Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems


Spanish Fork Wind Farm in Utah, U.S.

IEA Wind Task 26: Cost of Wind Energy

EWEA Annual Event –IEAWind Side Event

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Brussels, Belgium

IEA Wind Task 26: Cost of Wind Energy

- **Three-year, multi-national study on the cost of wind energy globally**
  - Participating countries include: Denmark, Germany, Netherlands, Spain, Sweden, Switzerland, United States (Operating Agent) and EWEA

- **Objectives:**

1. Identify the major drivers of wind energy costs
2. Develop an internationally accepted, transparent method for calculating the cost of wind energy
3. Derive wind energy cost and performance projections, or learning curves
4. Compare the cost of wind energy with those of other electricity generation technologies
5. Estimate the value of wind energy

IEA Wind Task 26: Cost of Wind Energy

- **Approach: Three Distinct Work Packages**

1. Work Package 1(Complete):
   - Wind Levelized Cost of Energy: A Comparison of Technical and Financial Input Variables
   - Multi-national Case Study of the Financial Cost of Wind Energy in 2008
2. Work Package 2 (In progress):
   - Explore methods of estimating future cost and performance of land-based and offshore wind projects
3. Work Package 3 (In progress):
   - Survey methods for estimating the value of wind energy and comparison with the cost of other energy generation technologies

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Cost of Wind Energy

- Four basic parameters
  - Capital cost, operating cost, finance parameters, and energy produced
- Data and assumptions critical
  - No single answer – all four parameters are project specific
  - Must develop transparent and consistent set of assumptions for comparisons
- Levelized Cost of Energy (LCOE) model developed to provide transparent method for comparing costs among participating countries
  - No standardized method, but with well-documented assumptions, data sources, and methodology, comparisons can be made

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Work Package 1: Multi-national Wind LCOE Comparison

- Use of publicly available ECN model to estimate wind LCOE in seven countries
- Originally designed to set Dutch feed-in tariff or feed-in tariff premium levels
- Model customized for this task; estimates *unsubsidized* country LCOE
- Represents the perspective of the project's investor/developer

Cash flow model for financial gap calculations

Wind: Netherlands 2008

	Symbol	INPUT PARAMETERS	Unit	Fixed or average value
Project features	U	Unit size	kW_e	15000
	H	Operational time / full load hours	h/yr	2200
	T_b	Economic life	yr	20
Costs	C_{tot}/U	Investment costs	€/kW	1325
		Decommisioning costs	€/kW	0
	c_f	Maintenance costs fixed	€/kW	31.39238321
	c_v	Maintenance costs variable	€/kWh	0.013363553
Market	p_e	Other revenues	€/kWh	0.080
		Other costs	€/kWh	0.0097
Policy support		Upfront tax-based investment subsidy		20%
		Upfront cash investment subsidy		0%
		Feed-in tariff	€/kWh	0.028
		Production-based tax credit	€/kWh	0.000
		Production-based tax deduction	€/kWh	0.000
Project financing features	R_d	Return on debt		5.0%
	R_e	Required return on equity		15.0%
	e	Equity share (excluding EIA benefit)		20%
	d	Debt share (including EIA benefit)		80%
		Corporate tax rate (Municipal/state)		0%
	τ	Corporate tax rate (National/federal)		25.5%
Time horizons	T_r	Loan duration	yr	15
	T_d	Depreciation period	yr	15
	T_p	Economic life	yr	20
Output	FG	Financial gap	€/MWh	-3
	LC	Levelized electricity generation cost	€/MWh	94

Country Data Collection: Onshore Wind

Representatives provided country-specific onshore wind energy cost estimates including investment costs, energy production, O&M and other variables

2008 "Typical" Wind Project Technical Parameters

	Denmark	Germany	Netherlands	Spain	Sweden	Switzerland	United States	Reference Case
Unit size (MW)	2.3	2.0	3.0	2.0	2.4	2.0	1.7	2.1
Number of turbines	7	5	5	15	41	6	50	34
Full load hours	2,695	2,260	2,200	2,150	2,600	1,750	3,066	2,628
Investment (€/kW)	1,250	1,373	1,325	1,250	1,591	1,790	1,377	1,449
Decommissioning costs (€/kW)	0.0	1.5	0.0	0.0	1.6	0.0	0.0	0.6
Other costs (€/MWh)	3	0	10	3	0	0	0	1
O&M costs fixed (€/kW-yr)	0.00	46.33	31.39	0.00	0.01	0.00	8.60	6.29
O&M costs variable (€/MWh)	12	0	13	20	11	31	5	11
Converted total O&M costs (€/MWh)	12	21	28	20	11	31	7	13
Reference Case Weight	6.1%	3.8%	5.7%	11.4%	36.6%	4.6%	31.8%	N/A

Reference Case weighted by project capacity

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Country Data Collection: Onshore Wind

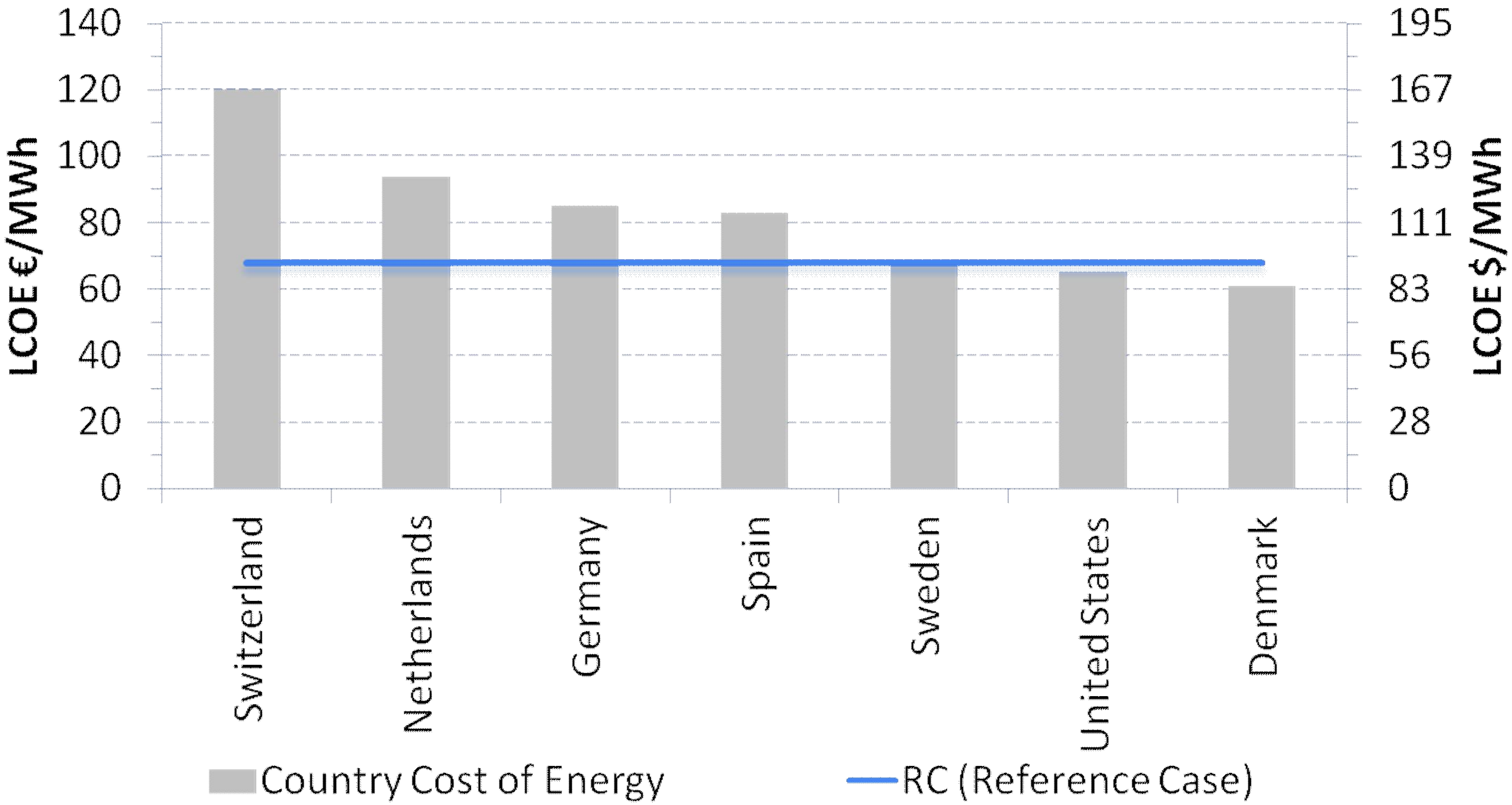
The LCOE calculation was based on a predefined return on equity that was provided by each country representative along with other financial input parameters

2008 "Typical" Wind Project Financial Parameters

	Denmark	Germany	Netherlands	Spain	Sweden	Switzerland	United States	Reference Case
Return on debt (%)	5.0	5.5	5.0	7.0	5.0	5.0	6.0	5.0
Return on equity (%)	11.0	9.5	15.0	10.0	12.0	7.0	7.5	10.0
Debt share (%)	80	70	80	80	87	70	0	80
Equity share (%)	20	30	20	20	13	30	100	20
Loan duration (yrs)	13	13	15	15	20	20	15	15
National tax rate (%)	25.0	29.8	25.5	30.0	28.0	21.0	38.9	28.0
WACC (%)	5.2	5.6	6.0	5.9	4.7	4.9	7.5	4.9

Reference Case value based on median country parameter value

Results: Country Specific LCOE and the Reference Case (€68/MWh)



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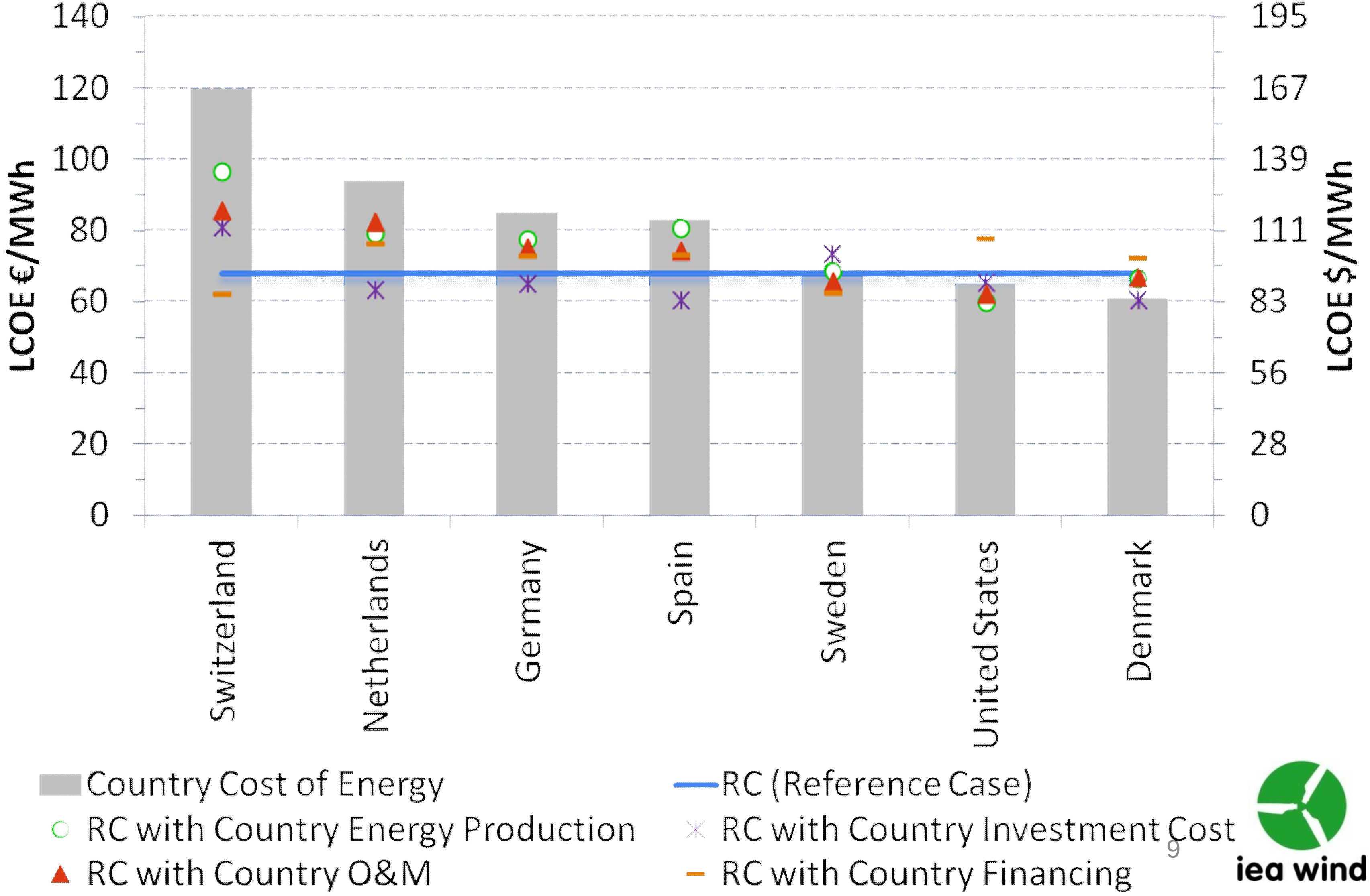
Results: Key Variable Comparisons Across Countries



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Country-Specific Cost Variations Due to (Non-exhaustive):

- **Energy Production**
  - DE: Poorer wind site selection due to land constraints (to Southern Germany)
  - DK: Social pressure to repower existing sites ahead of new development (premier sites already developed)
  - US limited transmission accessibility; forced energy curtailment/site selection
- **Investment Costs**
  - DE: Poorer site development requires larger turbine hubs & rotor diameters
  - DK: Interconnection costs paid by end user, not developer
  - SK: Highly simplified process for environmental reviews and interconnection
  - US: Economies of scale (both project and national levels) for turbine orders
- **Operations and Maintenance Costs**

➢ Limited reported data certainty/confidence across countries

  - DK: Creditors require mandatory service contracts 5-10 yrs (~€25/kW–yr)
  - NL: Land-rent varies significantly across sites (5-25€/kw-yr)
  - CH: Accessibility and turbine icing/turbulence leading to higher O&M expenditures
- **Financing Costs**

➢ Relatively similar across countries (U.S. excepted)

  - U.S. high equity ratios (often 100% in 2007-2008)
    - Due to nature of U.S. federal subsidies (intermittent tax-based incentives)
    - Debt, if used was often secured at the corporate and not a project-level

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Work Package 1: Country Chapters

U.S. Example (1 of 7 Country Chapters):

U.S. LCOE Results Summary (Onshore only to date in U.S):
•2008: €65/MWh ($90/MWh), FG: -€1/MWh (-1$/MWh)
•2007: €58/MWh ($81/MWh), FG: -€2/MWh (-$3/MWh)

2008 Data Sources:
•2008 Wind Technologies Market Report
- Installations: Wind Energy Trade Group
- Wind Energy Prices: Federal energy regulatory commission (FERC – govt. agency)
- Installation costs: Mix of FERC data, corporate press releases, publicly traded company filings, project developers
- Performance: FERC and Energy Information Administration (EIA – govt. agency)
- O&M: Annual self-reported data by investor owned utilities
- Financing: Industry conferences, interviews of financiers/developers, popular news media

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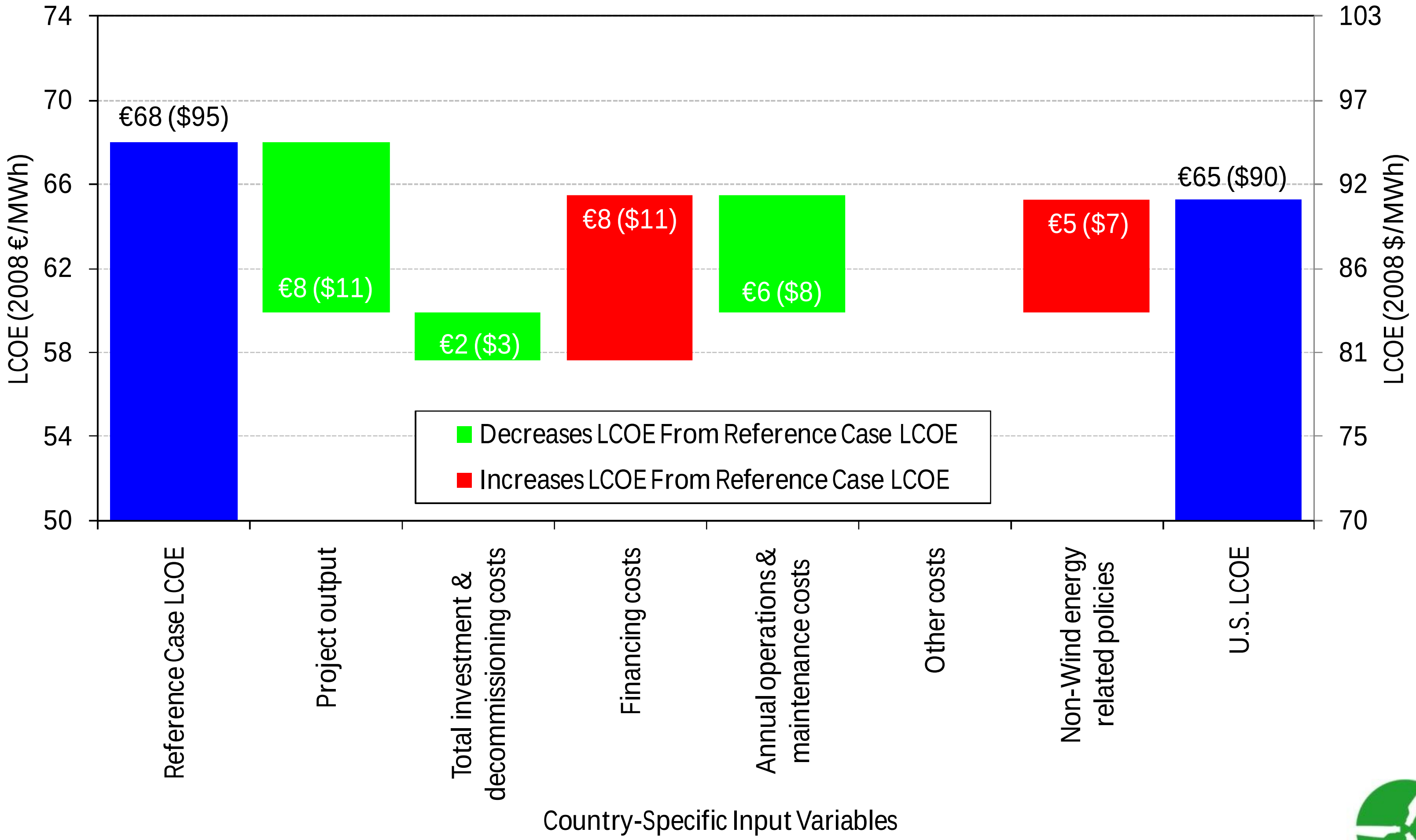
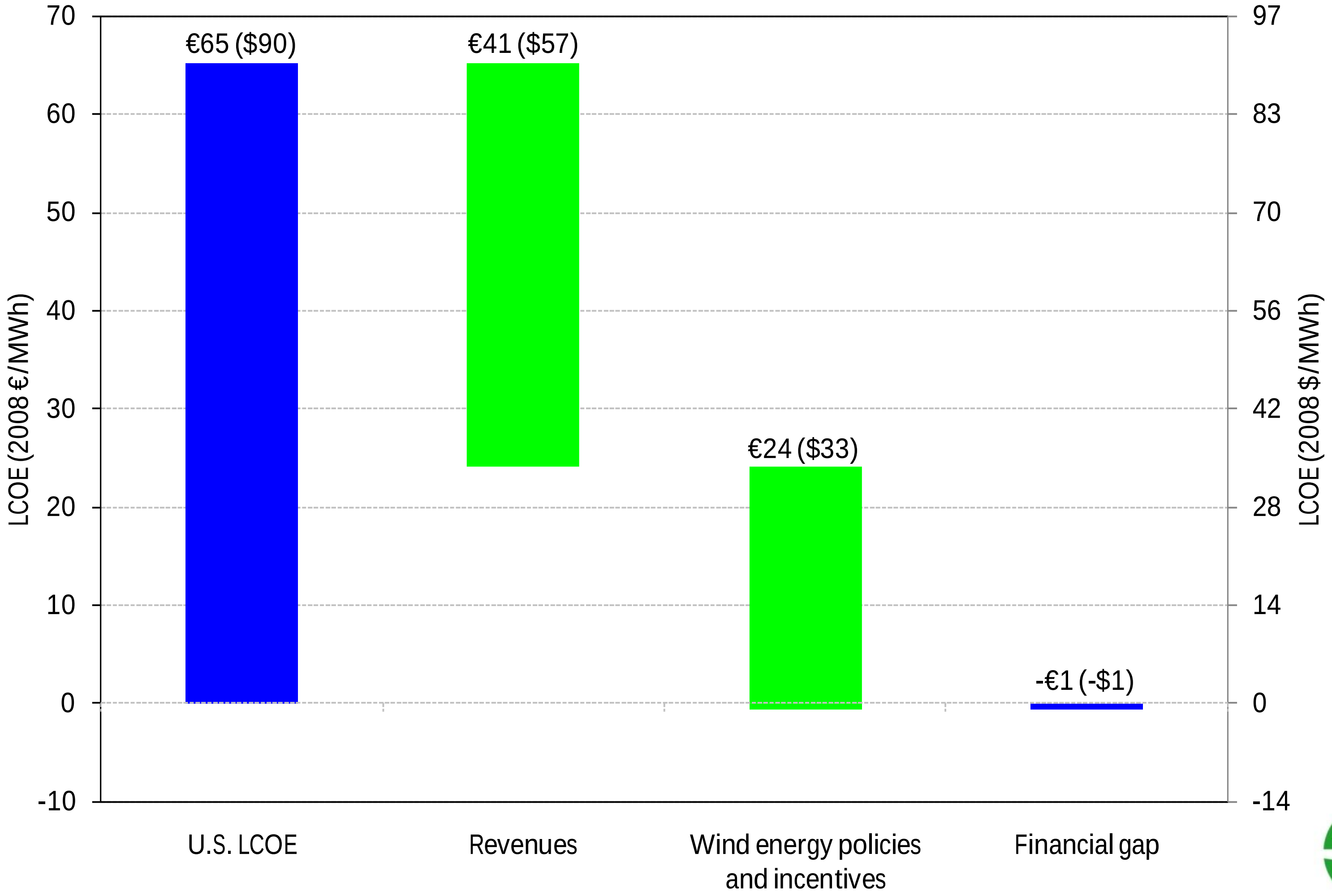
Reference Case and U.S. LCOE in 2008

Energy production, investment costs and O&M costs reduced the U.S. LCOE compared to the Reference Case. Financing and non-wind energy specific policies (e.g. corporate tax rate) increased the U.S. LCOE



Composition of U.S. LCOE in 2008

In 2008, around 2/3 of the U.S. LCOE is covered by revenue components while the remaining 1/3 is covered by wind energy policies and incentives



Conclusions From Work Package 1

- The unsubsidized LCOE for wind energy varies considerably among countries represented in this study from €61/MWh to €/120MWh
- As expected, the magnitude of the LCOE variation has been attributed to differences in country-specific energy production, investment outlays, operations and maintenance costs and financing costs
- A considerable amount of data uncertainty was experienced, particularly with regard to onshore O&M costs and all components of offshore LCOE (see supplemental slides)
- LCOE metric is not a universal calculation; it is critical to understand the particular methodology, the perspective being represented (i.e. public vs. private), the assumptions or parameters included

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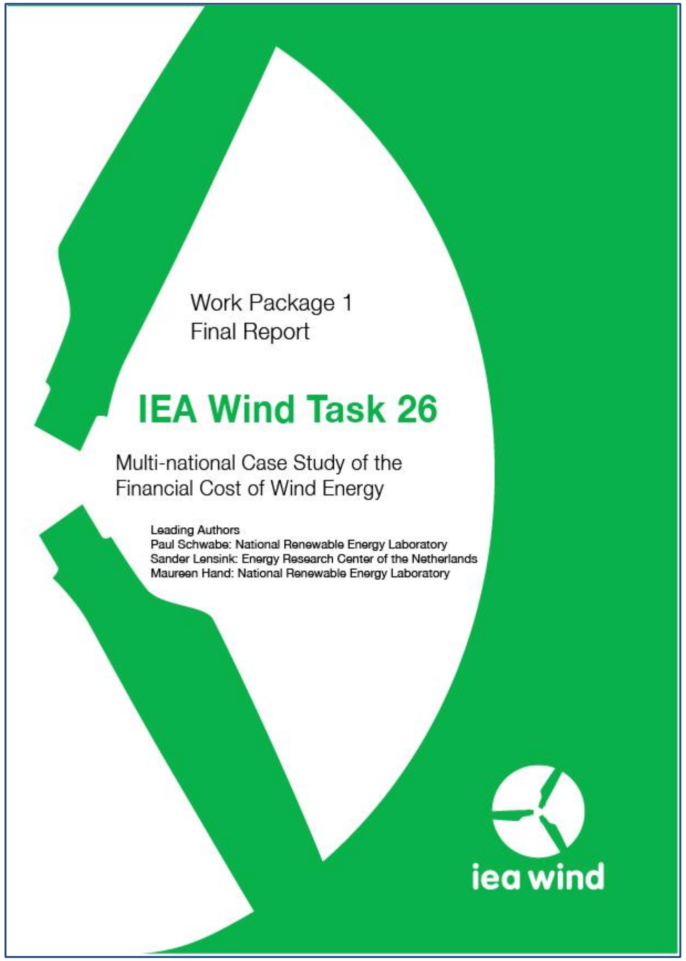

Work Package 1 Report available at:

http://www.ieawind.org/Task_26.html

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IEA Wind Task 26: Cost of Wind Energy

- **Approach: Three Distinct Work Packages**

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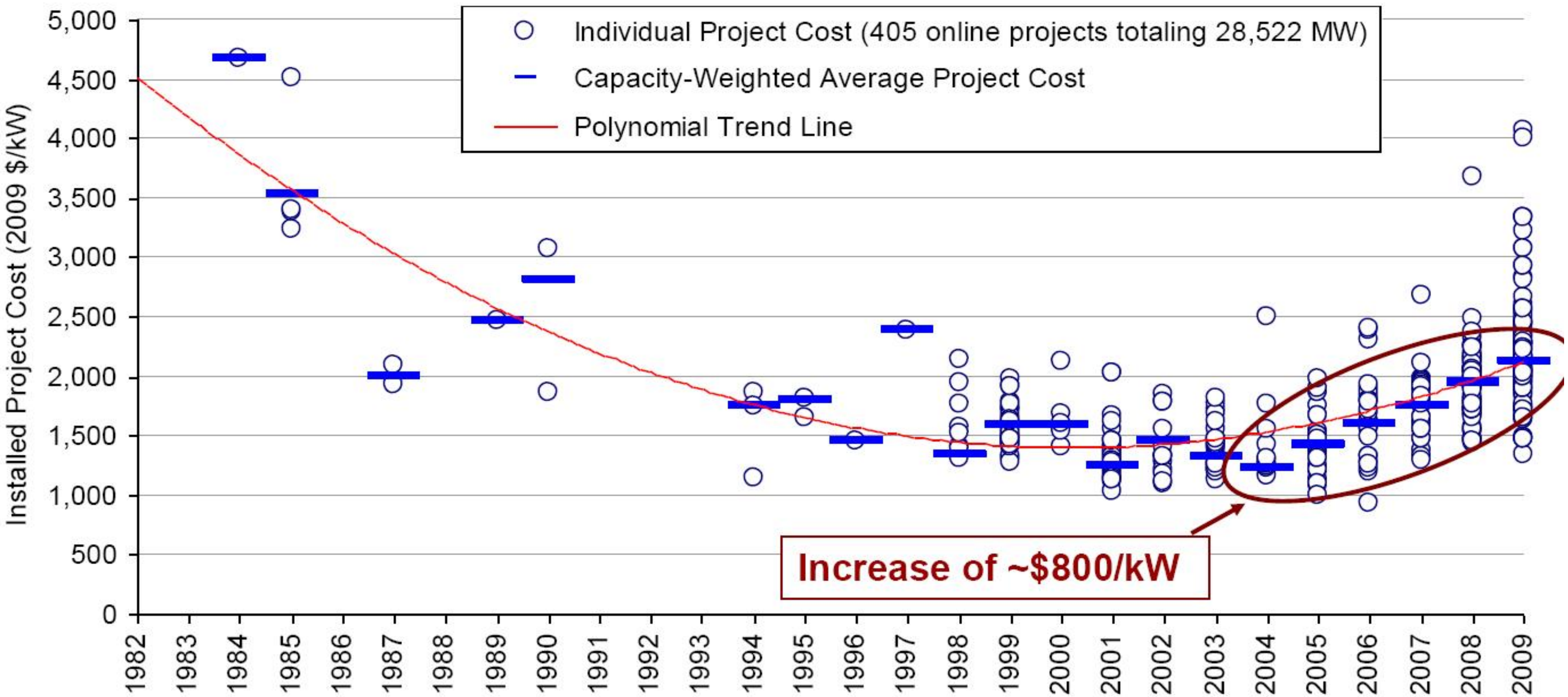
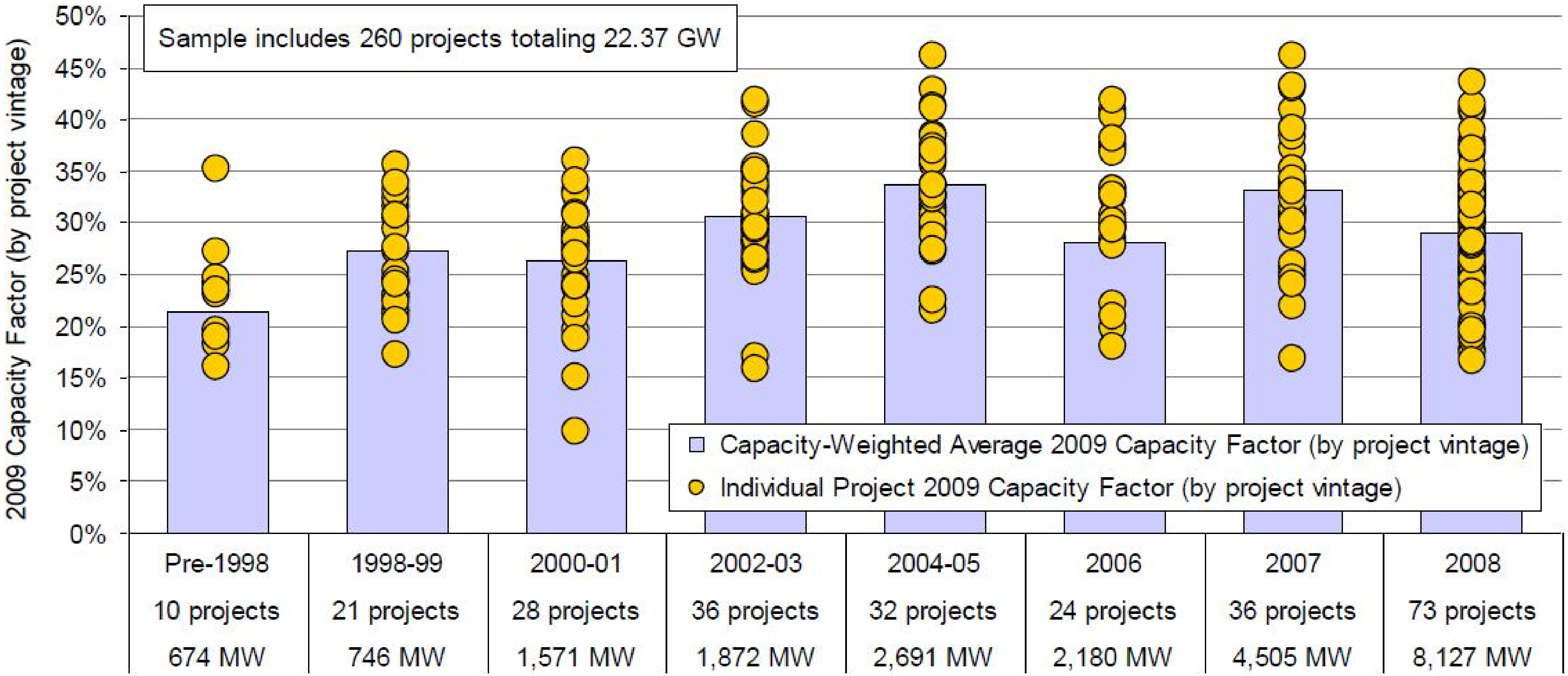
    - Wind Levelized Cost of Energy: A Comparison of Technical and Financial Input Variables
    - Multi-national Case Study of the Financial Cost of Wind Energy in 2008
2. Work Package 2 (In progress):
    - Estimate future cost and performance of land-based and offshore wind projects
        - Historical Trends
        - Learning Curves
        - Engineering Models
3. Work Package 3 (In progress):
    - Survey methods for estimating the value of wind energy and compare with the cost of other energy generation technologies

U.S. Installed Project Cost Increasing



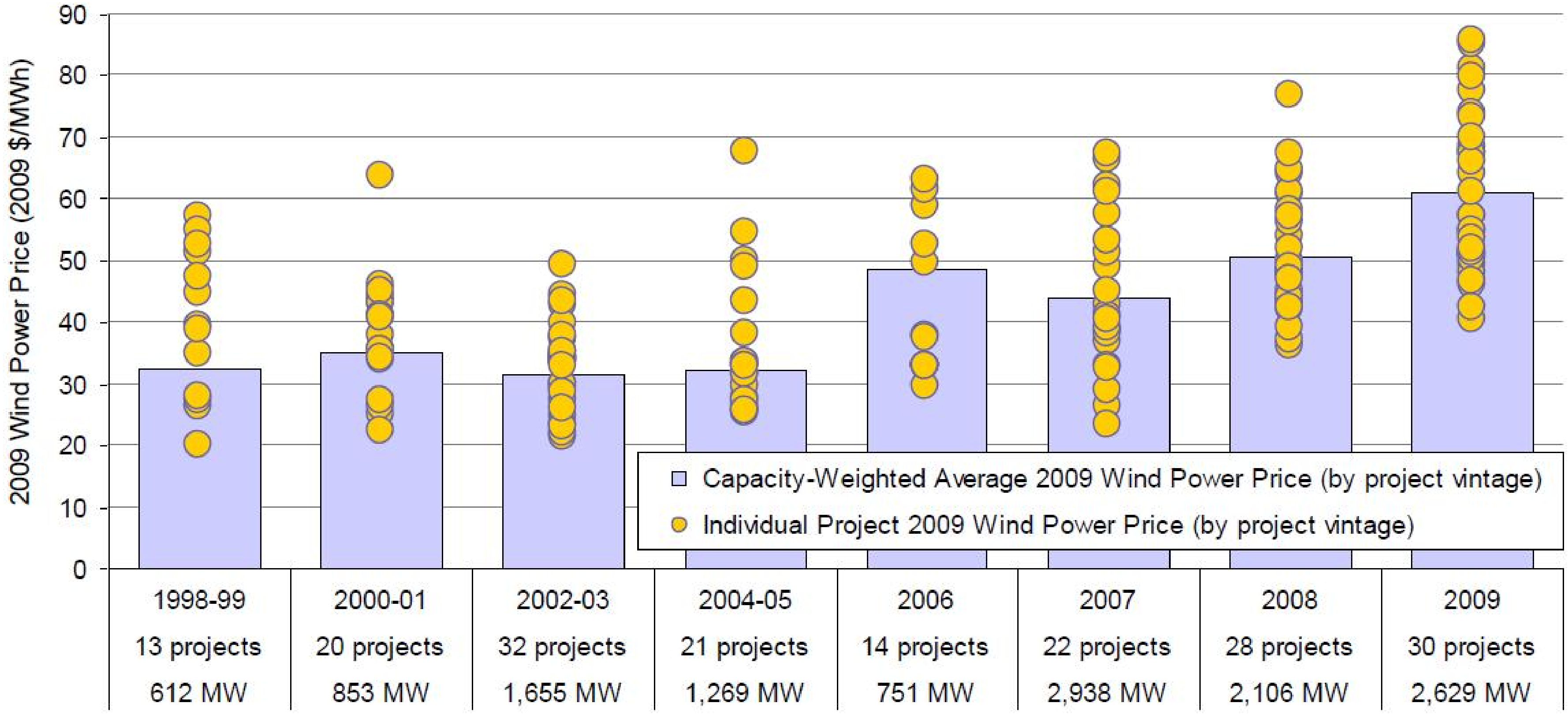
Source: Wiser, R. and M. Bolinger. (2010). *2009 Wind Technologies Market Report.* DOE/GO-102010-3107. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.

Newer Projects Have Higher Capacity Factors



Source: Wiser, R. and M. Bolinger. (2010). *2009 Wind Technologies Market Report.* DOE/GO-102010-3107. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.

Power Purchase Prices Rising



Source: Wiser, R. and M. Bolinger. (2010). *2009 Wind Technologies Market Report.* DOE/GO-102010-3107. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.

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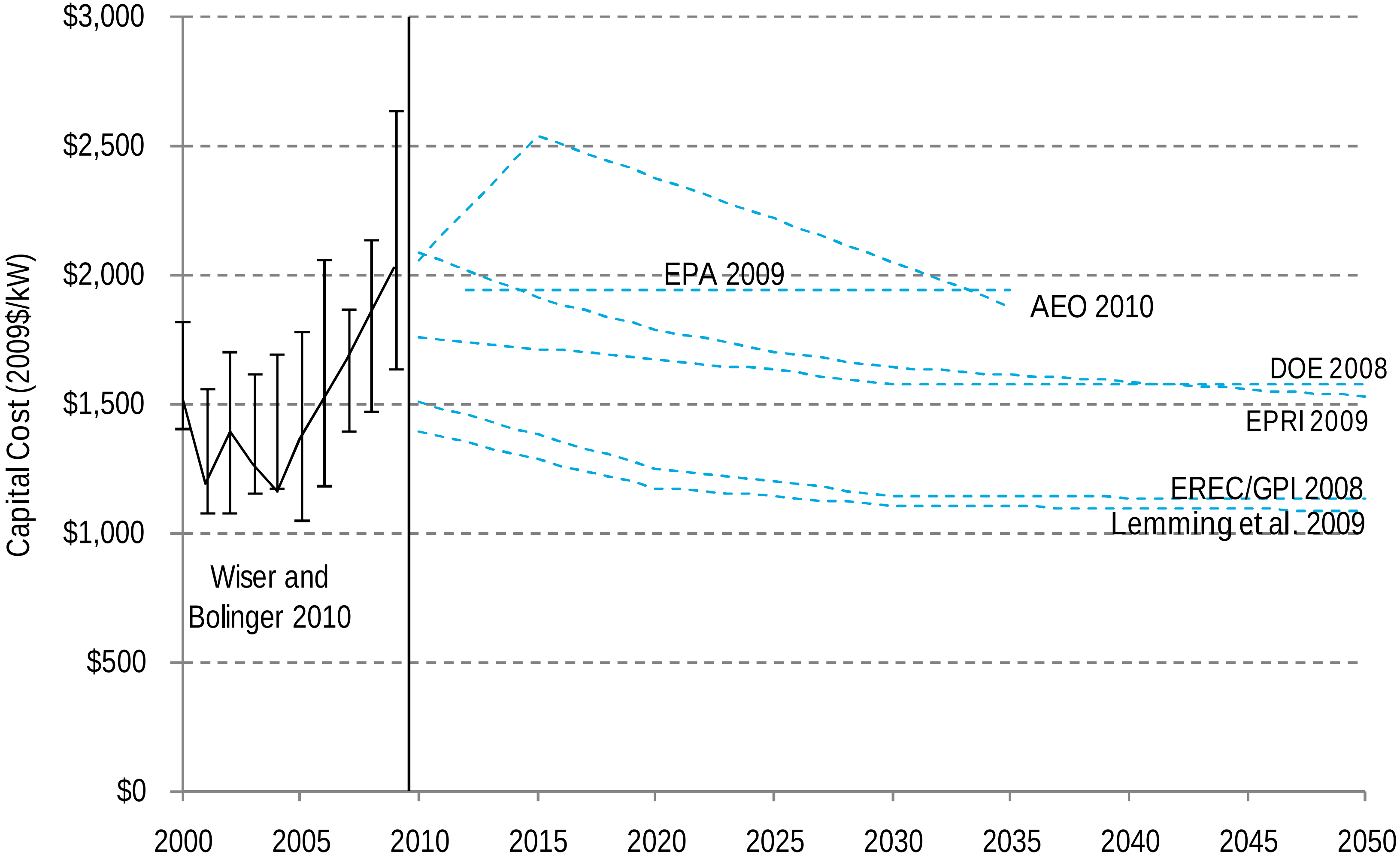
Future Cost Projections: Land Based Wind



Source: See list of references

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Learning Curves

- **Describe cost reduction potential as a function of cumulative experience related to cumulative installed capacity**

- **Do not attempt to identify specific factors that yield cost reductions**

- **Represent learning by R&D, learning by experience, learning by deployment, learning by doing …**

Learning curves provide a valuable approximation, however, their usefulness is somewhat limited by assumptions common to the methodology

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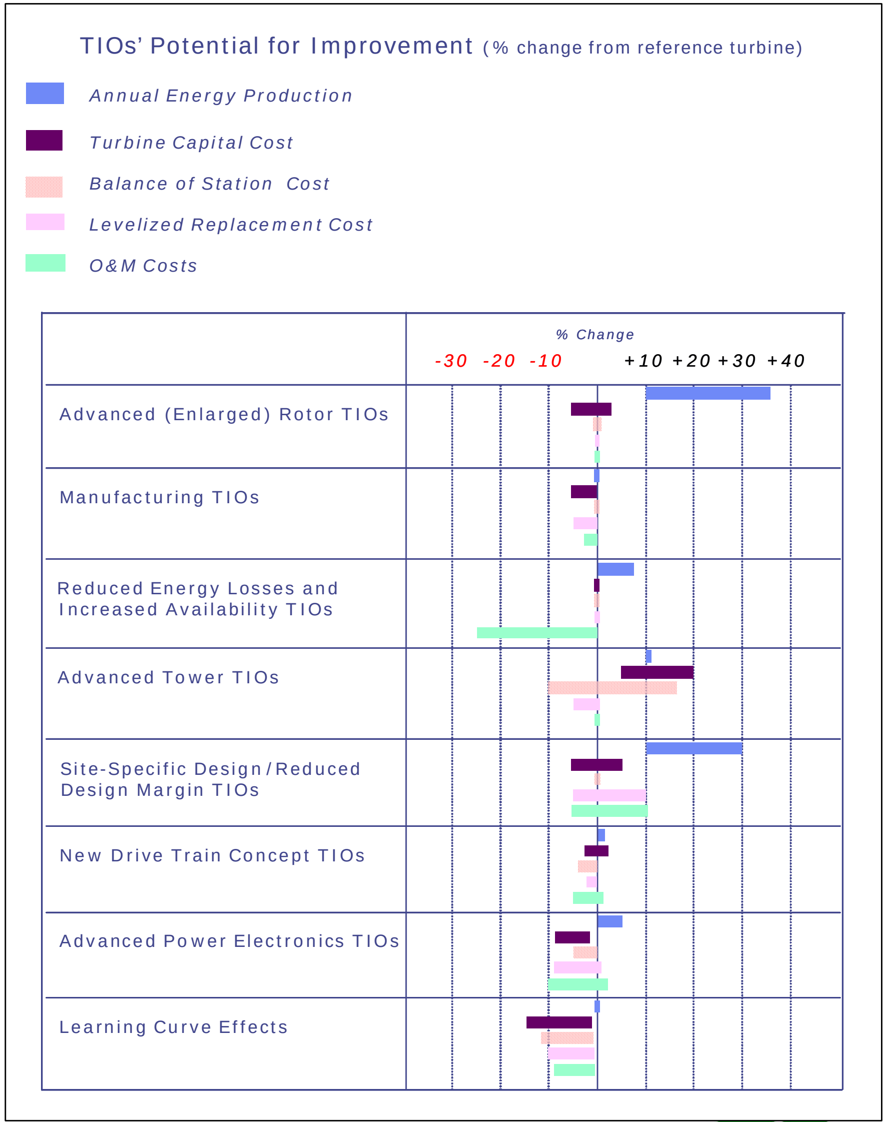
Expert Elicitation

- **Survey industry experts for range of possible technology outcomes**
- **Develop probability distributions associated with various technical outcomes**
- **Example**
    - **DOE Risk Analysis project conducted in association with WindPACT analytic studies**



Source: Cohen et al, 2008.

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Engineering Model

Bottom-up, component level, system analysis

1. **Evaluates tangible technology advancements:** proposed and anticipated technology advancements, with a focus on realizable opportunities
2. **Measures the potential value of individual innovations:** specific opportunities are quantified independently, results are combined to arrive at a cost estimate
3. **Considers installed cost and technology performance:** allows weighting of tradeoffs between cost increases and improvements in energy capture
4. **Offers the opportunity to substantiate a learning curve projection:** creates a pathway to a future point

Requires simplification of complex engineering problems

Does not typically represent economy of scale or volume-based cost improvements explicitly

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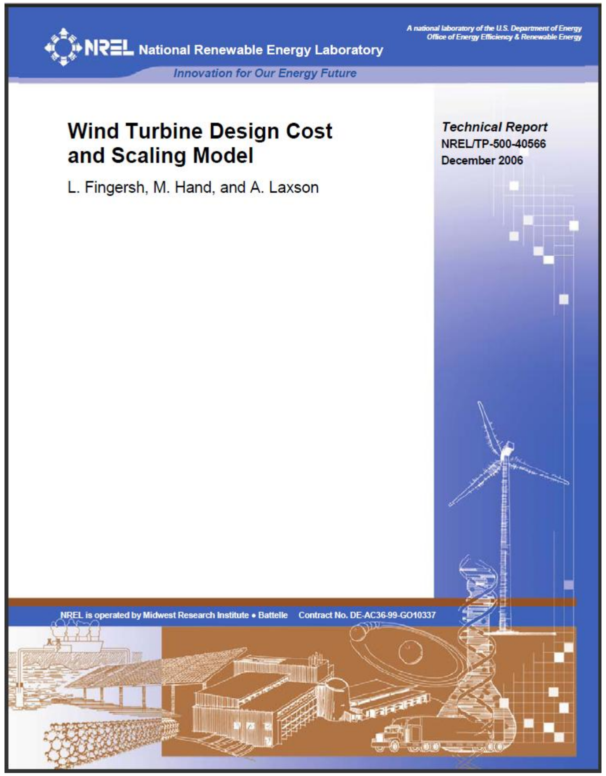
NREL's Wind Turbine Design and Cost Scaling Model



Flexible, modular, spreadsheet model :

- Perform trade-off studies of turbine technology options
  - o *Determine technology changes with greatest potential to reduce COE.*

- Generate wind technology cost and performance trajectories
  - o *Used in generation capacity expansion modeling.*

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Cost Model Features

- **Permits scaling of components to analyze turbine configurations**
  - Costs based on DOE WindPACT analysis (and development subcontracts)
  - Includes simple and advanced scaling curves

- **Illustrates some technology pathways in relation to industry**
  - Pathways based on industry trends and WindPACT analysis

- **Validated using industry data where possible**

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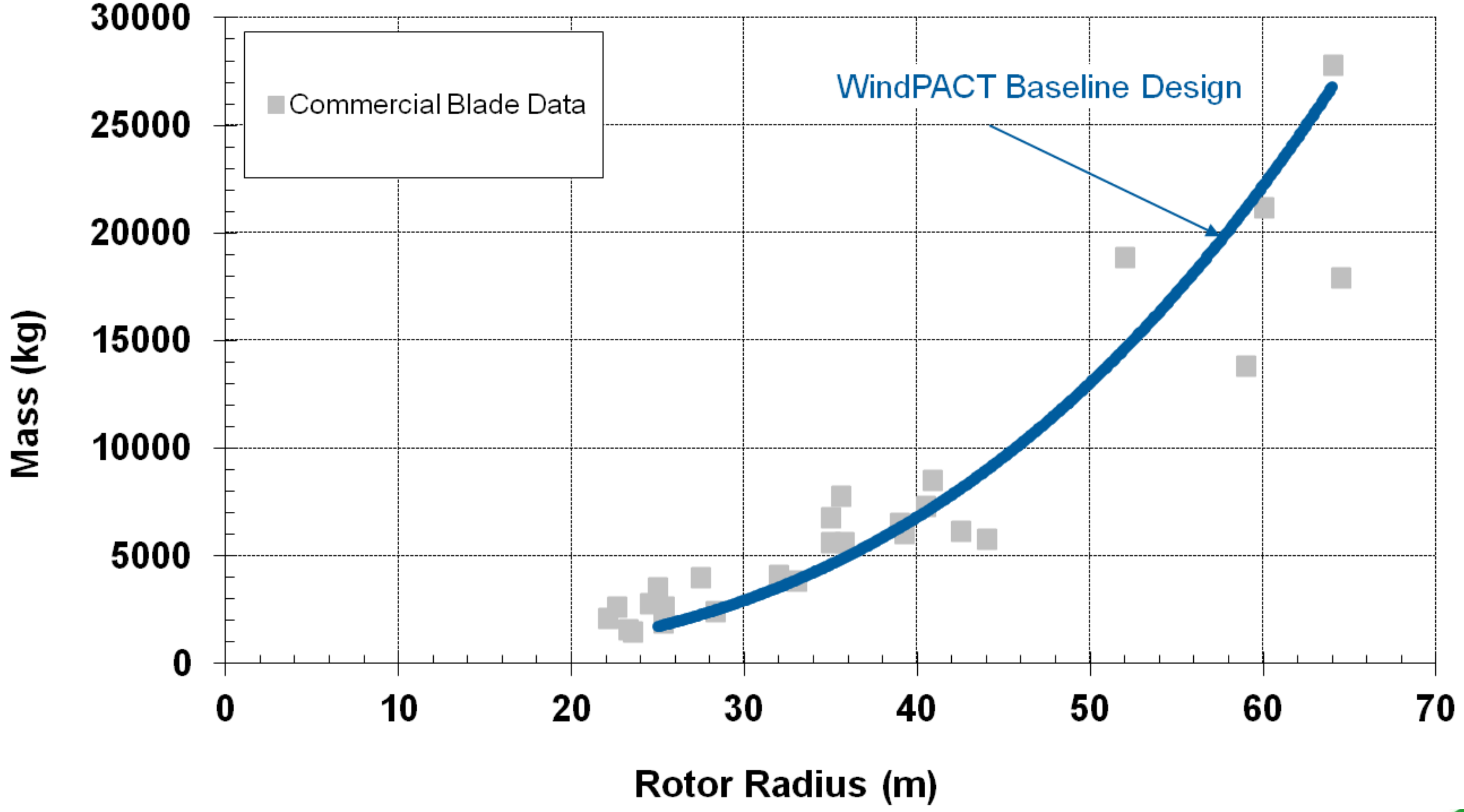
Wind Turbine Blade Innovation Pathway



Source: Based on Fingersh et al., 2006.

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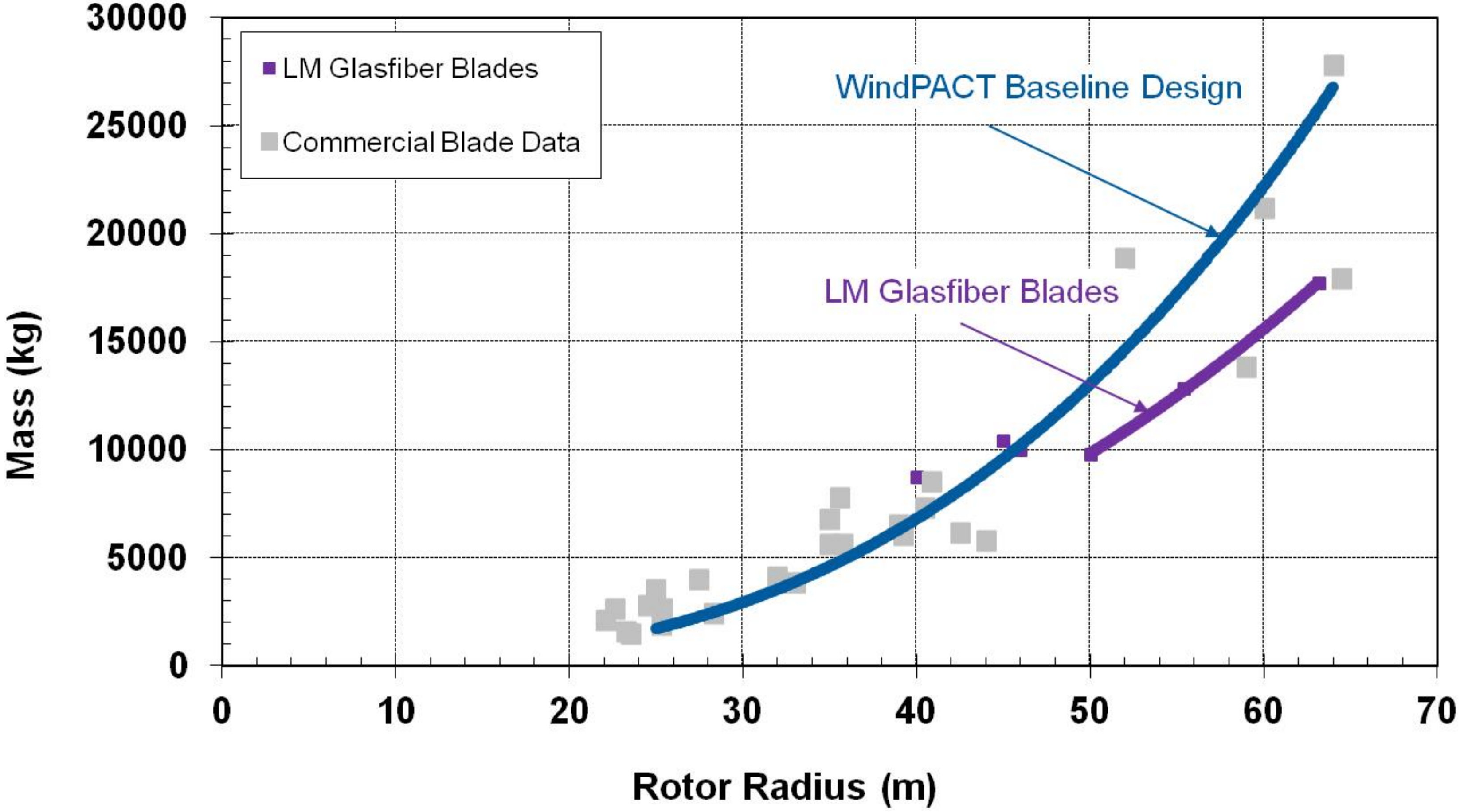
Wind Turbine Blade Innovation Pathway



Source: Based on Fingersh et al., 2006.

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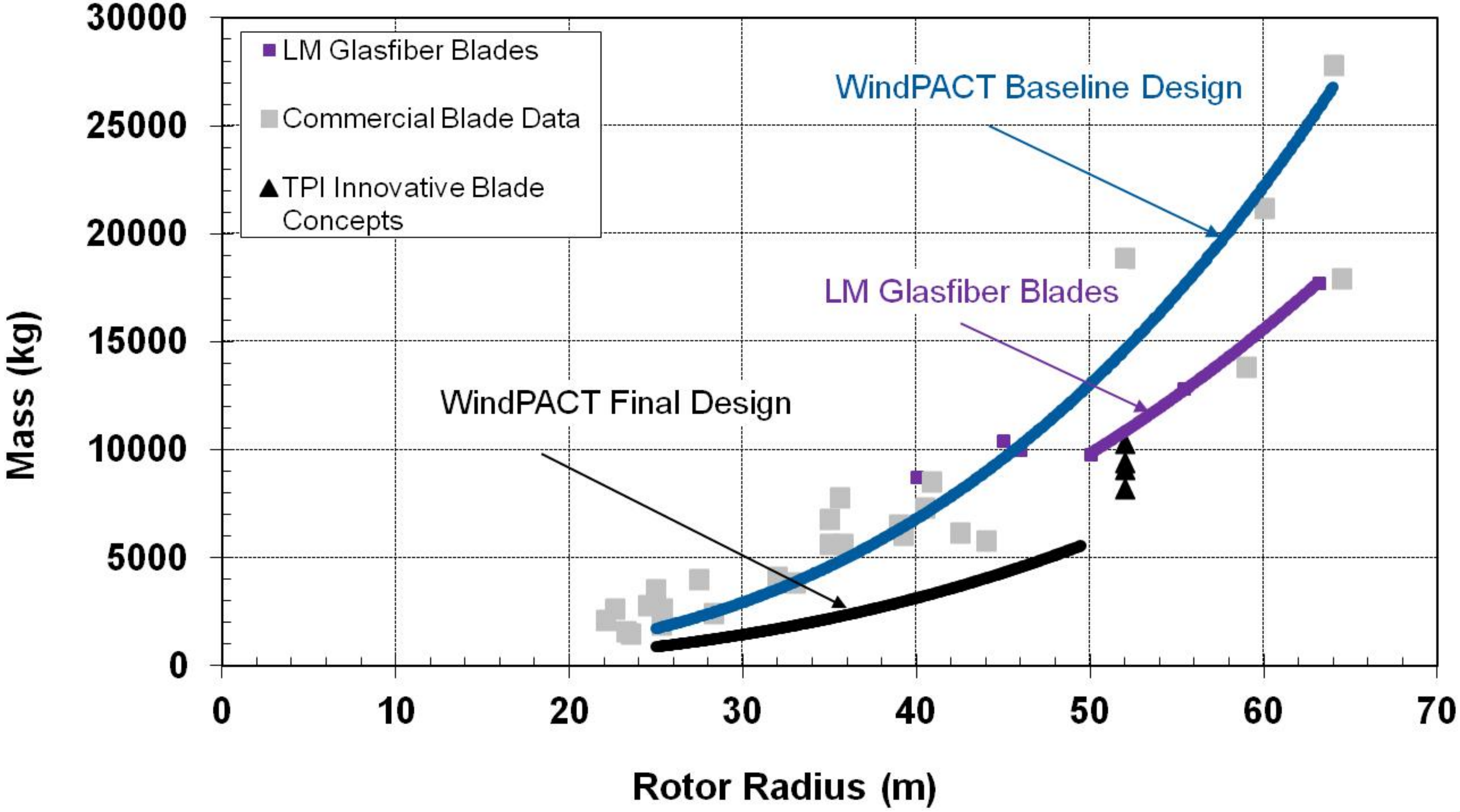
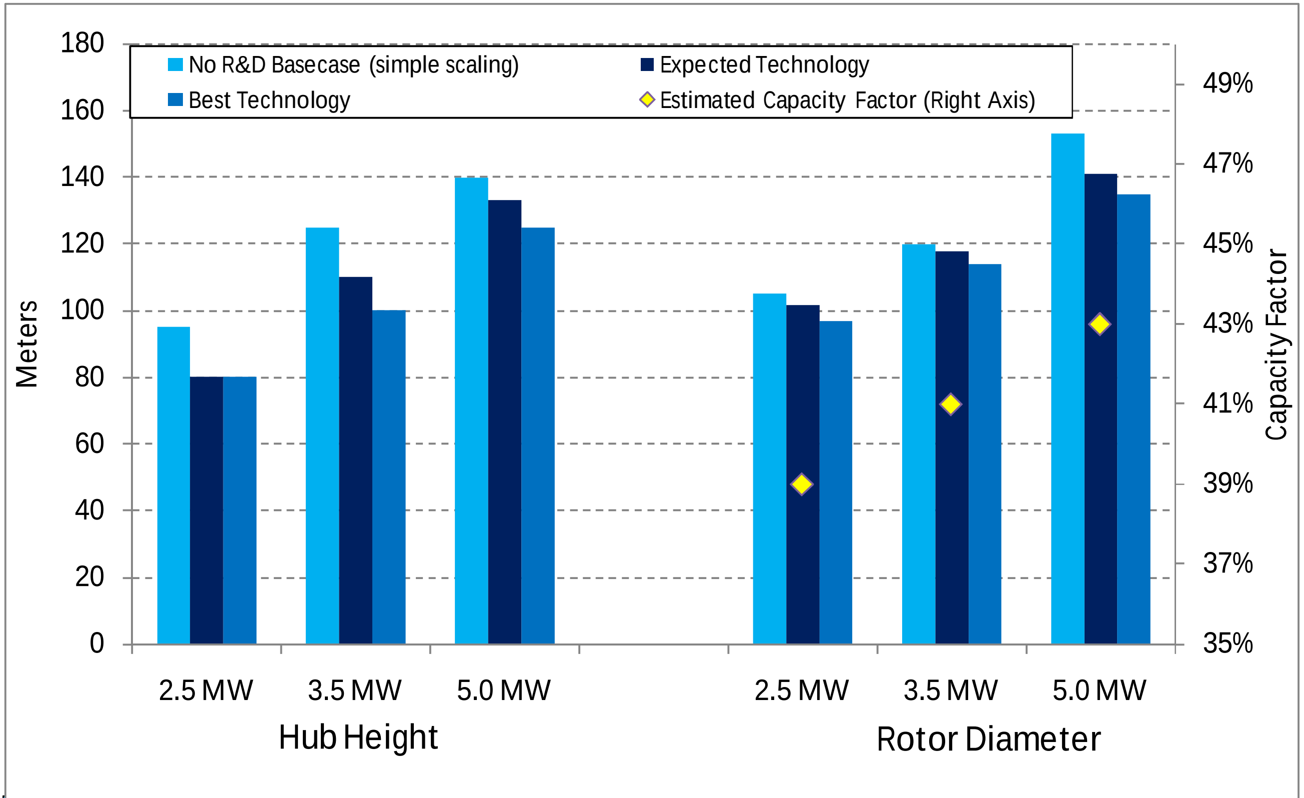
Wind Turbine Blade Innovation Pathway



Source: Based on Fingersh et al., 2006.

Land-based Wind Technology Development Pathway to Achieve 20% Wind Targets



	2.5 MW	*3.5 MW*	*5.0 MW*
No R&D Basecase (simple scaling)	3-stage geared		
Expected Technology	multi-generator	single-stage geared	direct drive
Best Technology			

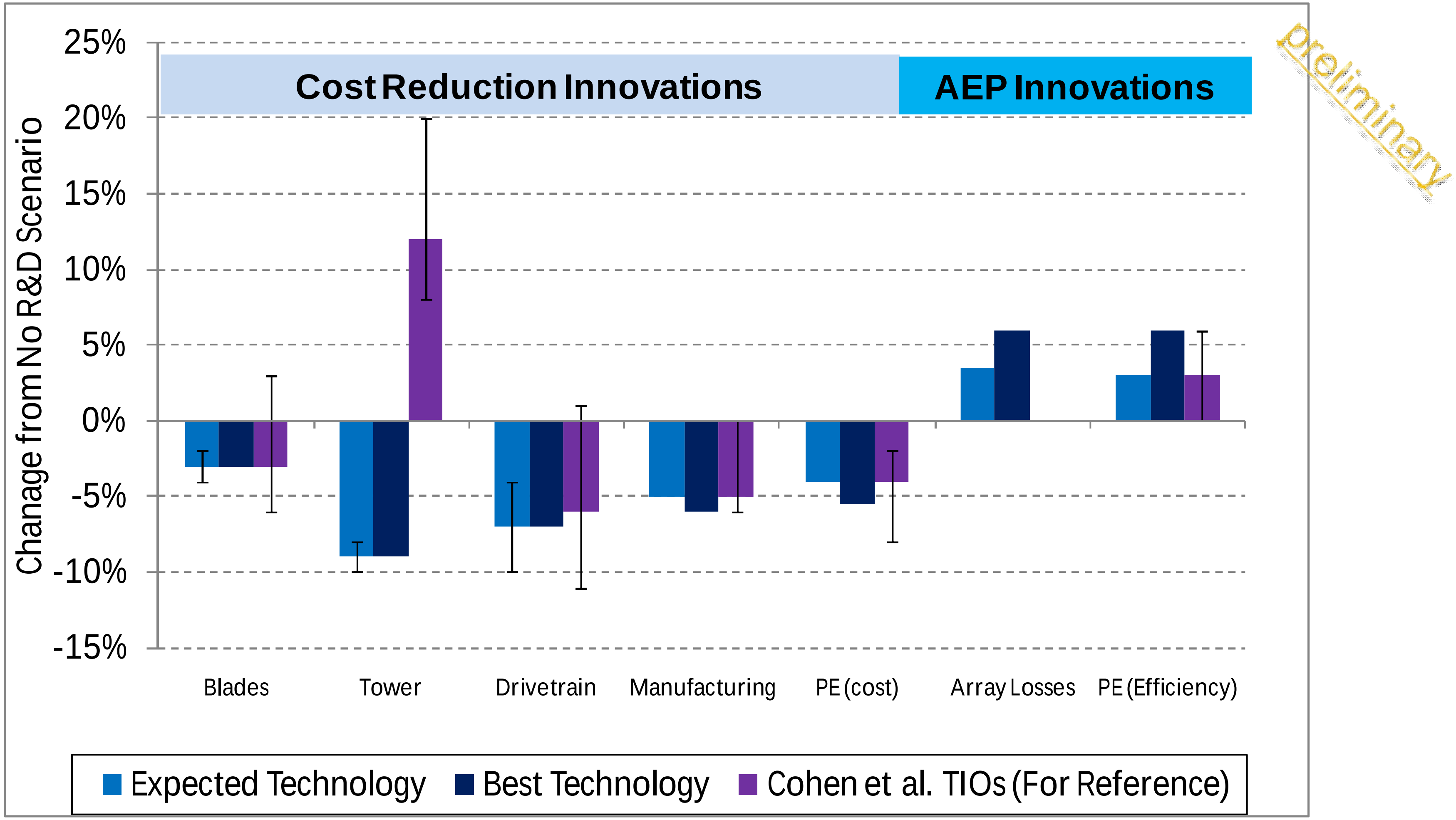
Notes: Technology scenario labels are generally defined by WindPACT risk analysis and summarized in Cohen et al. 2008. Individual turbine designs are optimized to reach capacity factor targets of 20% Wind Study; capacity factor targets assume continued scaling of turbines hence, higher capacity factor targets are expected for larger machines

Technology Captured by Inputs Range

preliminary

Turbine Cost Reduction	Innovations reflected in the advanced technology parameters	Input Data Source
Blade Technology	•Enhanced structural design, targeted reinforcement •High tech composites possibly including carbon fiber	Cost and Scaling Model Advanced Technology Scaling Curves
Tower Technology	•Tower feedback to blade pitch controls •Flap-twist coupling in blade design •Reduced blade chord with tip speed increase	
Drivetrain Technology	•Multi-generator drivepath •Single-stage, medium speed gearbox •Direct drive	
Manufacturing efficiency	•Increased automation •Improved resins with greater ease of use •Reduced design margins resulting from more consistent fabrication •Reduced profit margins as a result of increased volume	Cohen et al. 2008 TIOs (WindPACT Risk Analysis)
Power electronics	•High voltage circuitry •Multi-switch capacity •Semi-conductor devices	
AEP Increase		
Reduced losses	•Improved micro-siting to reduce array losses •Real-time monitoring and operational modifications •Low soil blades	Industry estimates
Power electronics (higher efficiency)	•High voltage circuit topologies •Multi-switch capacity	Cohen et al. 2008 TIOs

Modeling Changes to Cost and Performance



Note: One additional scenario considers best technology improvements combined with scaling at today's blade and nacelle mass ratios (i.e., scaling with proportionally comparable masses for blades and nacelles to those observed in the industry today).

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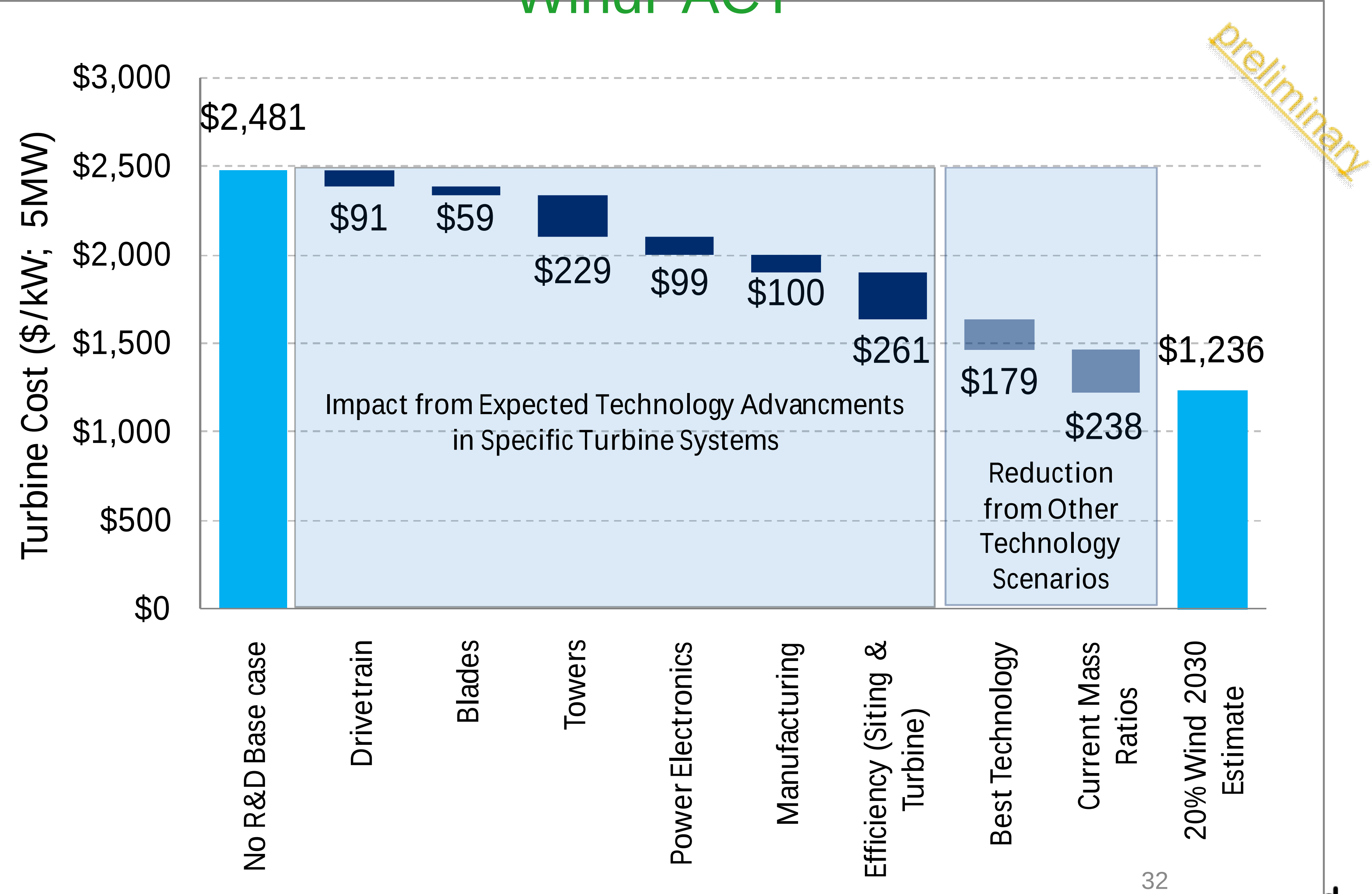
Cost and Performance Targets are Achievable with Incremental Advances Envisioned in WindPACT



Preliminary Conclusions for Work Package #2

- Engineering models can evaluate technology innovations
  - Learning curves and expert elicitation provide additional insight
- Cost is a critical element of these models
  - Data sources and assumptions are critical for representing accurate cost estimates
- System level analysis of technology innovations and associated cost impacts provides input to projections of future wind technology costs
  - Guide both industry and government in R&D investments, development of policy instruments

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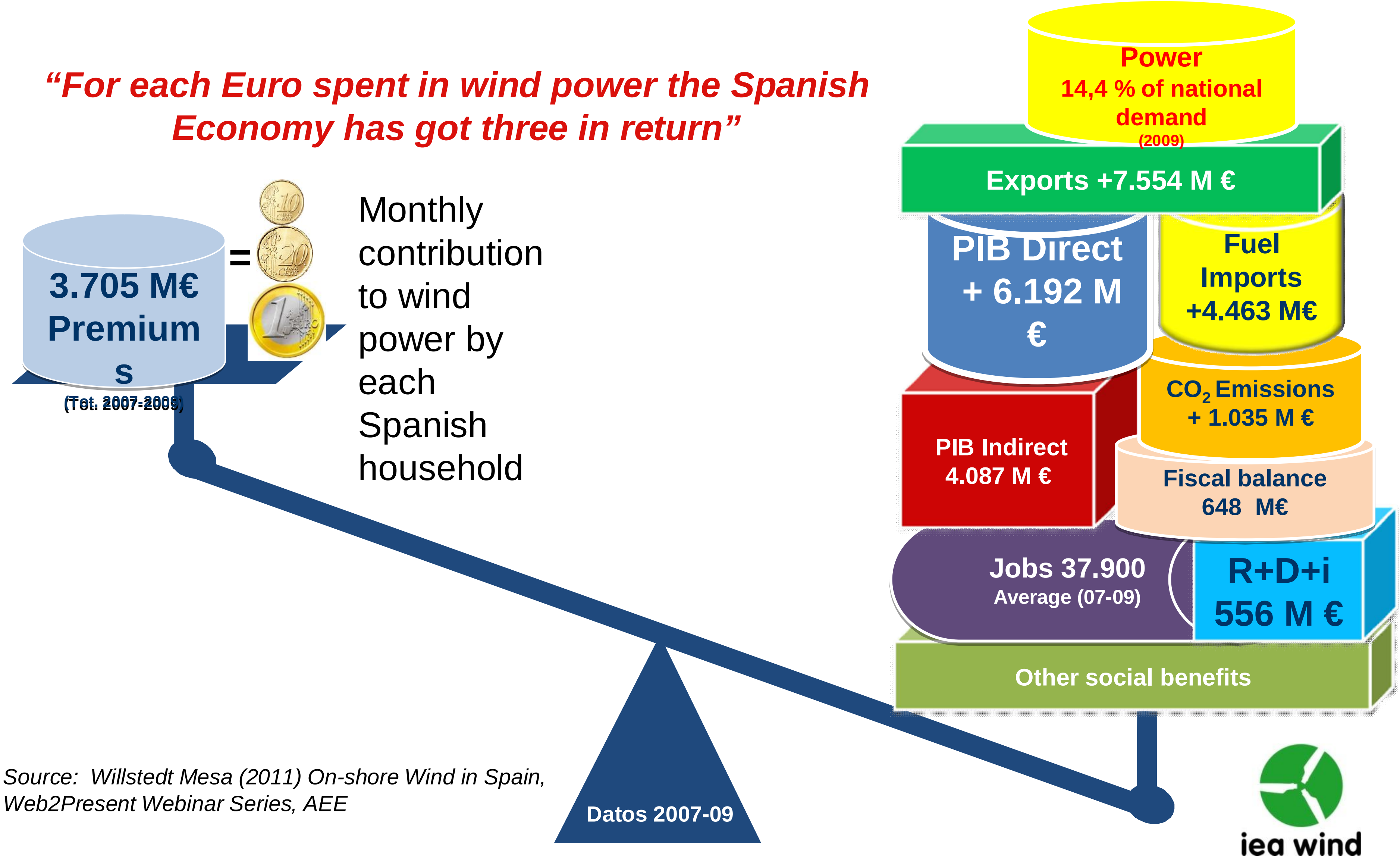
     - Quantify local benefits/impact (per project)
     - Quantify regional benefits/impact (geographic region specified)

THE SPANISH FEED-IN TARIFF HAS MADE POSSIBLE THE ACHIEVEMENT OF THE 2010 RES ELECTRICAL OBJECTIVE, AND AS A BONUS HAS ENABLED THE SPANISH WIND INDUSTY TO BECOME A WORLD PLAYER

"For each Euro spent in wind power the Spanish Economy has got three in return"



Source: Willstedt Mesa (2011) On-shore Wind in Spain, Web2Present Webinar Series, AEE

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Observations for Work Package #3

- Variety of methods used by participating countries for variety of purposes
- Models used range in complexity and geographic scope

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Thank You For Your Attention!

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Supplemental Slides

Limited Offshore Data Collection

	2007 Netherlands Prinses Amalia	2008 Denmark Rødsand II	2008 Germany Generic
Project Status	2007 Cost Projection	2008 Cost Projection	2008 Cost Projection
Year of completion	2007	Late 2010	Not Specified
Unit size (MW)	2.0	2.3	5.0
Number of turbines	60	90	12
Full load hours	3,350	3,800	3,700
Investment costs (€/kW)	3,315	1,883	3,230
Decommissioning costs (€/kW)	0	0	0
Other costs (€/MWh)	11	0	0
O&M costs fixed (€/kW)	149	0	123
O&M costs variable (€/MWh)	0	24	0
Converted Total O&M costs (€/MWh)	44	24	33
Economic life	15	25	20

Offshore Financial Parameters

	2007 Netherlands Prinses Amalia	**2008 Denmark Rødsand II**	**2008 Germany Generic**
Return on debt (%)	5.0	4.5	6.5
Return on equity (%)	12.0	11.2	15.0
Debt share (%)	50	26	70
Equity share (%)	50	74	30
Loan duration (yrs)	15	13	12
National tax rate (%)	25.5	25.0	29.8
WACC (%)	7.9	9.2	7.7

Financial Gap Calculation in ECN Model