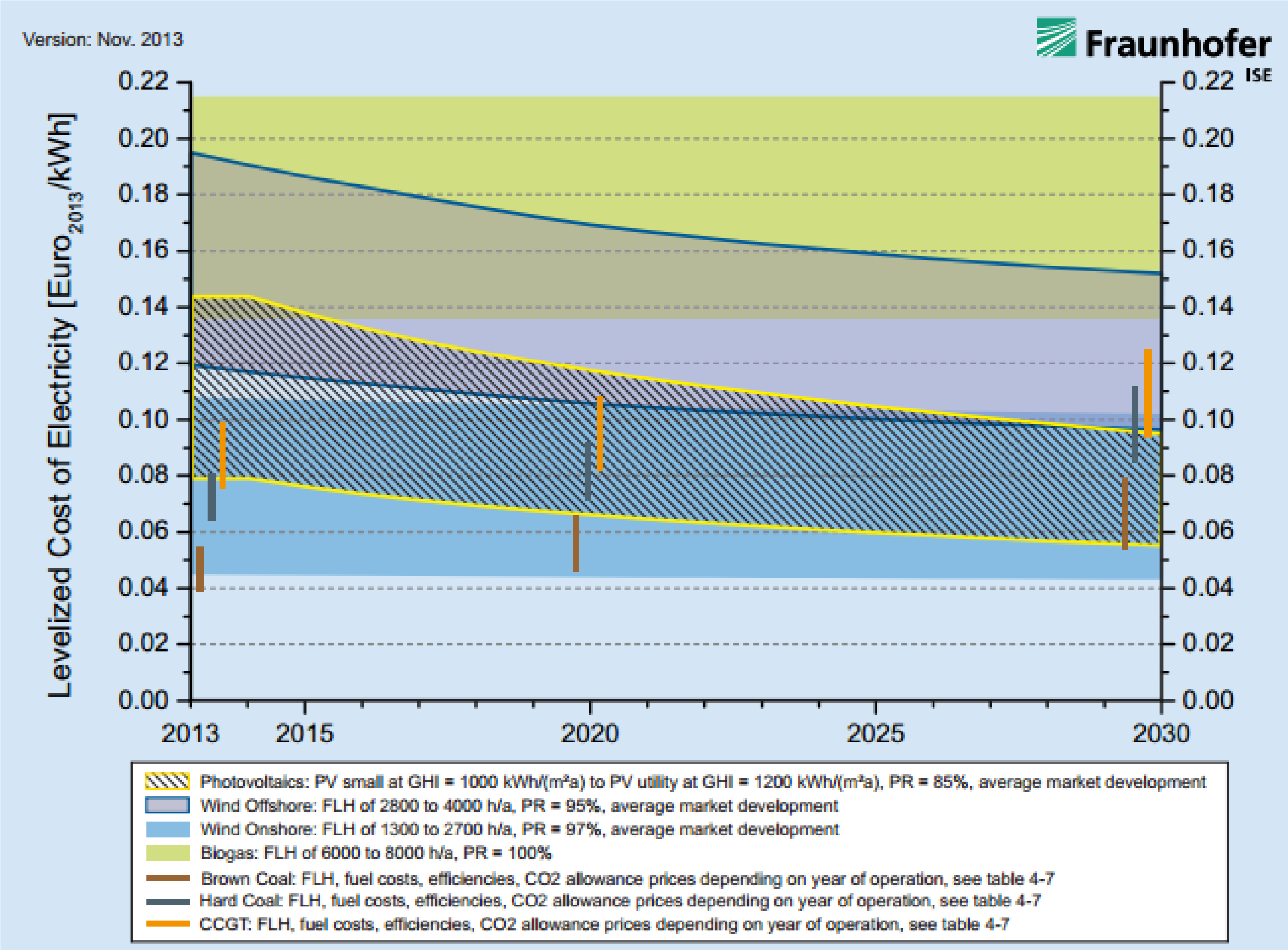



The European
offshore
wind industry
key trends and statistics 2013
January 2014
EWEA
418
new offshore wind turbines
in 12 wind farms
34% MORE
than in 2012
2,080
turbines are installed
and grid connected
4 MW
average size offshore
wind turbines
work carried out in: 21 wind farms
new projects:
22 GW
of consented
wind farms
CABLE SUPPLIERS
to offshore wind farms
European market
INTER ARRAY
39%
Nexans
27%
JDR
EXPORT
27%
Prysmian
21%
NKT
North Sea
72%
Baltic Sea
22%
Atlantic Ocean
6%
6,562 MW
CONNECTED TO THE GRID
IN EUROPE
30 km
average distance to shore
20 m
average water depth
AVERAGE SIZE OF
CONNECTED WIND FARMS
485 MW
78% more than in 2012
SUBSTRUCTURES - FOUNDATION TYPES (annual market)
MONOPILE
79%
TRIPOD
14%
JACKET
6%
TRIPILE
1%
GRAVITY
0.2%
wind turbine
MANUFACTURERS
74%
Siemens
12%
Bard
10%
Vestas
4%
Senvion (Repower)
0.2%
Alstom
0.2%
Gamesa
DEVELOPERS
48%
DONG
DOWNLOAD
FULL REPORT PDF
www.ewea.org/stats/eu-offshore-2013

2 Recap

- The wind is blowing steady in Northern Baltic Sea
- The Baltic Sea has several advantages for offshore developments
- Offshore developments are increasing the pace

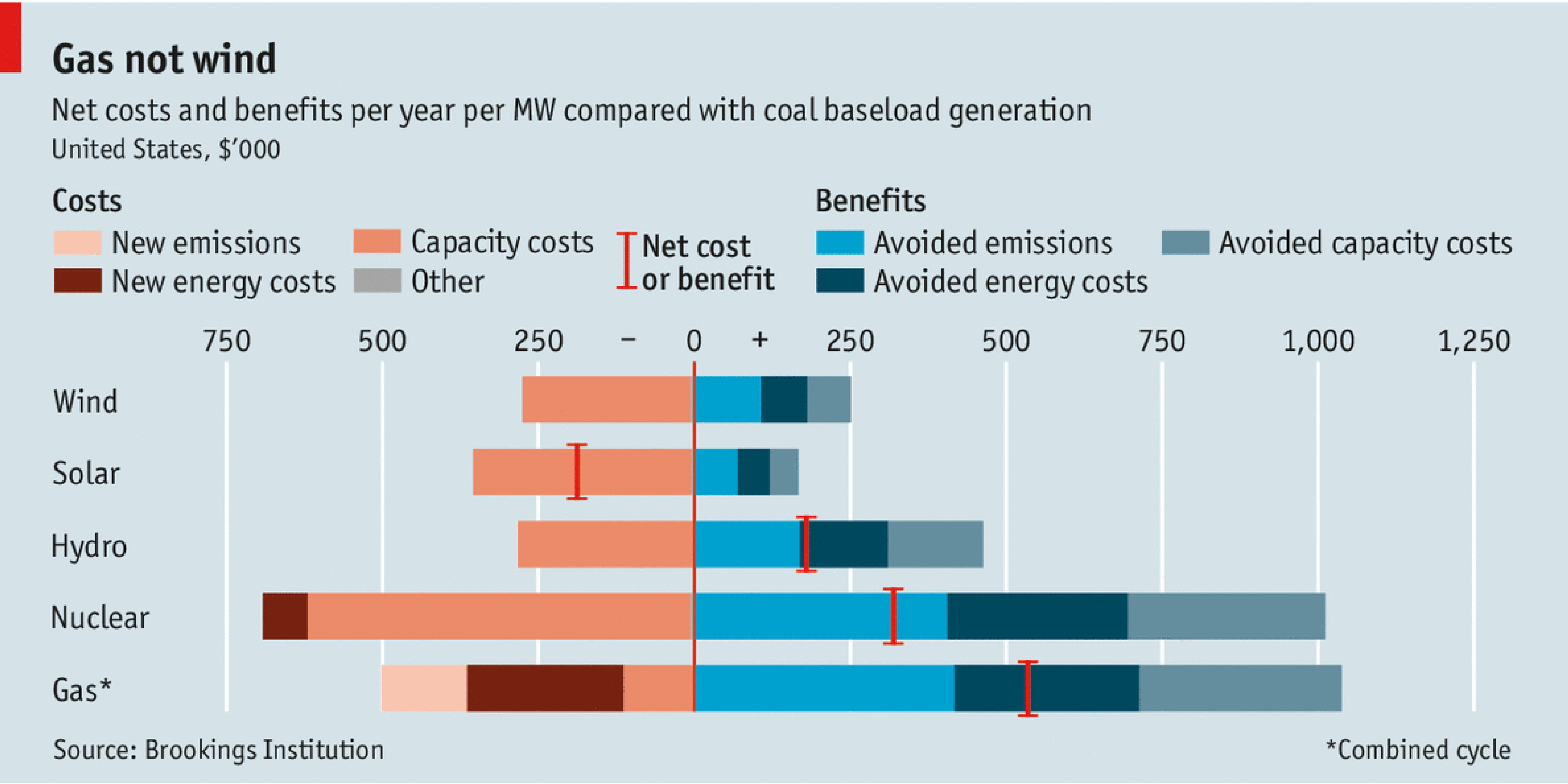
Levelized cost of electricity



Other perspective

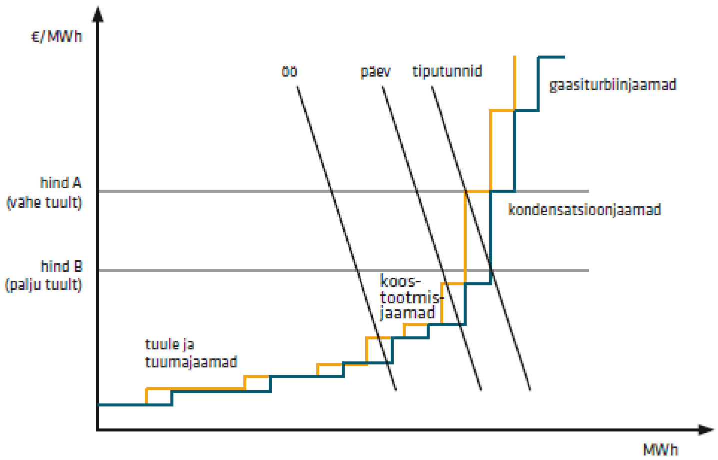
Charles R. Frank, Jr.; May 2014

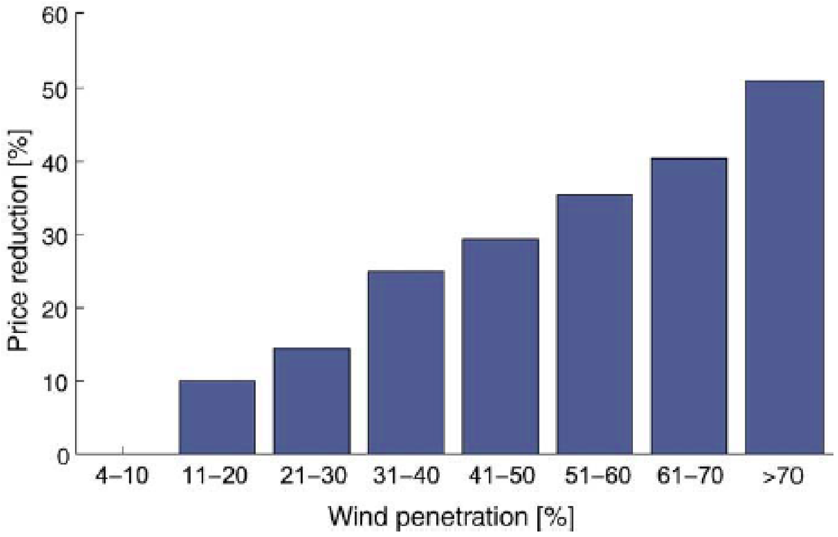
- Levelized cost not appropriate for ranking technologies.



Electricity price

- Electricity market works by usual demand & supply rule.
- When there is wind then there is extra supply available. Wind producers always want to sell their electricity because the marginal cost for each unit produced is really low or even negative in case there is extra subsidy.
- R= $\sum^{N_\Omega} \sum_{h=1}^{N_T} (\lambda_h^D P_h^D + \lambda_h^I P_h^I + \lambda_h^+ P_h^+ - \lambda_h^- P_h^-)$

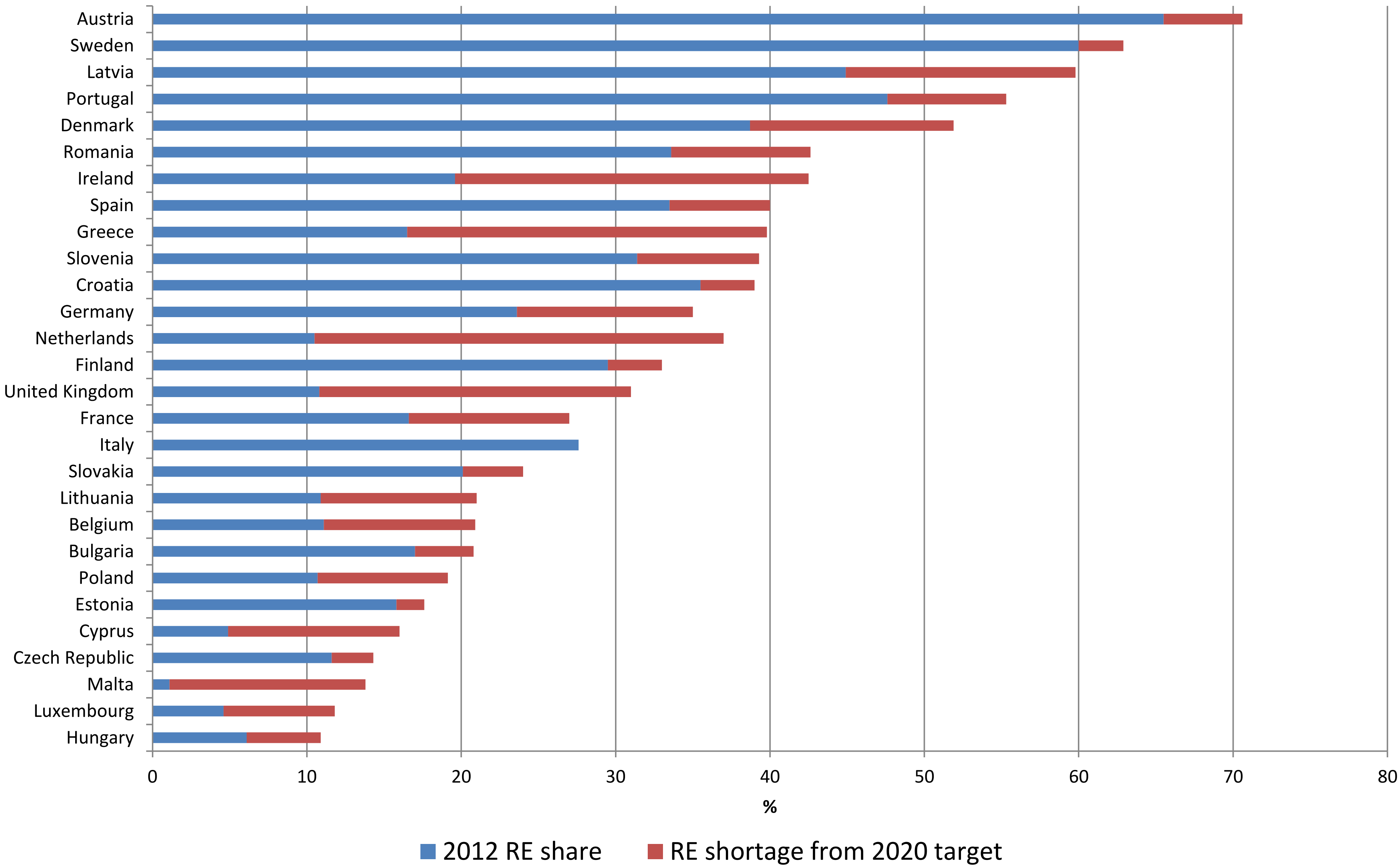




Support schemes

- There is a need for support to build new electricity plants.
- EU regulation is changing towards auction system to find the cheapest source for renewable energy.
- Currently most countries use feed-in schemes which means that the support is calculated based on the market price.

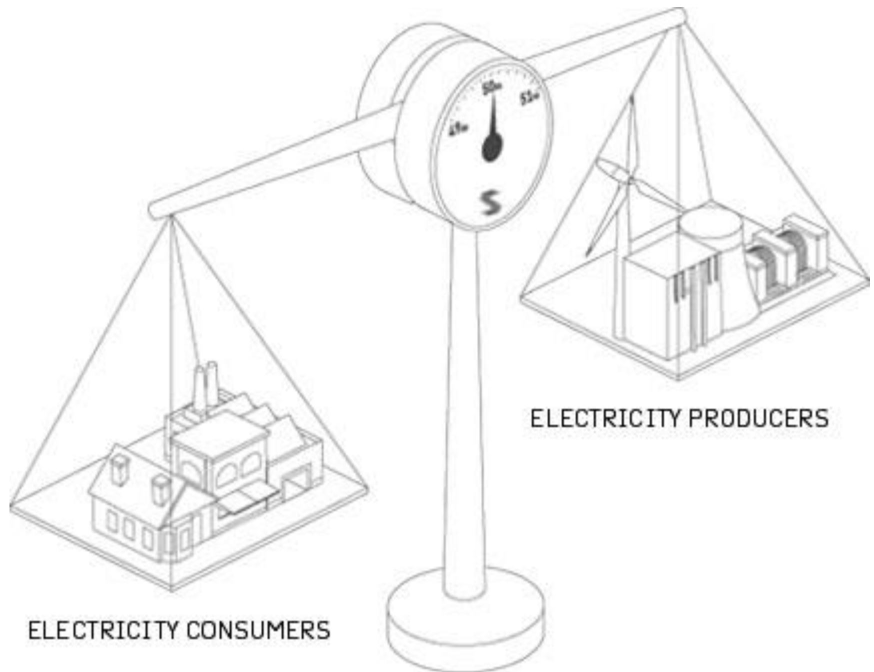
EU 2020 electricity targets



3 Recap

- Based on the levelized cost wind is the cheapest source of electricity (new power plant)
- The wind and solar is not that cheap take into account the variability. For us this is not that important because of Norway and Sweden hydro resources.
- Electricity price is determined by the demand and supply rule.
- EU 2020 targets are achievable. Different countries have different strategies.

Why is forecasting important?

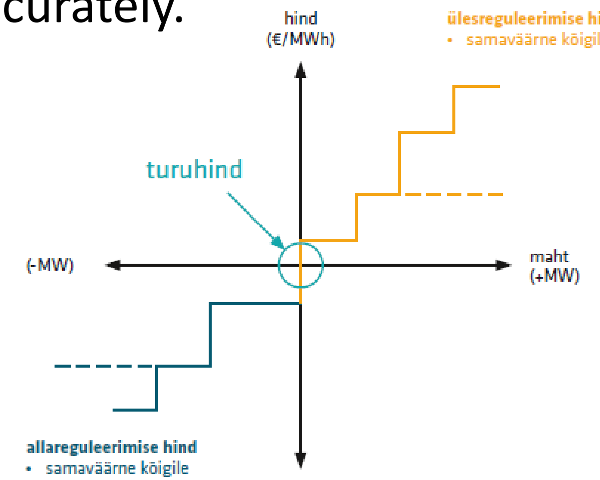


Methods to balance the grid

- Transmission System Operator (in Estonia) is responsible for securing the balance in the grid.
- TSO can
  - buy balance power from the special market,
  - use contracts with power suppliers to regulated production up or down (spinning reserves),
  - shut down or limit power plants production in the grid,
  - Etc…

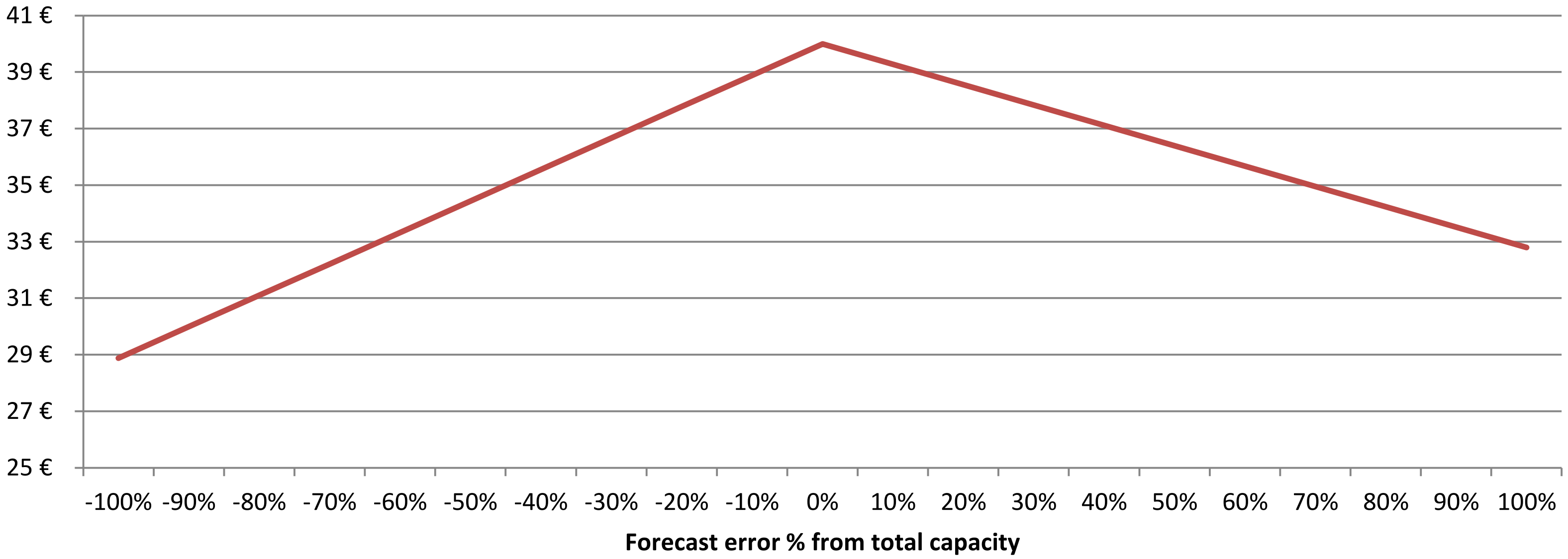
Balance in the power market

- The electricity producers sell electricity to the power market. Sold electricity will be produced.
- For wind turbines the production is forecasted and sold to the power market usually a day before for each hour on next day (spot market).
- Also there is possibility to trade on the same day (when you have more accurate forecast), but in Estonia it is not much used.
- If it is produced more or less than it was sold on power market then producers have to buy balacing power. The balacing power price is design so that it will give incentive to forecast accurately.



Conclusion from previous

- Wind power forecasting is needed for the Transmission System Operator to balance the grid and therefore keep the frequency stable. The ultimate goal is to avoid blackout and keep everything running.
- Wind power forecasting is needed for power producer to avoid paying for the balacing power and planning maintanance.

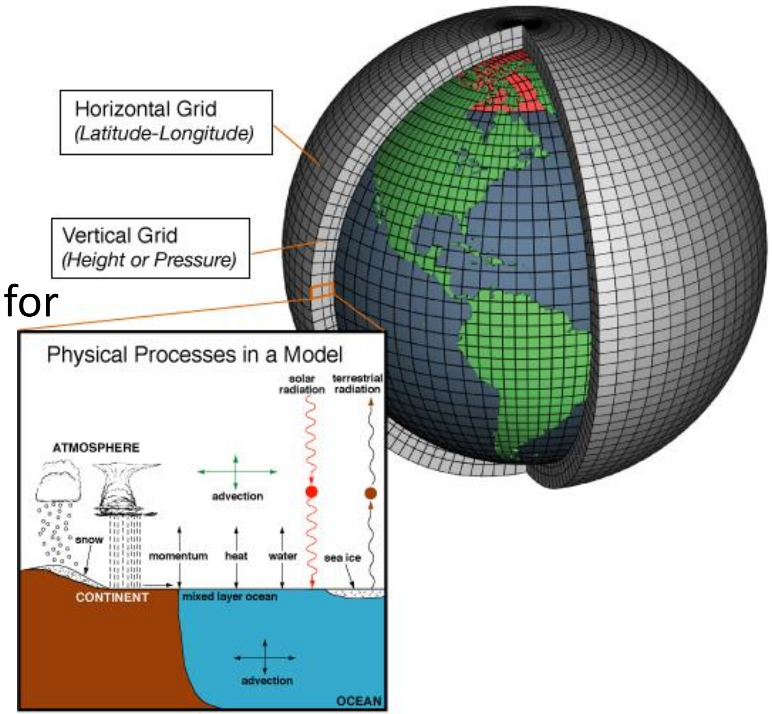


Wind power forecasting categories

- Very short term (few seconds to 30 minutes)
  - last minute transactions in power market,
  - controlling wind turbines.
- Short term (30 minutes to 48/72 hours)
  - planning transactions in power market,
- Middle term (48/72 hours to 1 week)
  - planning maintanance,
  - planning oprating of the production units
- Long term (1 week to 1 year)
  - planning maintanance,
  - planning budget,
  - in feasibility studies.

Forecasting methodologies

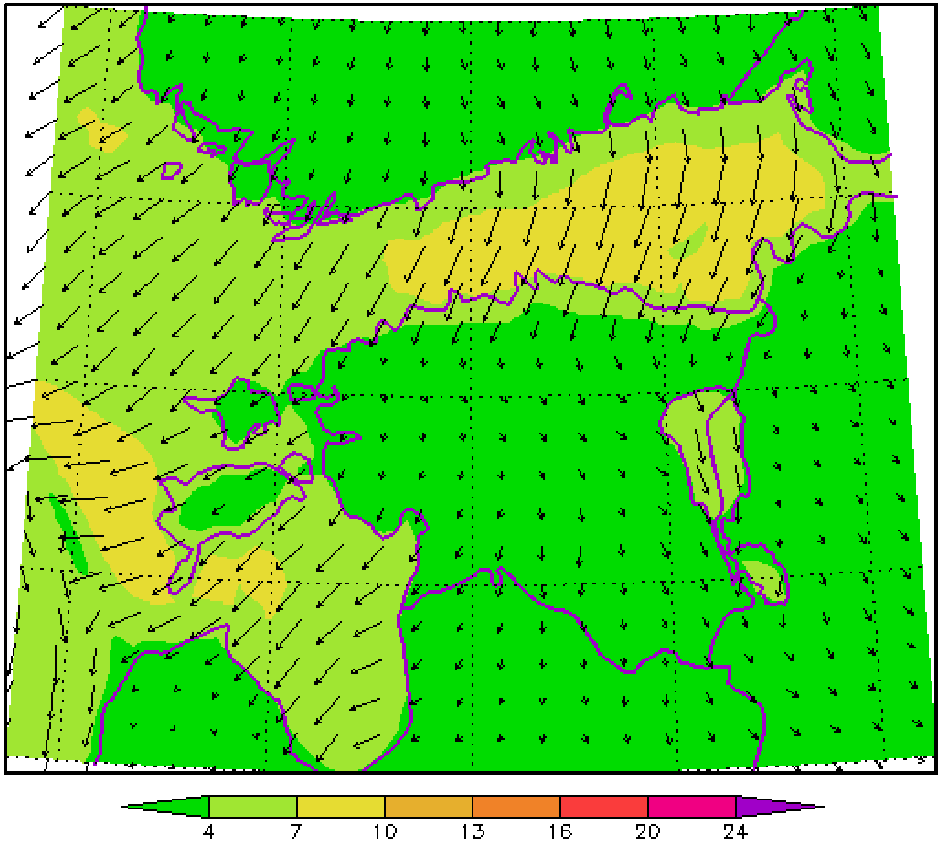
- Forecasting wind speed and production
- Forecasting productiondirectly
- Statistical approach
  - Based on historical data
  - Correlation between historical and wind park production/ wind speed data
- Numerical weather prediction
  - the output of an NWP model is a detailed forecast of the state of the atmosphere at a given time, not just the wind.
  - NWP forecasts are not specifically produced for the electricity industry and are used by a variety of industries, sectors and government agencies.



Local NWP model

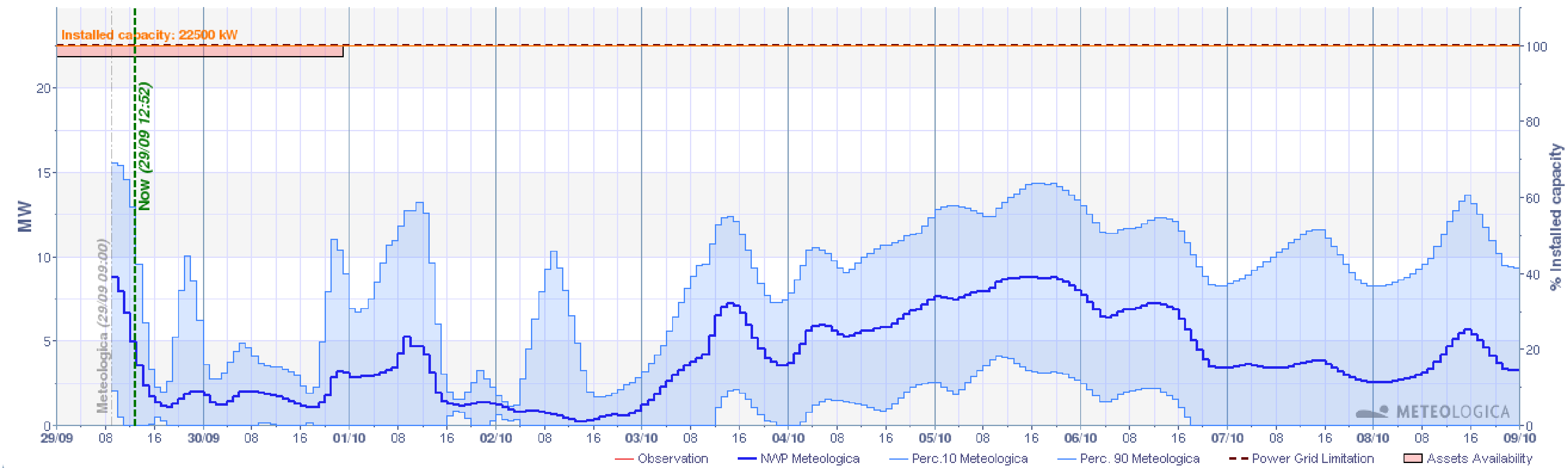
- Local NWP models focus on particular region and its phenomens.
- They run usually on higher resolution. And the forecast period is up to 3 days.
- EMHI HIRLAM:

  11x11km



Multi-scheme ensemble prediction

- Using the NWP models and changing one or few inputs to see how the output changes. Therefore understanding the uncertainty in the forecast.



Errors in forecasting

- Systematic error
  - Is bias in forecasting where the mean results differs significantly from the actual value.
  - For example it’s not correctly taken into account the obstacles near the wind farm and the wind speed is forecasted to be 2 m/s higher than actual.
- Random error
  - Random errors occur randomly and are unpredictable.
- It’s possible to minimize the systematic error by using statistical filters. For wind speed or power forecasting Kalman filter has shown very good results.
- The random error is minimized by grouping wind farms together.

Characterising forecast error

- There is no one universal standard how to evaluate forecasting error. There are many methods available how to do that:
- *ME – Mean error,*
- *MAE – Mean absolute error,*
- *MAPE – Mean absolute percentage error*,
- *MSE – Mean square error*,
- *RMSE – Root mean square error*,
- *Histograms of the frequency distribution of the error*,
- *Correlation coefficient R*,
- *Coefficient of determination*,
- *SDE – Standard deviation of the errors*,
- *NMAE – Normalized mean absolute error,*
- *NRMSE – Normalized root mean square error.*

Evaluation methods of forecasting accuracy

- The Mean error

$$ME_k = \overline{e}_k = \frac{1}{N}\sum_{t=1}^{N} e_{t+k|t}$$

where:

$e_{t+k|t} = P_{t+k} - \hat{P}_{t+k|t}$ Is the error corresponding to time t+k for the prediction made at time t;
P_{t+k} is the measured power at time t+k;
$\hat{P}_{t+k|t}$ is the power forecast for time t+k made at time t;
N is the number of prediction errors used for method evaluation.

- The Mean absolute error

$$MAE_k = \frac{1}{N}\sum_{t=1}^{N} \left|e_{t+k|t}\right|$$

- The Root Mean Square error

$$RMSE_k = \sqrt{MSE_k} = \sqrt{\frac{\sum_{t=1}^{N} e_{t+k|t}^2}{N}}$$

Evaluation methods of forecasting accuracy

- The Normalized Root Mean Square error

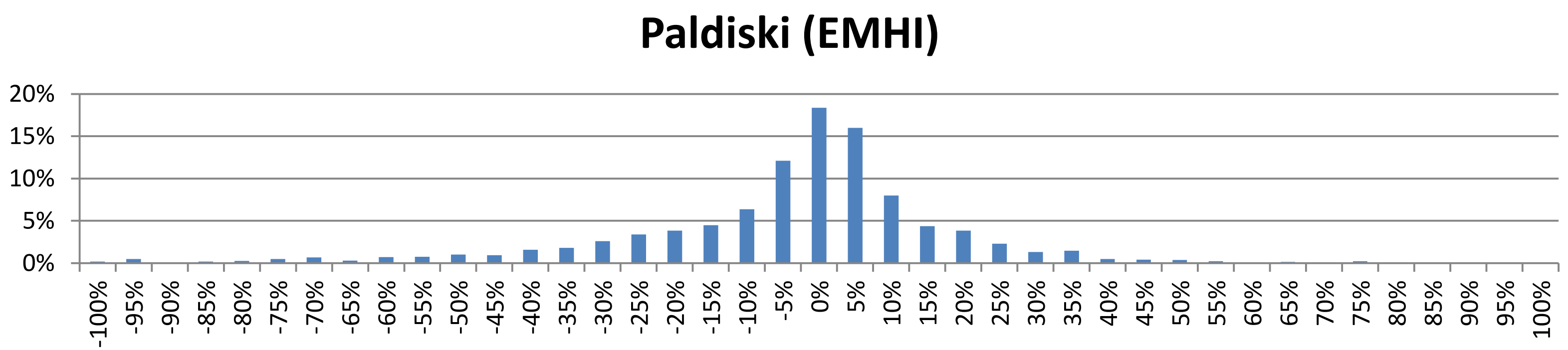
$$NRMSE_k = \frac{RMSE_k}{P_{inst}} = \frac{1}{P_{inst}}\sqrt{\frac{\sum_{t=1}^{N} e_{t+k|t}^2}{N}}$$

where: P_{inst} is the wind farm installed capacity.

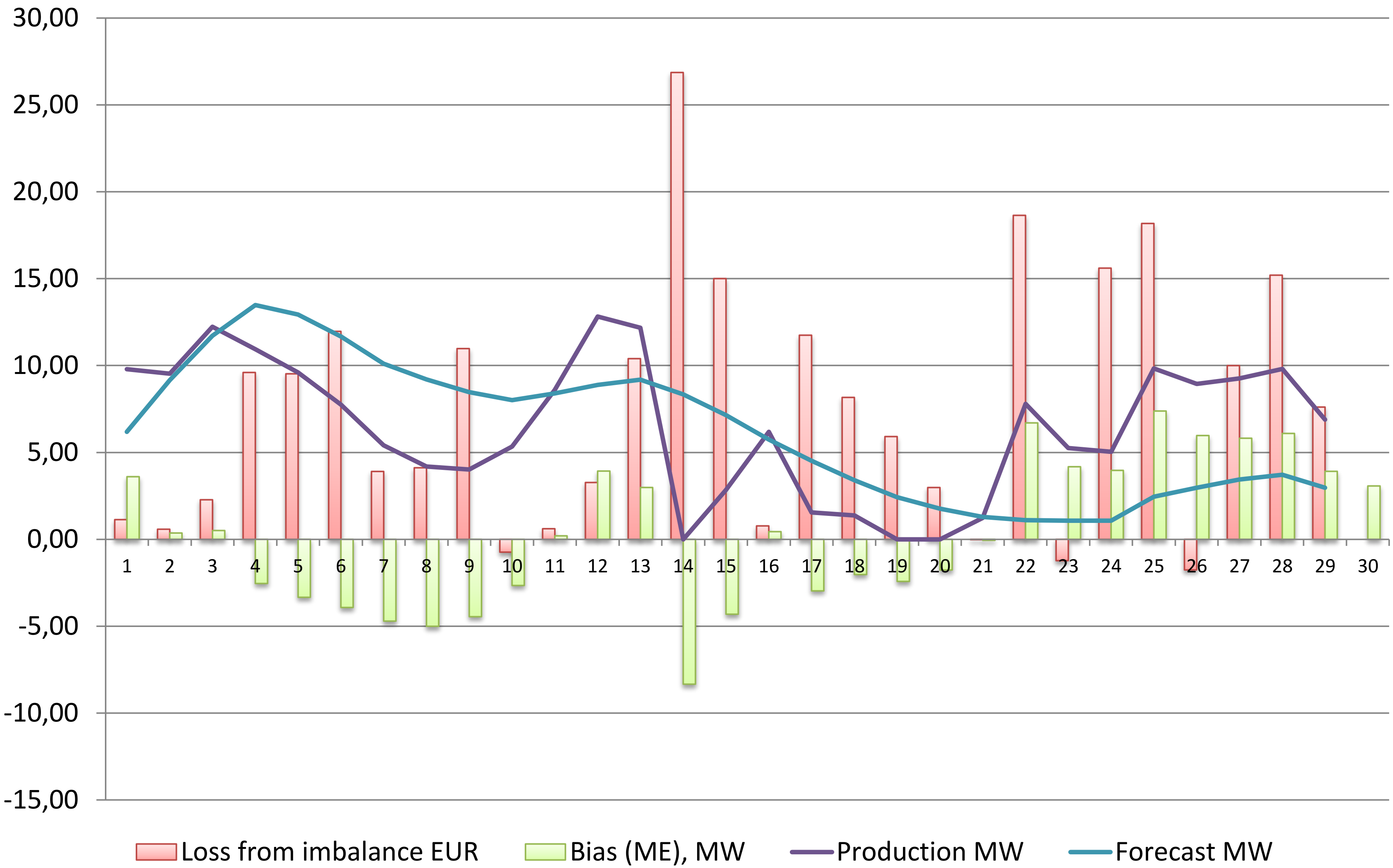
- The Normalized Mean Absolute error

$$NMAE_k = \frac{MAE_k}{P_{inst}} = \frac{1}{P_{inst}} \cdot \frac{1}{N}\sum_{t=1}^{N} \left| e_{t+k|t} \right|$$

- The Histograms of the frequency distribution of the error

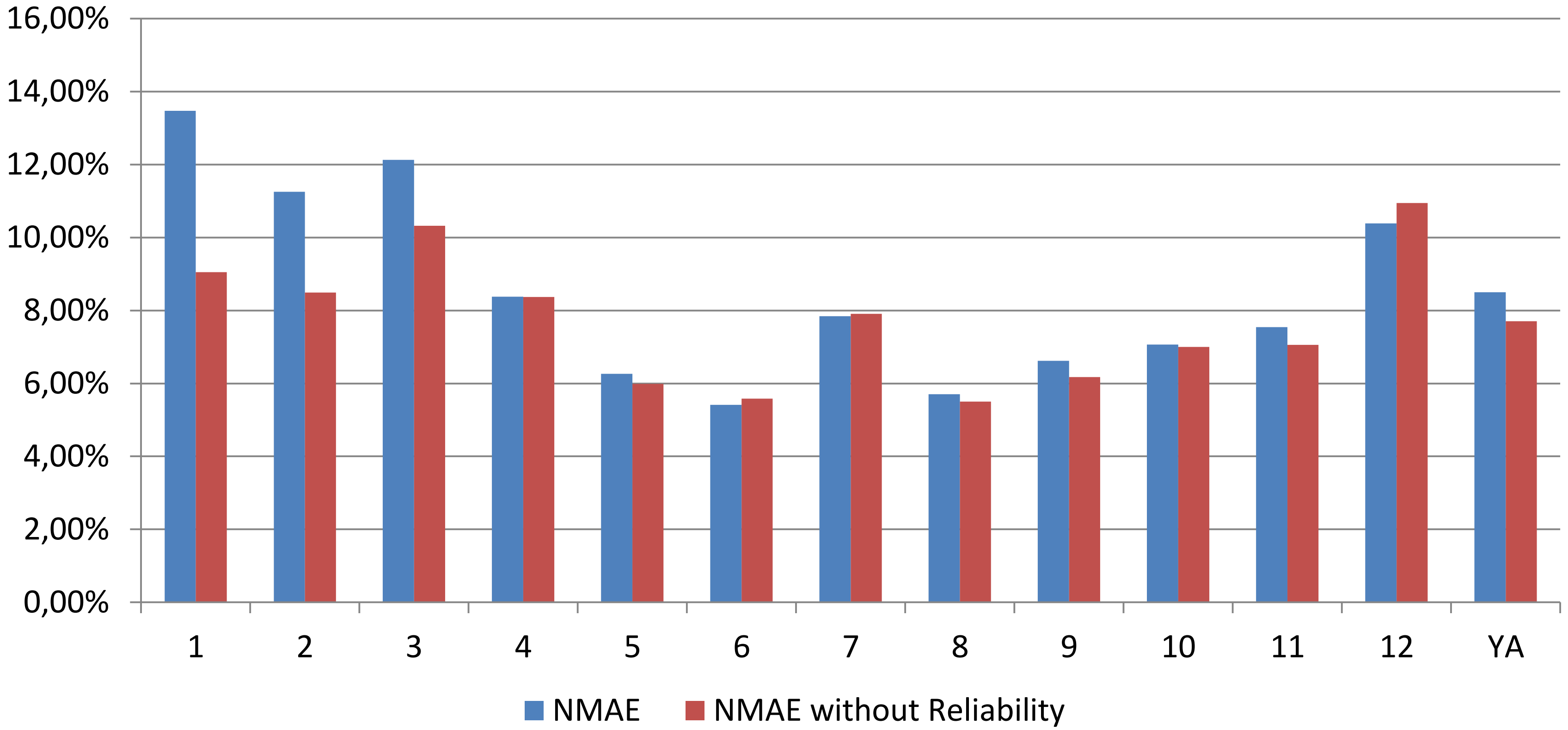


Economical effect



Reliability share on forecasting inaccuracy

- Wind farm with low reliability
- Difference 0,8% and 73 000 €.



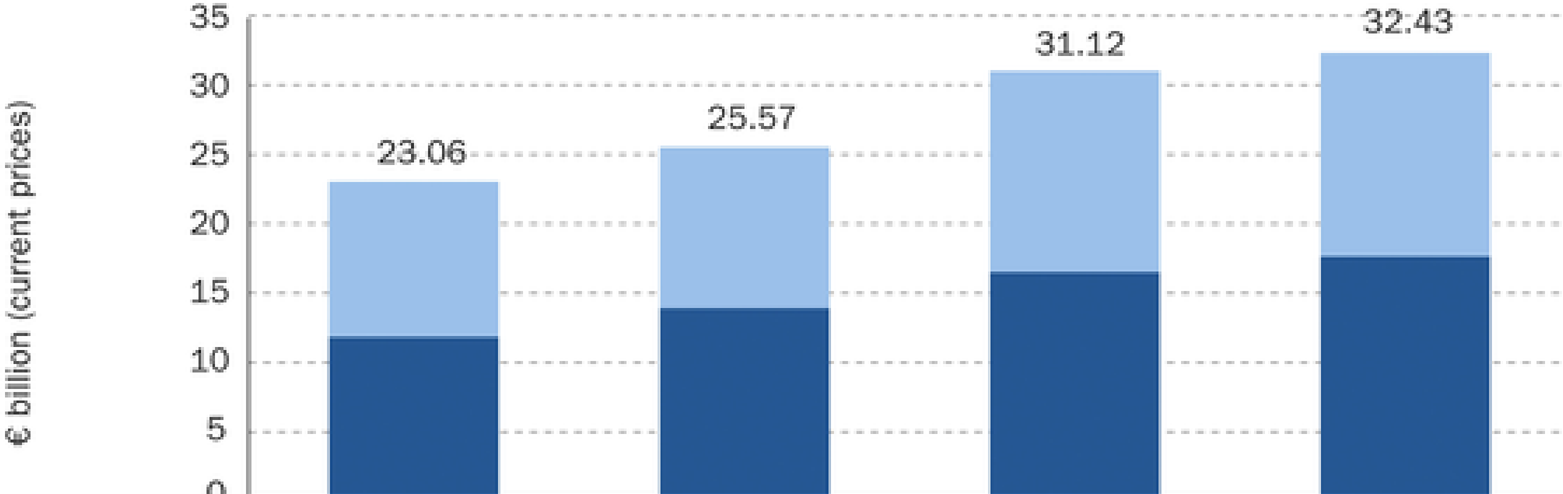
4 Recap

- In the electricity grid the production and consumption has to be equal.
- Wind farm owners forecast the production, when forecasted incorrectly then it’s necessary to pay for the balancing energy.
- Forecasting is evolving rapidly to achieve more accurate forecast.
- Economical incentive for producers.
- Reliability does play role but marginal.

Small wind turbines

- The most important thing is the place
- The second important thing is to use higher tower
- The manufacturer is also important
- Usually the small wind turbine does not meet the expectations

Economic benefits of wind

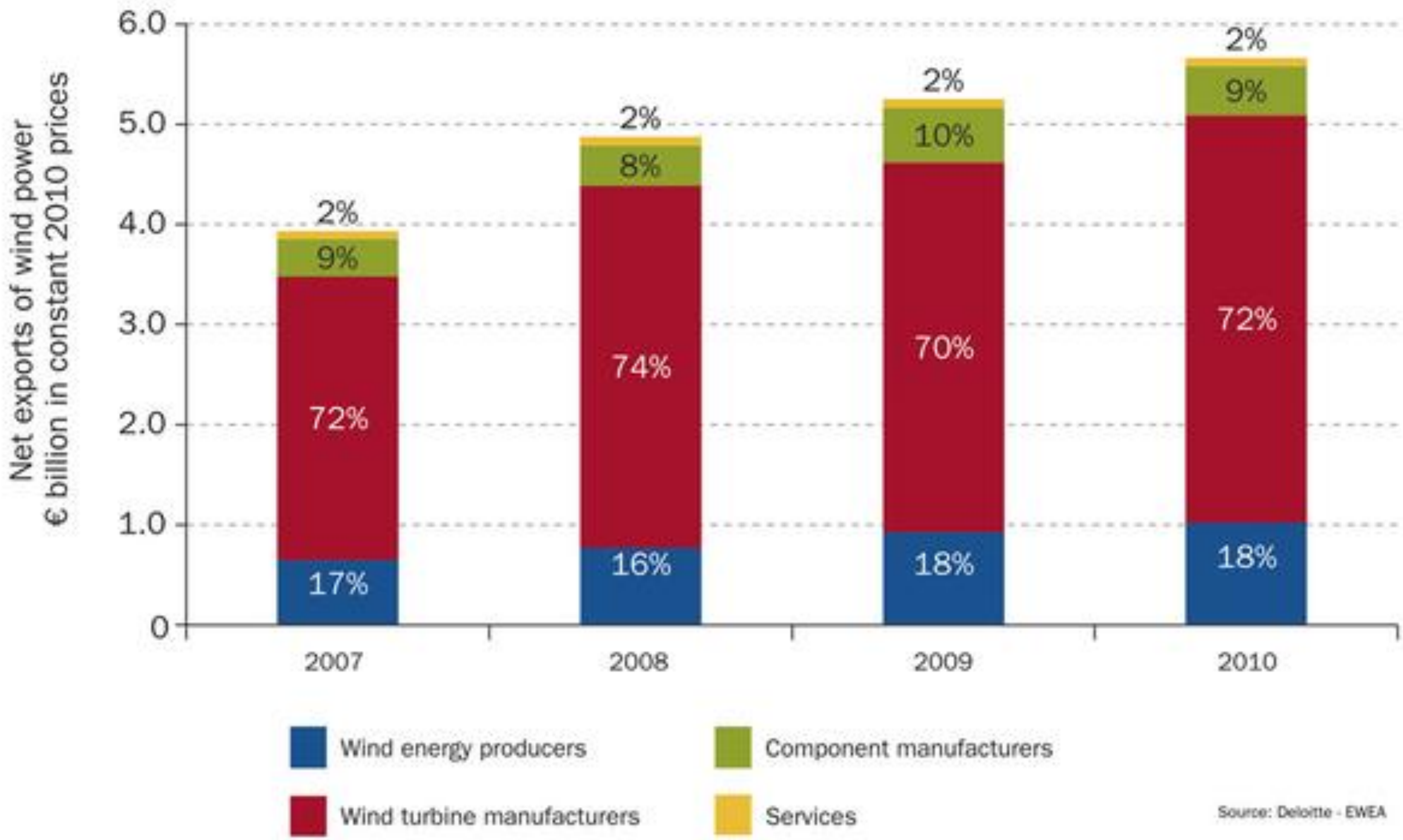


	2007	2008	2009	2010
Direct impact	11.77	13.86	16.48	17.61
Indirect impact	11.29	11.72	14.65	14.82
Total impact	23.06	25.57	31.12	32.43

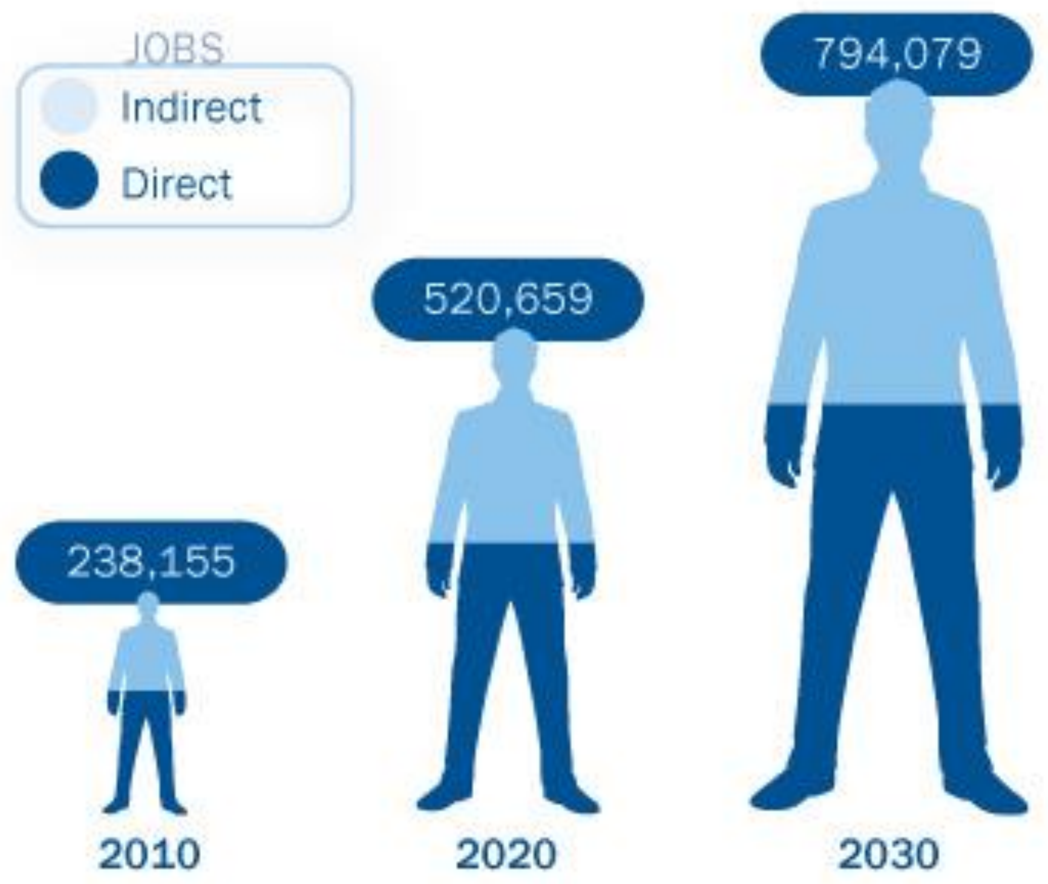
Source: Deloitte

In 2010 the wind energy industry contributed €32.4bn to the EU's economy, almost 0.3% of the EU's total GDP.

Export from EU – Wind sector



EU wind industry employment



Thank you!