Photovoltaics

Introduction

This course

- Solar **resource**
- **Physics** of solar cells
- PV **technologies**
- PV systems
  - **Grid** connected
  - **Stand alone** systems
  - **Building** integrated systems
  - **Vehicle** integrated systems
  - **Floatvoltaics**
  - **Agriphotovoltaics**
  - **Concentrated** solar power

This course

This course - grading

- **Test**: 50%
- **Lab work**: 15%
- **Home work**: System design (15%)
- **Presentation**: Advanced topics (20%)

and/or

- **Final exam**: everything (100%)

Today

- (Summary of this course)
- Brief history of photovoltaics
- PV global market
- PV in Portugal

Brief history of photovoltaics

1839: Edmund Becquerel, a French experimental physicist, discovered the photovoltaic effect.

1873: Willoughby Smith discovered the photoconductivity of selenium.

1876: Adams and Day observed the photovoltaic effect in solid selenium.

1883: Charles Fritts, an American inventor, described the first solar cells made from selenium wafers.

1904: Einstein published his paper on the photoelectric effect.

1916: Millikan provided experimental proof of the photoelectric effect.

1951: A grown p-n junction enabled the production of a single-crystal cell of germanium.

1954: Bell Labs researchers Pearson, Chapin, and Fuller reported their discovery of 4.5% efficient silicon solar cells.

Brief history of photovoltaics

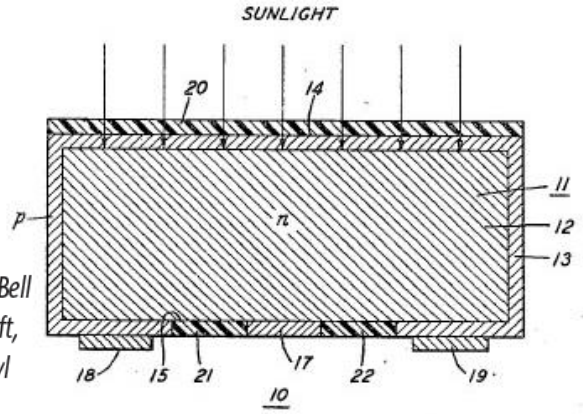
The inventors of the Bell Solar Battery, from left, Gerald Pearson, Daryl Chapin, and Calvin Fuller, check devices for the amount of solar electricity derived from sunlight, here simulated by a lamp.

Feb. 5, 1957 D. M. CHAPIN ET AL 2,780,765

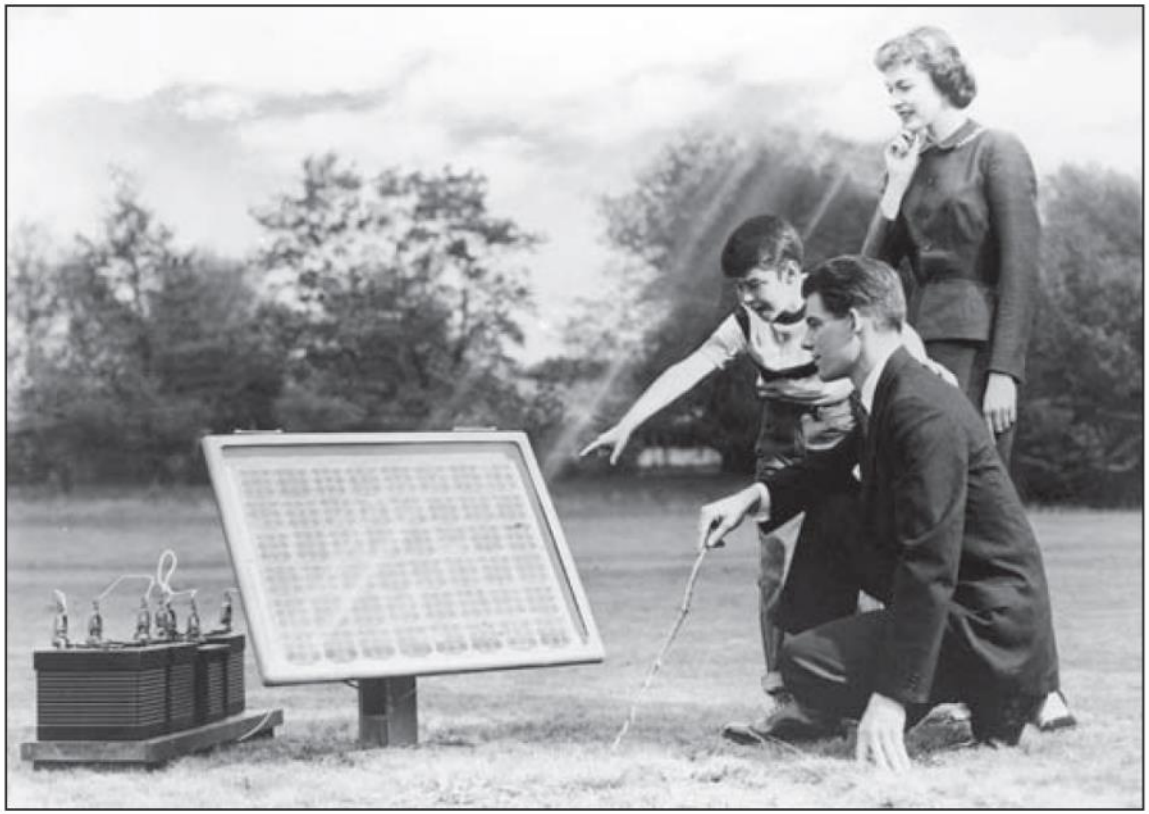
SOLAR ENERGY CONVERTING APPARATUS

Filed March 5, 1954

FIG. 1

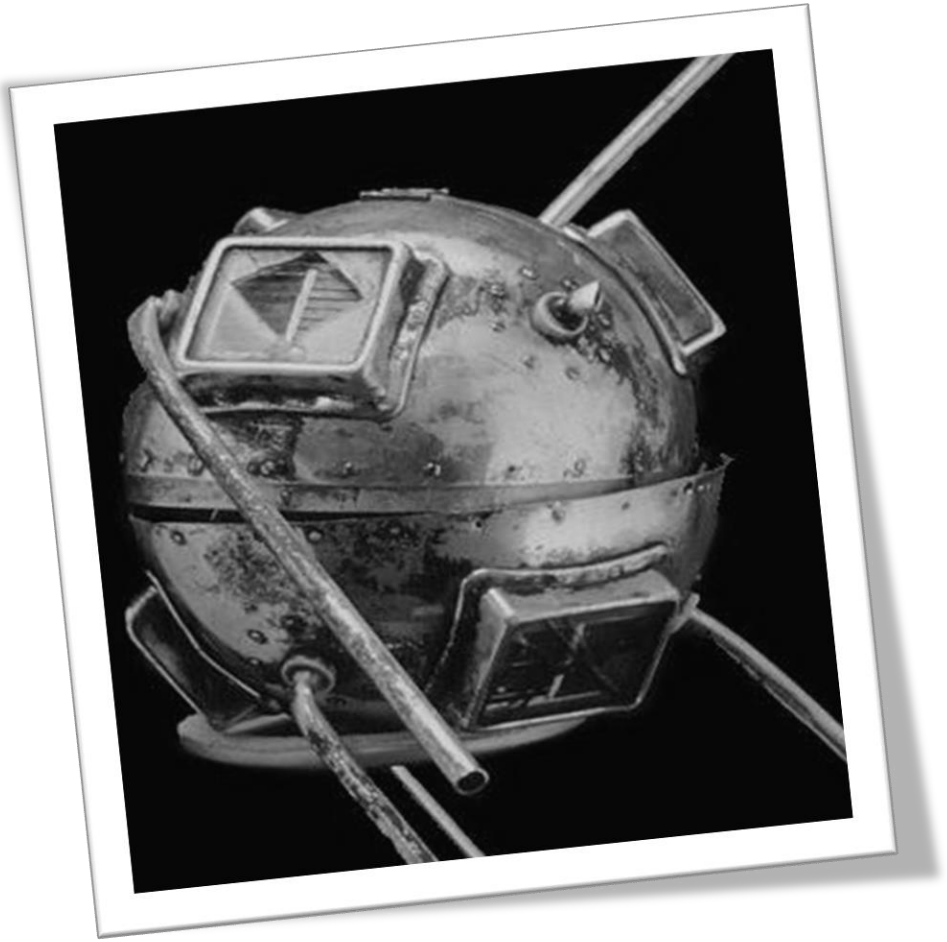


Brief history of photovoltaics

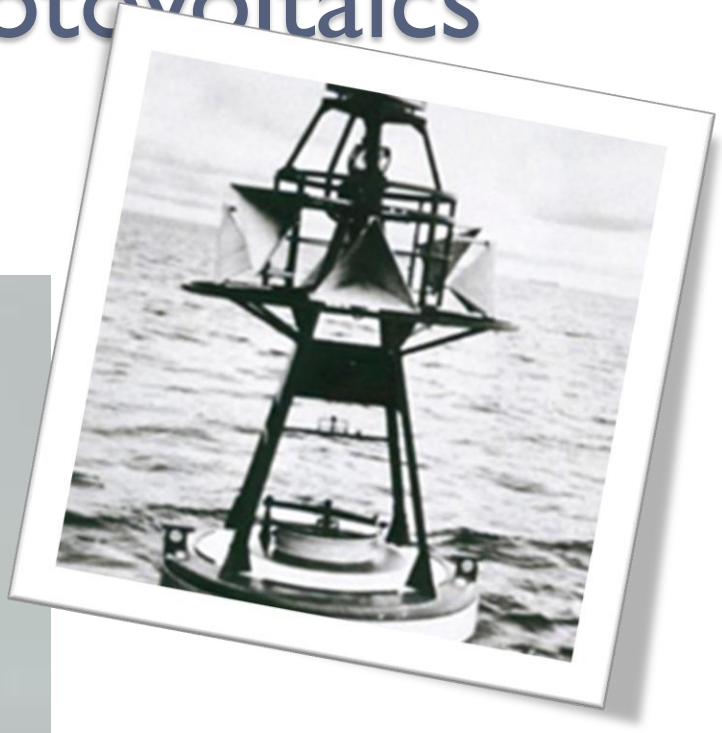


Advertisement photos, such as this one that appeared in the 1956 issue of Look Magazine, show off the "Bell Solar Battery" to the American public.

Brief history of photovoltaics



Brief history of photovoltaics

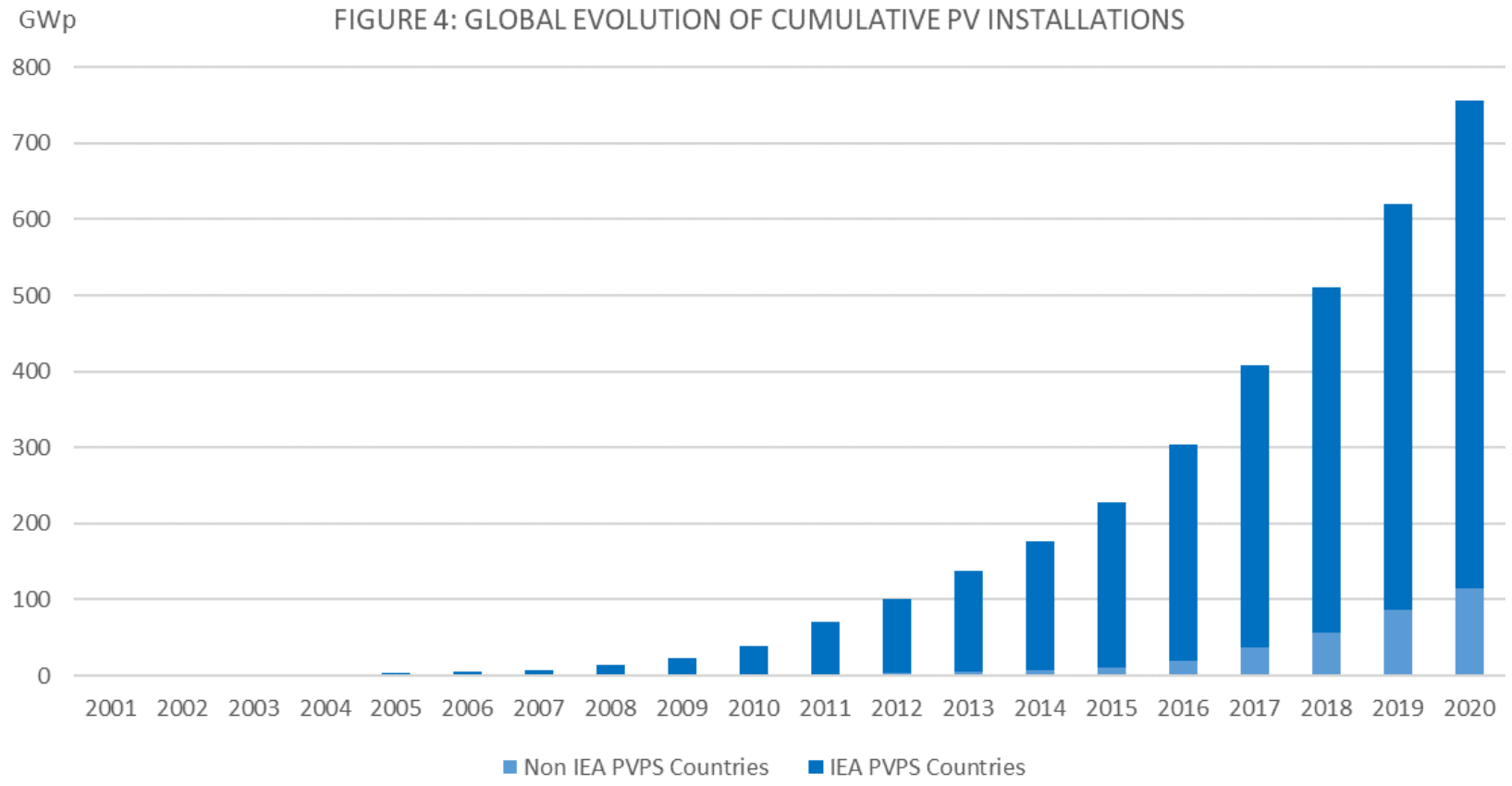



HELVETIA
SOLARIMPULSE
OMEGA


TÛRANOR PlanetSolar

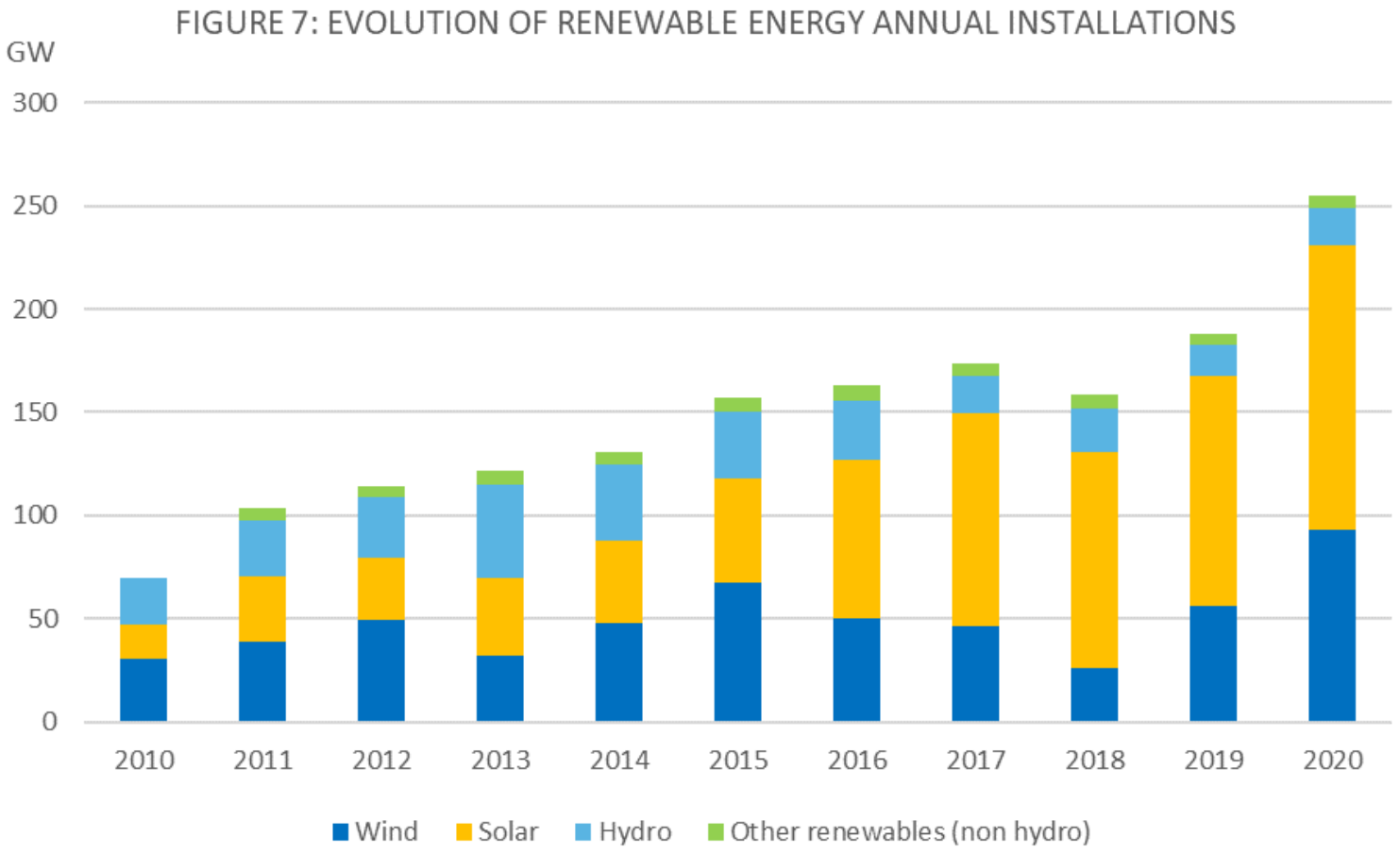

TAFE
ENGINEERING
UNSW
TAFE

PV fast development



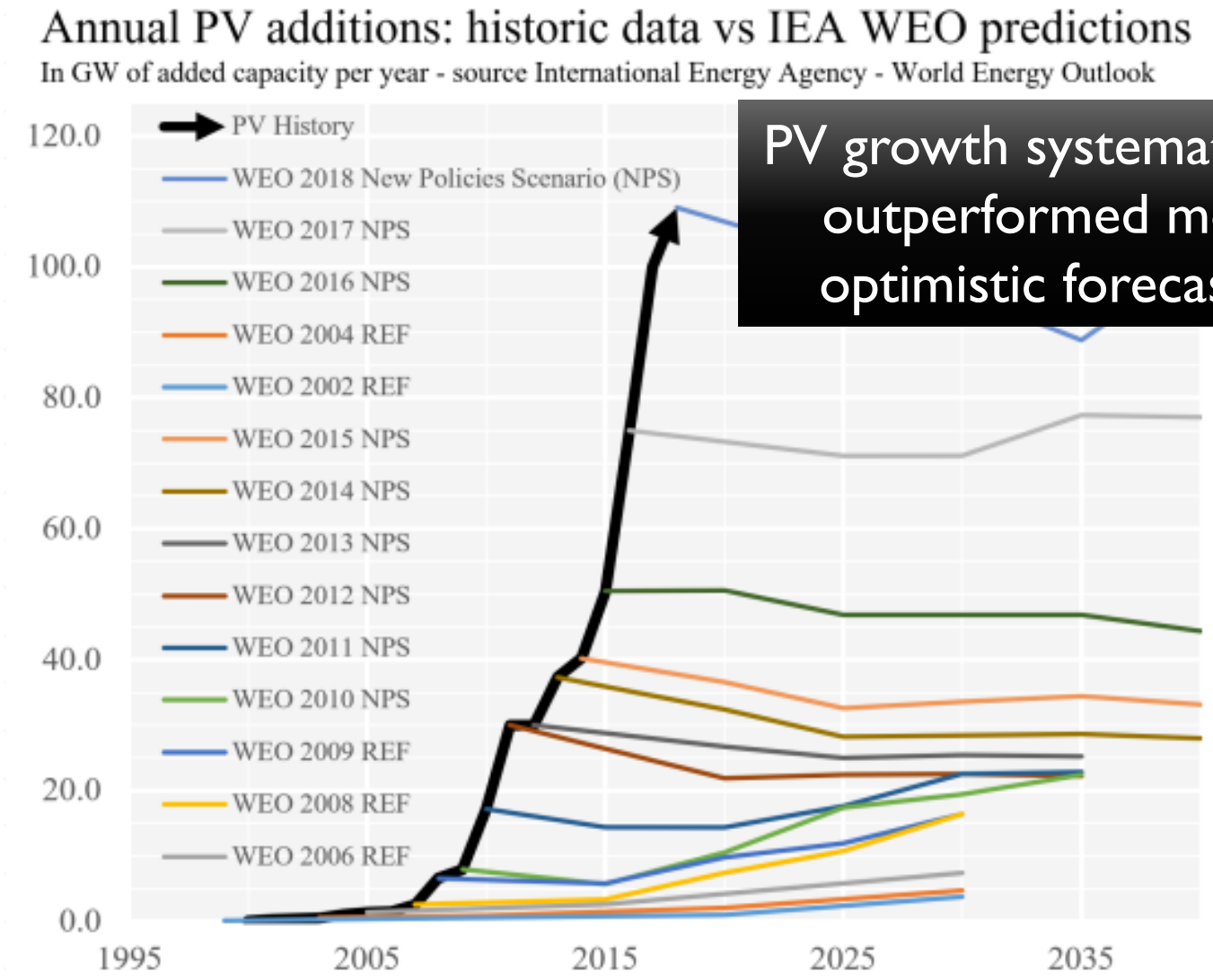
PV installed capacity growing exponentially

PV fast development



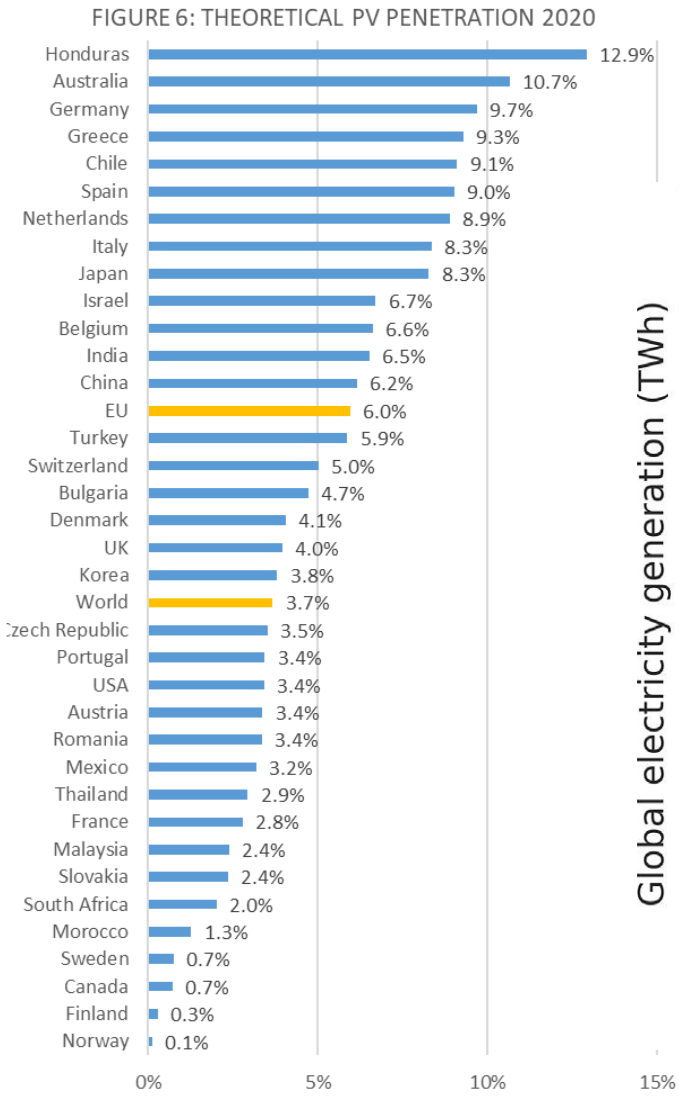
PV is the fastest growing power source worldwide

PV fast development

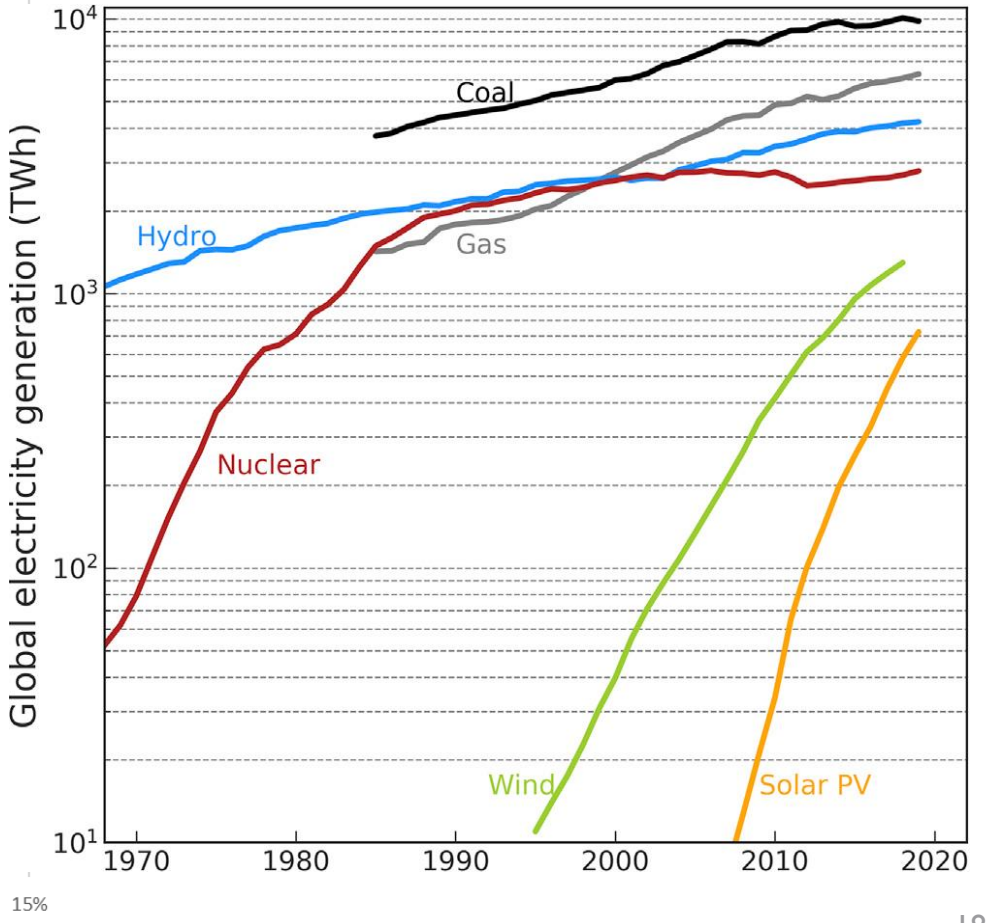


PV growth systematically outperformed most optimistic forecasts!

PV fast development



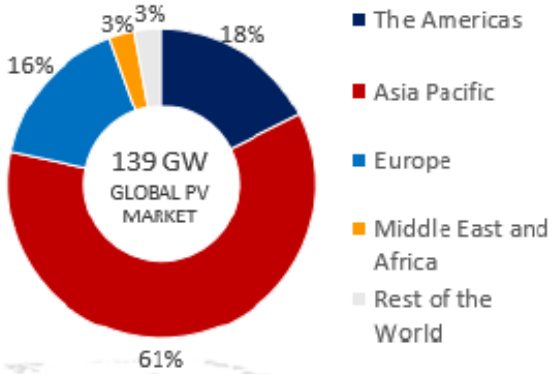
Despite growing installed capacity
PV is only about 3% total demand

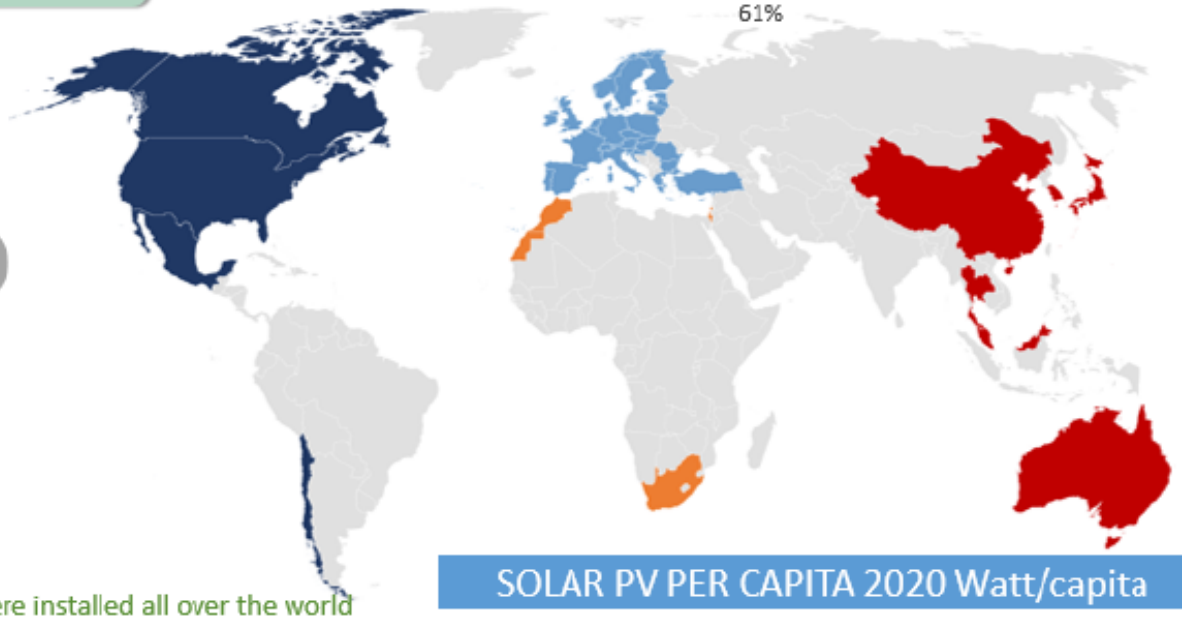


PV fast development

TOP PV MARKETS 2020

CHINA	48,2 GW
EU	19,6 GW
USA	19,2 GW





CO_2eq

877 Mt CO_2 emissions avoided in 2020

- **760,4 GW** were installed all over the world by the end of 2020
- **China** is the world's **#1** PV market
- **20** countries installed at least **1 GW** of PV in 2020
- **14** countries have installed at least **10 GW** of cumulative capacity at the end of 2020

SOLAR PV PER CAPITA 2020 Watt/capita

1st	AUSTRALIA	795
2nd	GERMANY	649
3rd	JAPAN	565

Cost of photovoltaics

Cost and **price** are very different, often not even correlated!

There are 3 traditional measures of PV cost:

- Cost per Watt-peak installed
- Levelized cost of electricity
- Grid parity

Cost of photovoltaics

Cost per Watt-peak

Units: **€/W**

Simple and objective to determine, usually refers to module cost (Spot market? Factory gate? End user?) and thus it does not represent full installation system cost.

It is not comparable to other (renewable or fossil) energy sources due to the different capacity factor.

Comparing different PV technologies not trivial.

Cost of photovoltaics

Levelized cost of electricity (LCoE)

Units: **€/kWh**

The cost that really matters!

But depends on location (insolation), financial costs (discount rate, subsidies,…) and assumptions on lifetime (25 or 40 years?) or O&M costs (10 or 30$/kW/year)

Cost of photovoltaics

Grid parity

Electricity prices will increase

PV costs will decrease

… PV **WILL BE** COST COMPETITIVE.

Wholesale or end-user electricity price?

Socket parity – defined as the point where a household can make 5% or more return on investment in a PV system just by using the energy generated to replace household energy consumption.

Cost of photovoltaics

Grid parity

Electricity prices will increase

PV costs will decrease

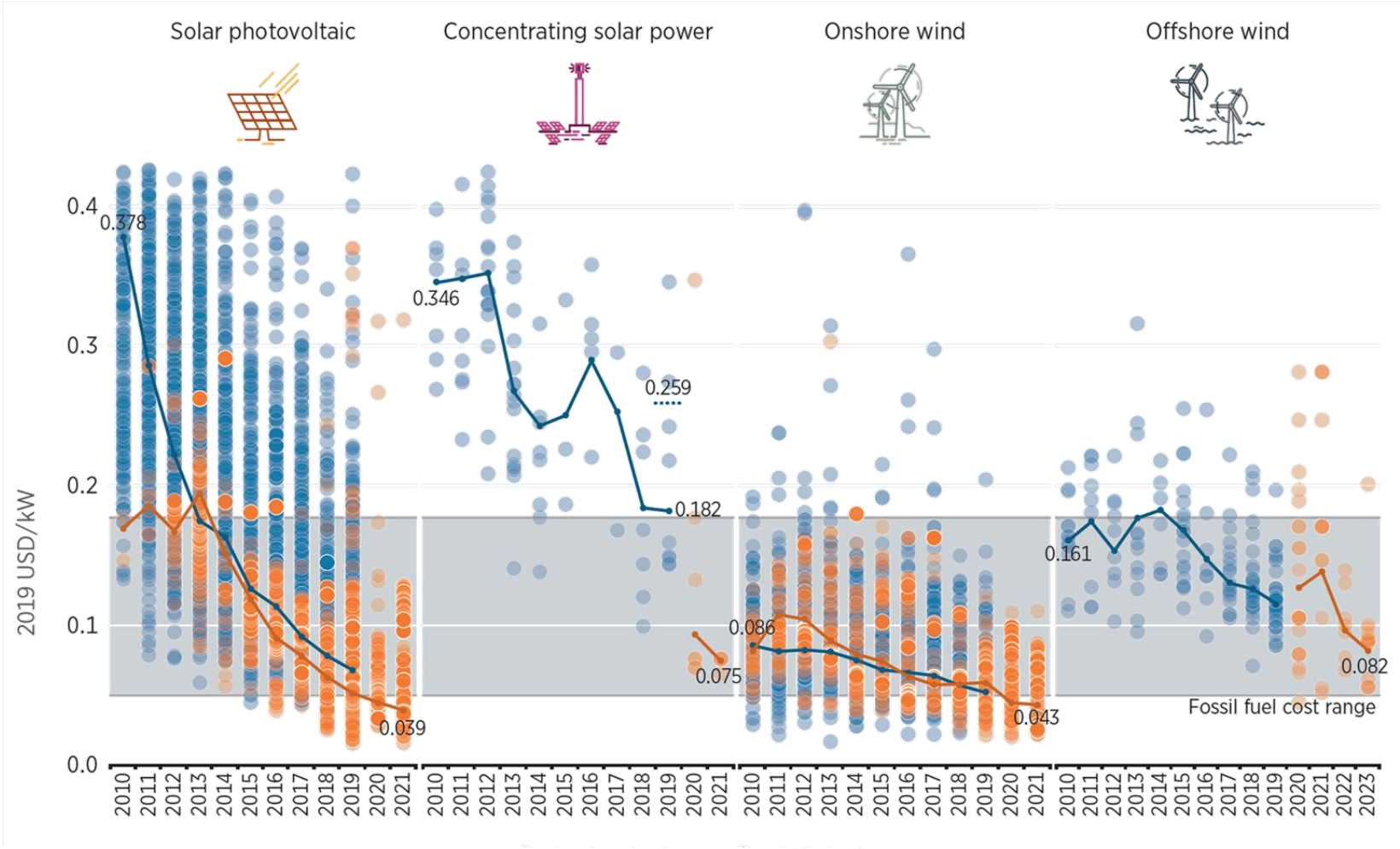
… PV **WILL BE** COST COMPETITIVE.

When?

Where?

At what time of the day/year?

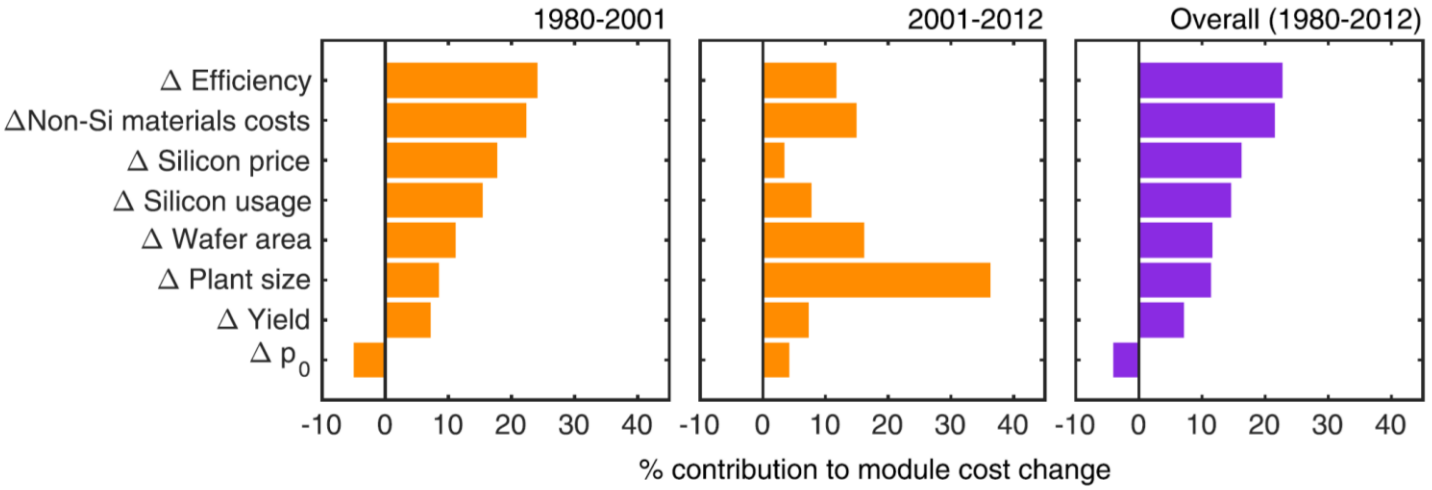
Cost of photovoltaics

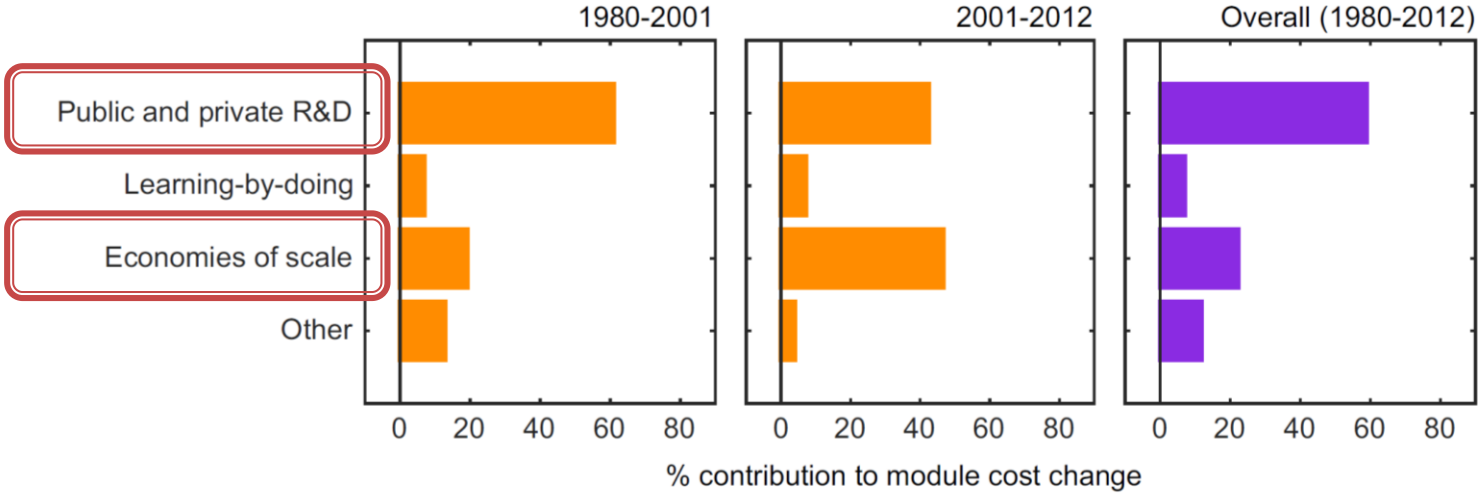


10 times cheaper in the last 10 years!!

IRENA (2020), Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi.

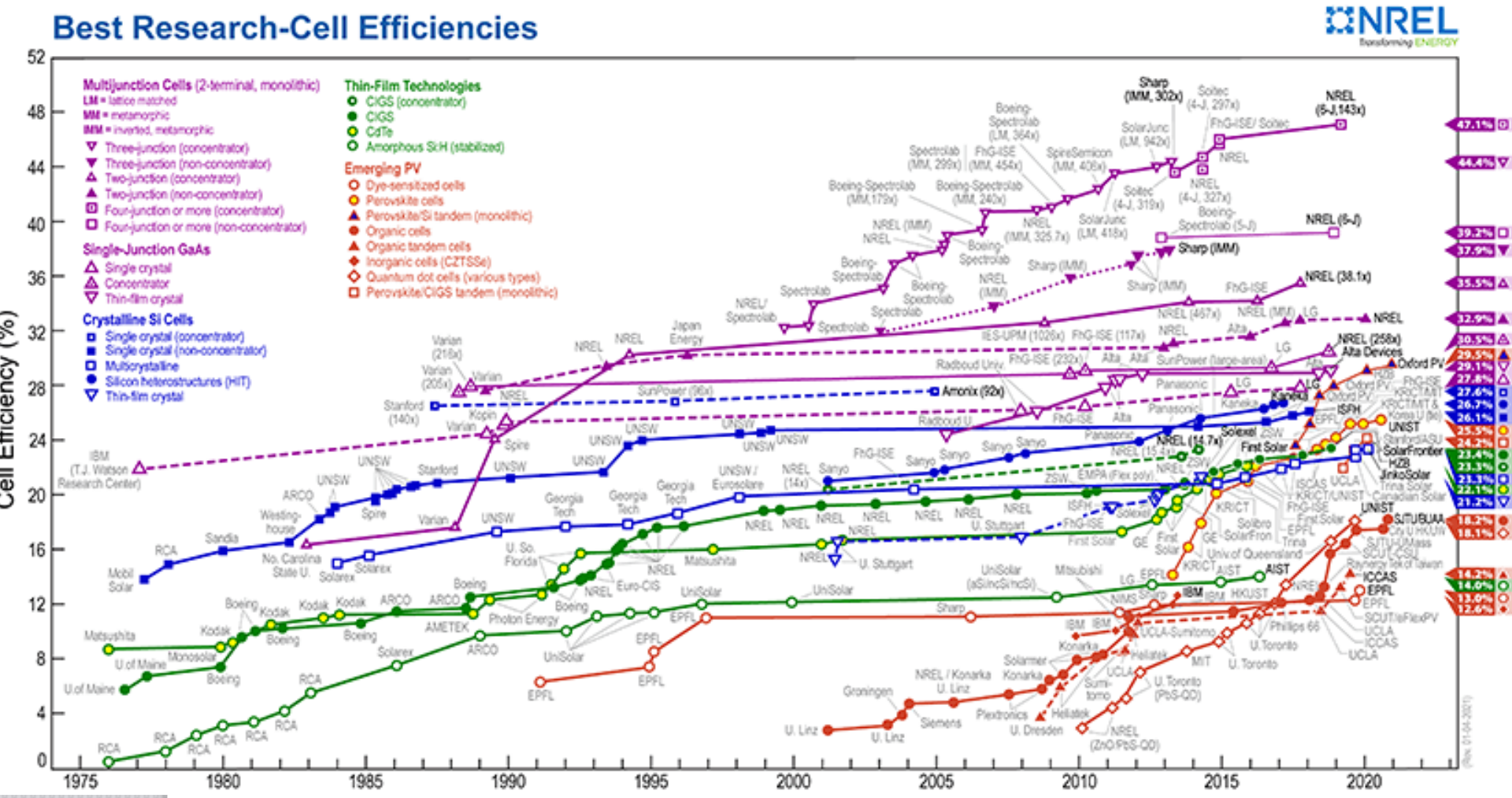
Drivers for cost reduction



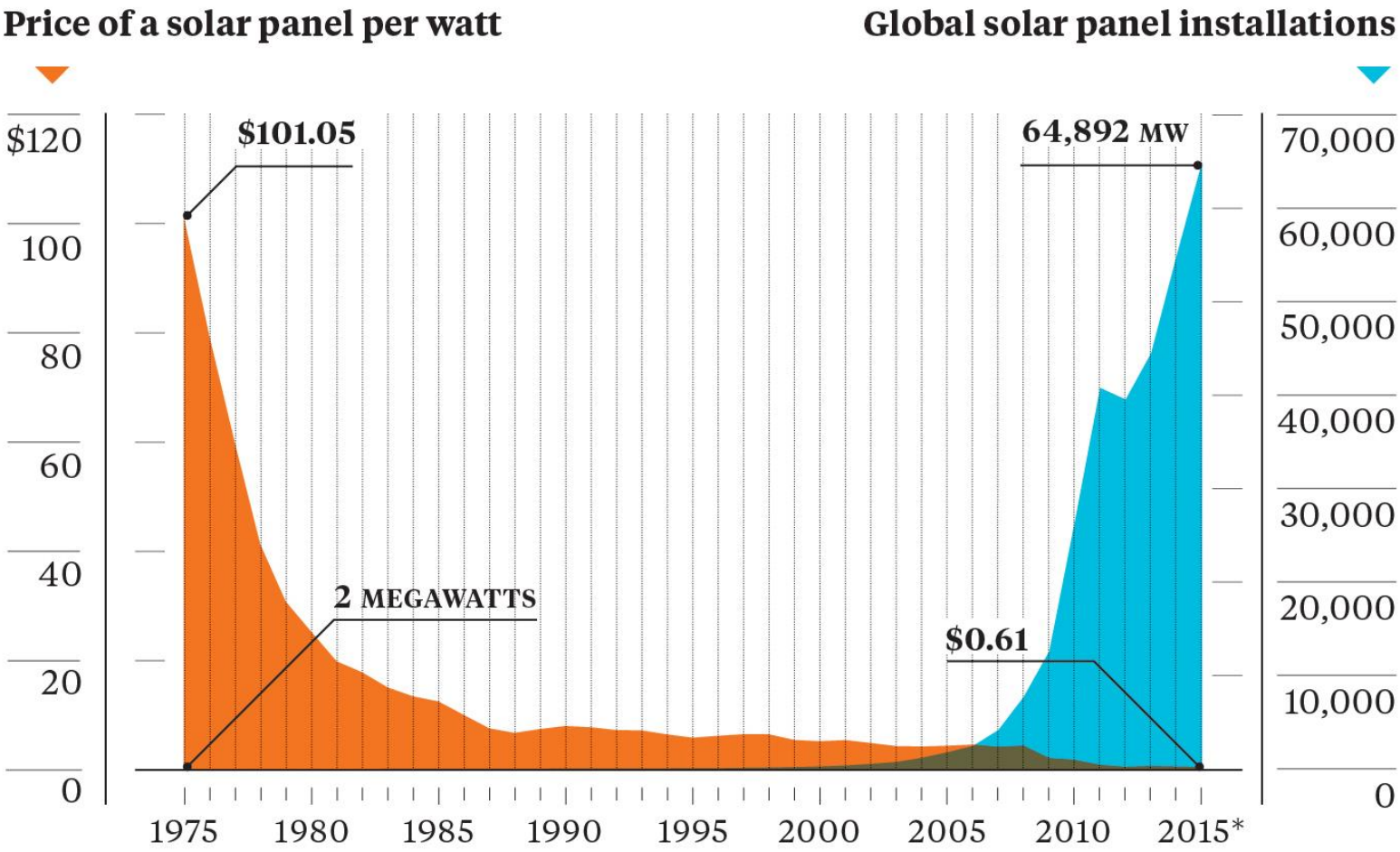


Energy Policy 123 (2018) 700–710; 707

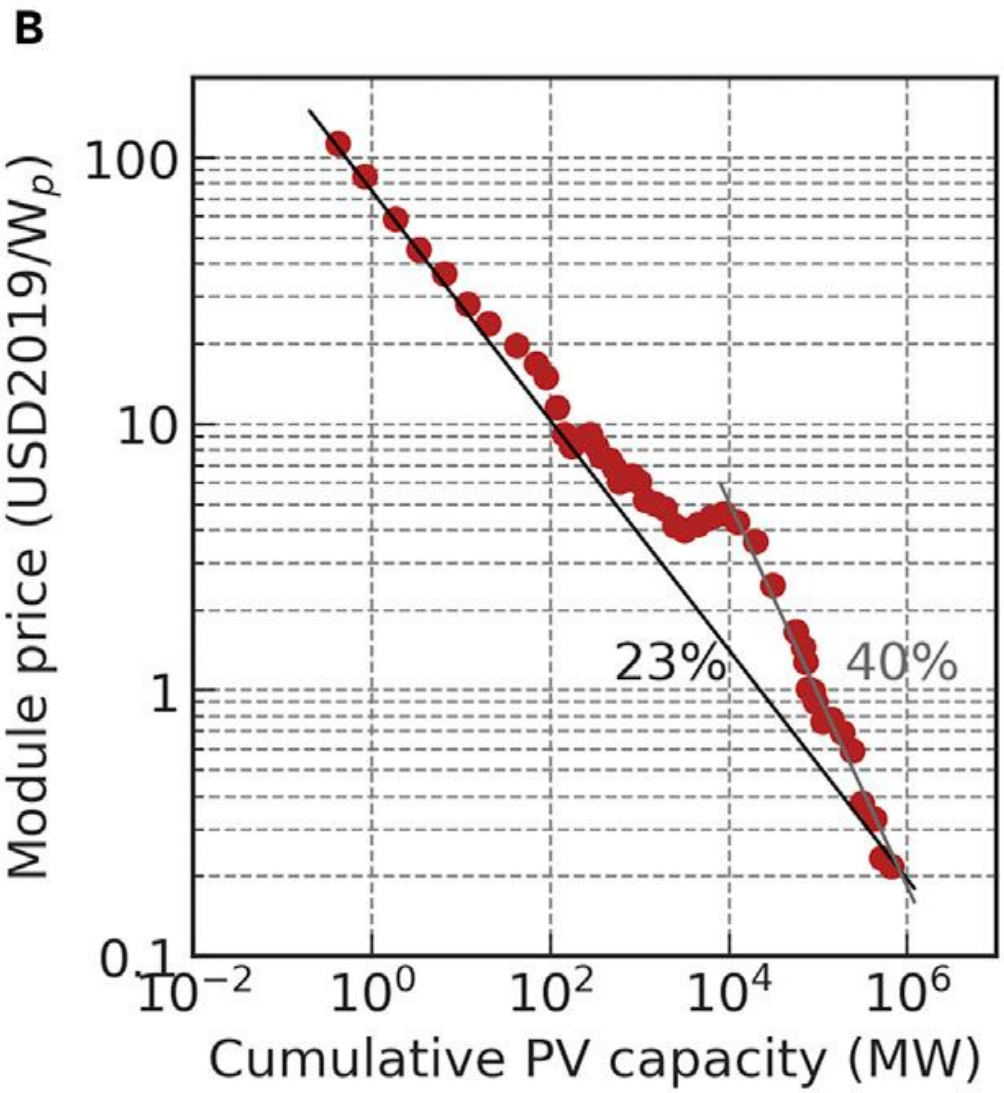
Drivers: technology



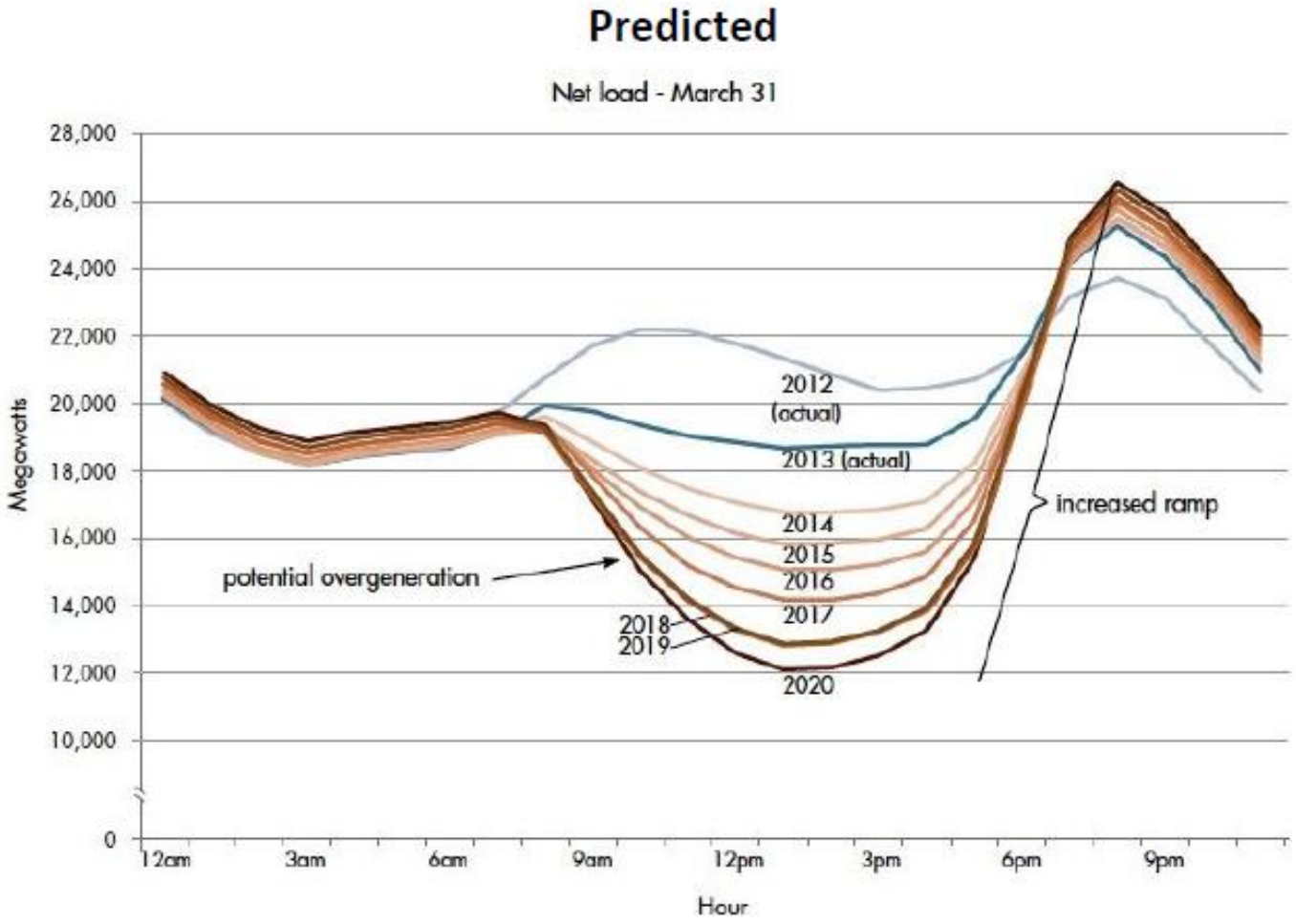
Drivers: economies of scale



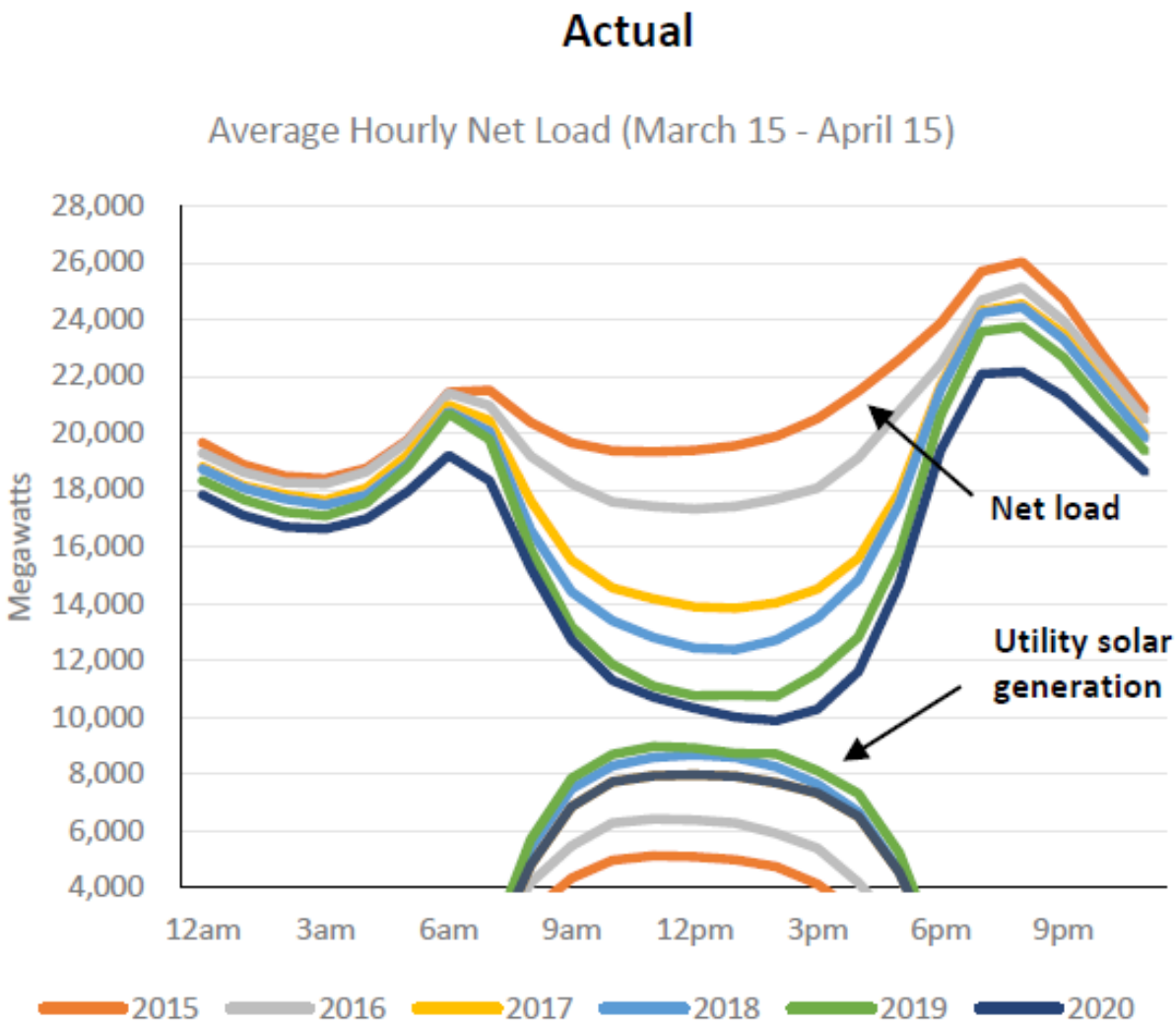
Drivers: economies of scale



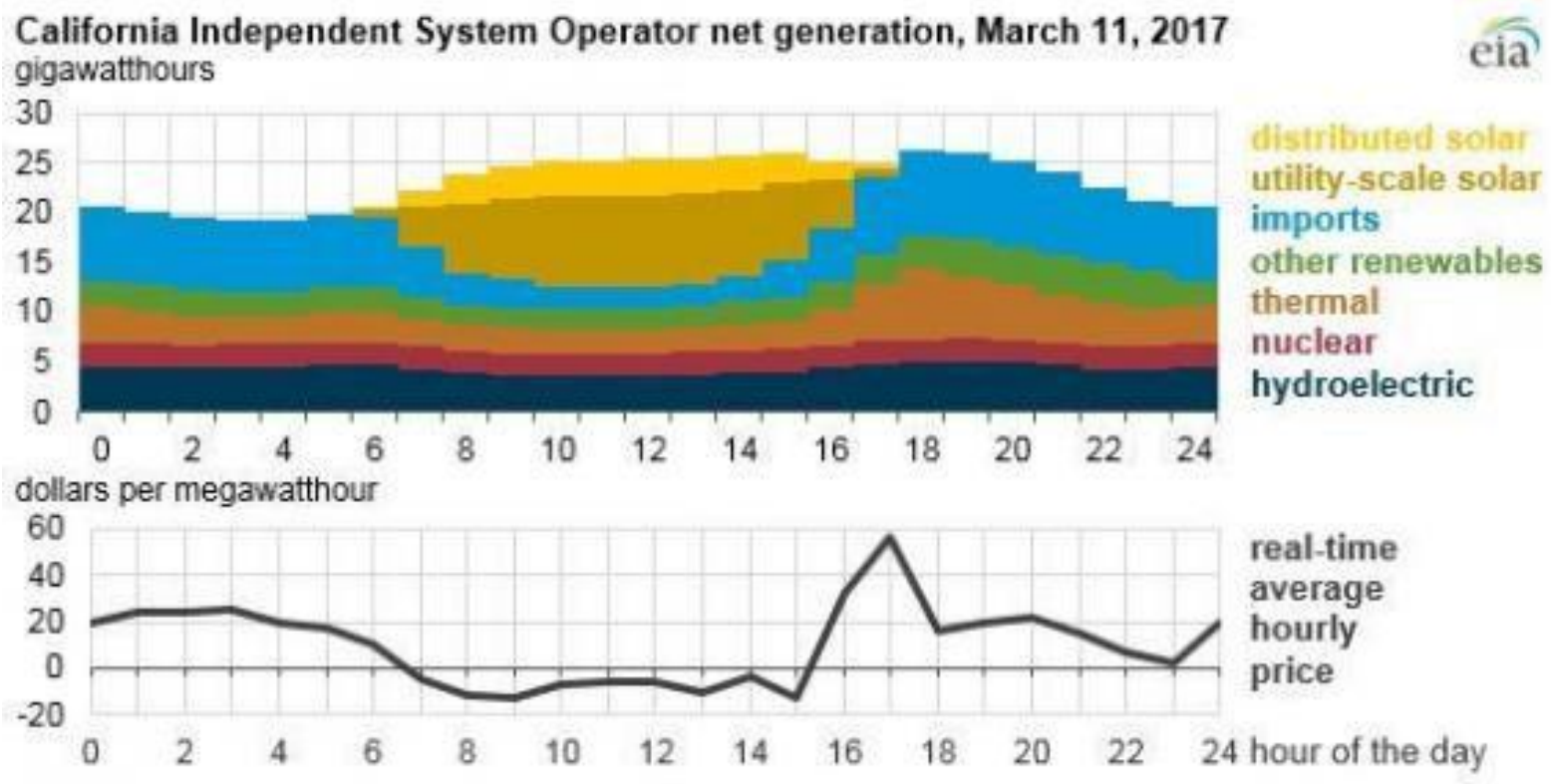
Impacts of lots of PV



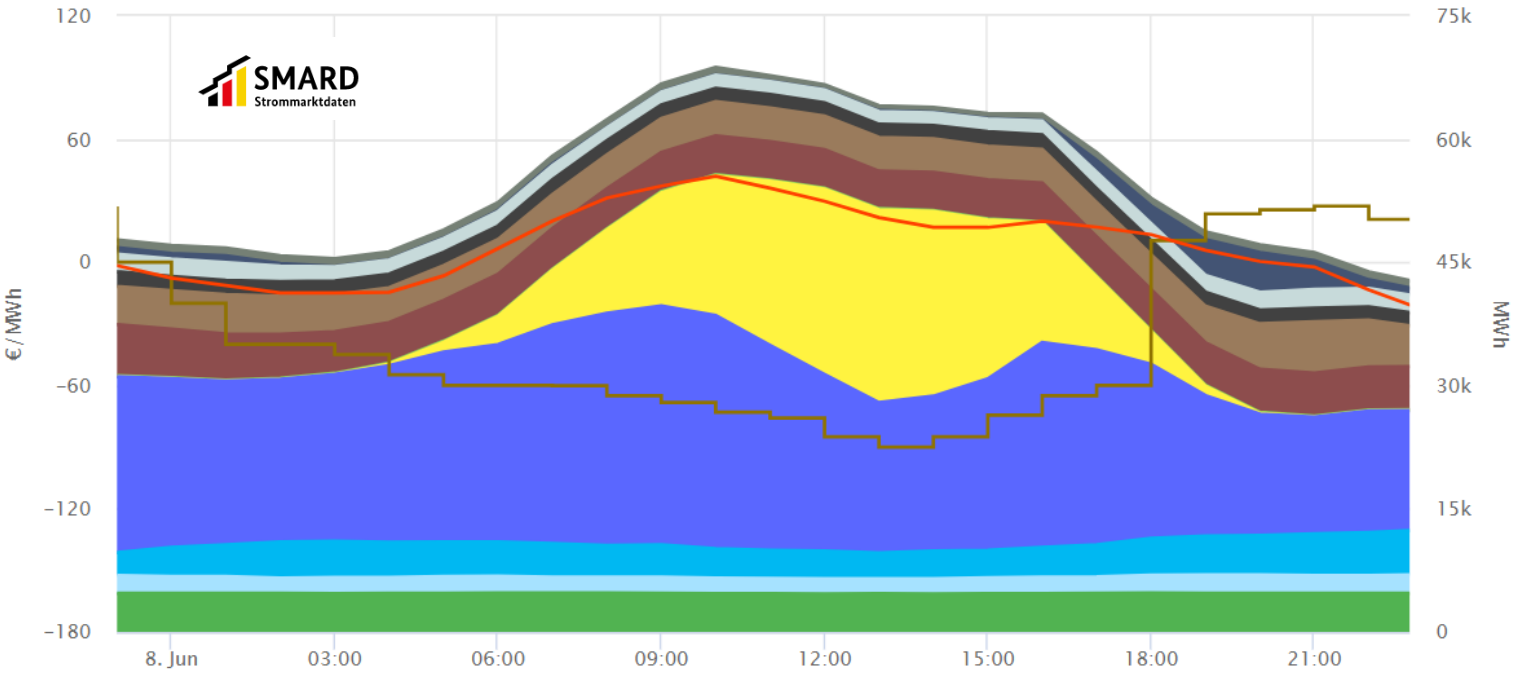
Impacts of lots of PV



Impacts of lots of PV



Impacts of lots of PV



Electricity generation - Actual generation

Biomass
Hydropower
Wind offshore
Wind onshore
Photovoltaics
Other renewable
Nuclear
Fossil brown coal
Fossil hard coal
Fossil gas
Hydro pumped storage
Other conventional

Impacts of lots of PV

Solar meets 100 per cent of South Australia demand for first time

Giles Parkinson 12 October 2020 46

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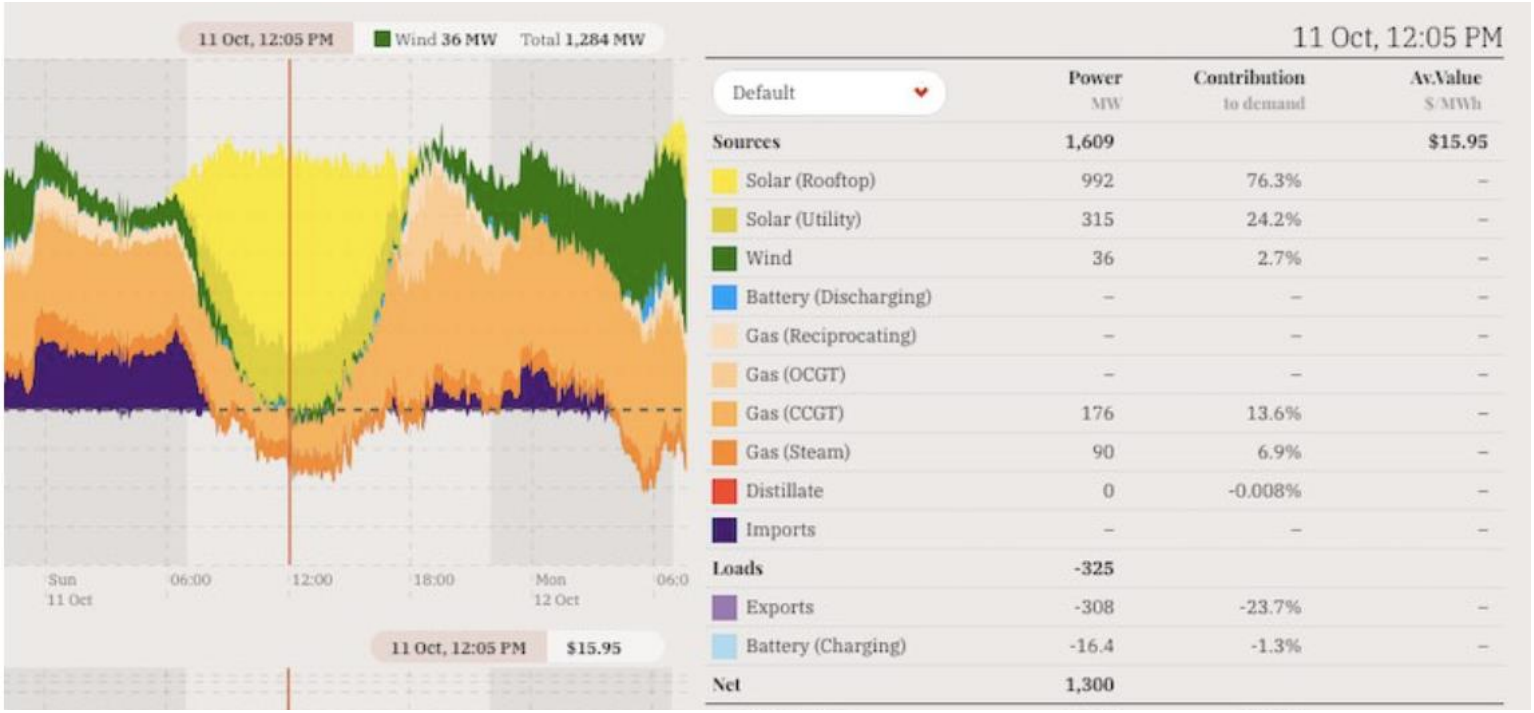


Brief history (2): markets

1990's – Japan

- Subsidies to installation

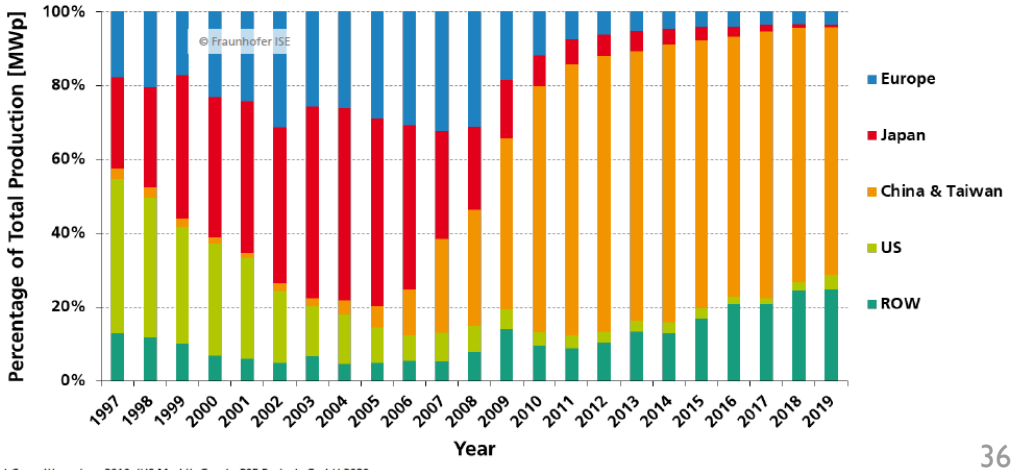
2000's – Germany (and the rest of EU)

- Feedin tariff

2010's – China

- Industrial support

PV Module Production by Region 1997-2019
Percentage of Total MWp Produced



Data: Up to 2009: Navigant Consulting; since 2010: IHS Markit. Graph: PSE Projects GmbH 2020

Brief history (2): markets

1990's – Japan

Subsidies to installation

2000's – Germany (and the rest of EU)

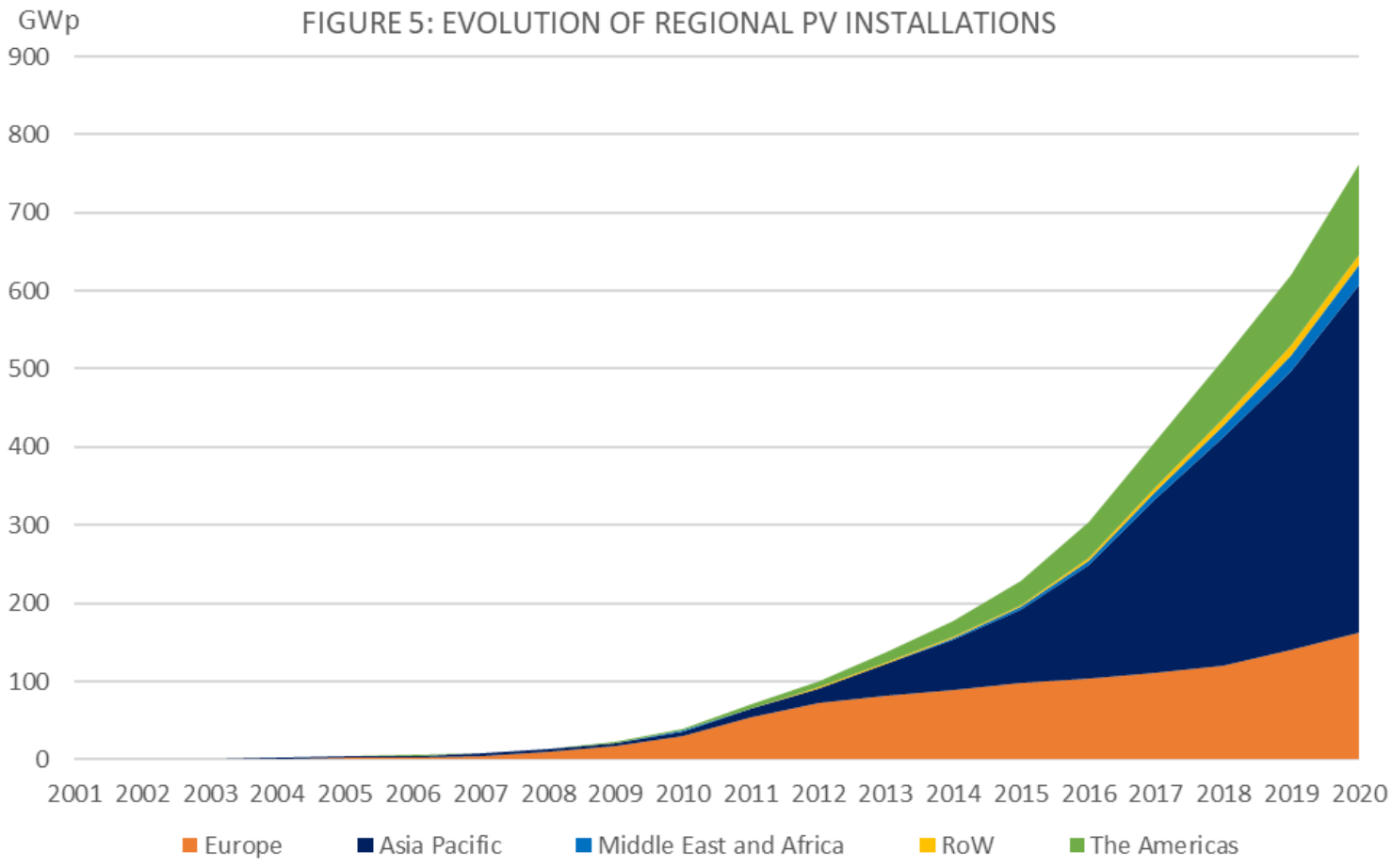
Feedin tariff

2010's – China

Industrial support

- Very large industrial scale
- Local supply chain
- Adoption of green standards
- High quality products (strong innovation)
- Largest world market

China is largest market



China is largest producer

FIGURE 4.2: SHARE OF PV POLYSILICON PRODUCTION IN 2019

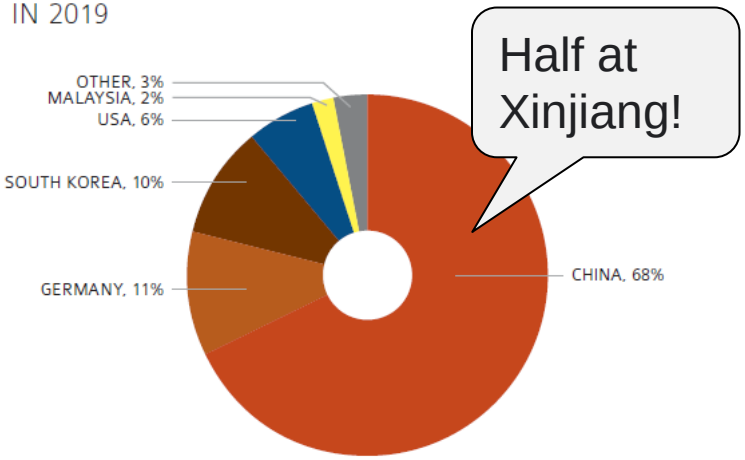


FIGURE 4.3: SHARE OF PV WAFERS PRODUCTION IN 2019

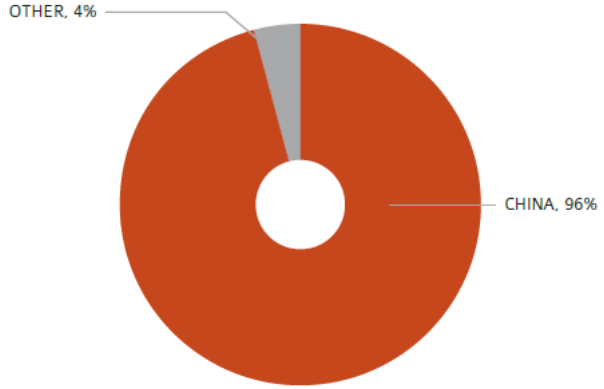


FIGURE 4.4: SHARE OF PV CELLS PRODUCTION IN 2019

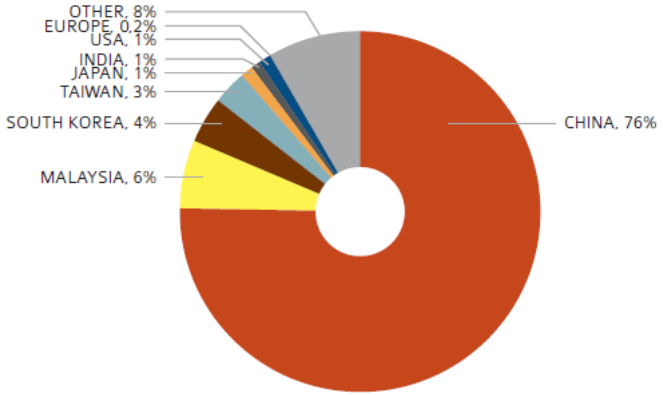
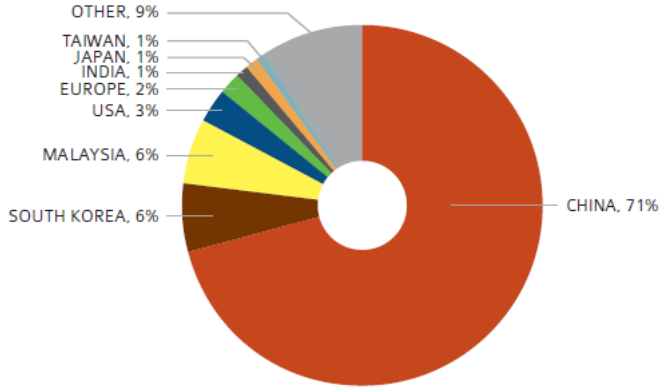
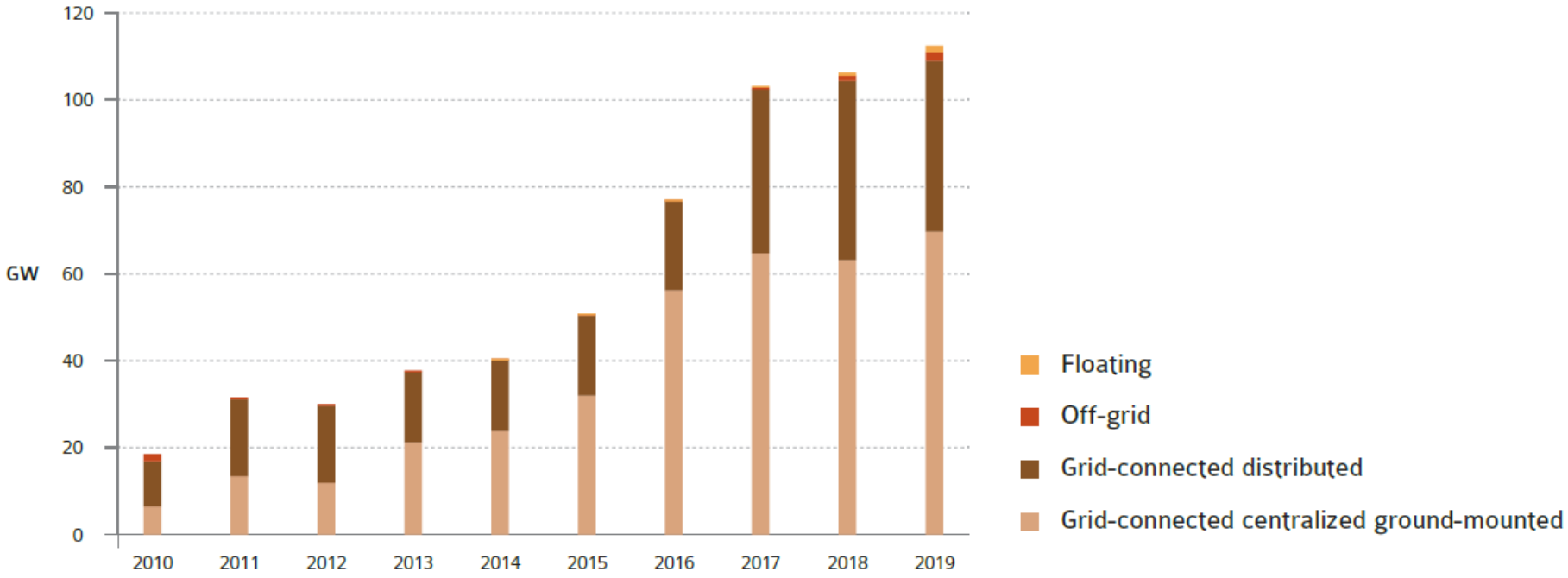


FIGURE 4.5: SHARE OF PV MODULES PRODUCTION IN 2019



PV market today

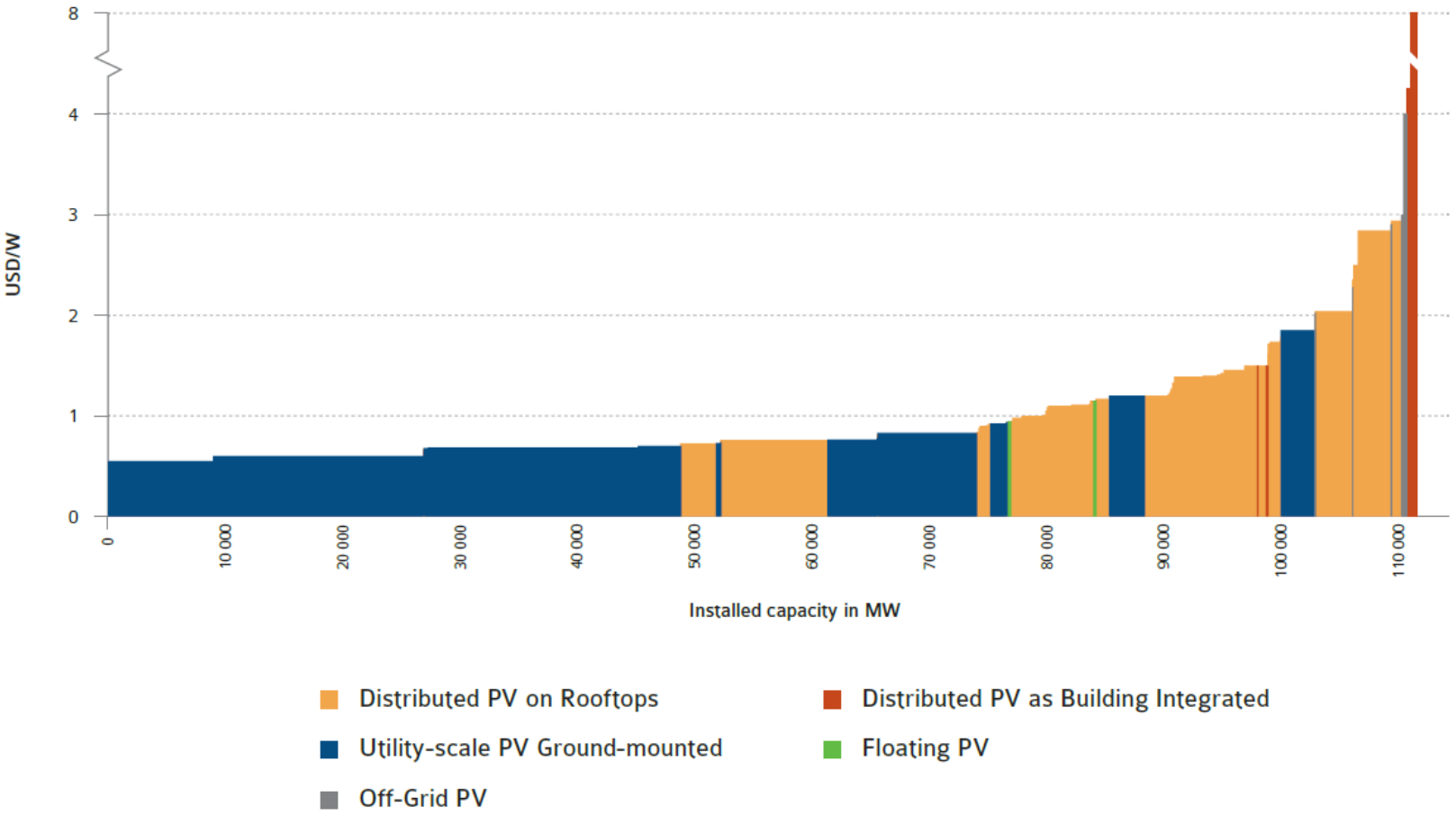
FIGURE 2.9: ANNUAL SHARE OF CENTRALIZED, DISTRIBUTED, OFF-GRID AND FLOATING INSTALLATIONS



All sectors growing but
Utility scale PV is the largest segment
Off grid solar is almost negligible

PV market today

FIGURE 6.3: 2019 PV MARKET COSTS RANGES



PV market today

FIGURE 6.8: UTILITY-SCALE SYSTEM HARDWARE COST BREAKDOWN

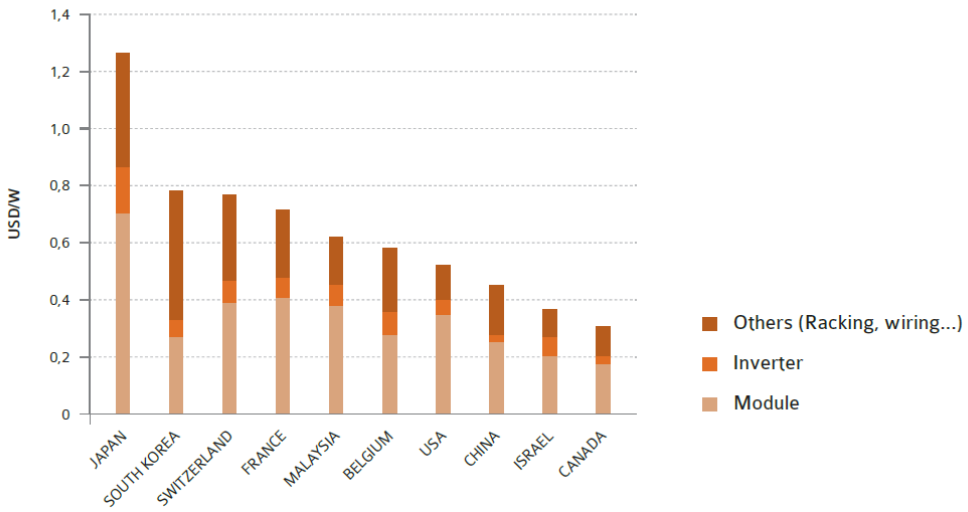
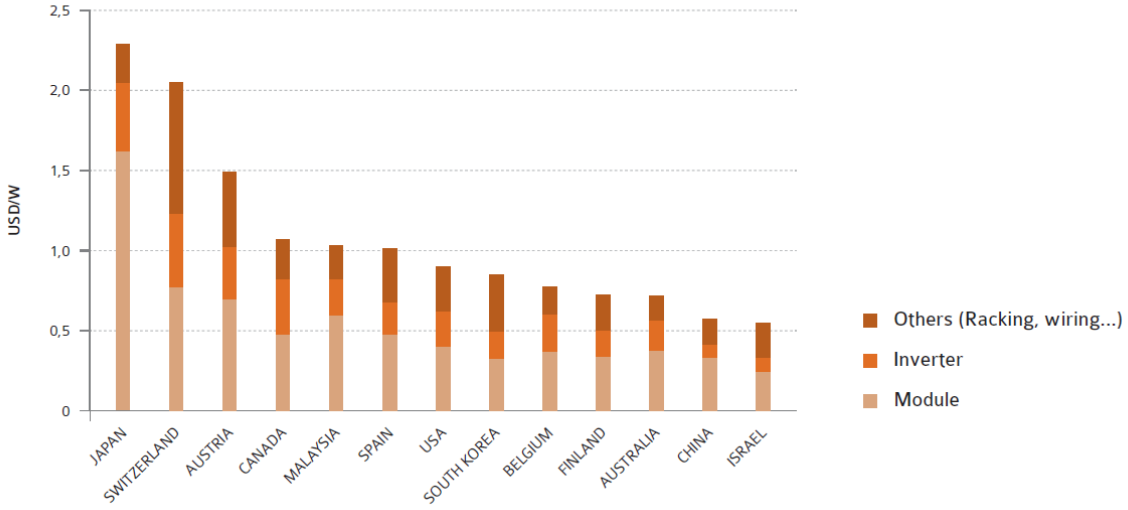
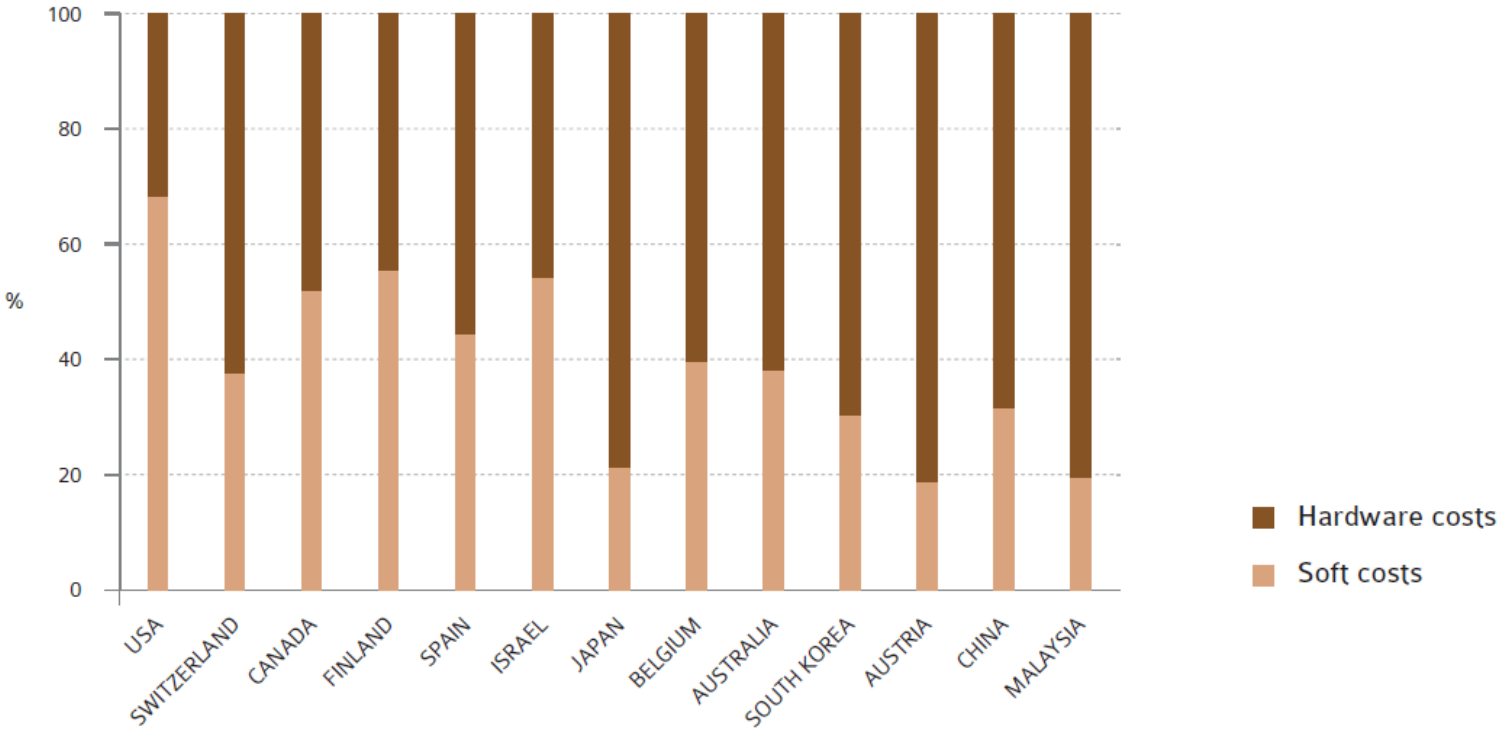


FIGURE 6.6: RESIDENTIAL SYSTEM HARDWARE COST BREAKDOWN



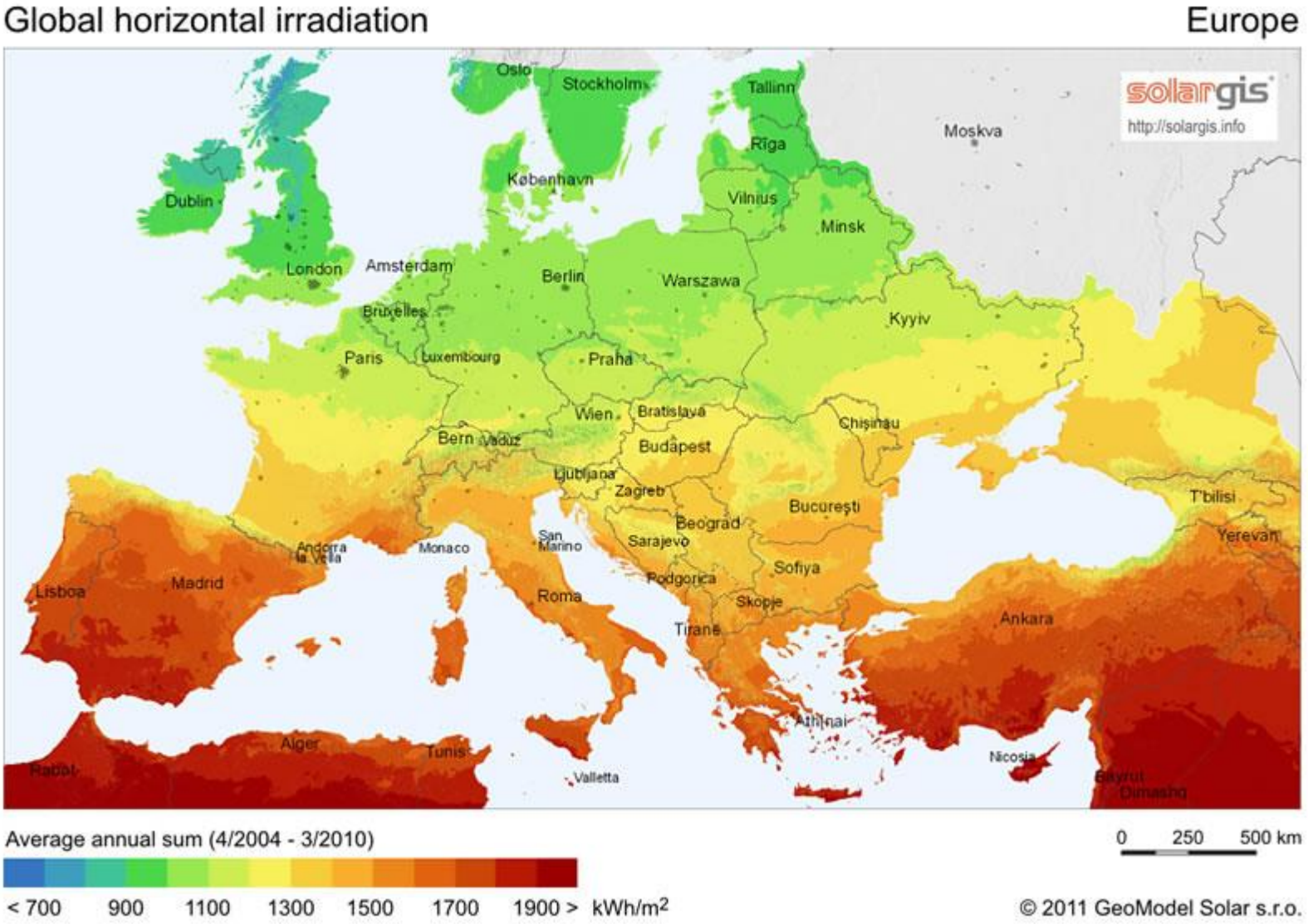
PV market today

FIGURE 6.5: AVERAGE COST BREAKDOWN FOR A RESIDENTIAL PV SYSTEM < 10kW

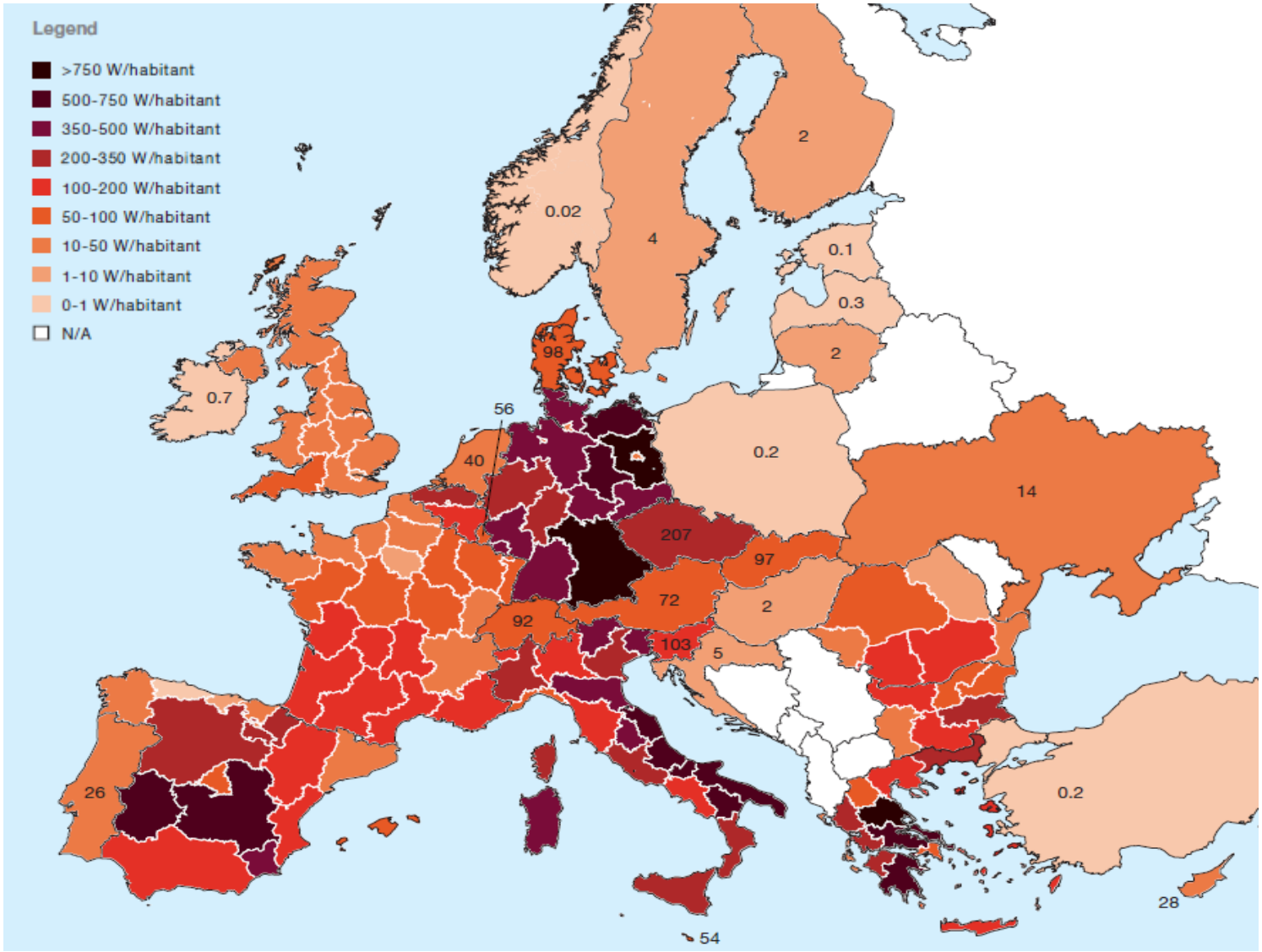


PV in Portugal

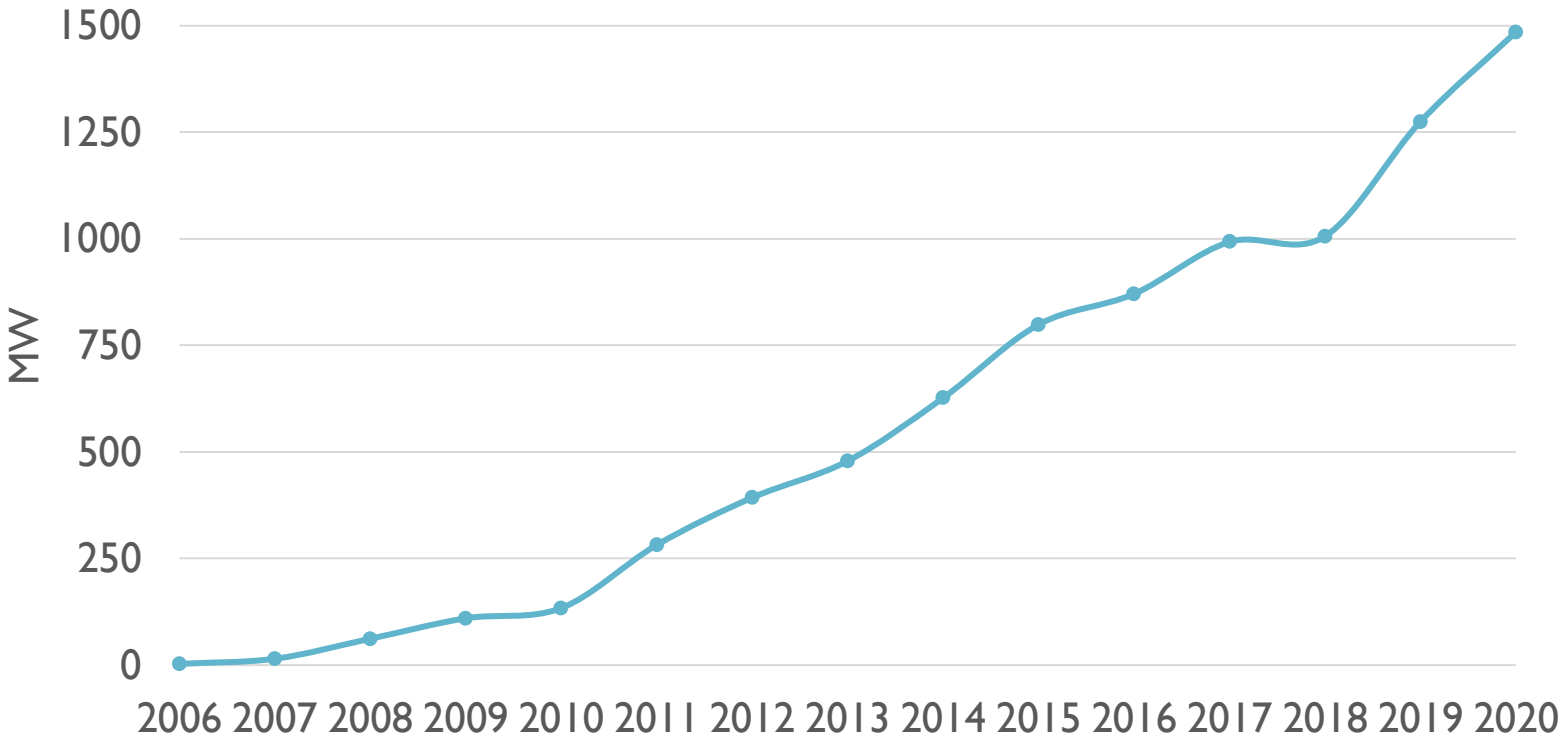
High resource



Low installed capacity

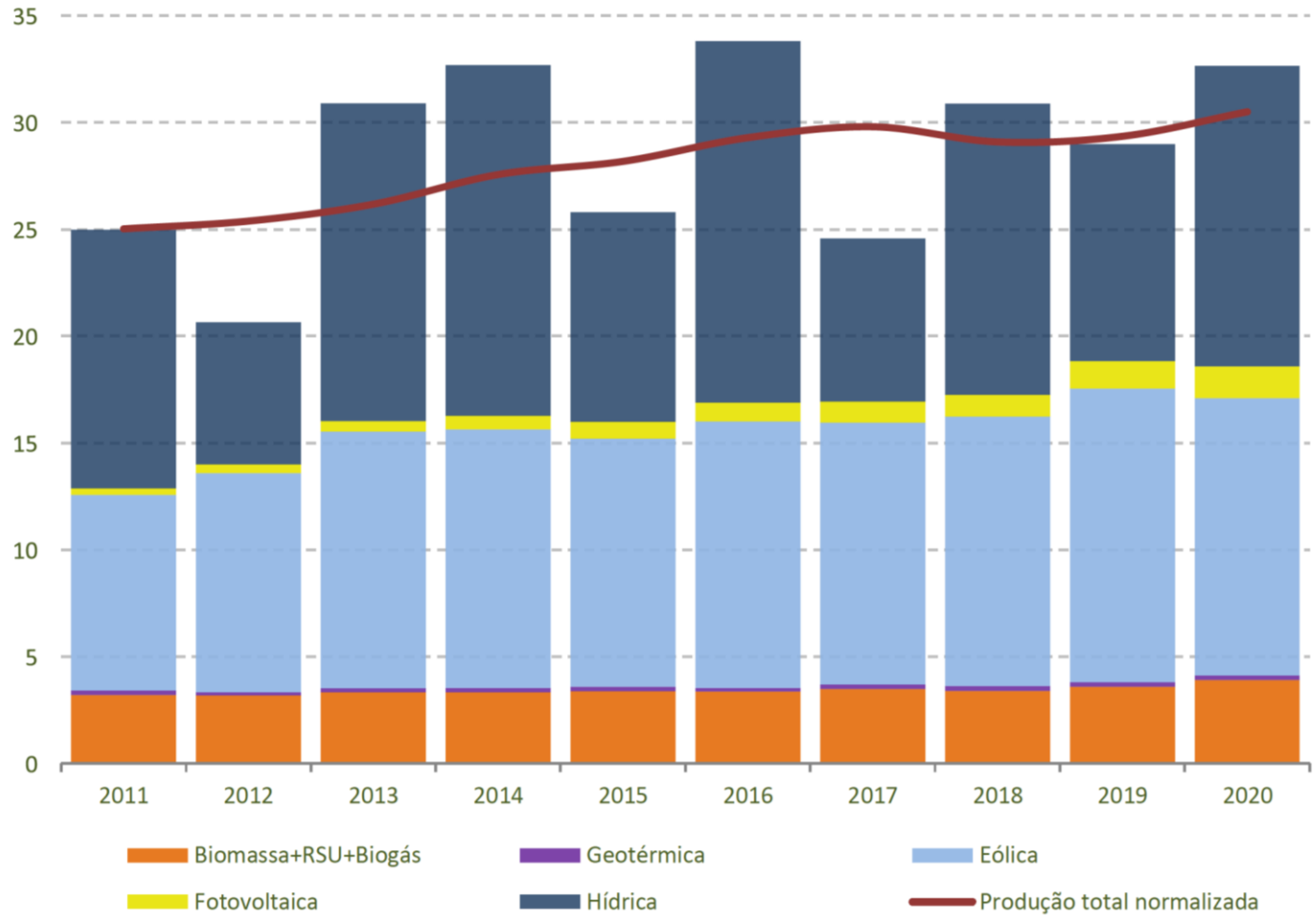


Increasing capacity



Estatísticas rápidas, DEGEG, Julho 2020

Only a fraction of the RES fleet



Estatísticas rápidas, DEGEG, Julho 2020

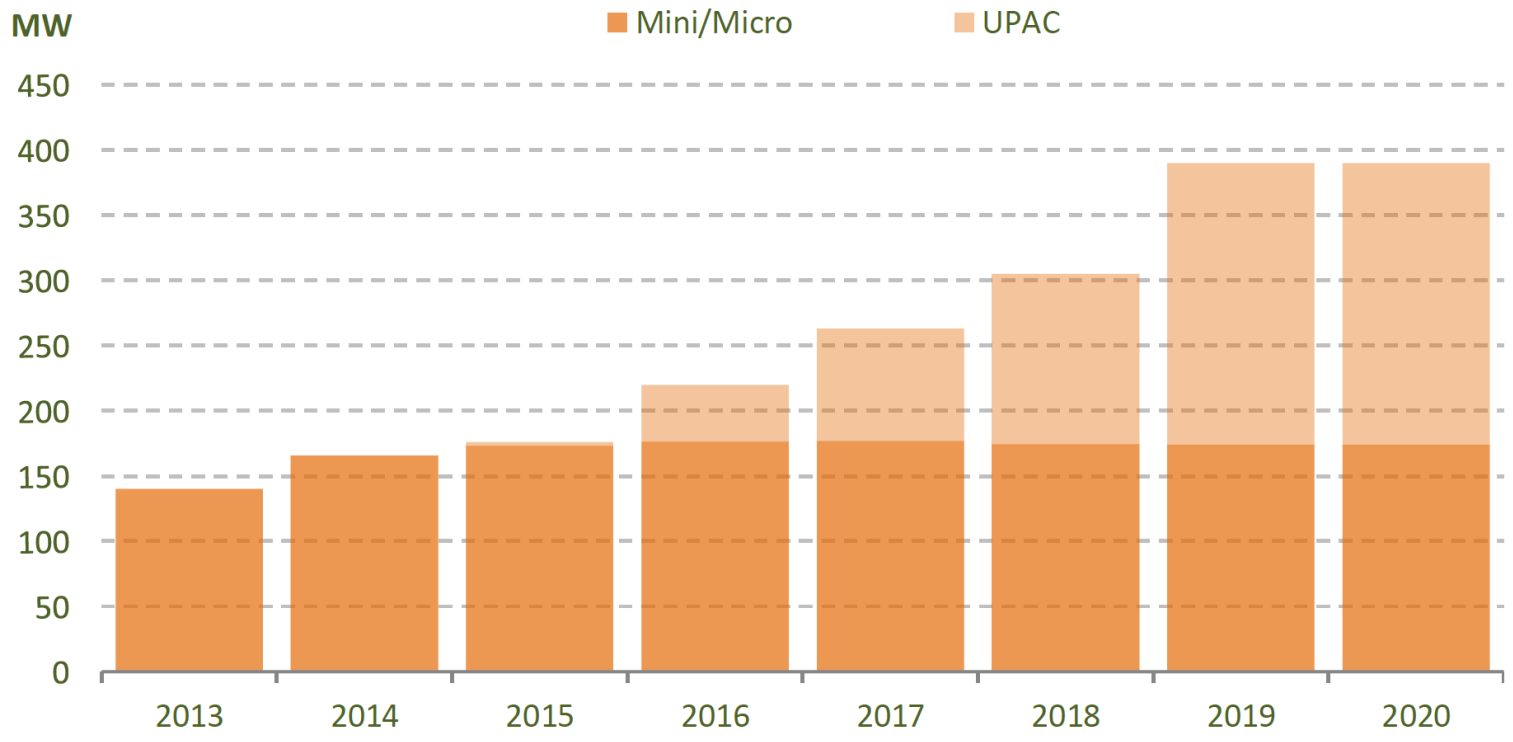
Legal landscape

Roadmaps

2030: 10 GW 2050: 20 GW

- Micro-generation: Renewables-on-demand (19.6c€/kWh/8 anos + 16.5c€/kWh/7 anos)
  [2008; 2010; 2013]
- Mini-generation |DL 34/2011]
  (<20kW: 25c€/kWh; <250kW: auction)
- Self-demand |DL 153/2014]
- Solar auctions (2019 & 2020)

Small PV



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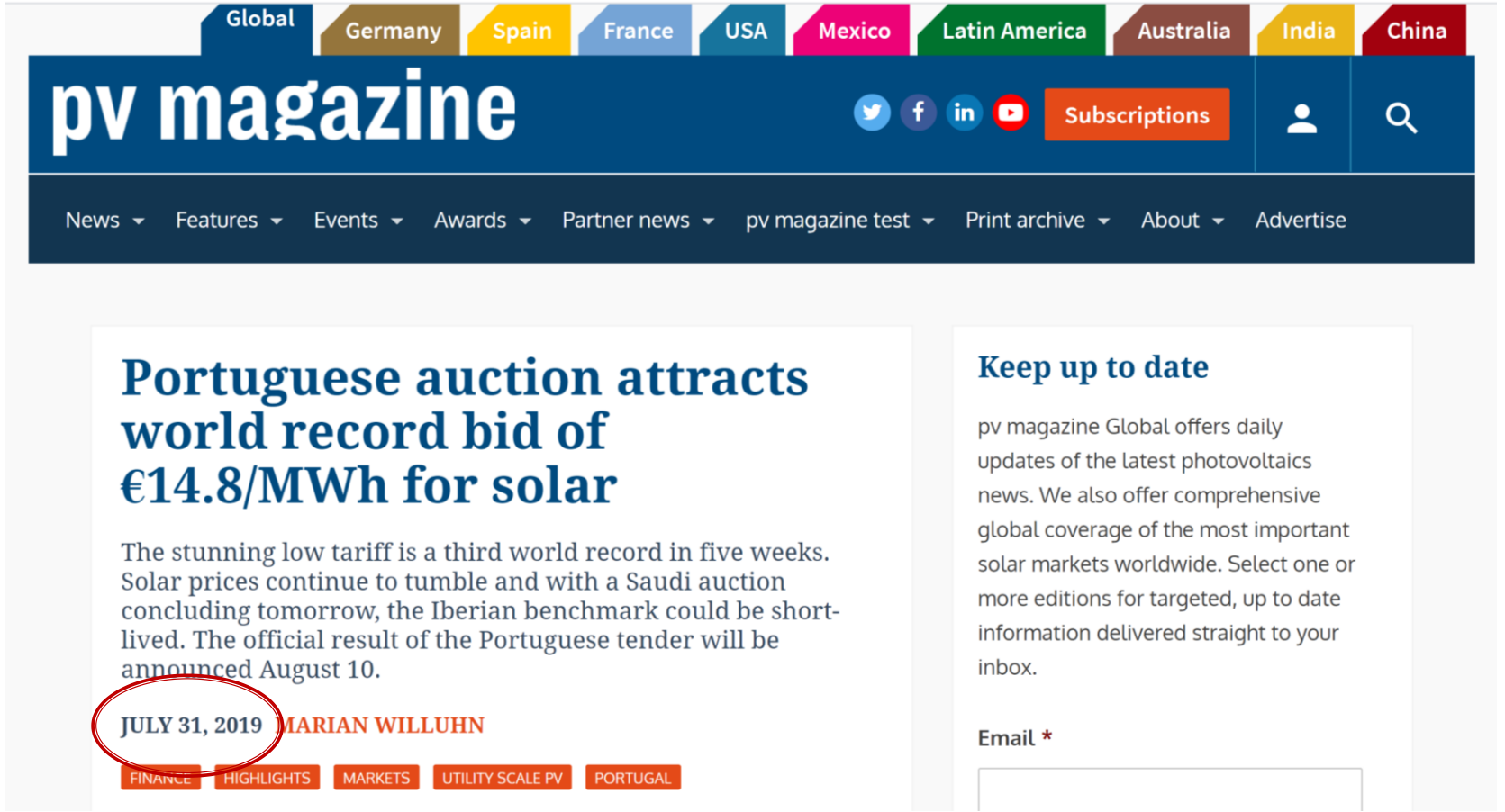
Big PV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Portuguese auction attracts world record bid of €14.8/MWh for solar
The stunning low tariff is a third world record in five weeks. Solar prices continue to tumble and with a Saudi auction concluding tomorrow, the Iberian benchmark could be short-lived. The official result of the Portuguese tender will be announced August 10.
JULY 31, 2019
MARIAN WILLUHN
FINANCE
HIGHLIGHTS
MARKETS
UTILITY SCALE PV
PORTUGAL
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pv magazine Global offers daily updates of the latest photovoltaics news. We also offer comprehensive global coverage of the most important solar markets worldwide. Select one or more editions for targeted, up to date information delivered straight to your inbox.
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Big PV

Novas centrais solares que vão nascer em Portugal

VALORES EM MEGA VOLT-AMPERES (MVA)

2018 2019 2020 2021

PORTO

Fabrica Ikea Industry	Ikea Industry Portugal	6

SANTARÉM

Glória (Granho)	Central Solar da Glória	24
Infantado	Central Solar do Infantado	24
Mexeeiro	Power&Sol	28
Alcanhões	Hypericon	21

ÉVORA

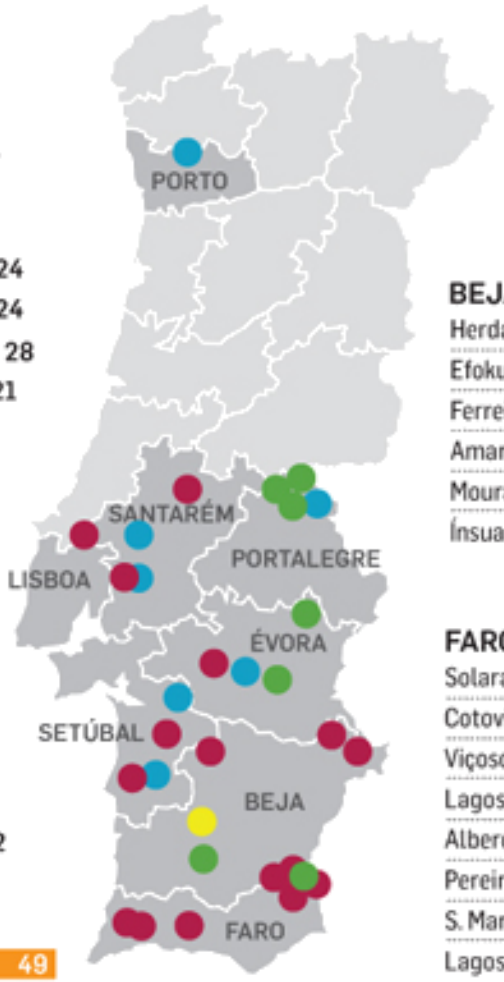
Évora 3	Expoentfokus	29
Montes Novos	Contrate o Sol	3
Vale de Moura	Hyperion	29

LISBOA

Cadaval	Valperal - Soc. Agropecuário	2

SETÚBAL

Herdade da Casa Nova	C. Solar de Casa Nova	12
Vale Matanças	Warwick Portugal	7
Barros	Teclavertente	5
Morgavel	Solarango	49



PORTALEGRE

Falagueira I	Expoentfokus	16
Falagueira II	Expoentfokus	15
Falagueira III	Expoentfokus	21
Tendeiros	C. Solar de Tendeiros	24

BEJA

Herdade dos Murzelos	Morning Chapter	46
Efokus Ourique	Expoentfokus	49
Ferreira do Alentejo	Hyperion	42
Amareleja	Hyperion	16
Moura	Hyperion	48
Ínsua	Goldalqueva	49

FARO

Solara 4	Solara 4	221
Cotovio	Goldiport Solar	49
Viçoso	Goldnalco	48
Lagos	Hyperion	27
Albercas	Muki Solar	28
Pereiro	Muki Solar	29
S. Marcos	Muki Solar	49
Lagos	Lagos Solar Power	21

Expresso

EXCLUS

ÚLTIMAS OPINIÃO ECONOMIA EXPRESSO CURTO PODCASTS TRIBUNA EURO 2020 COVID-19 MULTIMÉDIA

Está prevista no projeto inicial de uma central solar para a vila de Cercal do Alentejo a instalação de 553 800 módulos fotovoltaicos.

REINALDO RODRIGUES/GLOBAL IMAGENS

O plano de painéis solares em Cercal do Alentejo de que ninguém gosta

ENERGIA A instalação de uma central solar está a gerar polémica em Cercal do Alentejo com moradores a contestar a iniciativa. A câmara e a junta de freguesia acompanham as preocupações e esperam que haja uma alteração profunda do projeto.

SOCIEDADE

Torre Bela. Abate de animais para construção de central fotovoltaica começou há meses

OBSERVADOR

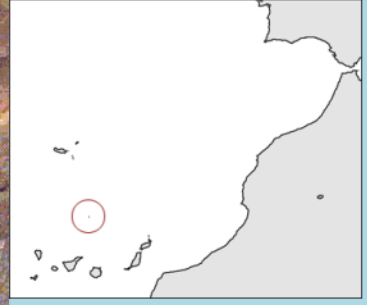
Assinar

Zero considera que apenas um em nove projetos de centrais solares é exemplo a seguir

Dos nove projetos, apenas um tem a intenção de instalar a central numa "área concessionada para exploração de recursos geológicos" e alguns exigem áreas contínuas que "ultrapassam os mil hectares".

Flagship projects

- Selvagem Grande, Madeira (1983, 660W)
- Solar XXI, Lisbon (1989; 2.2kW)+ (2005; 12+6kW)
- Brinches, Serpa (2007; 11MW)
- Amareleja, Moura (2008; 46MW)
- Ourika (2018; 46 MW – sem tarifas)



16° W
Palheiro de Terra
Palheiro do Mar
Ponta do Corgo da Areia
Ponta do Risco
Pico dos Tornozelos
Pico da Atalaia
Selvagem Grande
Enseada das Pedreiras
Enseada da Atalaia
Ilhéu Sinho
Enseada das Cagarras
Pico do Inferno
Ponta de Leste
Ponta do Inferno
Oceano Atlântico
Atlantic Ocean
Ilhéus do Norte
Ilhéu Redondo
Ilhéu Comprido
Ilhéu Alto
Ponta do Norte
Ponta de Oeste
Selvagem Pequena
Pico do Veado
Canal da Selvagem Pequena
Ilhéu de Fora
Ponta de Leste
Ilhéu Pequeno
Ilhéu Grande
Ponta dos Garajaus
Ponta do Sul
Ilhéu do Sul
30° N


SOLAR XXI

Governo inaugura primeira central solar da Europa sem tarifas garantidas

A central já está a funcionar no concelho de Ourique. As restantes, parte da Central Solar Fotovoltaica Ourika!, devem funcionar em pleno até 2021.

Dinheiro Vivo/Lusa

26 Julho, 2018 • 05:22


C1
C4

INTRODUCTION

Remarks - PV in Portugal

- Almost no manufacturing
- Commercialization & installation suffers from policy hesitations
- Current legal framework favors very small installations for residential users and industrial installations
- Unsubsidized market is emerging, big time!
- Untapped huge solar potential