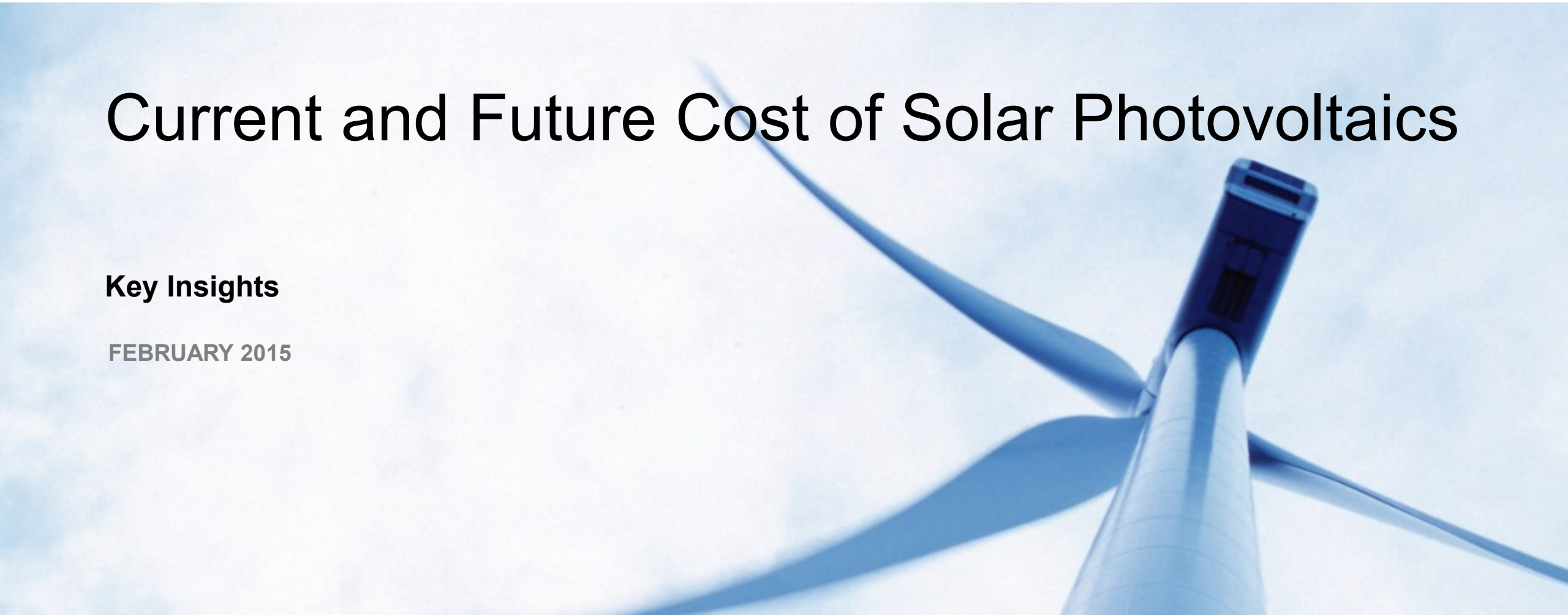
Agora Energiewende

Current and Future Cost of Solar Photovoltaics

Key Insights

FEBRUARY 2015



Agora Energiewende - who we are

- Independent and non-partisan Think Tank, 18 Experts
- Financed with 15 million Euro by the Mercator Foundation and the European Climate Foundation (Project duration: 2012-2017)
- Mission: How do we make the *Energiewende* in Germany a success story?
- Analyzing, assessing, understanding, discussing, putting forward proposals

Starting point: uncertainty about the future role of solar PV among experts and policy makers

Agora Energiewende

Today: solar photovoltaics becomes mainstream

Source: ©iStock/trekandshoot

http://washpost.bloomberg.com/Story?docId=1376-NJJ39B6JIJVD01-3IVODTLTL6845GSMJHEF9LCLR3

Future: very different perspectives on solar power

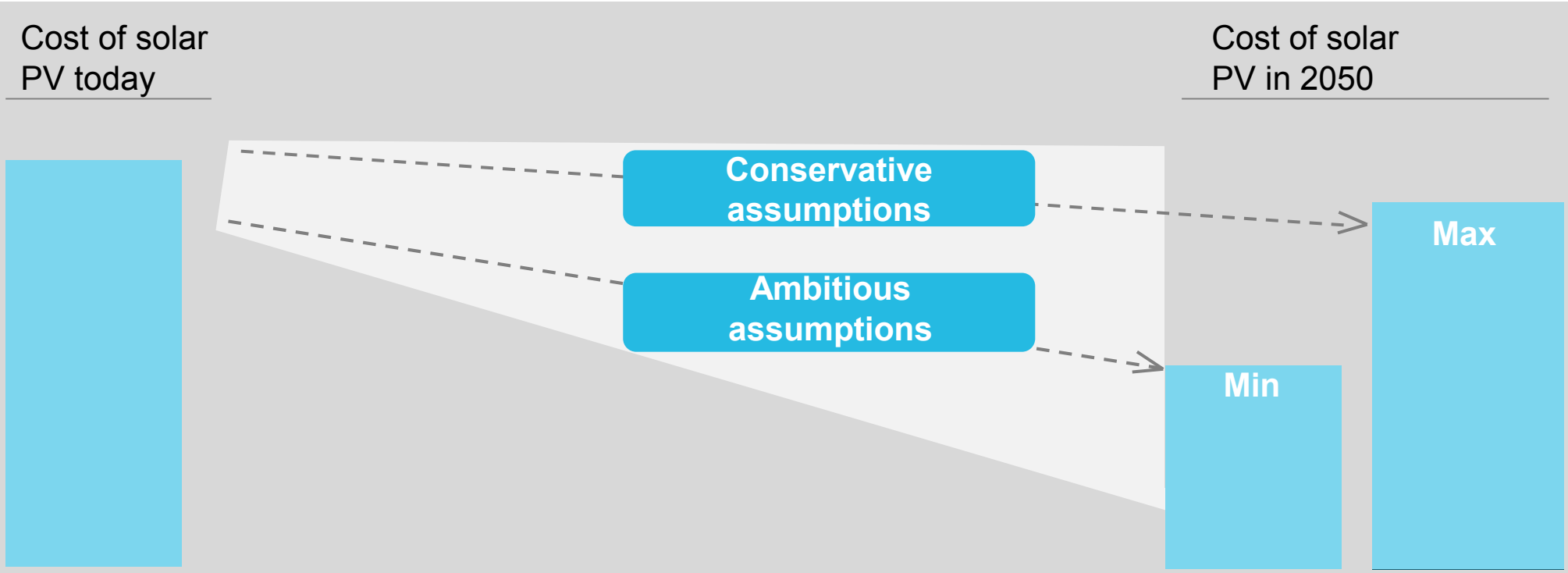
- Cost for solar power will decrease
- „The future will be based on solar power“
- „Solar is a game-changer for energy industry“

?

- Cost for solar power will rise again soon
- „Solar will remain a rich-people-technology“
- „The solar bubble is about to burst“

Own illustration

Objective:
provide a range of future cost scenarios to support discussion on role of solar PV



Own illustration

Focus on large scale systems and crystalline silicon technologies – breakthroughs are far from impossible but not considered here

Solar PV system size

Focus

1kW | 10 kWp | 100 kWp | 1 MWp | 10 MWp | > 100 MWp

Private house | Industry | Ground-mounted

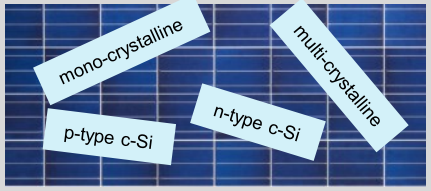
Source: Fotolia/Smileus

Source: Naturstrom AG

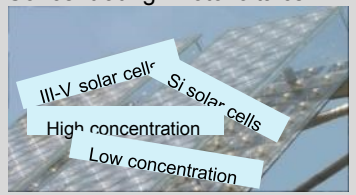
Solar PV technology

Focus

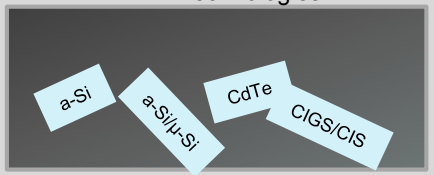
Crystalline Silicon-Technologies



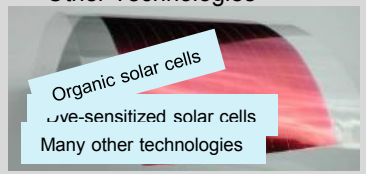
Concentrating Photovoltaics



Thin-film-Technologies



Other Technologies



Sources: Fotolia/ls_design, Fraunhofer ISE

Einteilung nach: EPIA, Solar Generation 6, 2011

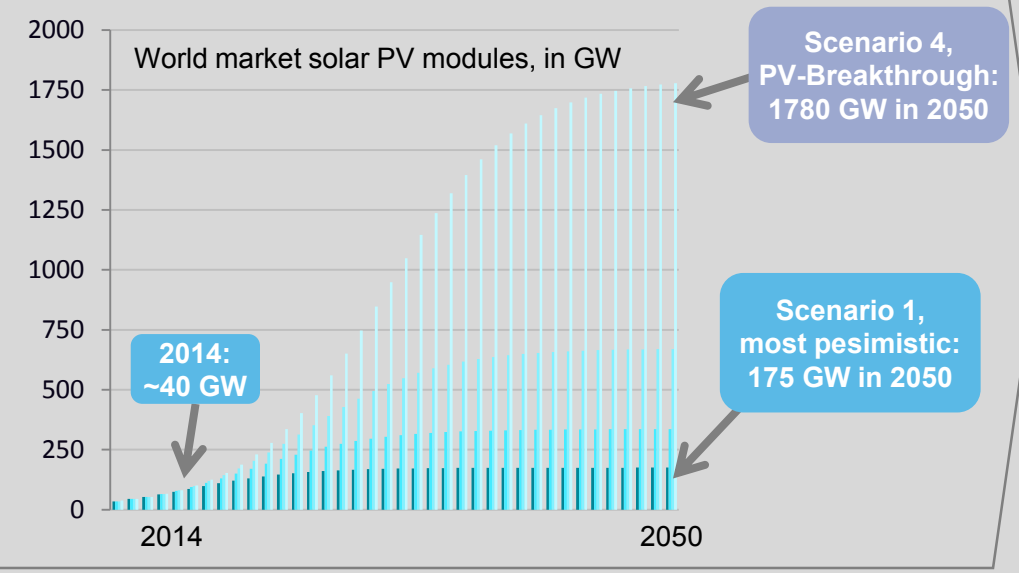
Own illustration

Backup

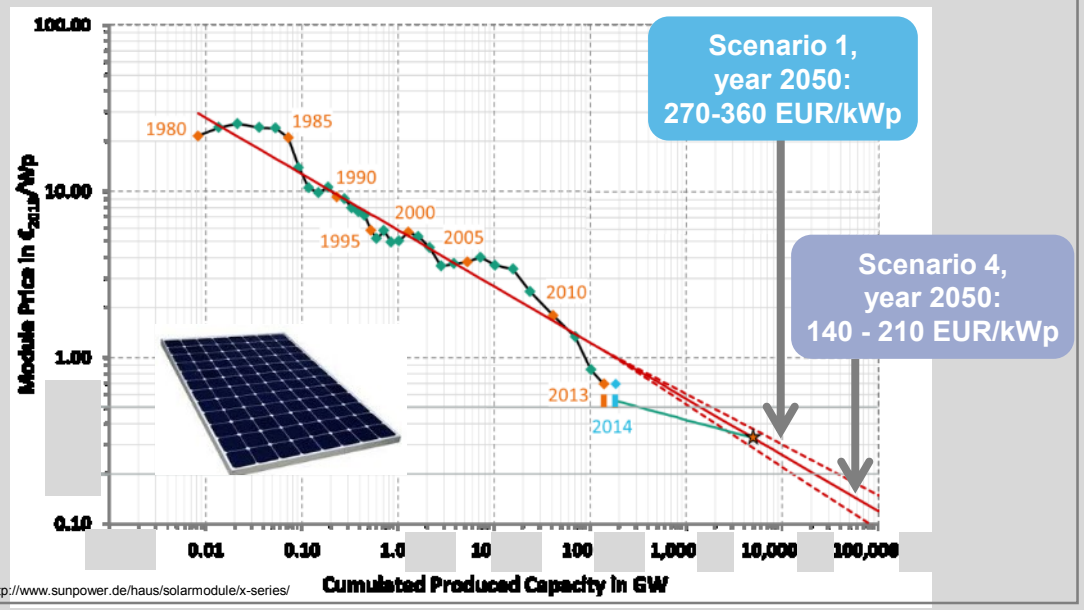
Future solar module prices in different scenarios are based on the historical “learning rate”

Example of methodology used

Expert discussion: Scenarios of market development



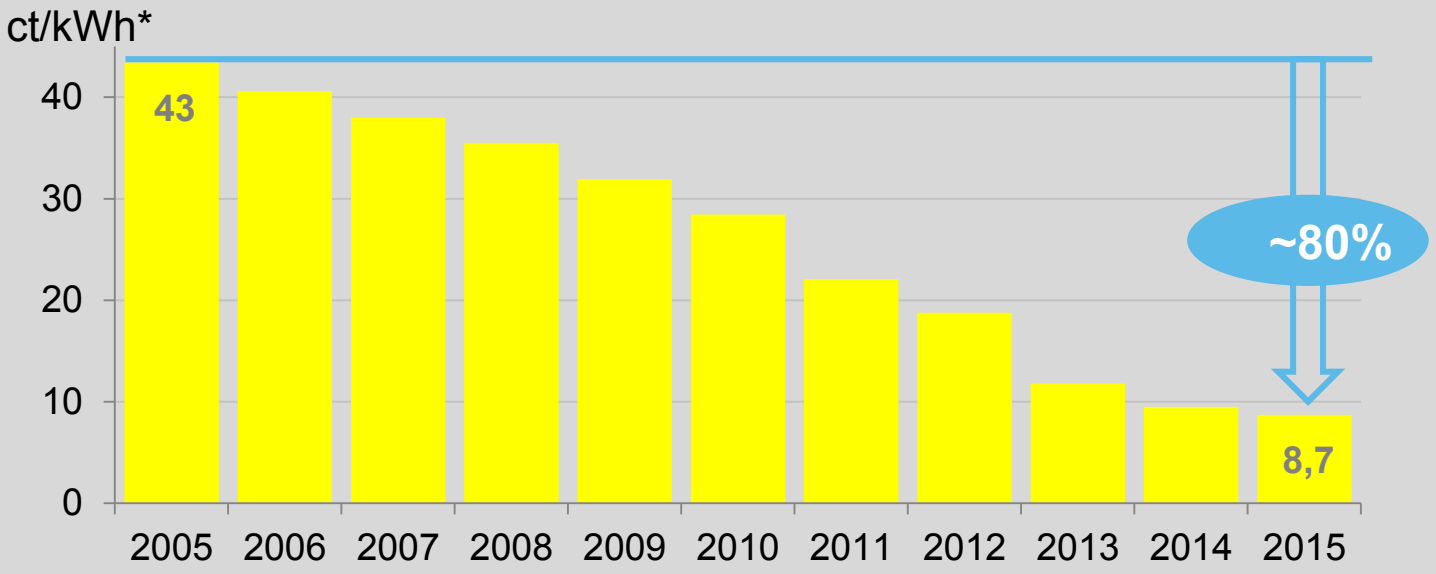
Resulting cost of solar modules based on „learning rate“



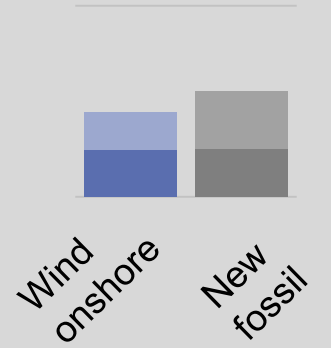
Own illustration

Key Insight 1:
Solar photovoltaics is already today a low-cost renewable energy technology

Feed-in tariff for new large-scale solar photovoltaic in Germany



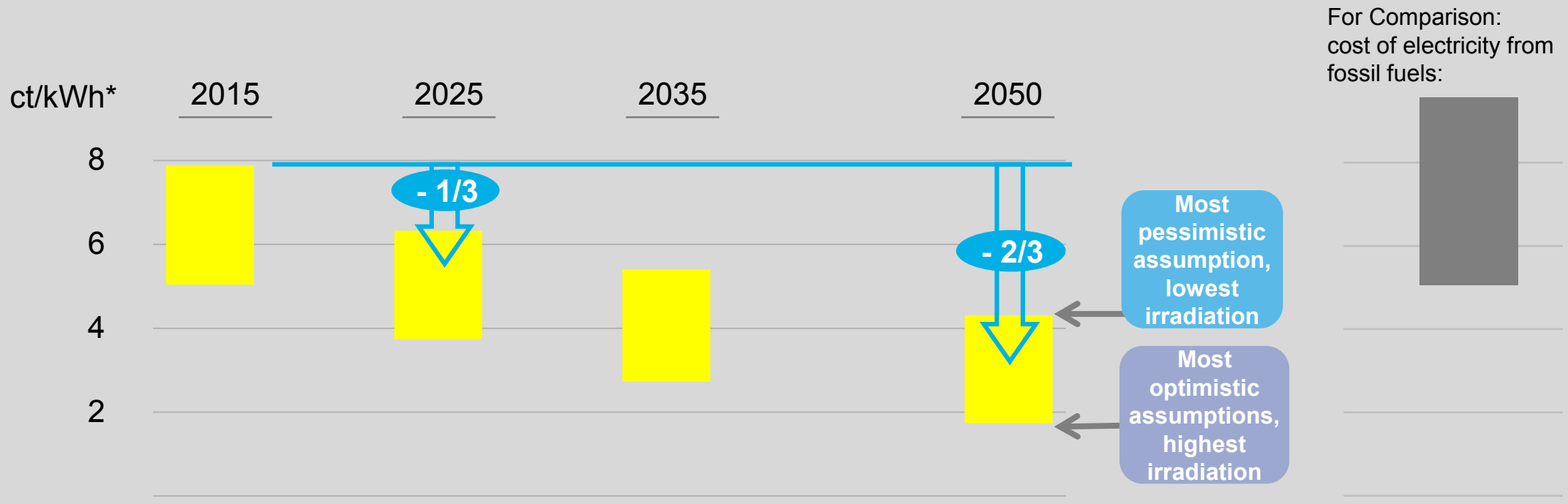
For Comparison:



*Nominal values, Feed-in tariff applicable at first of January each year, value 2015 excl. adjustment of 0,4 ct/kWh for direct marketing.
Source: German renewable energy law, Agora Energiewende

Key Insight 2:
Solar power will soon be the cheapest form of electricity in many regions of the world.

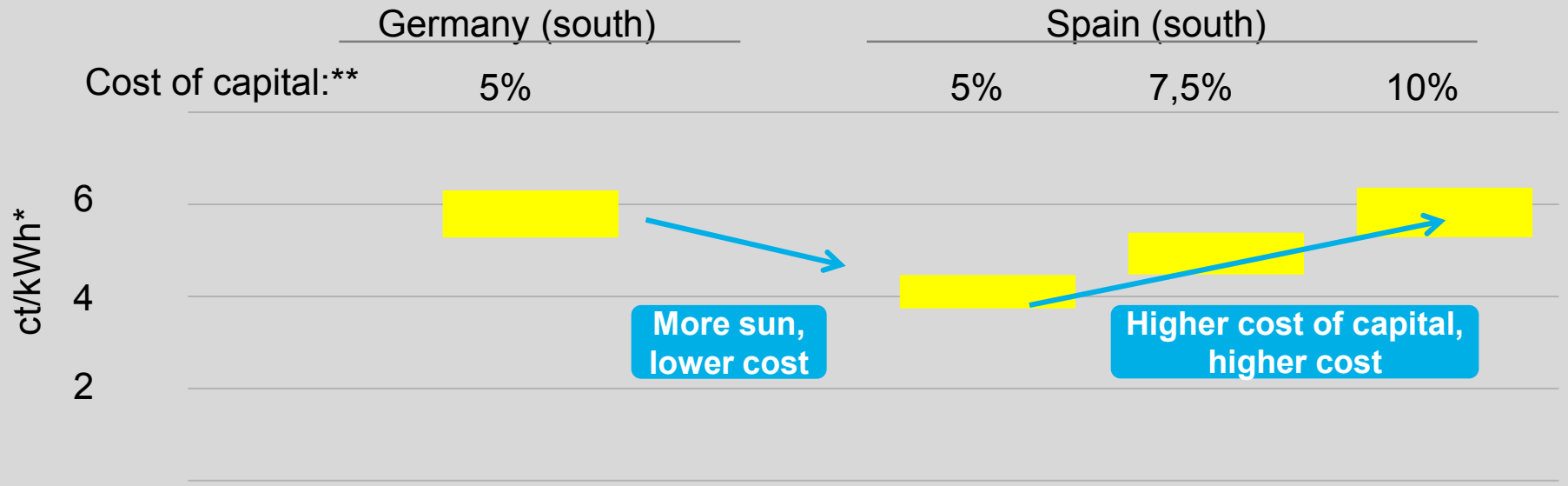
Cost of electricity from new solar power plants in Southern and Central Europe



*Real values in EUR 2014; bandwidth represent different scenarios of market, technology and cost development, as well as power plant location between south of Germany (1190 kWh/kWp/y) and south of Spain (1680 kWh/kWp/y). Source: Own illustration

Key Insight 3:
Financial and regulatory environments will be key to reducing cost in the future.

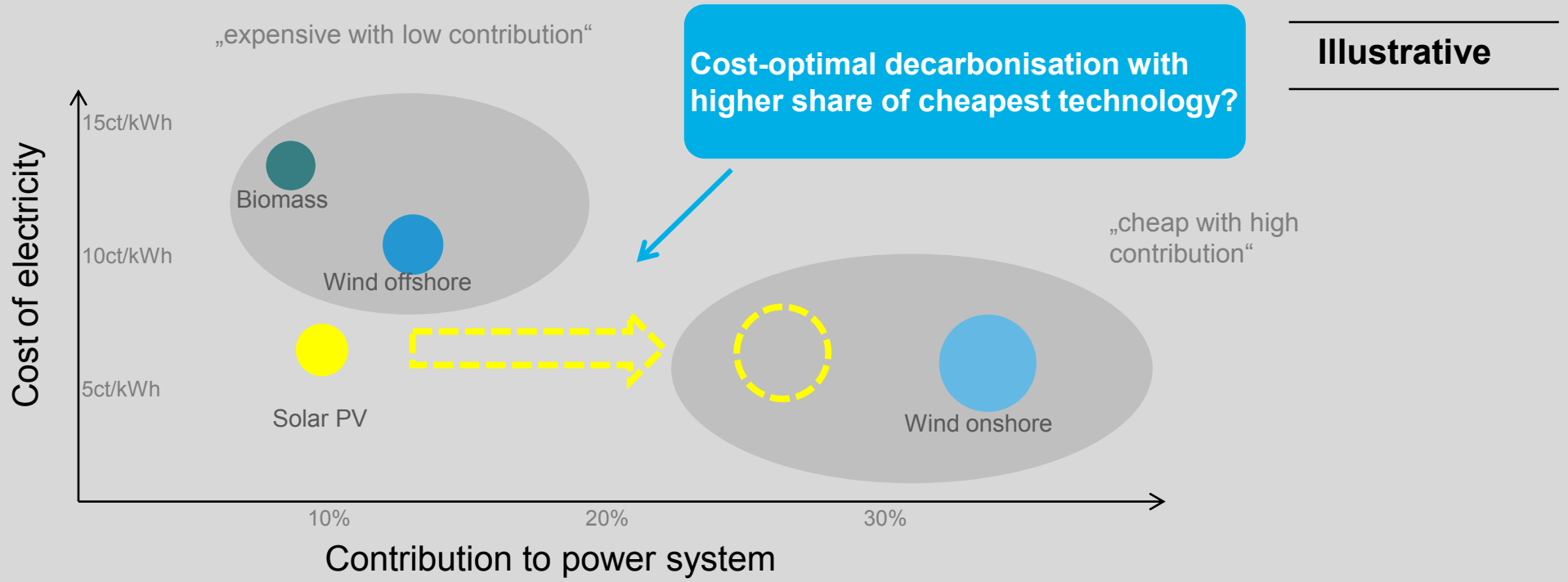
Cost of electricity of solar PV at different costs of capital, example southern Germany and southern Spain in 2025



* Real values in EUR 2014 ** Weighted average cost of capital (WACC)
Source: own illustration

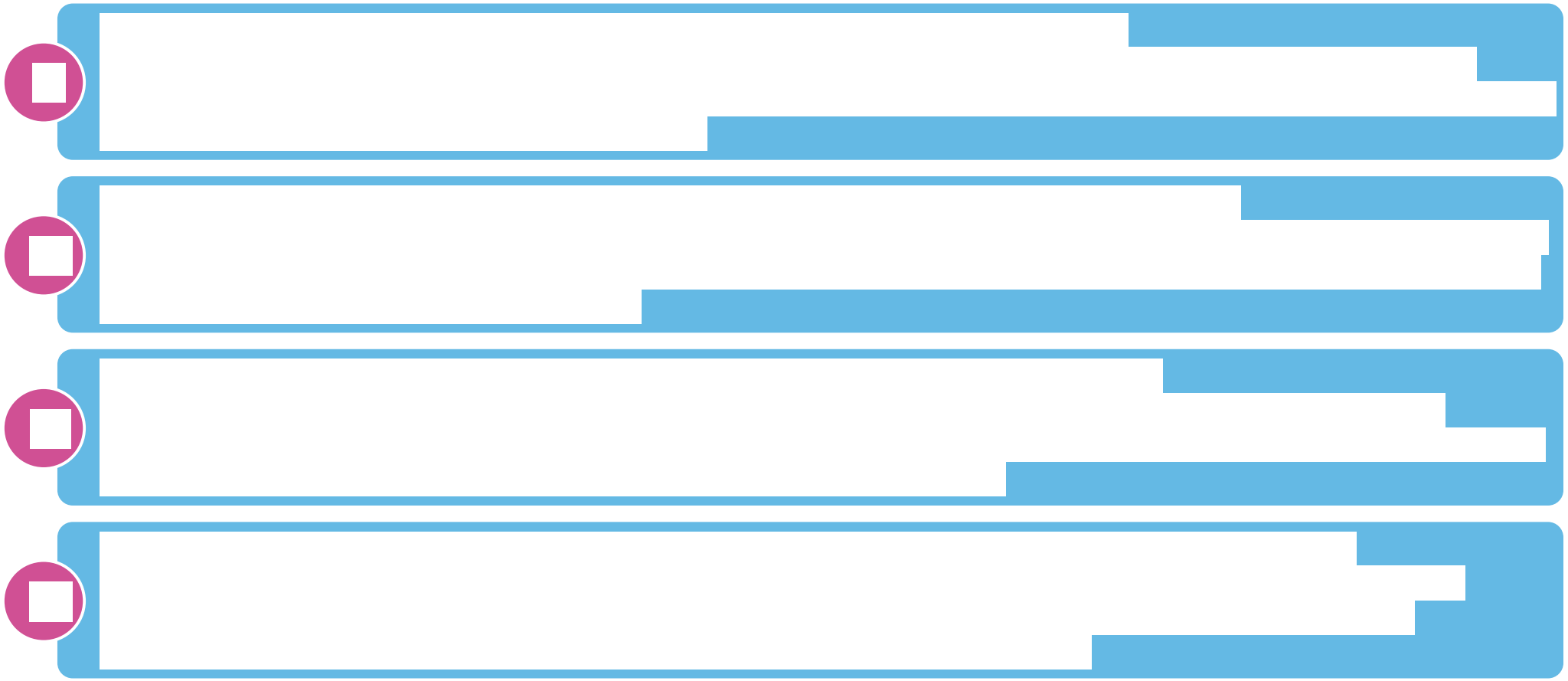
Key Insight 4:
Most scenarios fundamentally underestimate the role of solar power in future energy systems.

Cost of electricity and contribution to power system per technology, scenario for Germany 2035*



* Contribution of renewables based on scenario B2035 of grid development plan 2015, cost of electricity for other technologies based on Agora Energiewende 2014
Source: own illustration

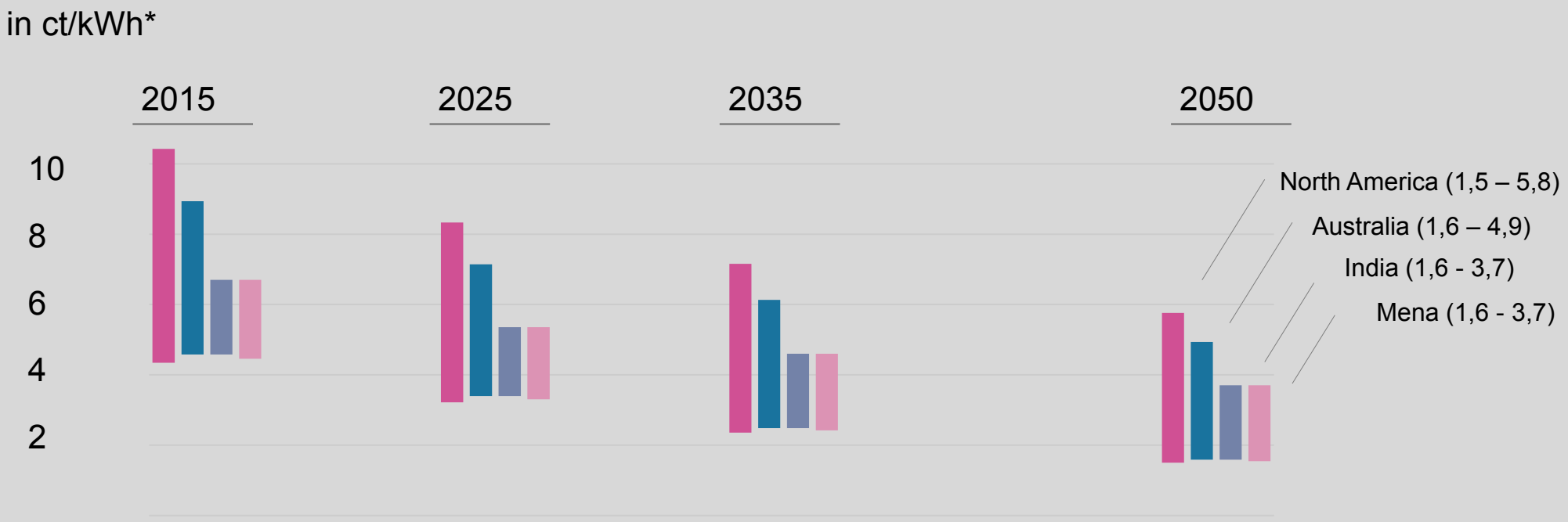
Summary: Key Insights



Deep-dive regions and countries

Solar power will soon be the cheapest form of electricity in many regions of the world.

Cost of electricity from new solar power plants in North America, Australia, India and Mena region



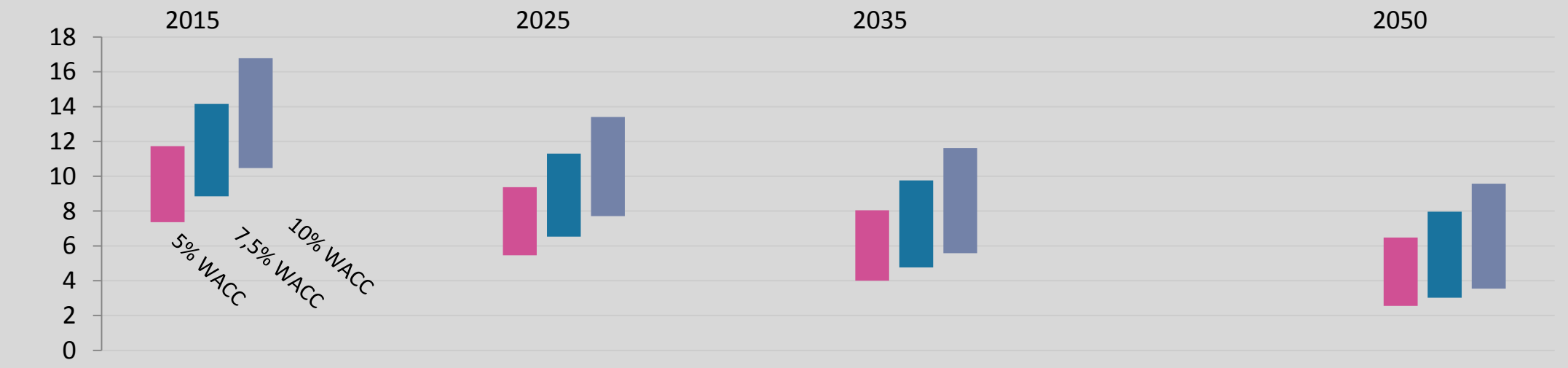
* Real values EUR 2014; full load hours based on [27], investment cost bandwidth based on different scenarios of market, technology and cost development; assuming 5% (real) weighted average cost of capital; Source: Own illustration

Currency: EUR

UK: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: United Kingdom

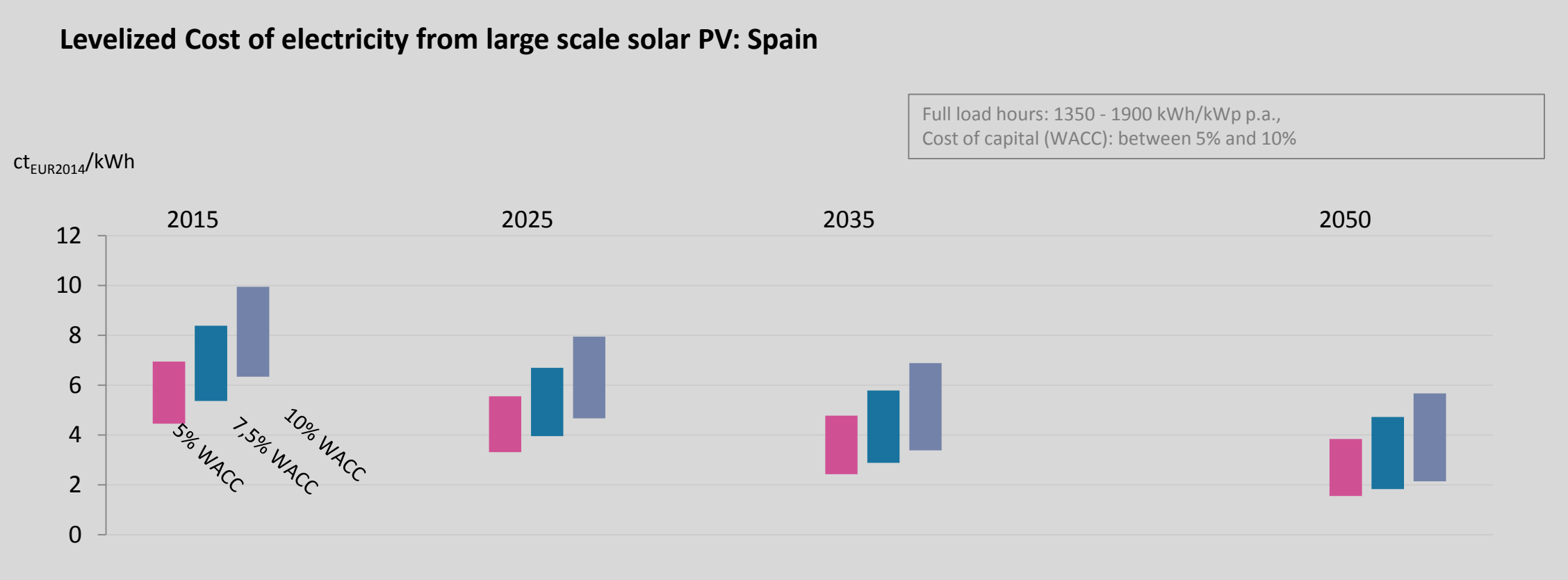
Full load hours: 800 - 1150 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Spain: Current and future cost of solar energy



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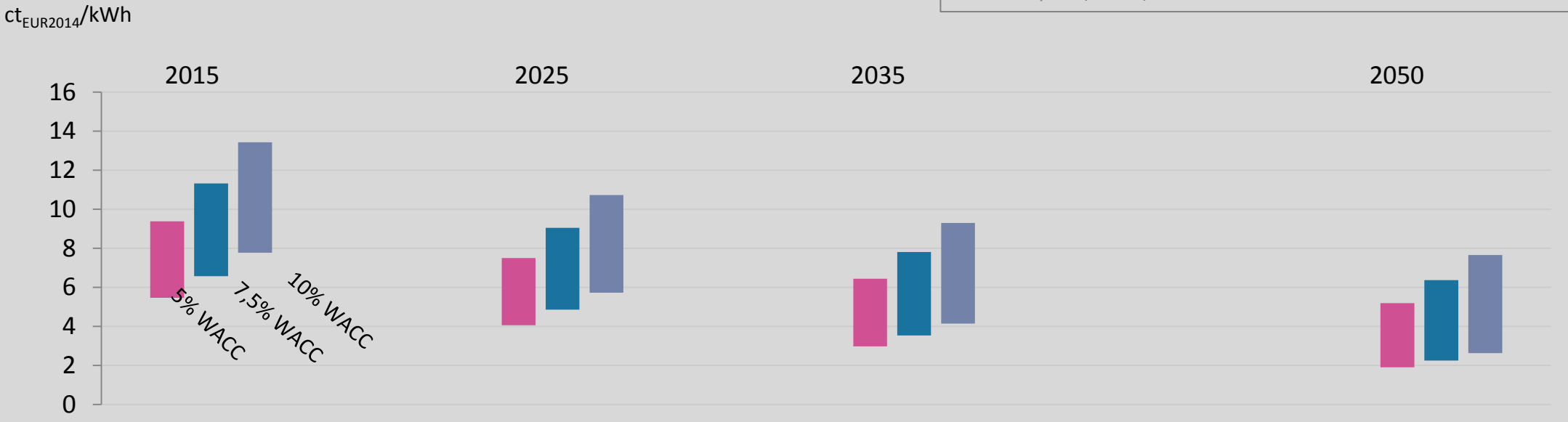
Currency: EUR

France: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: France

Full load hours: 1000 - 1550 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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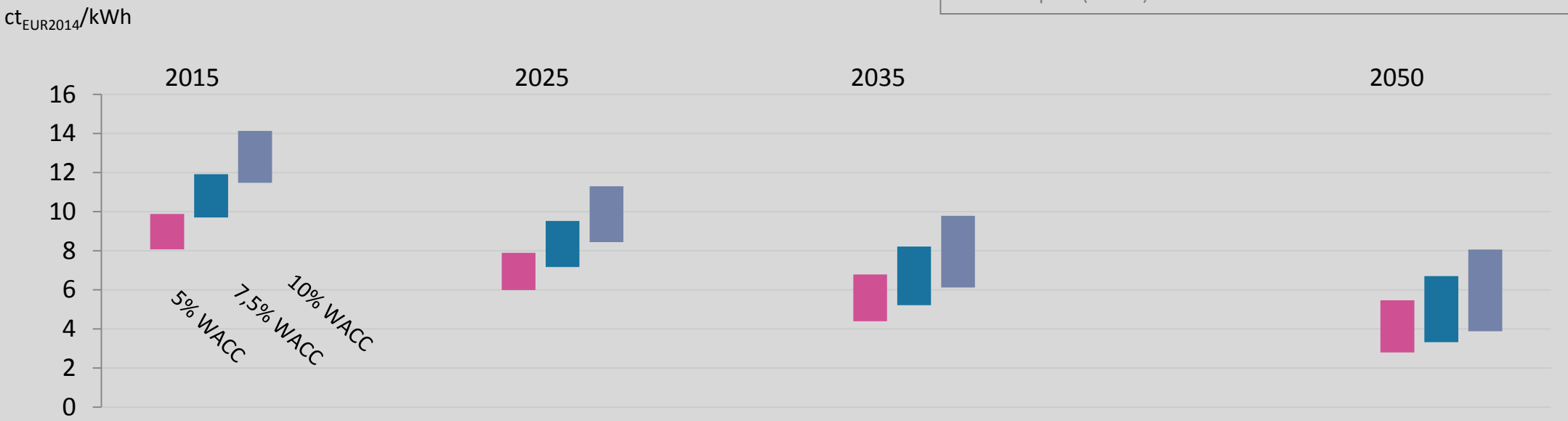
Currency: EUR

Poland: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Poland

Full load hours: 950 - 1050 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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Full report available at: **http://www.agora-energiewende.org/**

Comments and feedback welcome!

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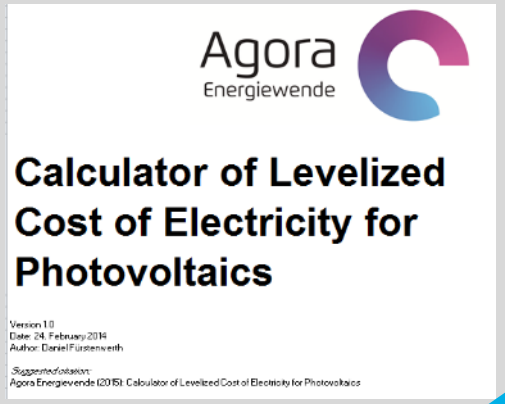
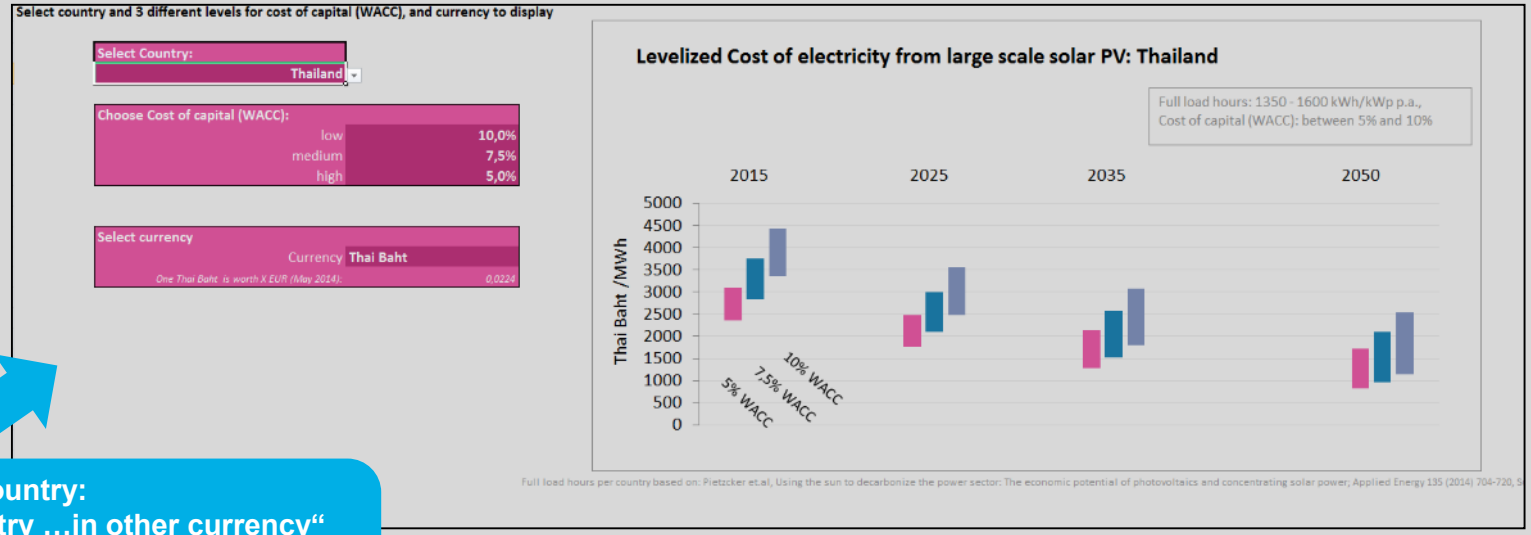
Backup – Excel tool and further country-results

Online tool (Microsoft Excel) allows calculation of current and future cost of solar PV in different countries and currencies

Available (for free) at: www.agora-energiewende.org/pv-lcoe





To calculate cost of electricity in your country:

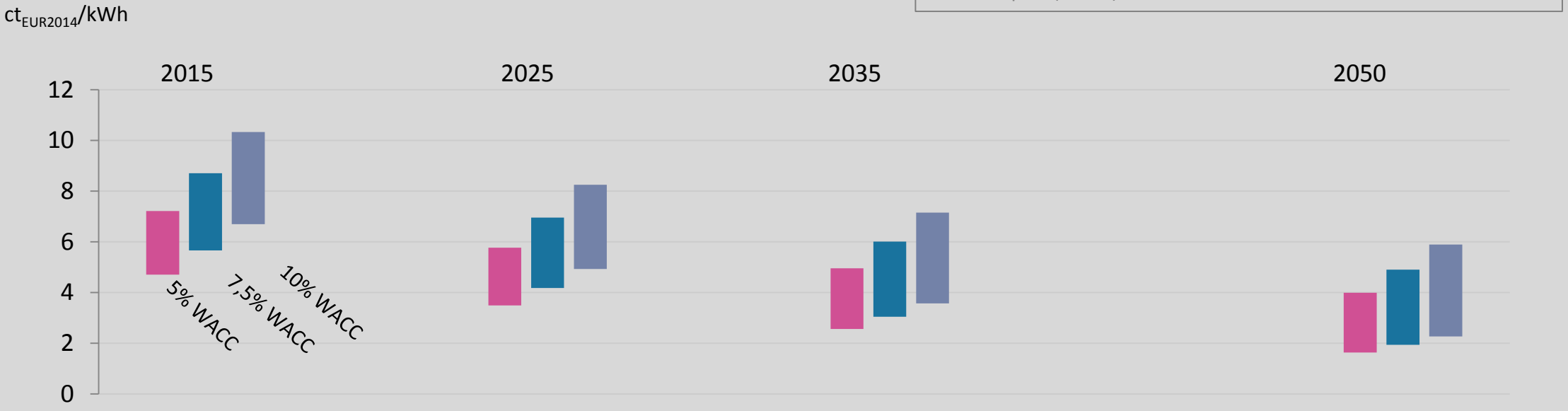
1. Go to tab „Cost of solar per country …in other currency“
2. Select a country
3. (Select cost of capital - optional)
4. Select currency to display

Currency: EUR

Greece: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Greece

Full load hours: 1300 - 1800 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



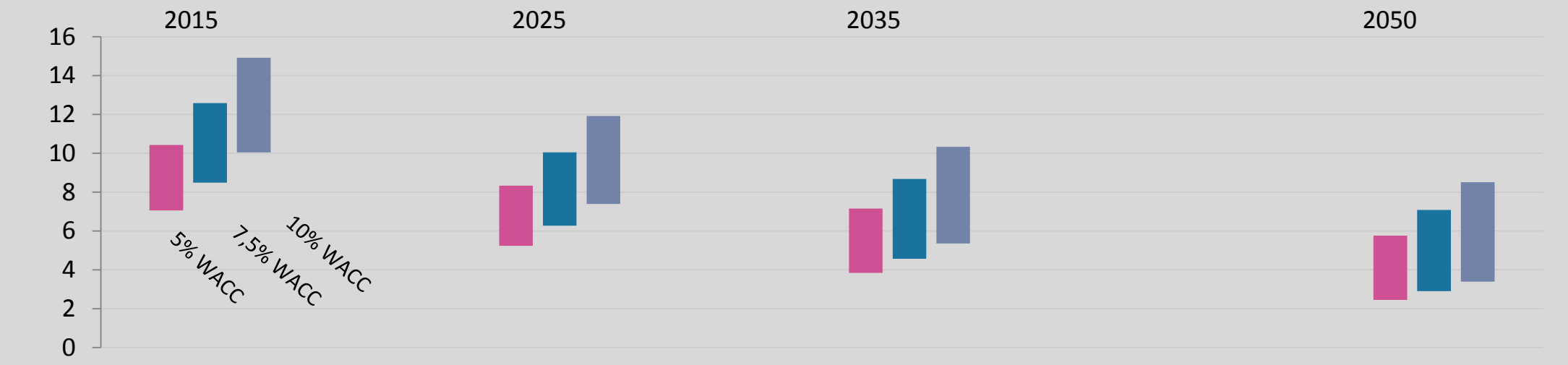
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Germany: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Germany

Full load hours: 900 - 1200 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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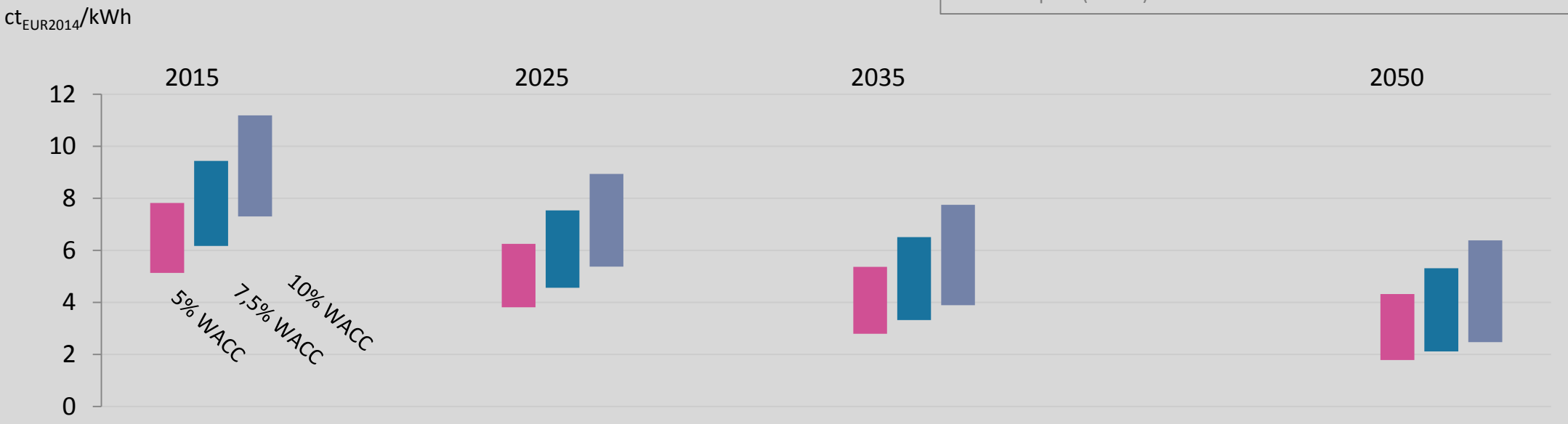
Currency: EUR

Italy: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Italy

Full load hours: 1200 - 1650 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



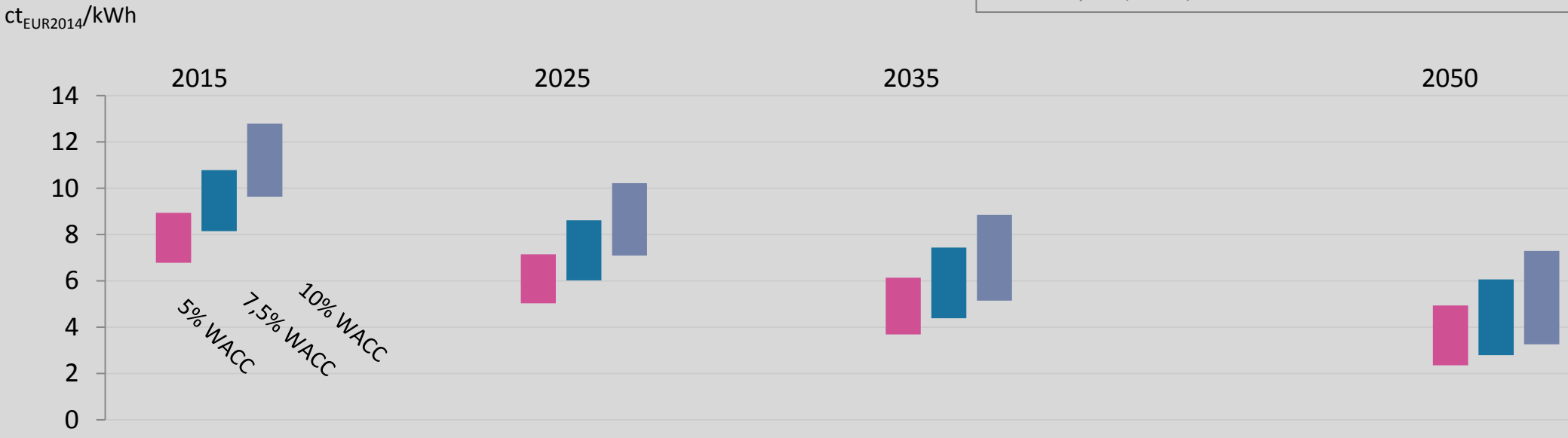
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Austria: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Austria

Full load hours: 1050 - 1250 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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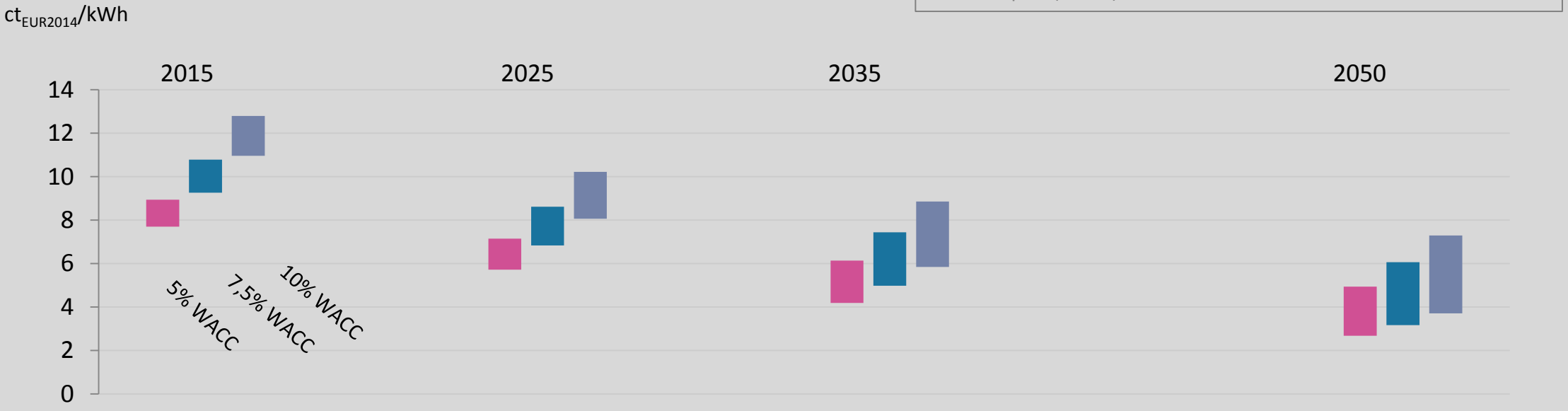
Currency: EUR

Denmark: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Denmark

Full load hours: 1050 - 1100 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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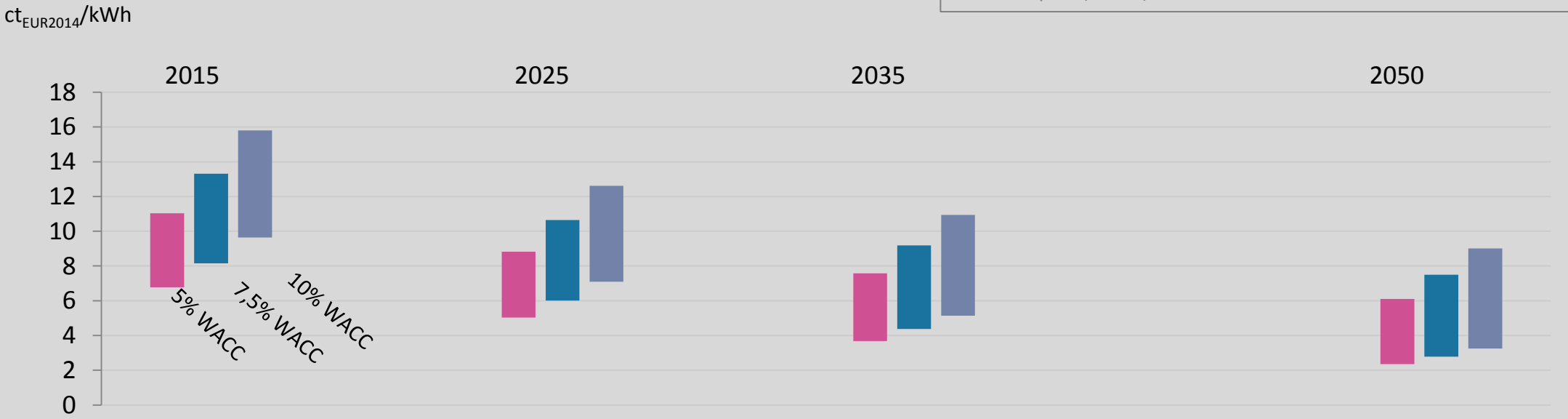
Currency: EUR

Finland: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Finland

Full load hours: 850 - 1250 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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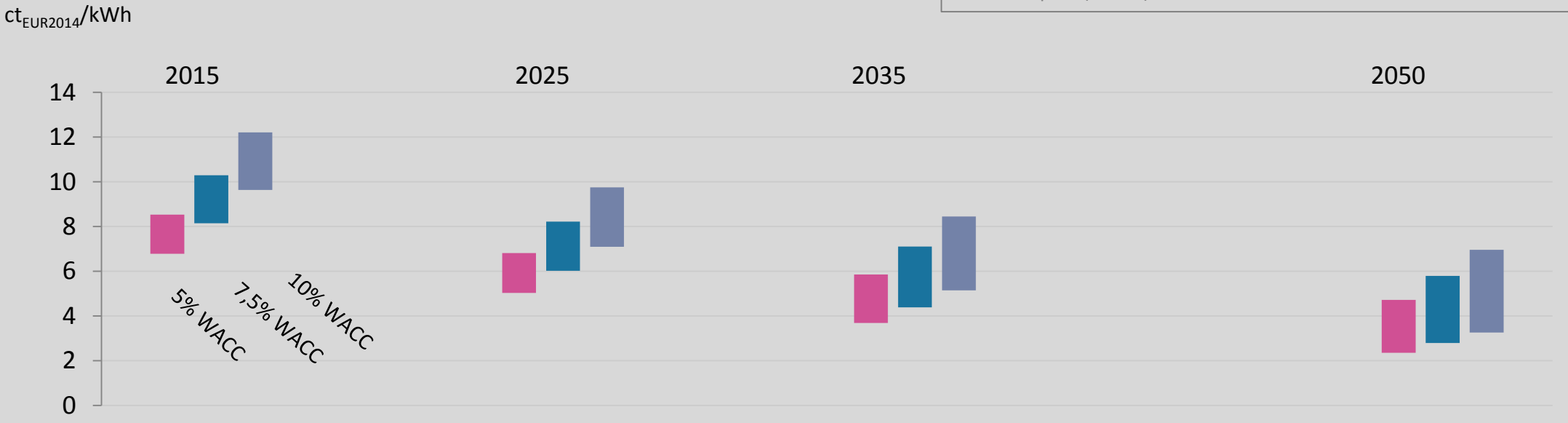
Currency: EUR

Latvia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Latvia

Full load hours: 1100 - 1250 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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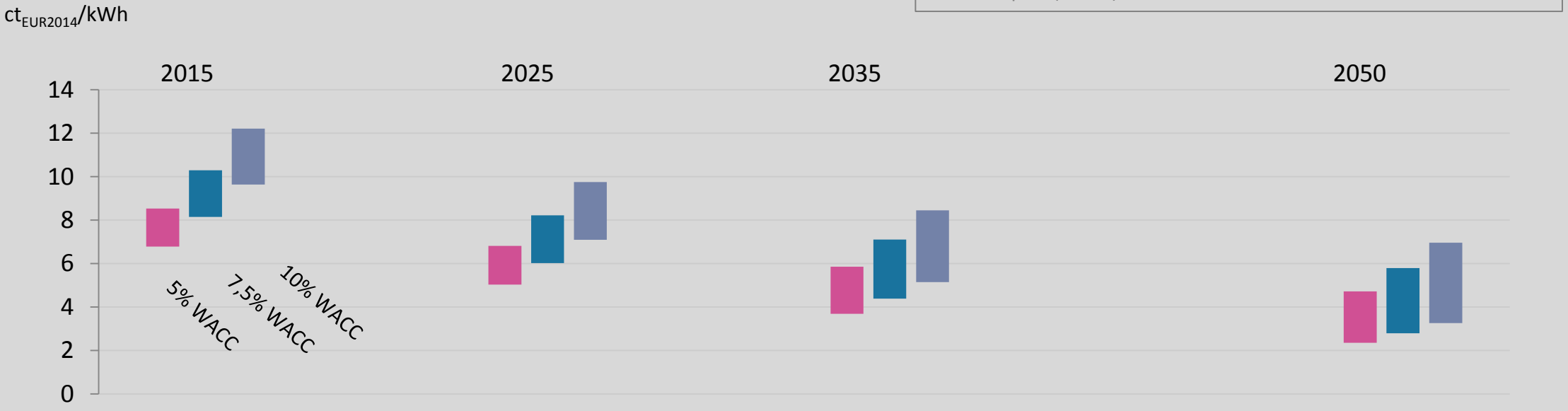
Currency: EUR

Romania: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Romania

Full load hours: 1100 - 1250 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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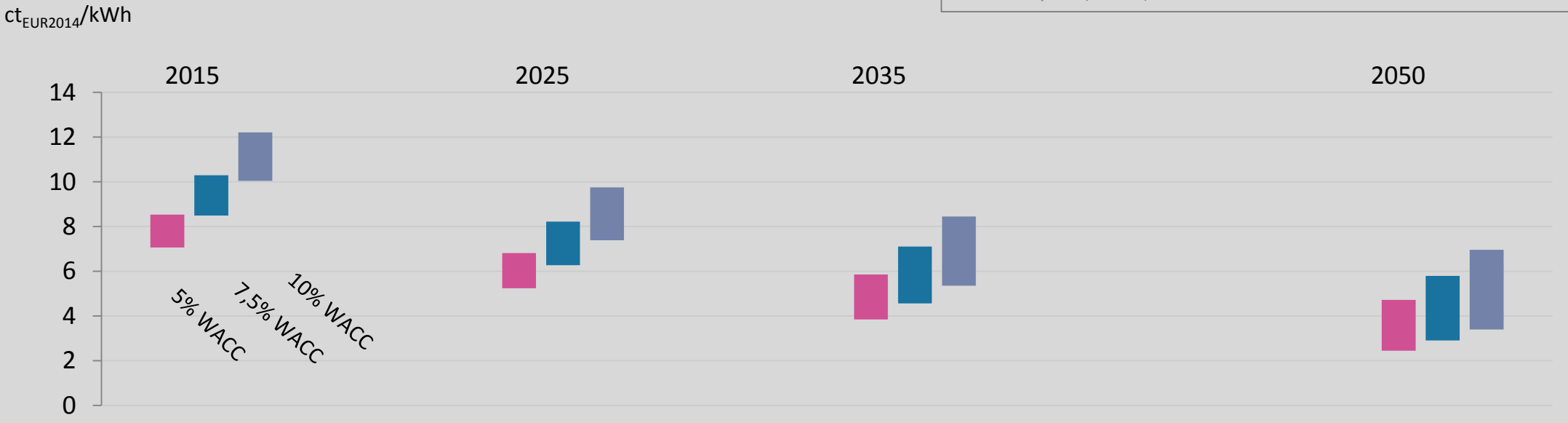
Currency: EUR

Hungary: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Hungary

Full load hours: 1100 - 1200 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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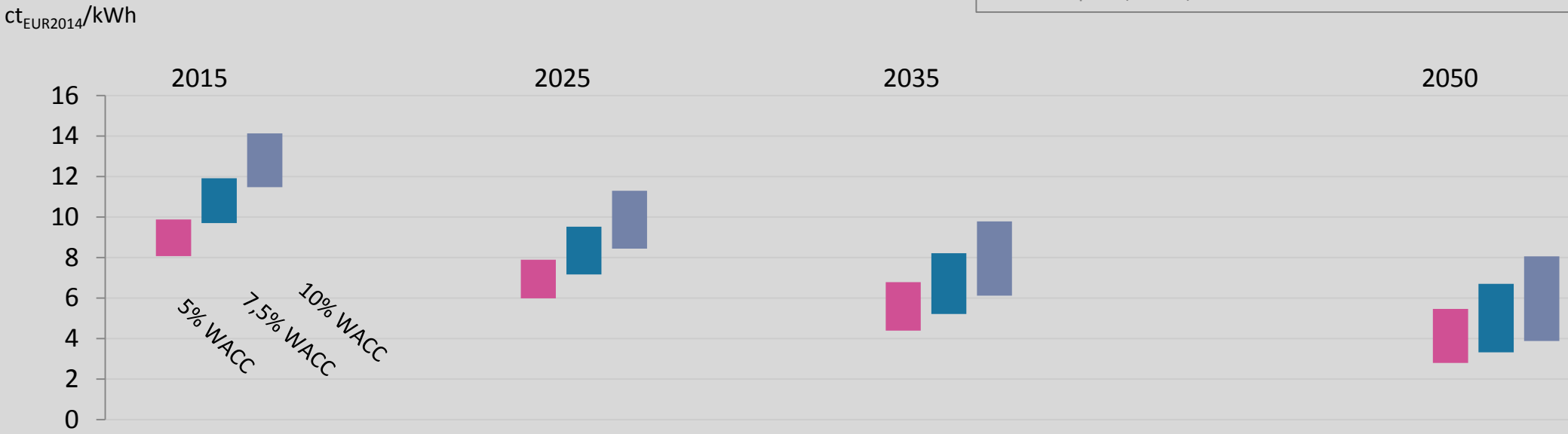
Currency: EUR

Czech Republic: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Czech Republic

Full load hours: 950 - 1050 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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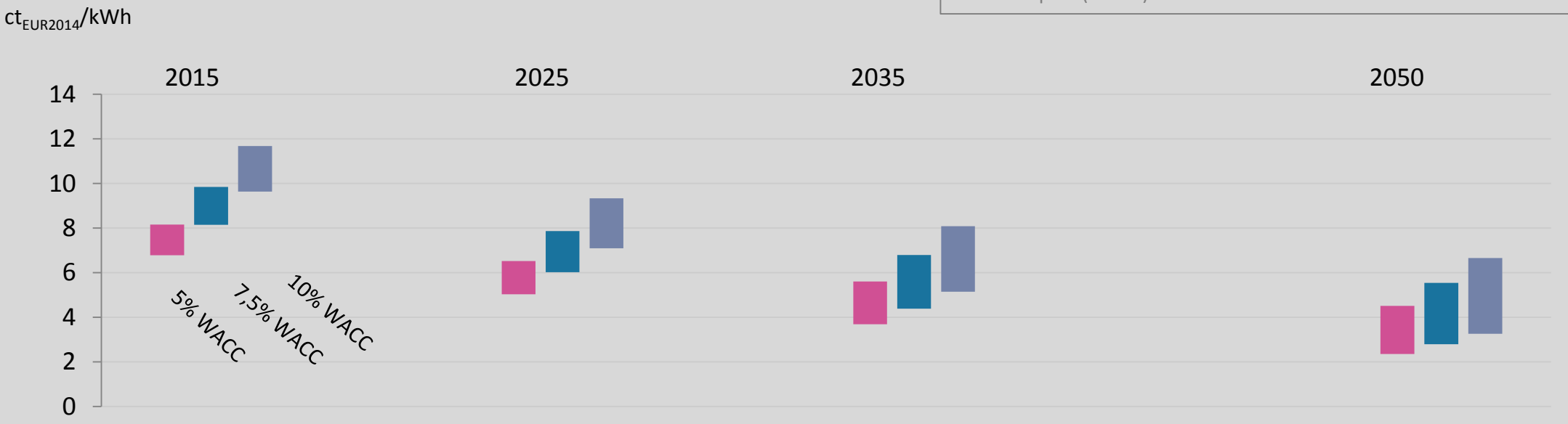
Currency: EUR

Estonia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Estonia

Full load hours: 1150 - 1250 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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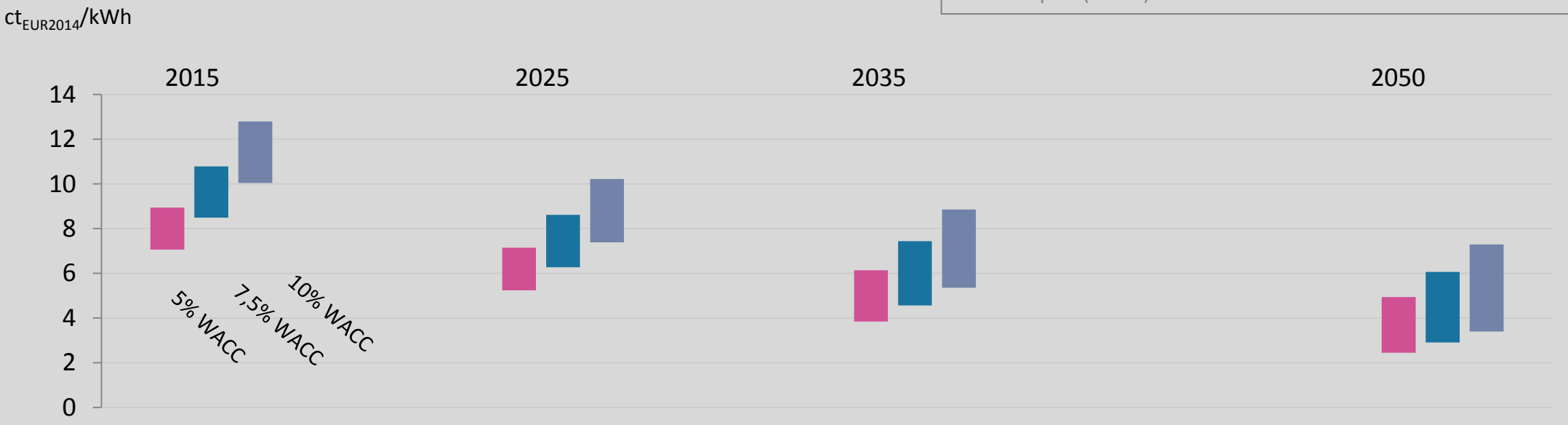
Currency: EUR

Lithuania: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Lithuania

Full load hours: 1050 - 1200 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



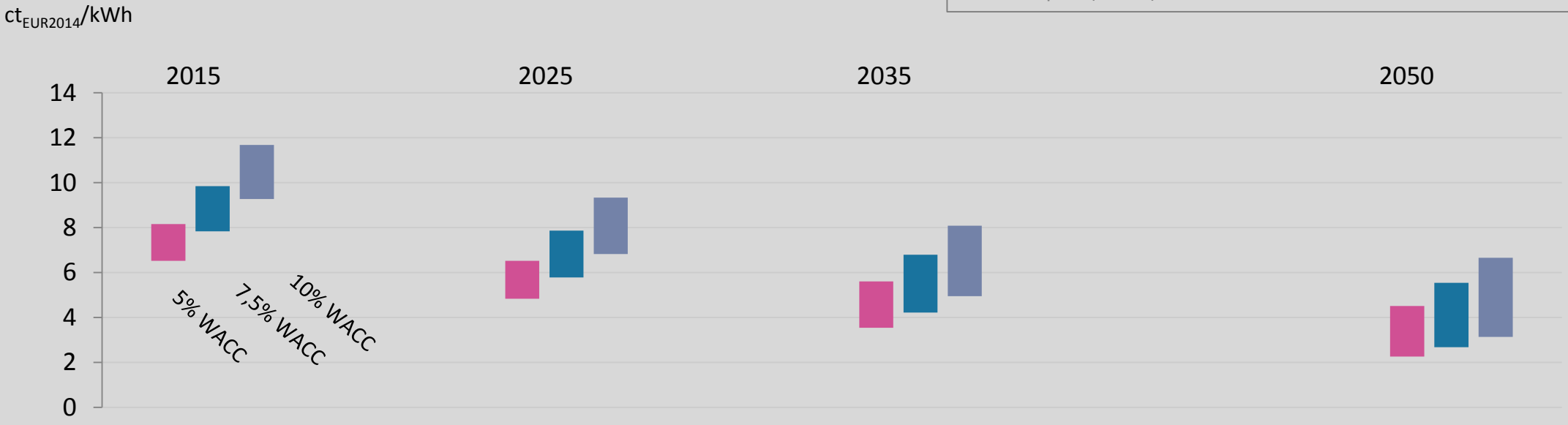
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Bulgaria: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Bulgaria

Full load hours: 1150 - 1300 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



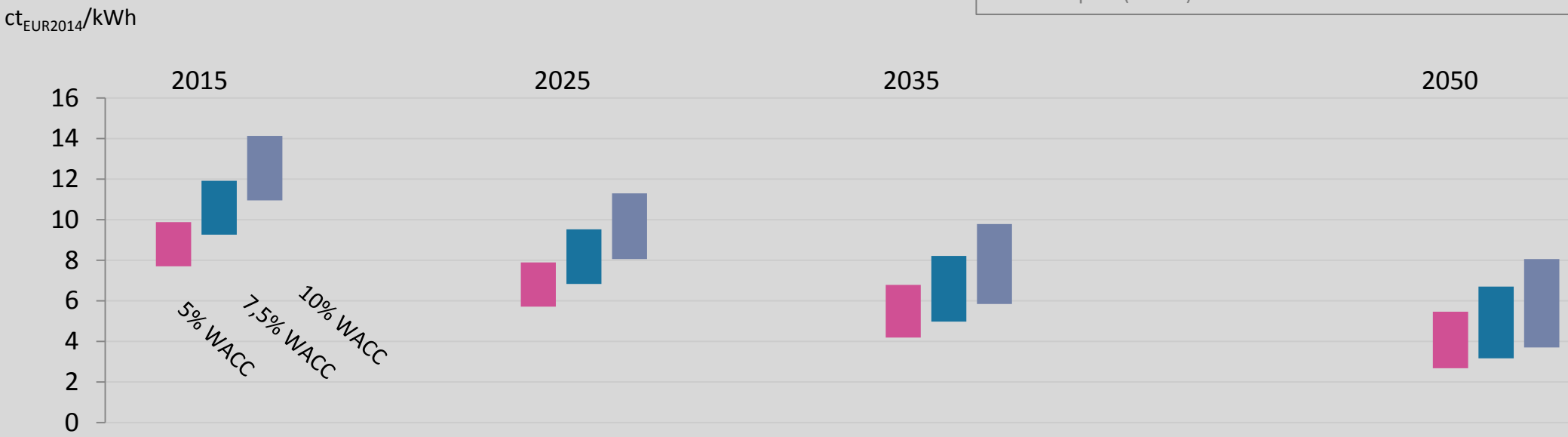
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Slovakia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Slovakia

Full load hours: 950 - 1100 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



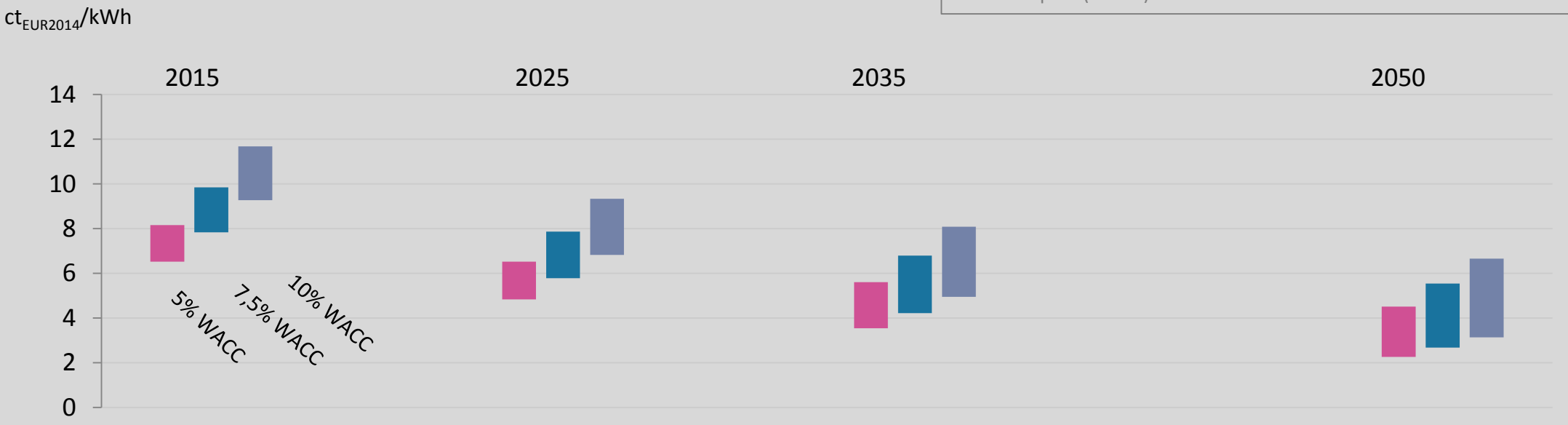
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Slovenia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Slovenia

Full load hours: 1150 - 1300 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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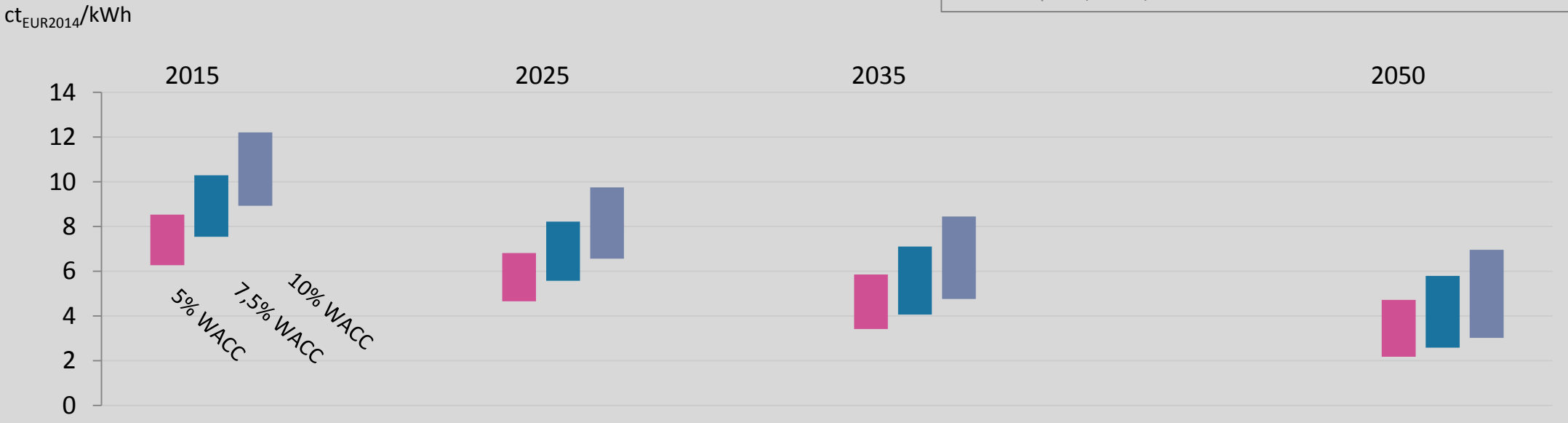
Currency: EUR

Montenegro: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Montenegro

Full load hours: 1100 - 1350 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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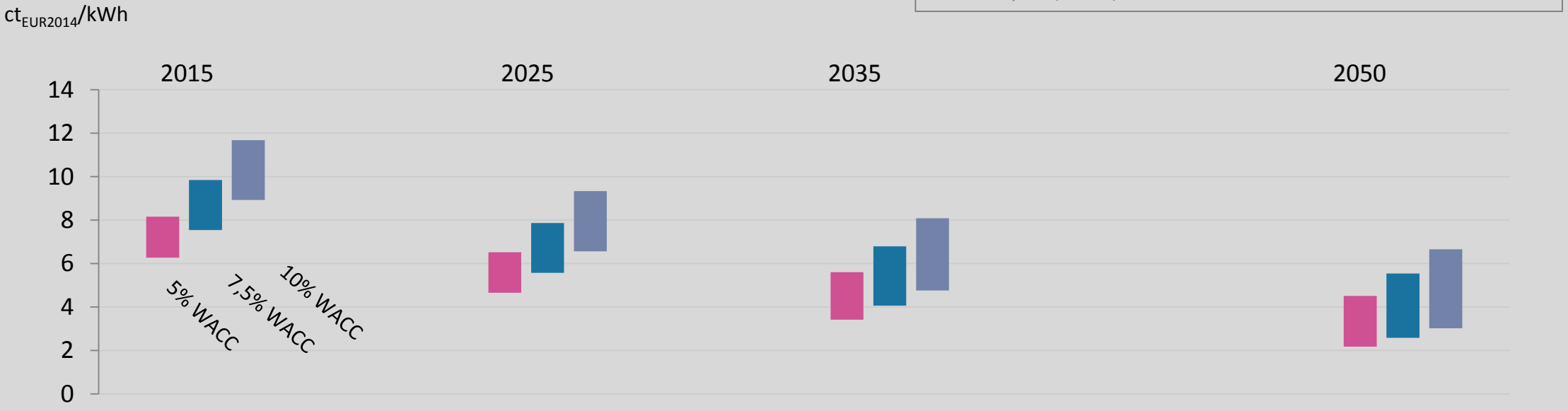
Currency: EUR

Macedonia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Macedonia (FYROM)

Full load hours: 1150 - 1350 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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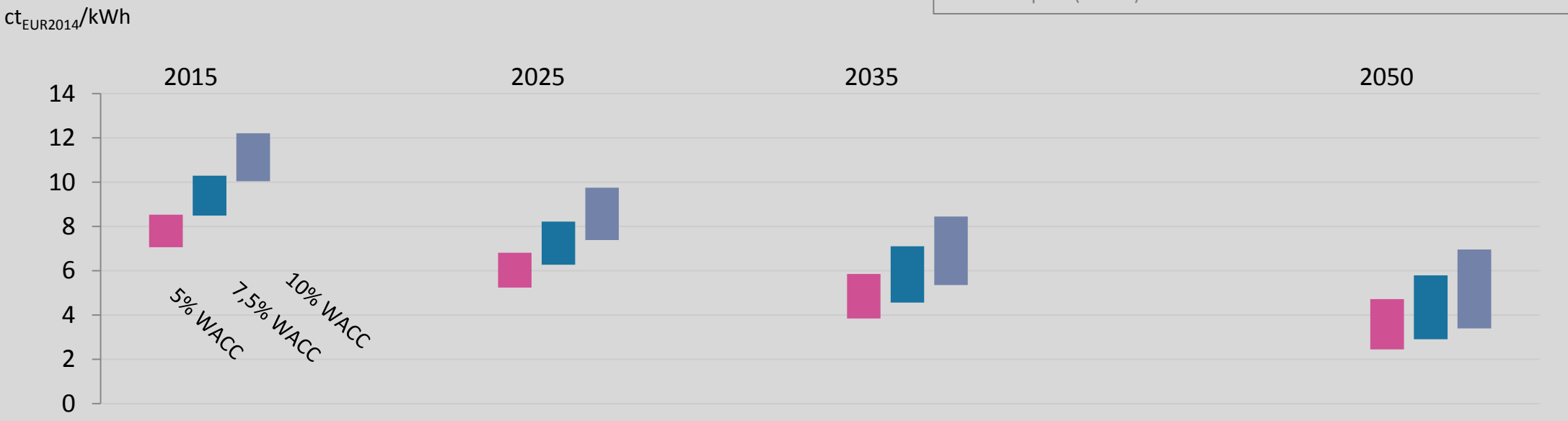
Currency: EUR

Serbia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Serbia

Full load hours: 1100 - 1200 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

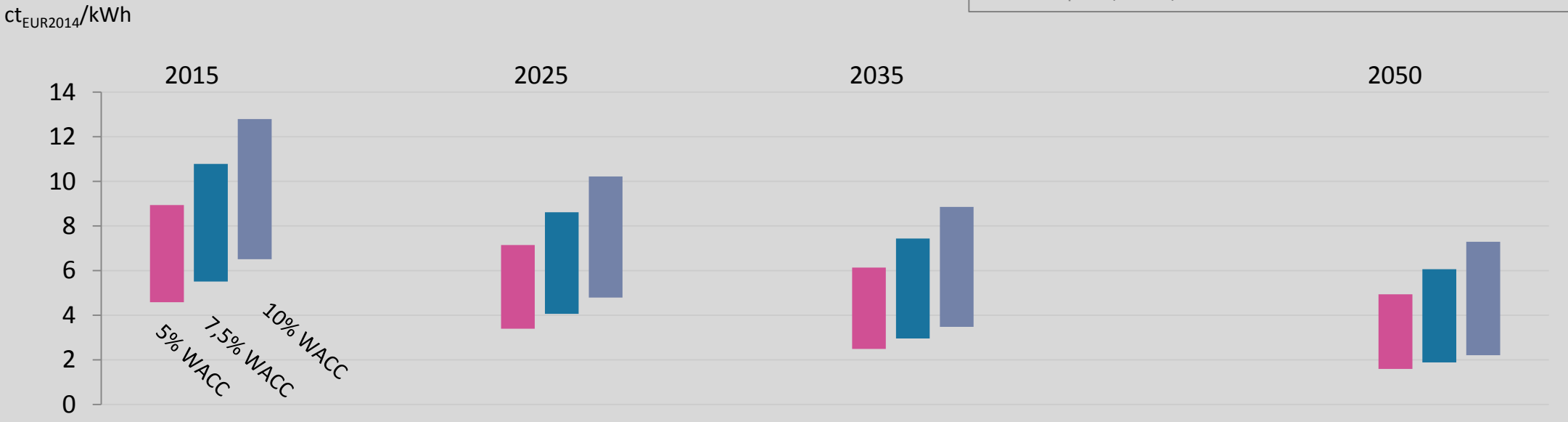
Backup – Non-EU countries

Currency: EUR

Australia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Australia

Full load hours: 1050 - 1850 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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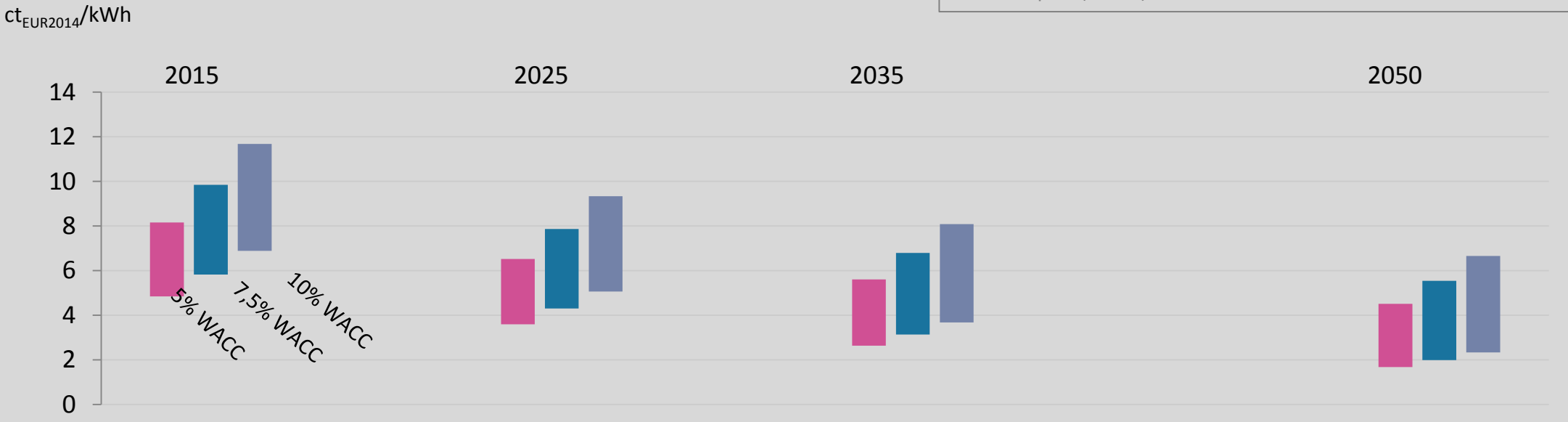
Currency: EUR

China: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: China

Full load hours: 1150 - 1750 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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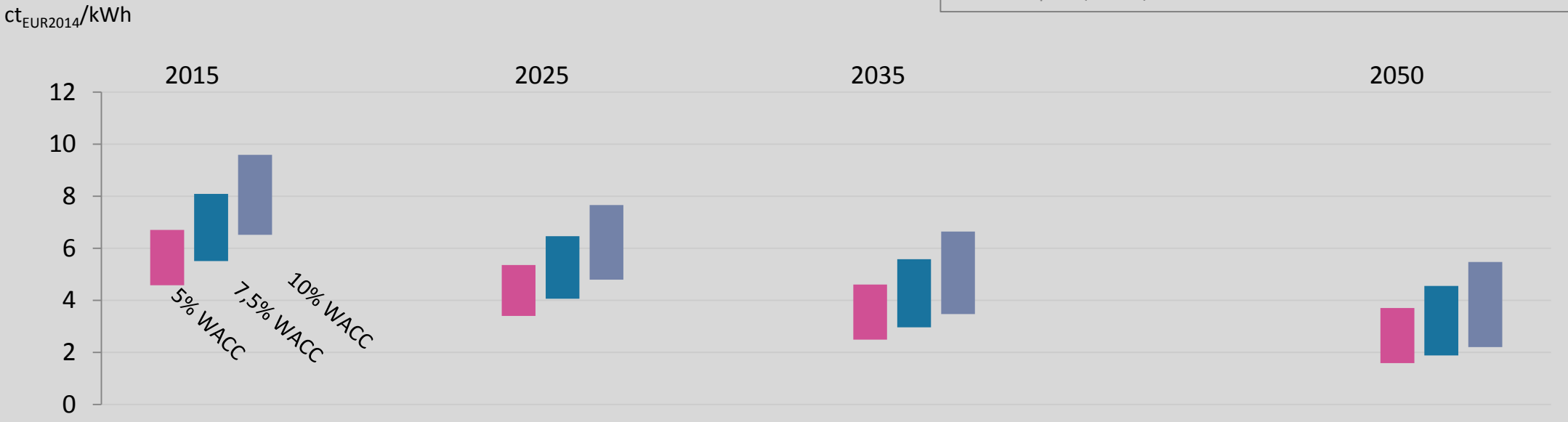
Currency: EUR

India: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: India

Full load hours: 1400 - 1850 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



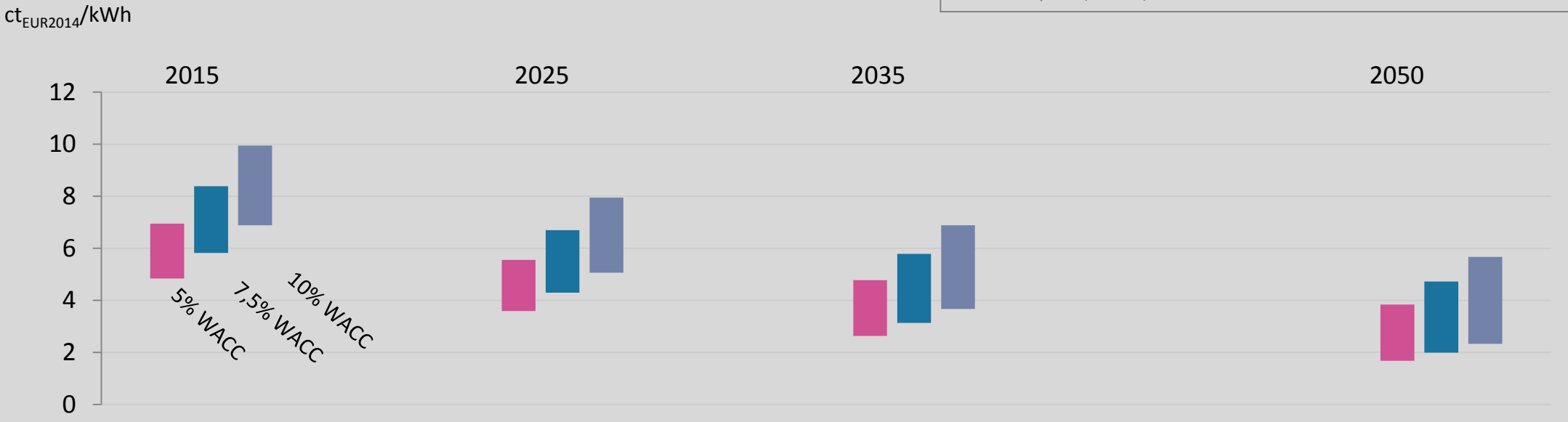
Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Turkey: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Turkey

Full load hours: 1350 - 1750 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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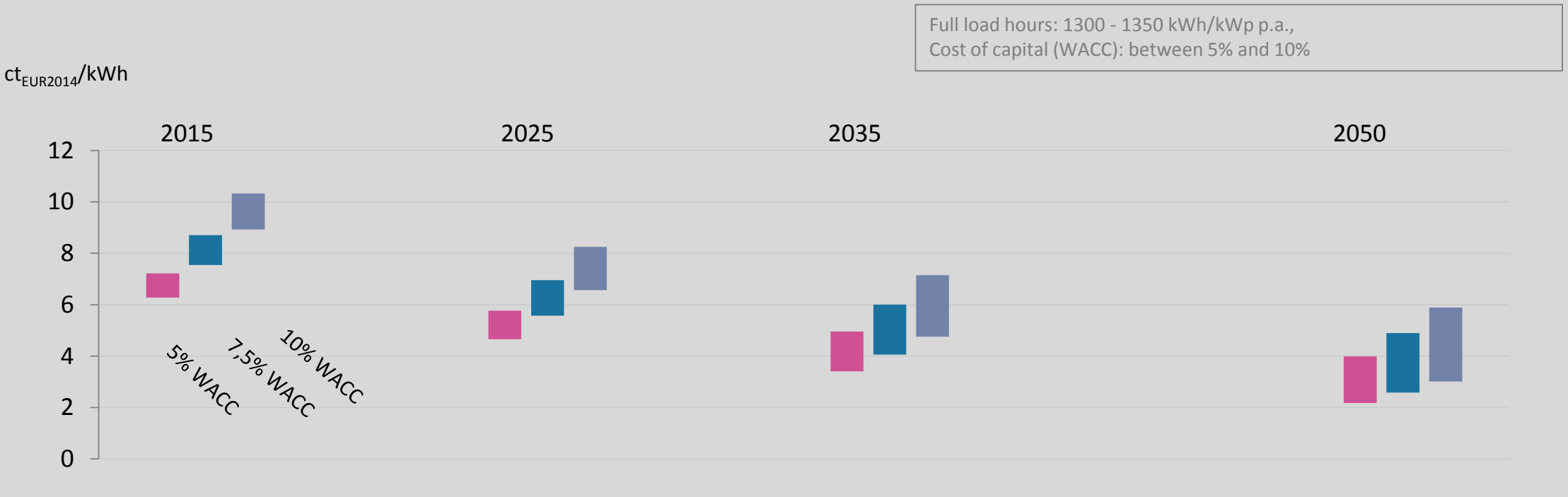
Currency: EUR

South Korea: Current and future cost of solar energy

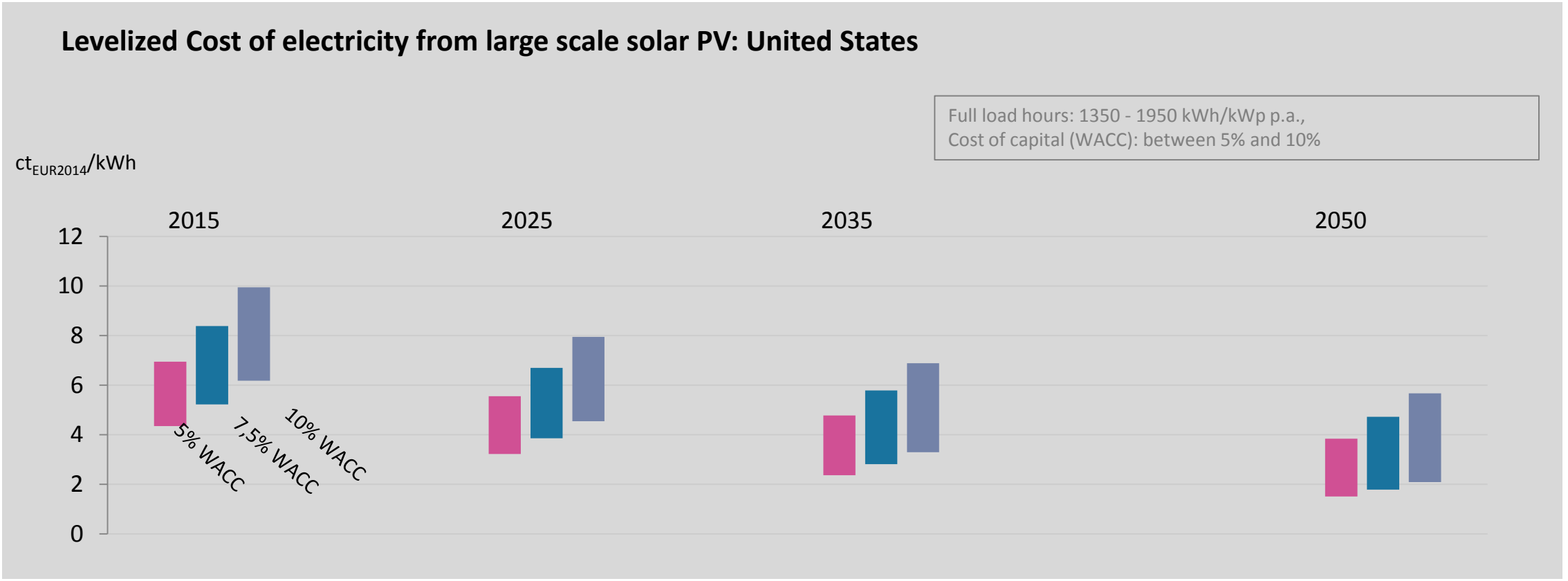
Levelized Cost of electricity from large scale solar PV: Korea, South



Exchange rates based on time of analysis (may 2014); ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

USA: Current and future cost of solar energy



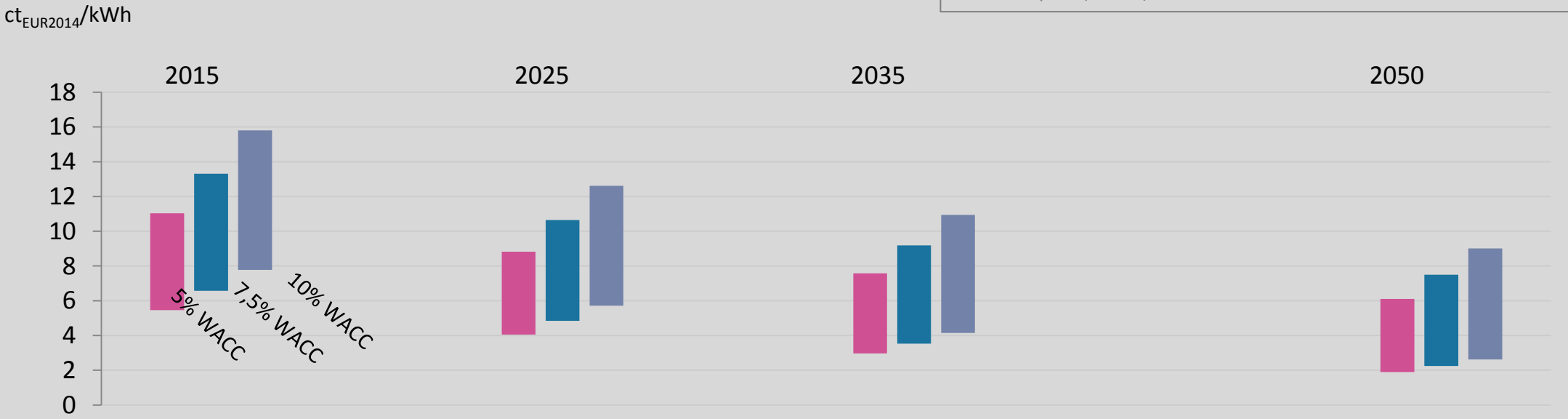
Ranges include differences in solar irradiation within the country as well as scenarios of technology and global market development; a global market for modules, inverters and other cost components is assumed, short-term effects of higher cost in new markets (e.g. first GW in a specific country) are not considered

Currency: EUR

Russia: Current and future cost of solar energy

Levelized Cost of electricity from large scale solar PV: Russia

Full load hours: 850 - 1550 kWh/kWp p.a.,
Cost of capital (WACC): between 5% and 10%



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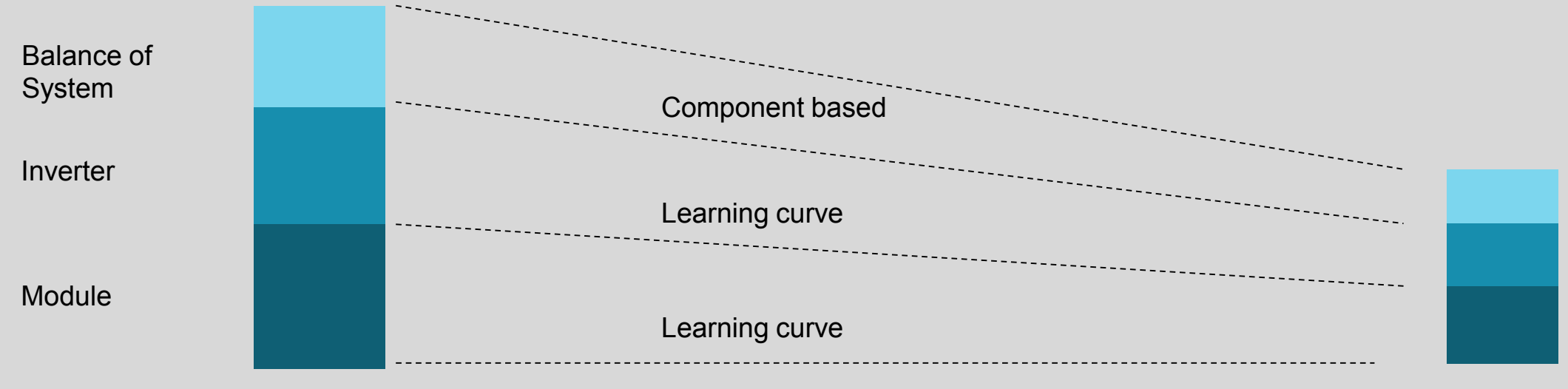
Backup – further details on analysis

Backup

Different approaches were applied to estimate future cost of components and were discussed in detail in expert workshops

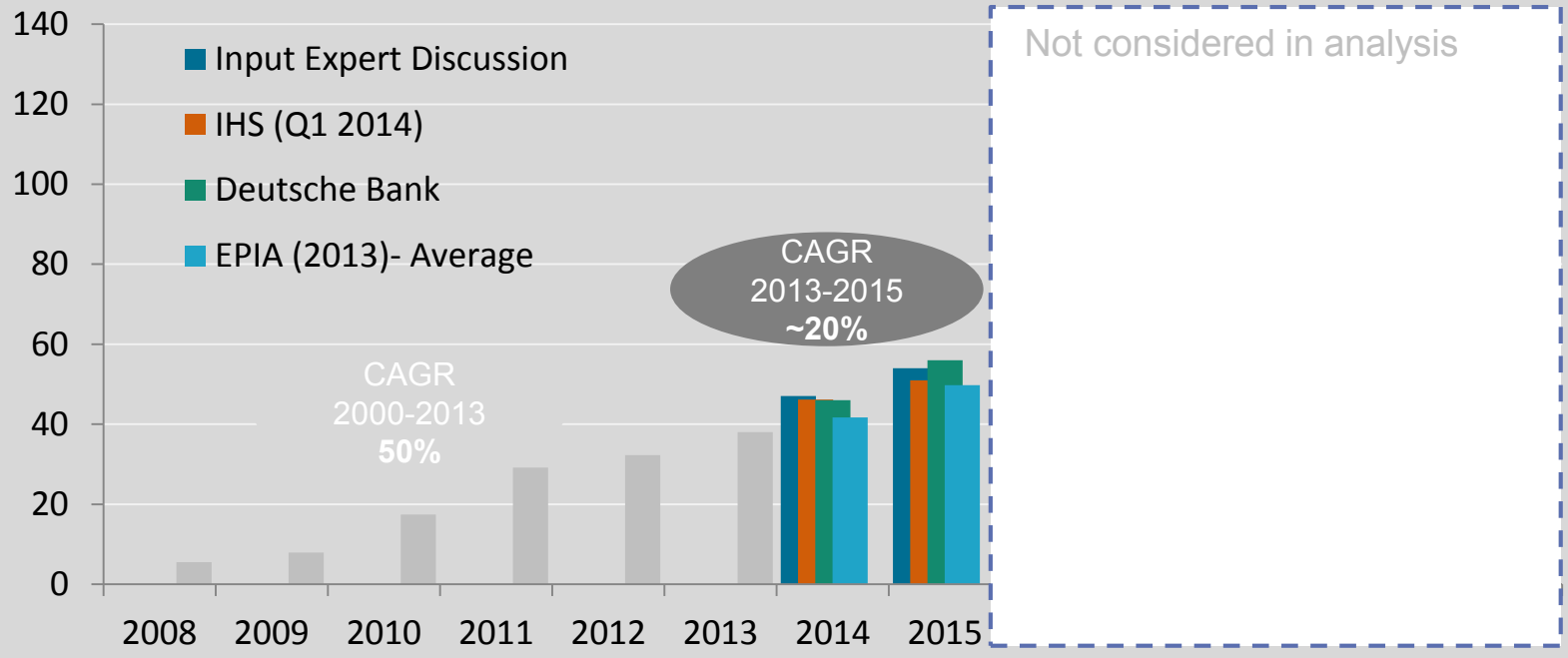
Overview of Methodology Applied to Estimate Total System Cost in 2050



Backup

Short term market estimations for 2015 are used as starting point for scenario estimations*

PV market development, GW per year

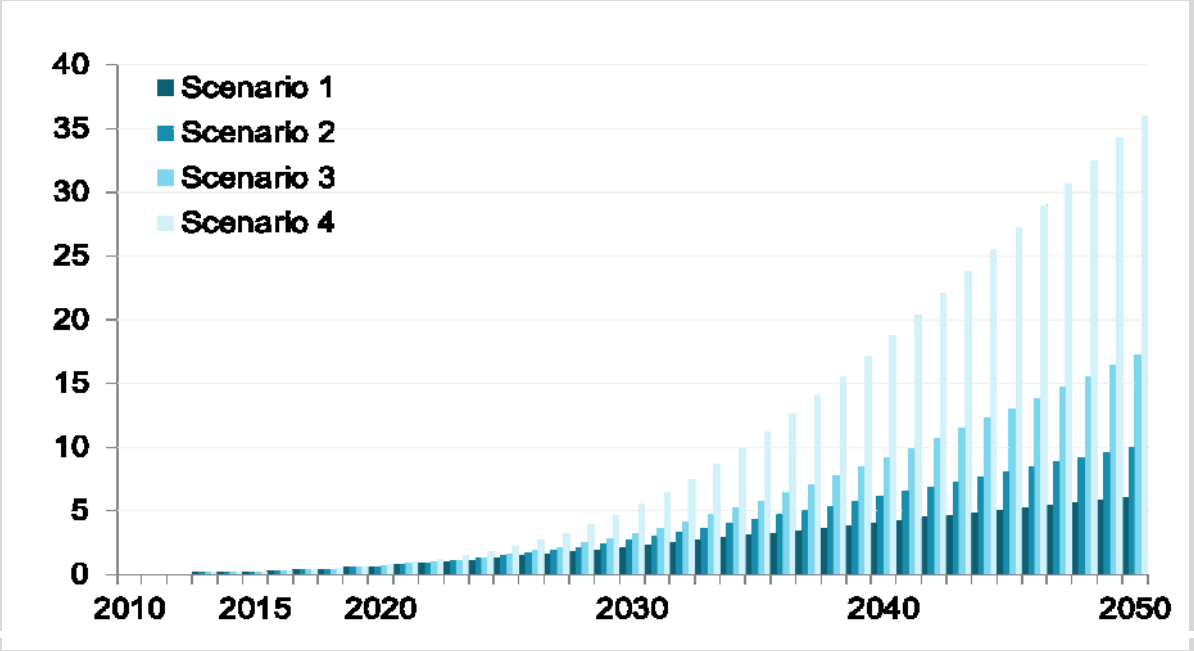


*For 2015, the average of 4 available market forecast is used
Own illustration

Backup

Number of Duplications in Cumulated Production Does not Differ Strongly Across All Scenarios

Cumulated PV production in scenarios, in TW; duplications



Number of Duplications 2013-2050

8

7

6,2

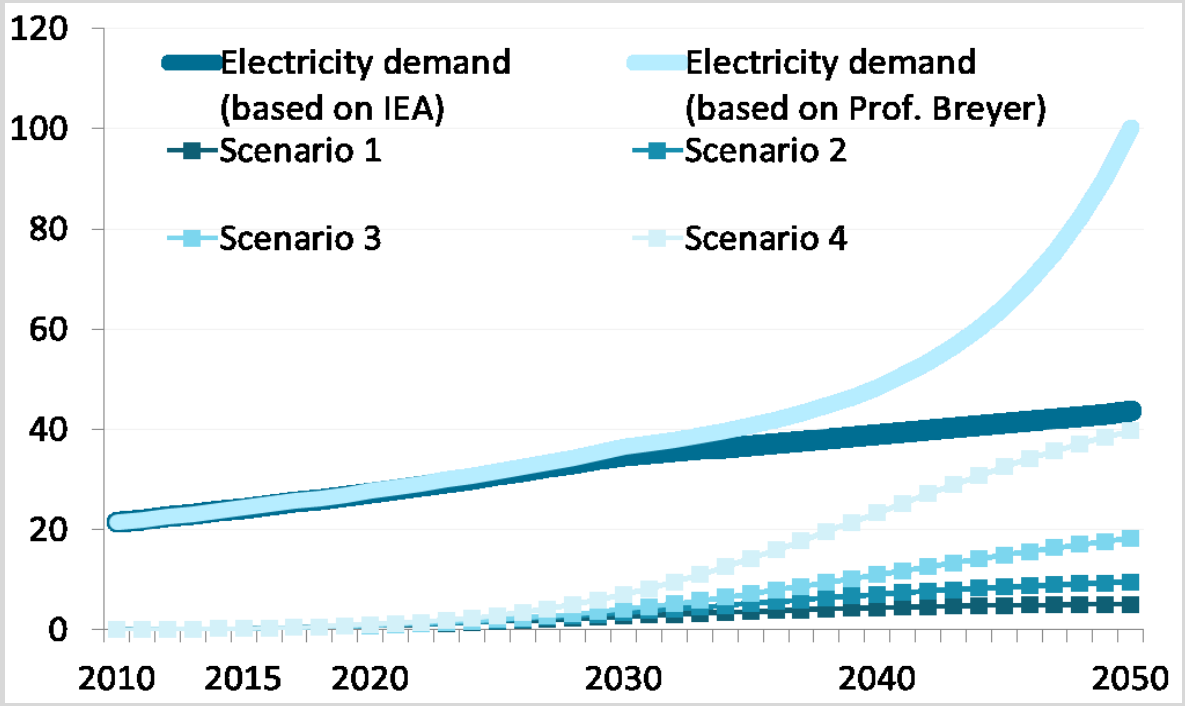
5,5

Own illustration

Backup

Crosscheck with global electricity demand: PV break-through scenario only feasible with Electricifcation

Global Electricity Demand and PV Generation, in 1000*TWh



Crosscheck of scenarios: PV share of electricity demand in 2050

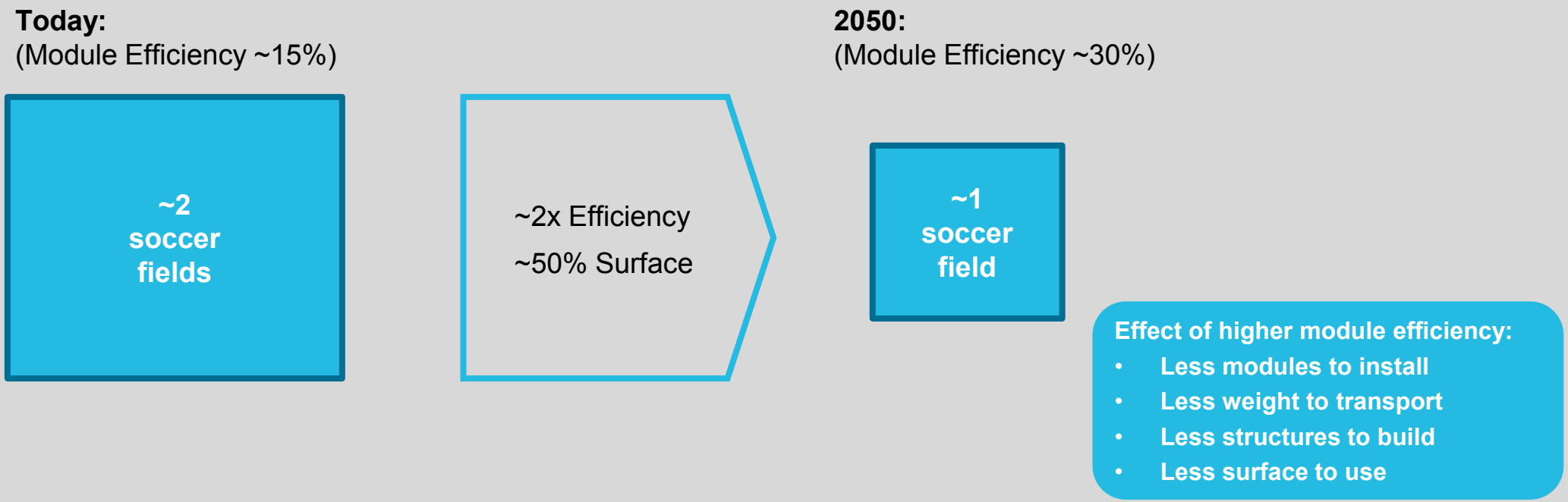
Demand based on…	IEA	Prof. Breyer
Scenario 1	91% ✗	40% ✓
Scenario 2	42% ✓	18% ✓
Scenario 3	22% ✓	10% ✓
Scenario 4	12% ✓	5% ✓

Own illustration

Backup

Increasing module efficiency will lead to cost reductions in all other parts of the power plant

Total land area needed for PV power plant with 1 MWp

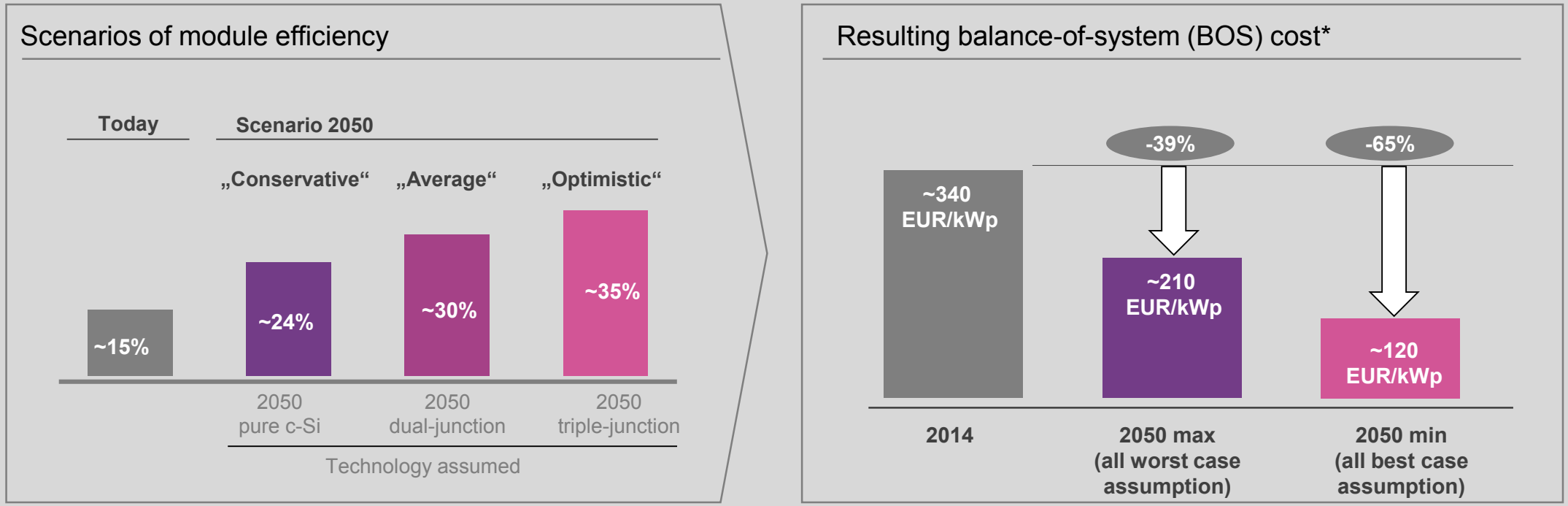


Own illustration

Backup

Future Balance-of-System cost are based on scenarios of module efficiency and further analysis

Example of methodology used



*Detailed analysis of cost drivers and impacts, including those beyond module efficiency, as well as results of expert discussions included in study
Own illustration

Backup

Inverter for large scale solar PV power plants have developed tremendously over the last decade

Example of technology development: Inverter

30 kW PV-inverter
manufactured 2004
370 kg -> 12 kg/kW

30 kW PV-inverter
manufactured 2008
155 kg -> 5 kg/kW

Possible technical progress:

- SiC power modules
- higher switching frequency →higher power density
- higher voltage levels in utility scale inverters

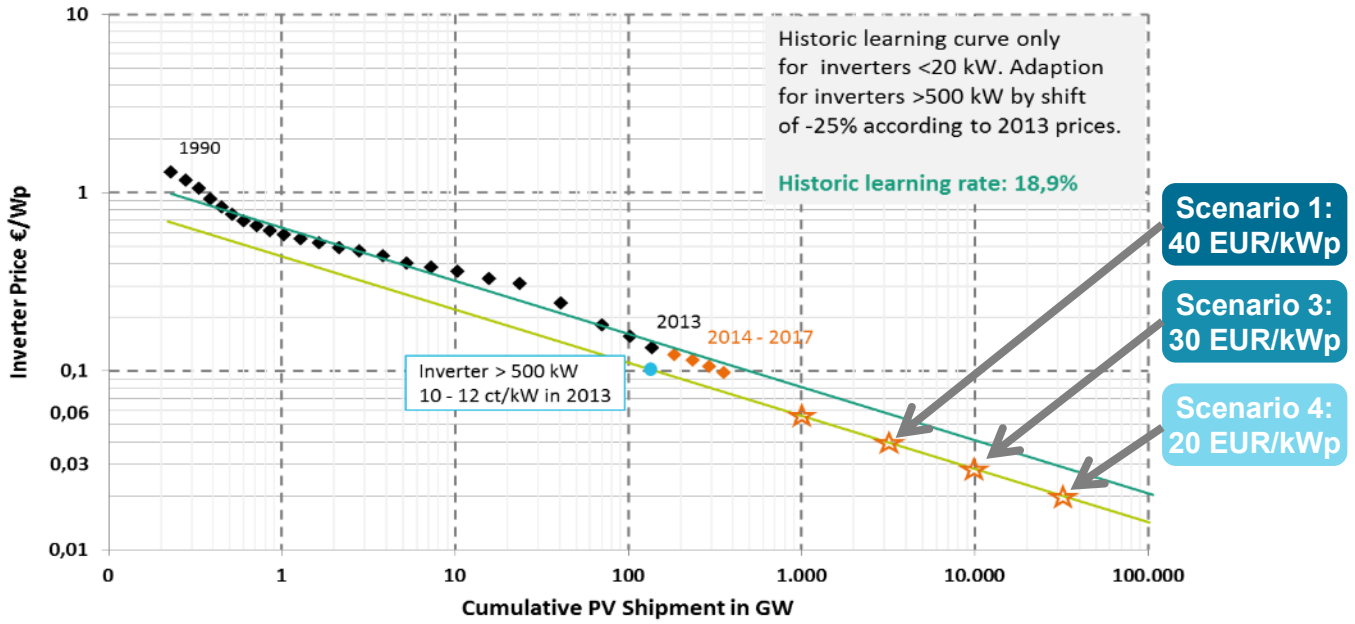
20 kW PV-inverter
manufactured 2014
40 kg -> 2 kg/kW

Own illustration, Fraunhofer ISE

Backup

Future Cost of Inverters are estimated based on the „Price Experience Curve“

Inverter Price, Cumulated Produced Capacity



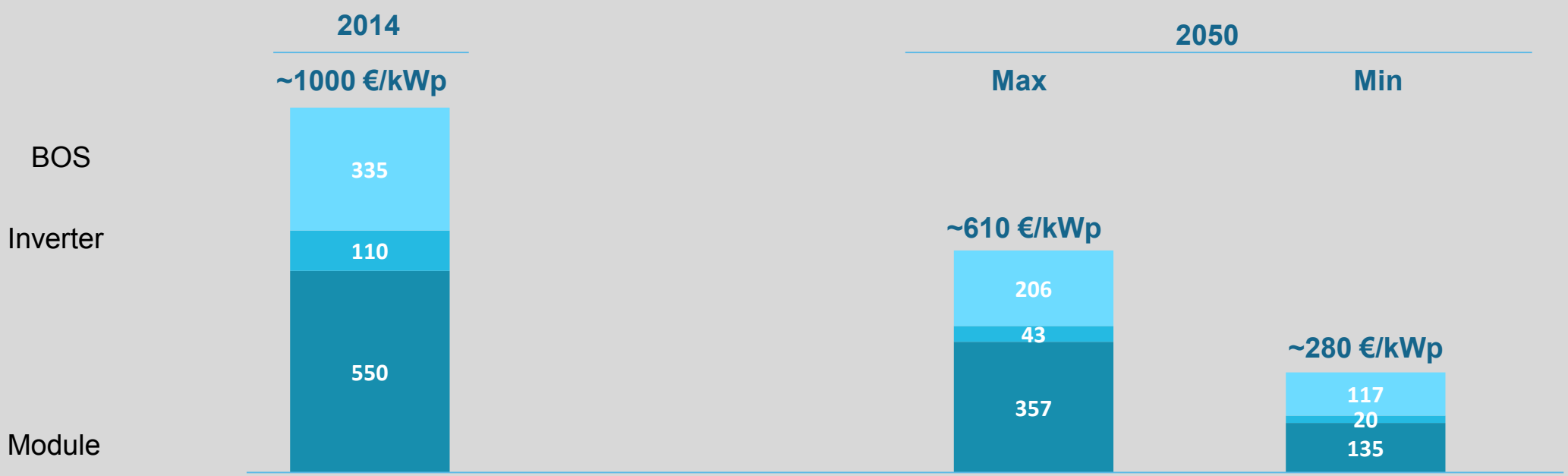
Source of historic data: SMA

Own illustration, Fraunhofer ISE

Backup

Resulting total cost of ground mounted PV systems in 2050 ranges between 280 and 610 EUR/kWp – assuming no technology breakthroughs (conservative estimate)

Cost of PV System, in EUR/kWp



Own illustration