Photovoltaics

Introduction

Today

- *Summary of the course*
- Brief history of photovoltaics
- PV global market
- PV in Portugal

Course assessment

- Lab work reports: **20%**
  - Indoor PV modules characterization
  - Outdoor PV modules characterization
  - PV system battery charge controller
- PV project: **30%**
  - Groups of 3 people
  - Topic tbd week 2
  - Deadline end-of-term
- Test (date to be defined): **50%**

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

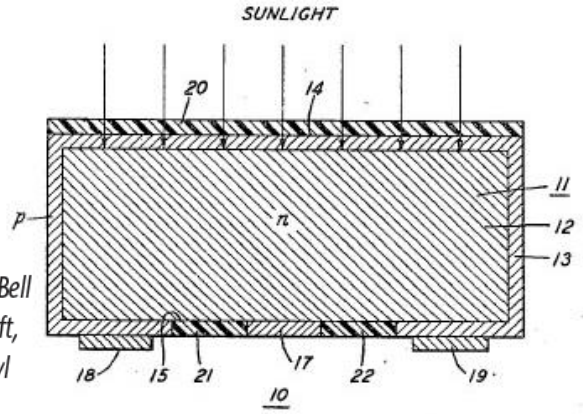
The inventors of the Bell Solar Battery, from left, Gerald Pearson, Daryl Chapin, and Calvin Fuller, check devices for the amount of solar electricity derived from sunlight, here simulated by a lamp.

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

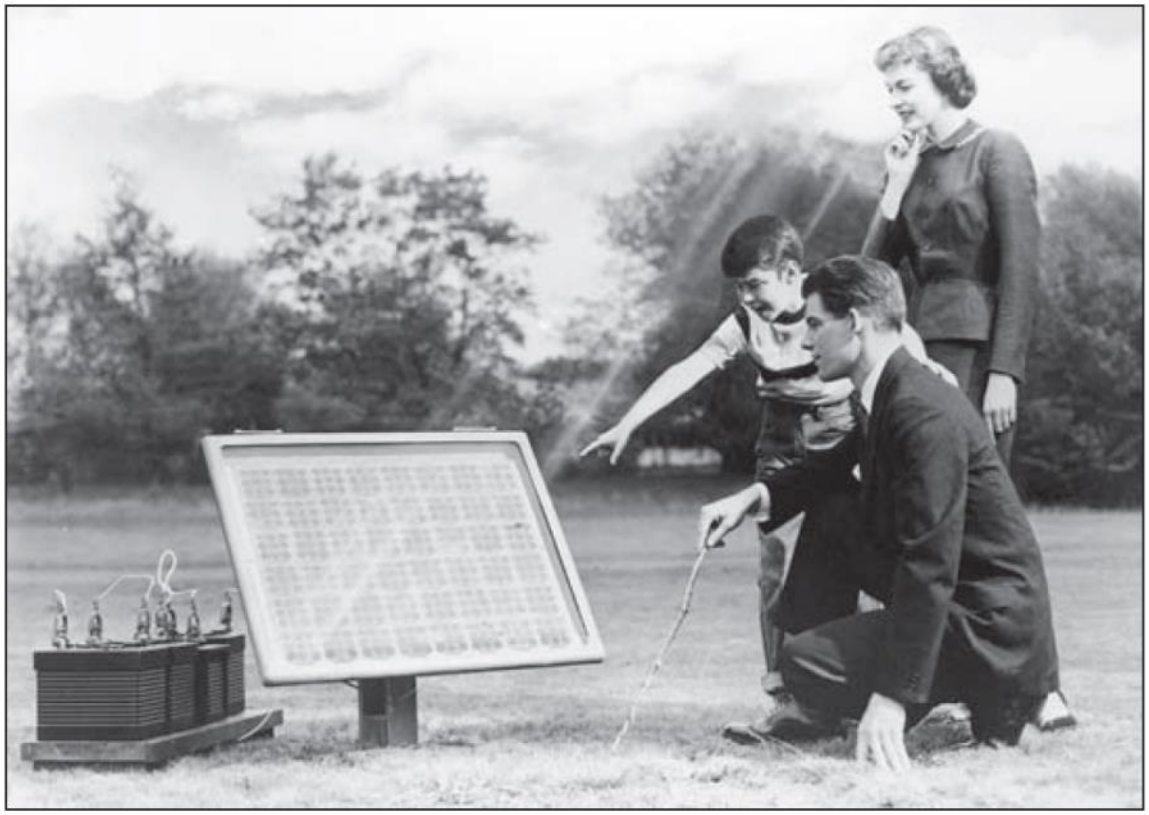
SOLAR ENERGY CONVERTING APPARATUS

Filed March 5, 1954

FIG. 1

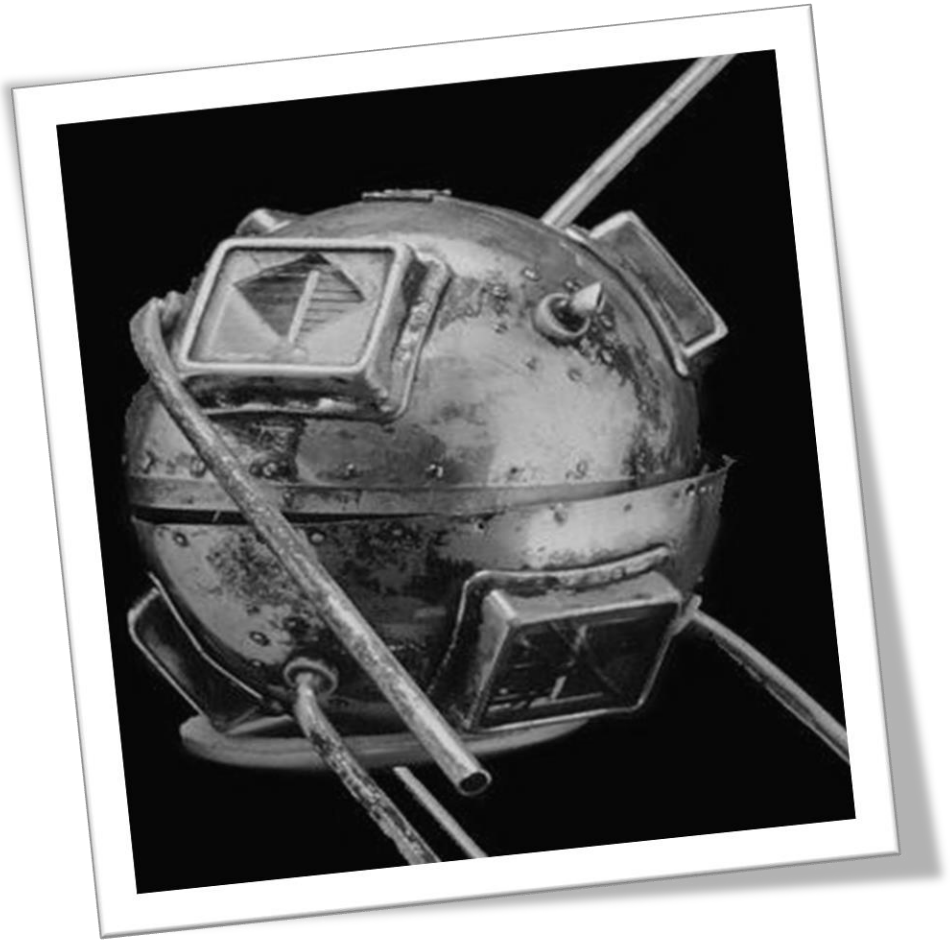


Brief history of photovoltaics

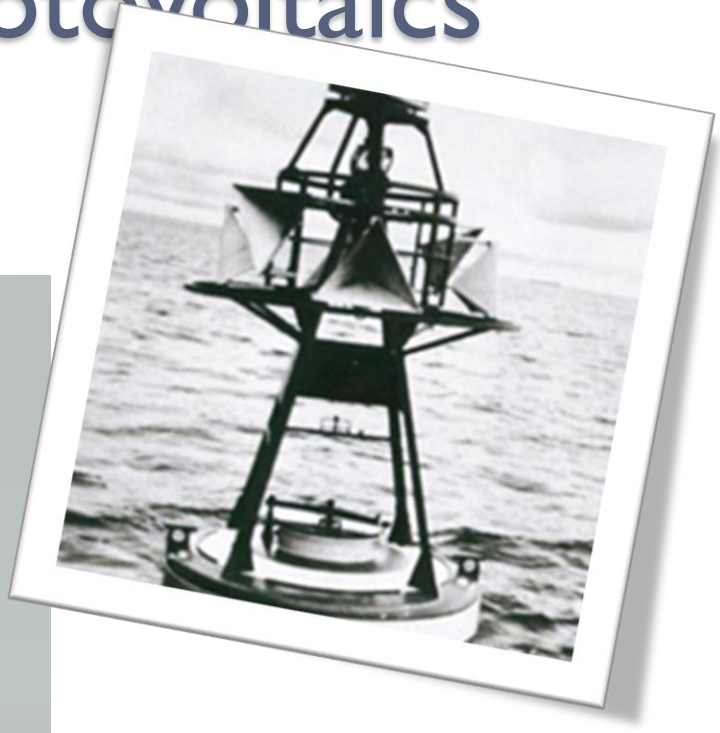


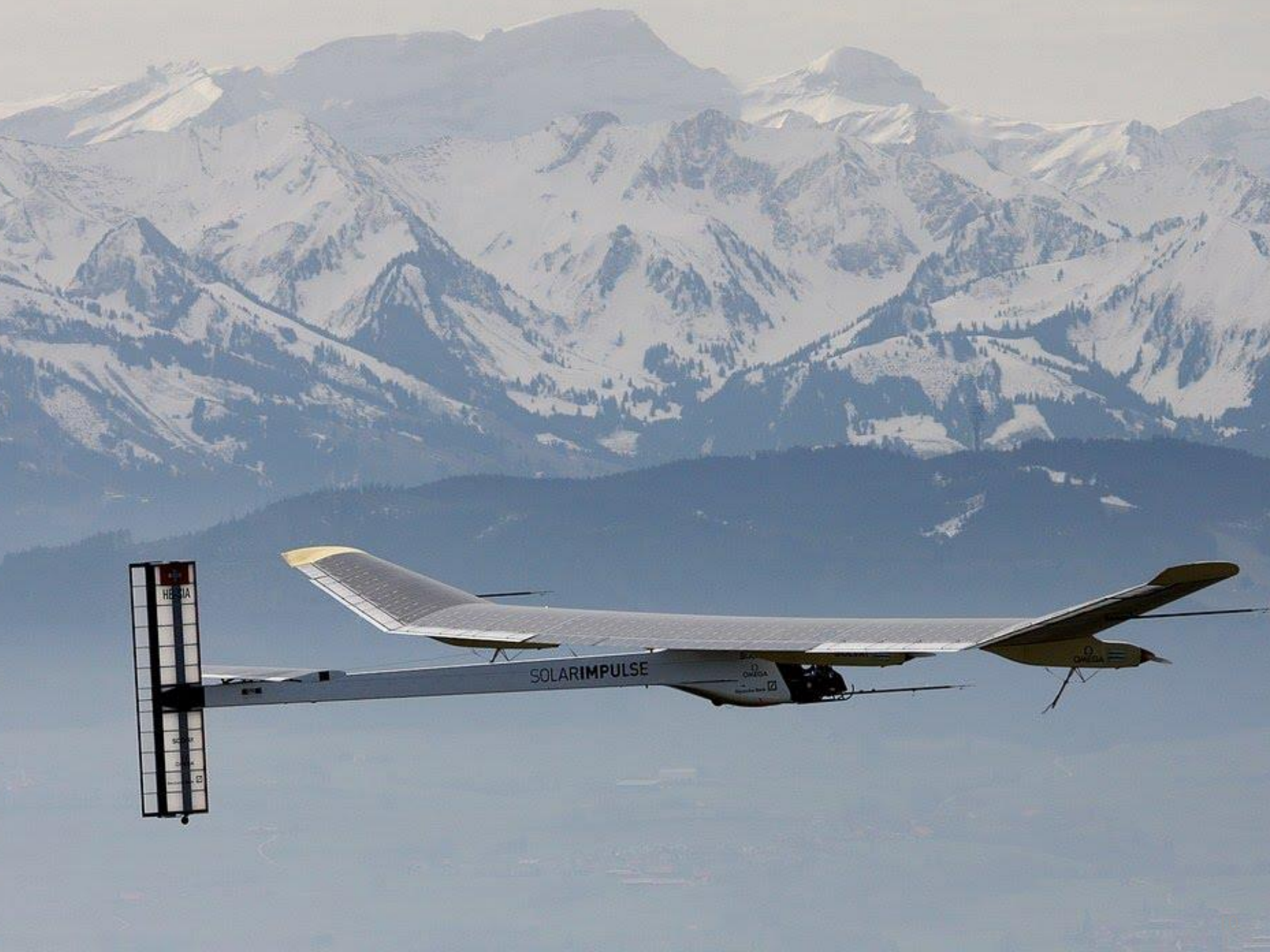
Advertisement photos, such as this one that appeared in the 1956 issue of Look Magazine, show off the "Bell Solar Battery" to the American public.

Brief history of photovoltaics



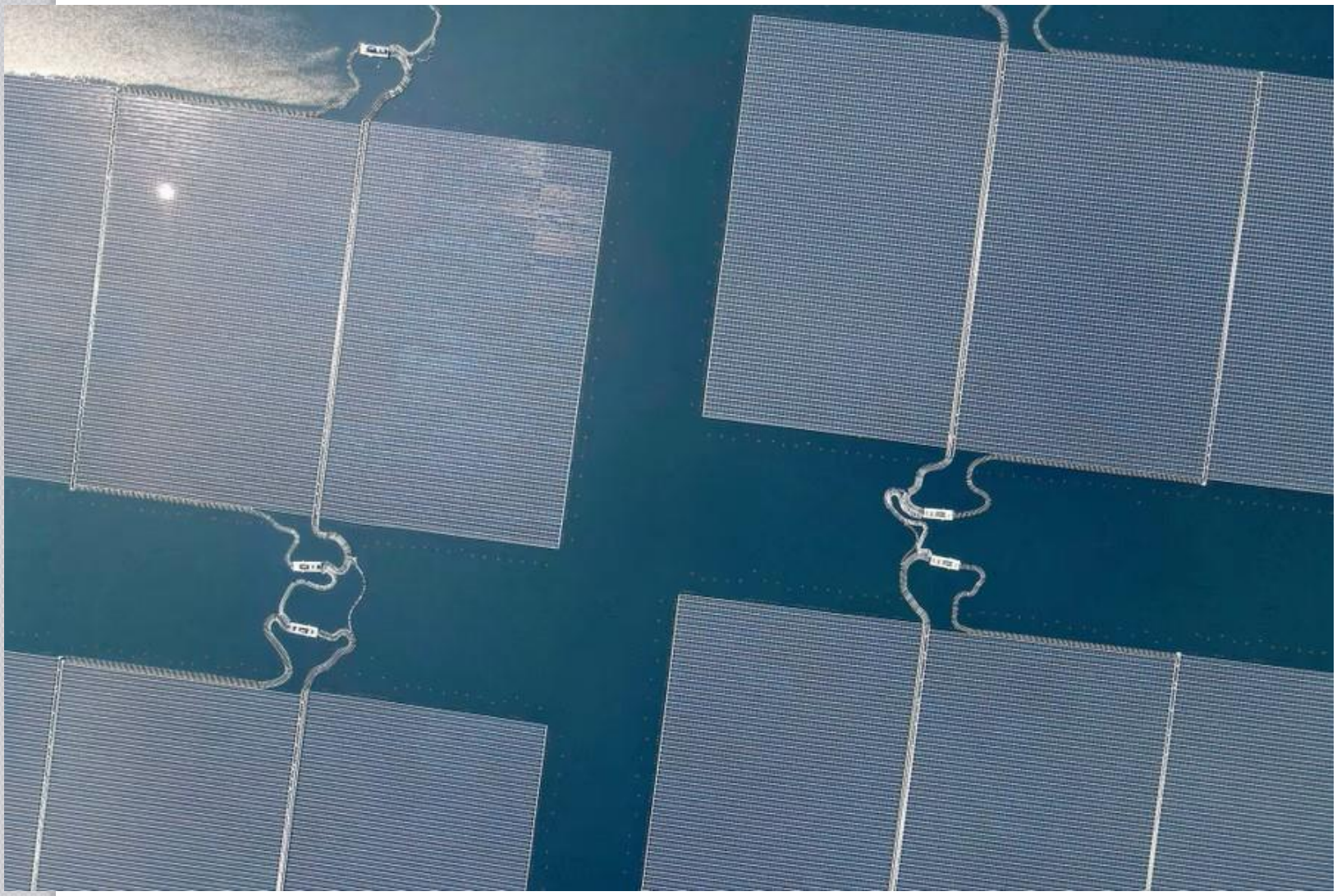
Brief history of photovoltaics

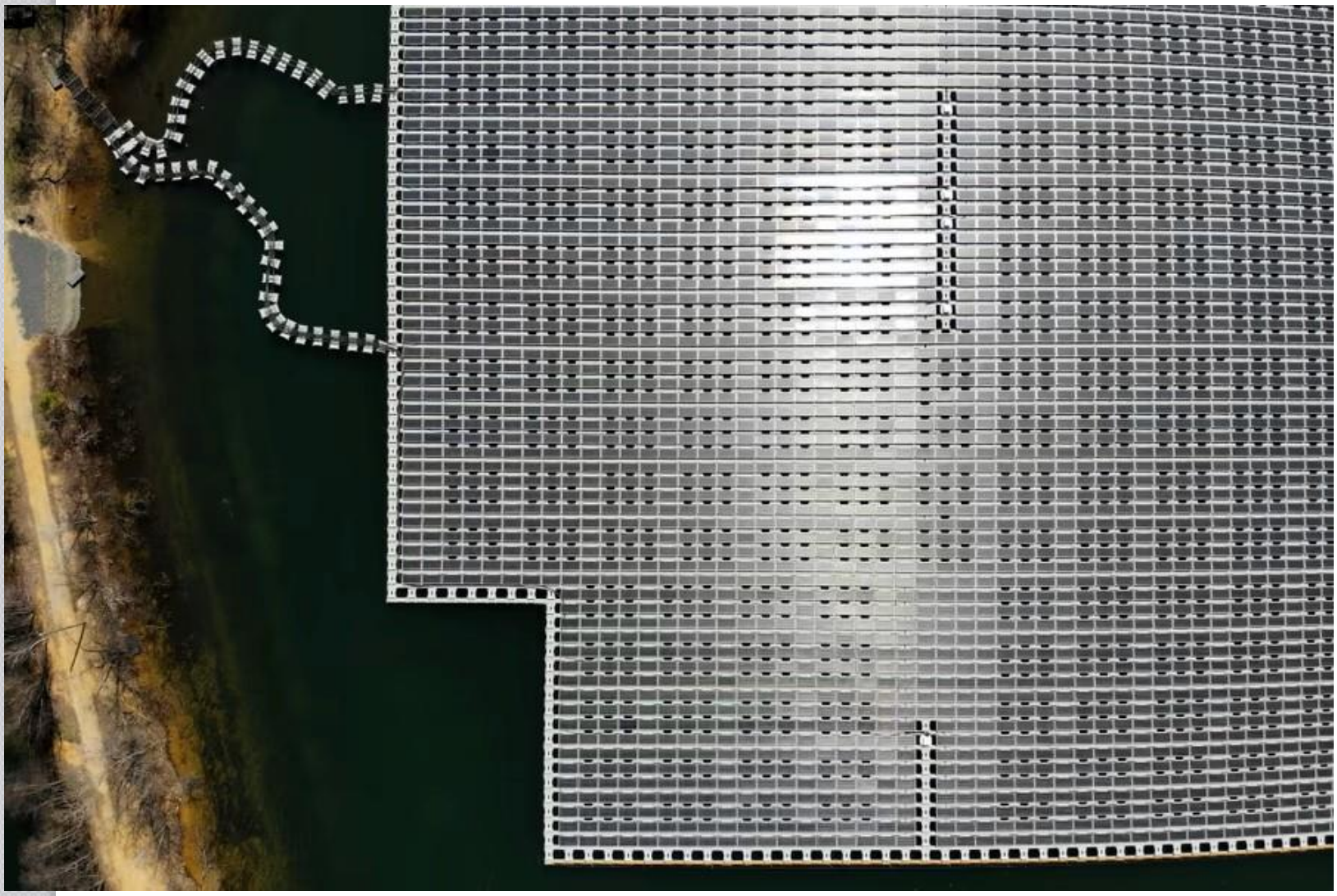



HB-SIA
SOLARIMPULSE
OMEGA
OMEGA


TÛRANOR PlanetSolar

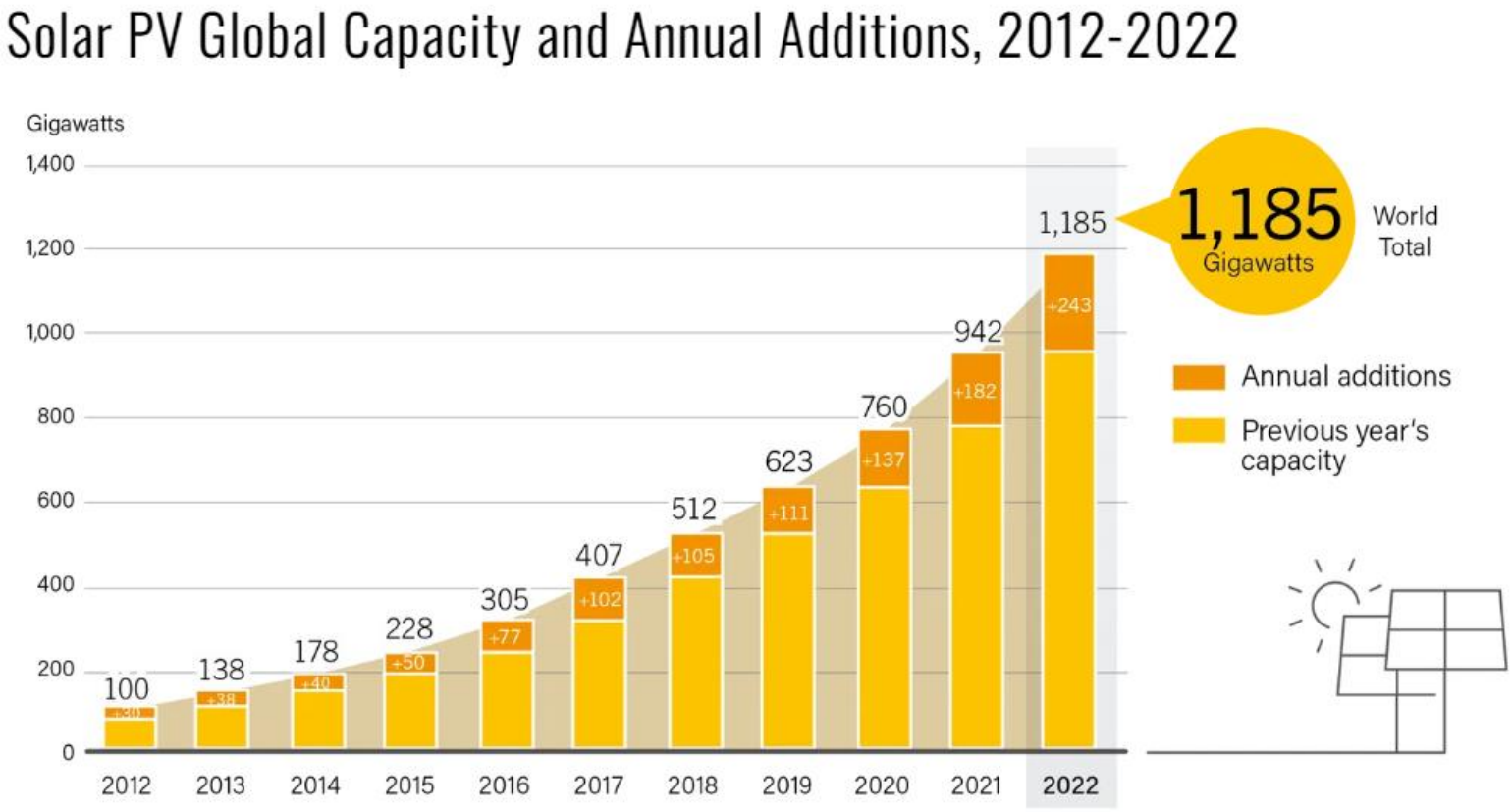

ENGINEERING
UNSW






CLAAS
LEXION
CLAAS
V70
COMO

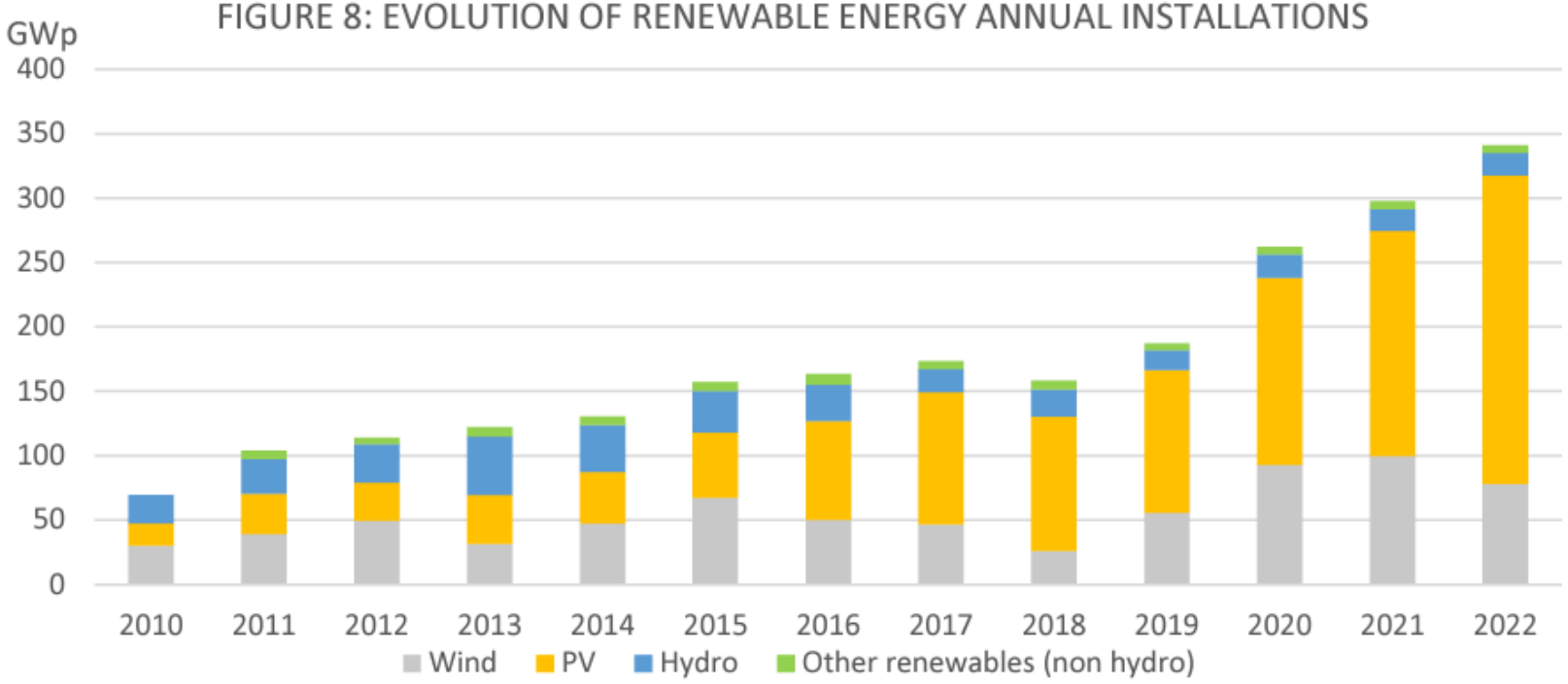
PV fast development



PV installed capacity growing exponentially

PV fast development

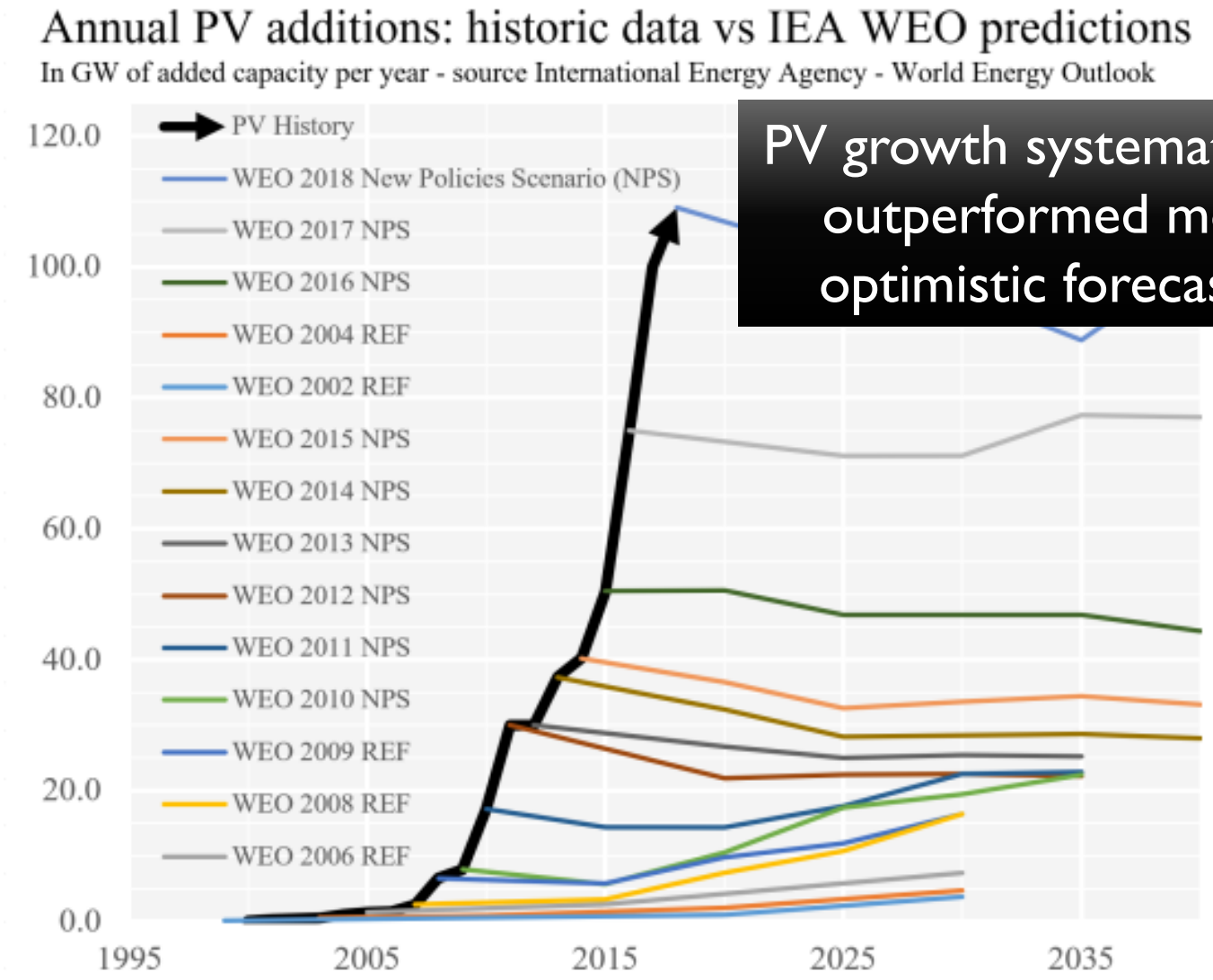
FIGURE 8: EVOLUTION OF RENEWABLE ENERGY ANNUAL INSTALLATIONS



Sources: compilation of IEA PVPS, BNEF, GWEC, IRENA and estimations for 2022

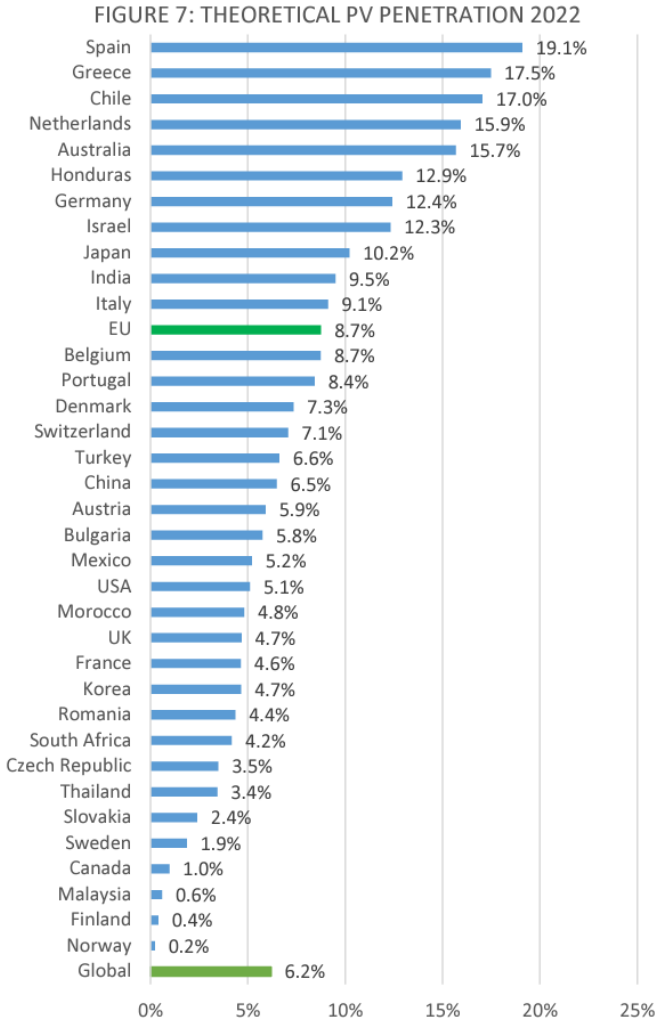
PV is the fastest growing power source worldwide

PV fast development

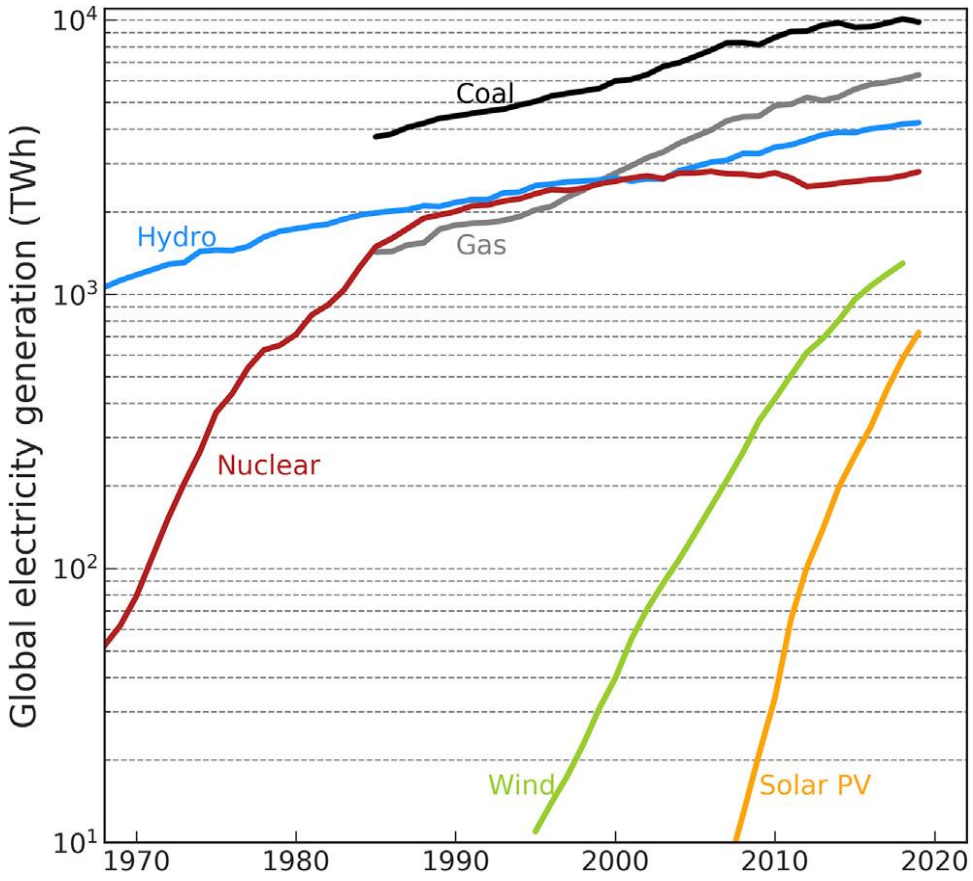


PV growth systematically outperformed most optimistic forecasts!

PV fast development



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



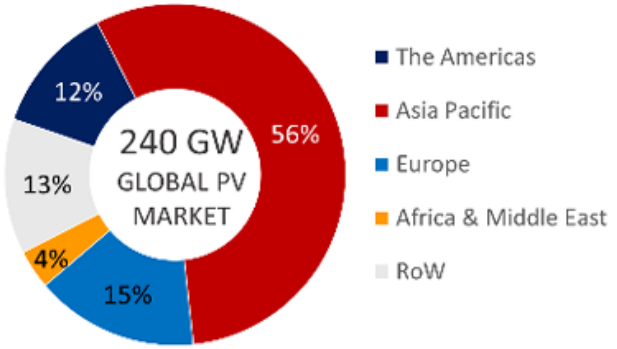
PV fast development

TOP PV MARKETS 2022

CHINA 106 GW

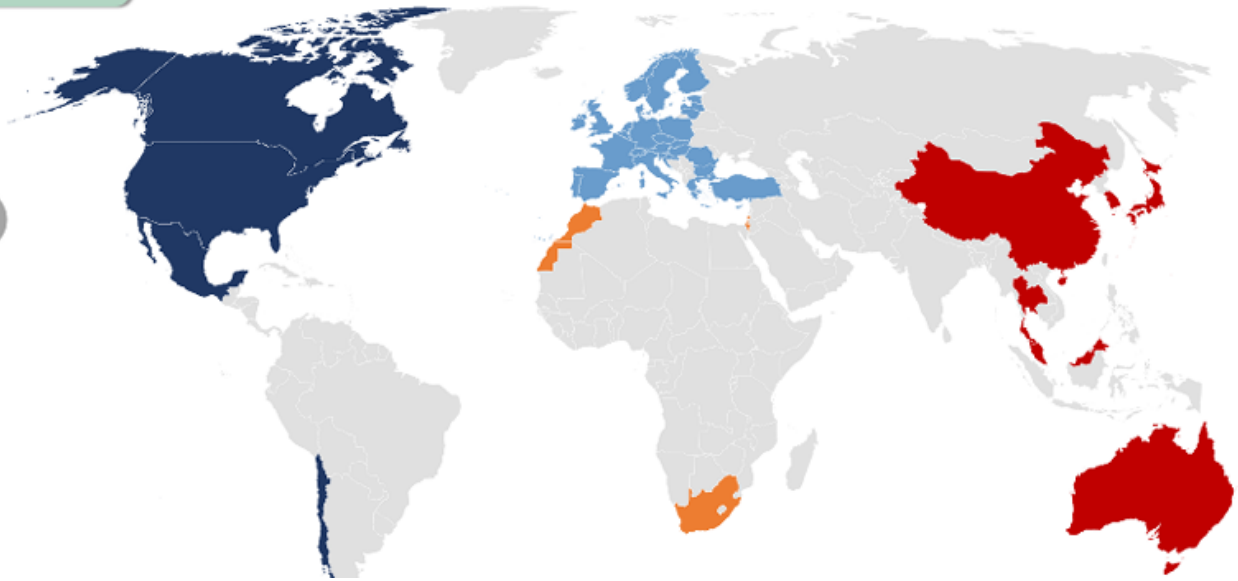
EU 38,7 GW

USA 18,6 GW

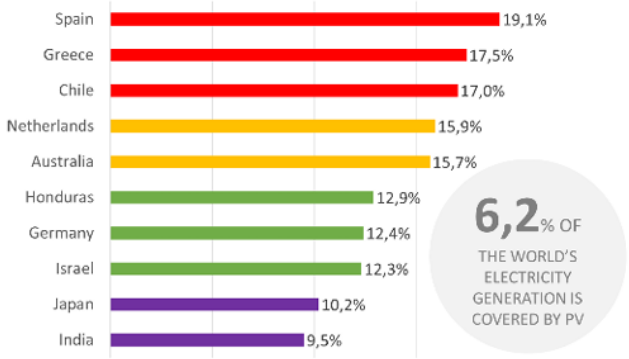


CO_2eq

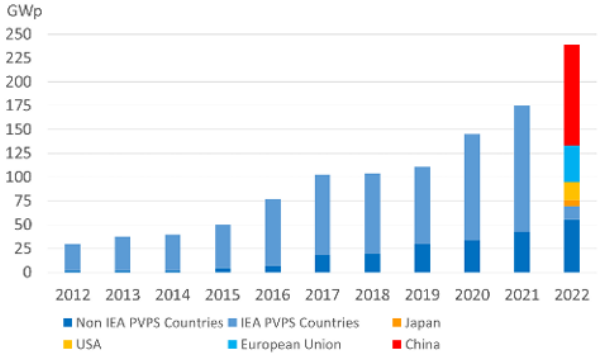
1 399 Mt
CO_2 emissions
avoided in 2022



COUNTRIES WITH HIGHEST PV PENETRATION



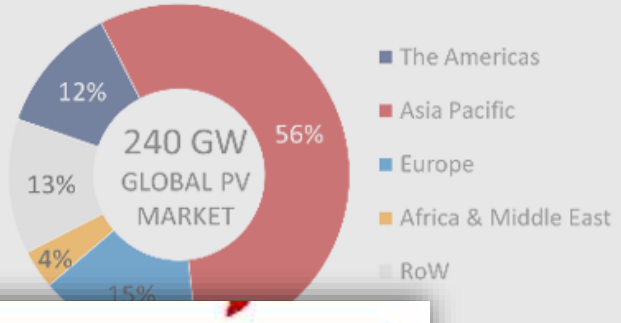
EVOLUTION OF ANNUAL PV INSTALLATIONS



TOP PV MARKETS 2022

CHINA 106 GW

EU 38,7 GW

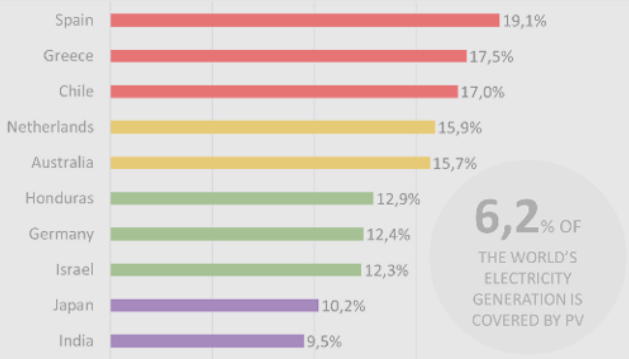


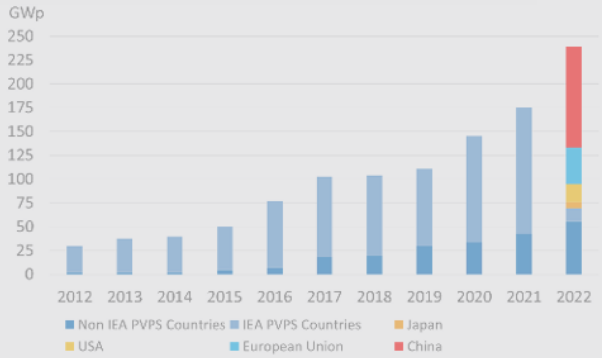
SOLAR PV PER CAPITA 2022 Watt/capita

1st AUSTRALIA 1 166

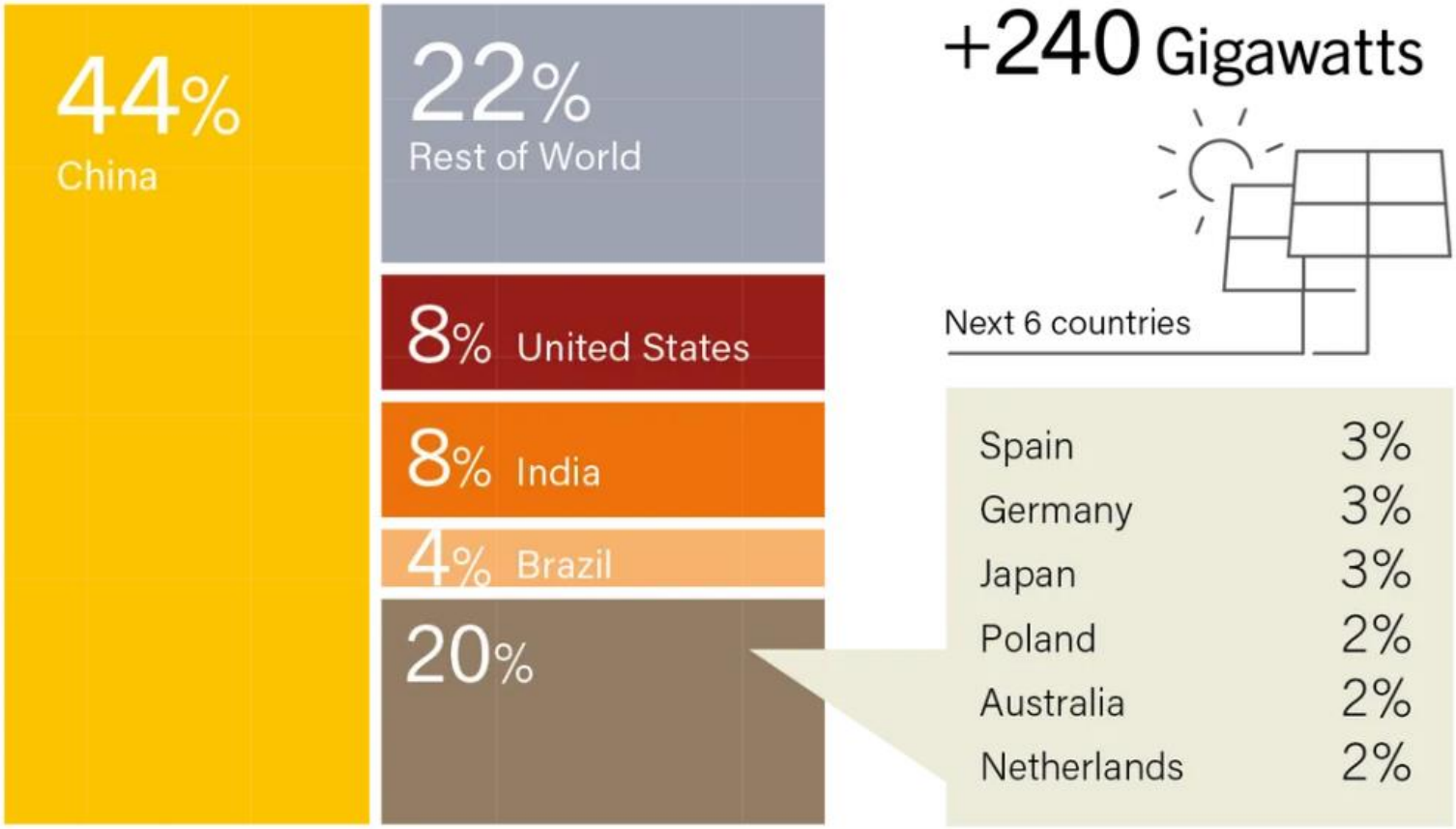
2nd NETHERLANDS 1 040

3rd GERMANY 807





Solar PV Global Capacity Additions, Shares of Top 10 Countries and Rest of World, 2022



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

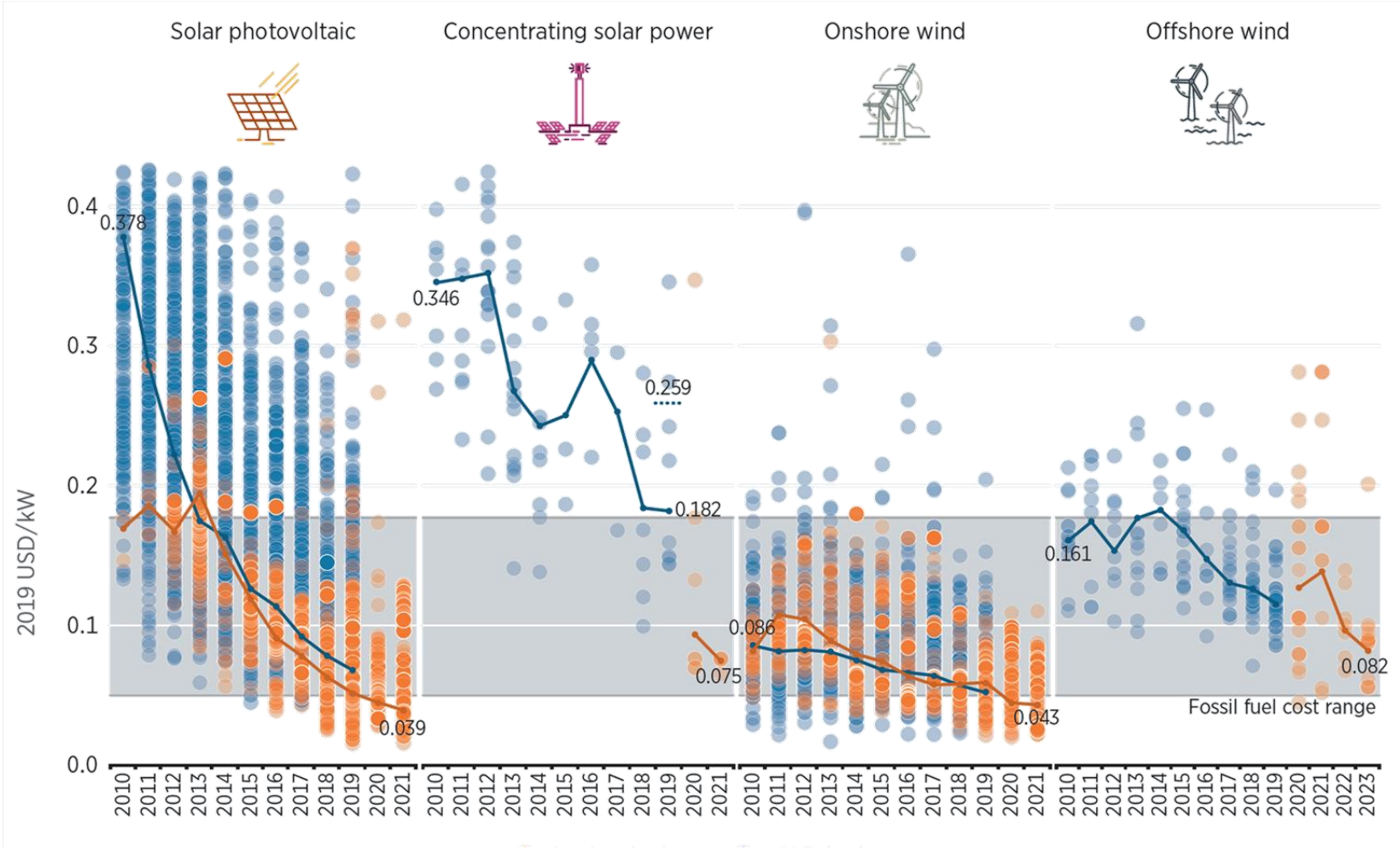
… PV **WILL BE** COST COMPETITIVE.

When?

Where?

At what time of the day/year?

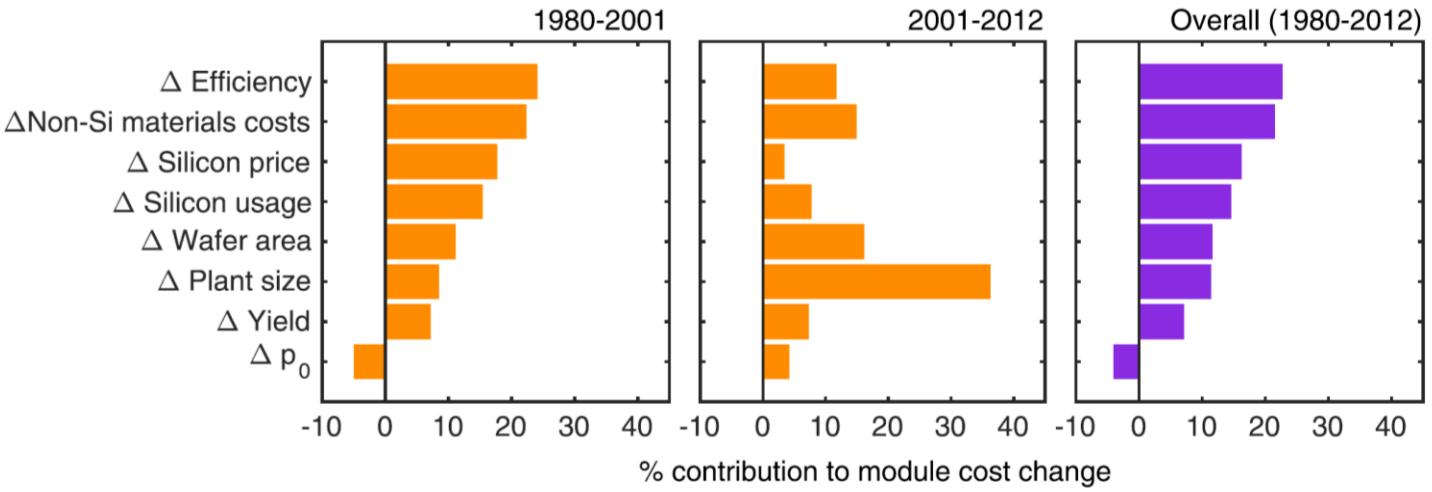
Cost of photovoltaics

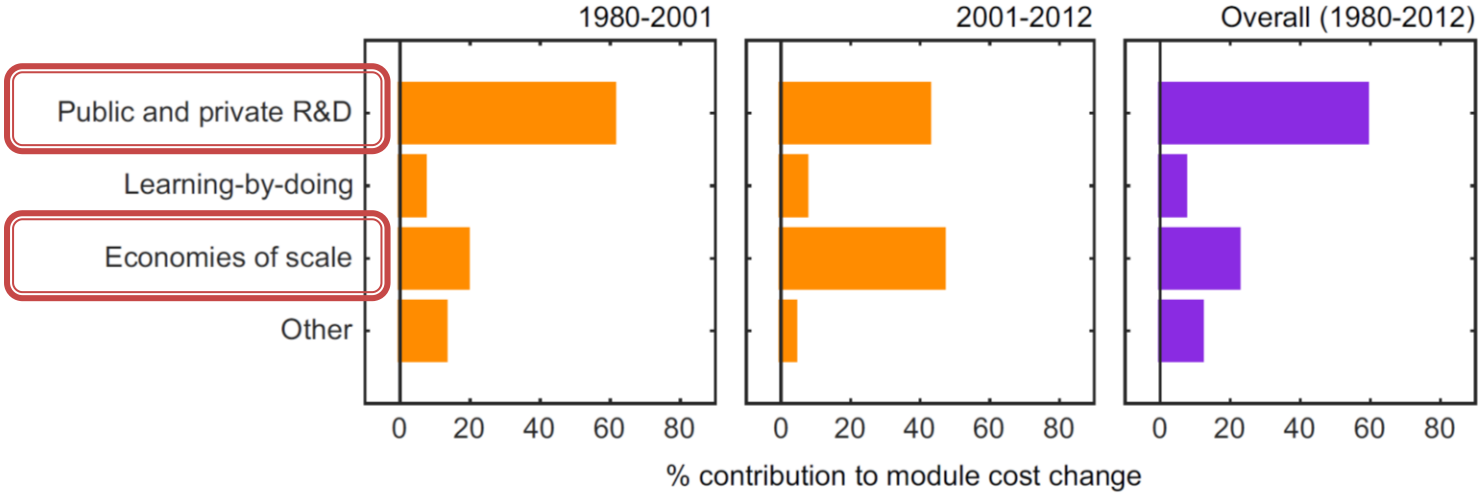


10 times cheaper in the last 10 years!!

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

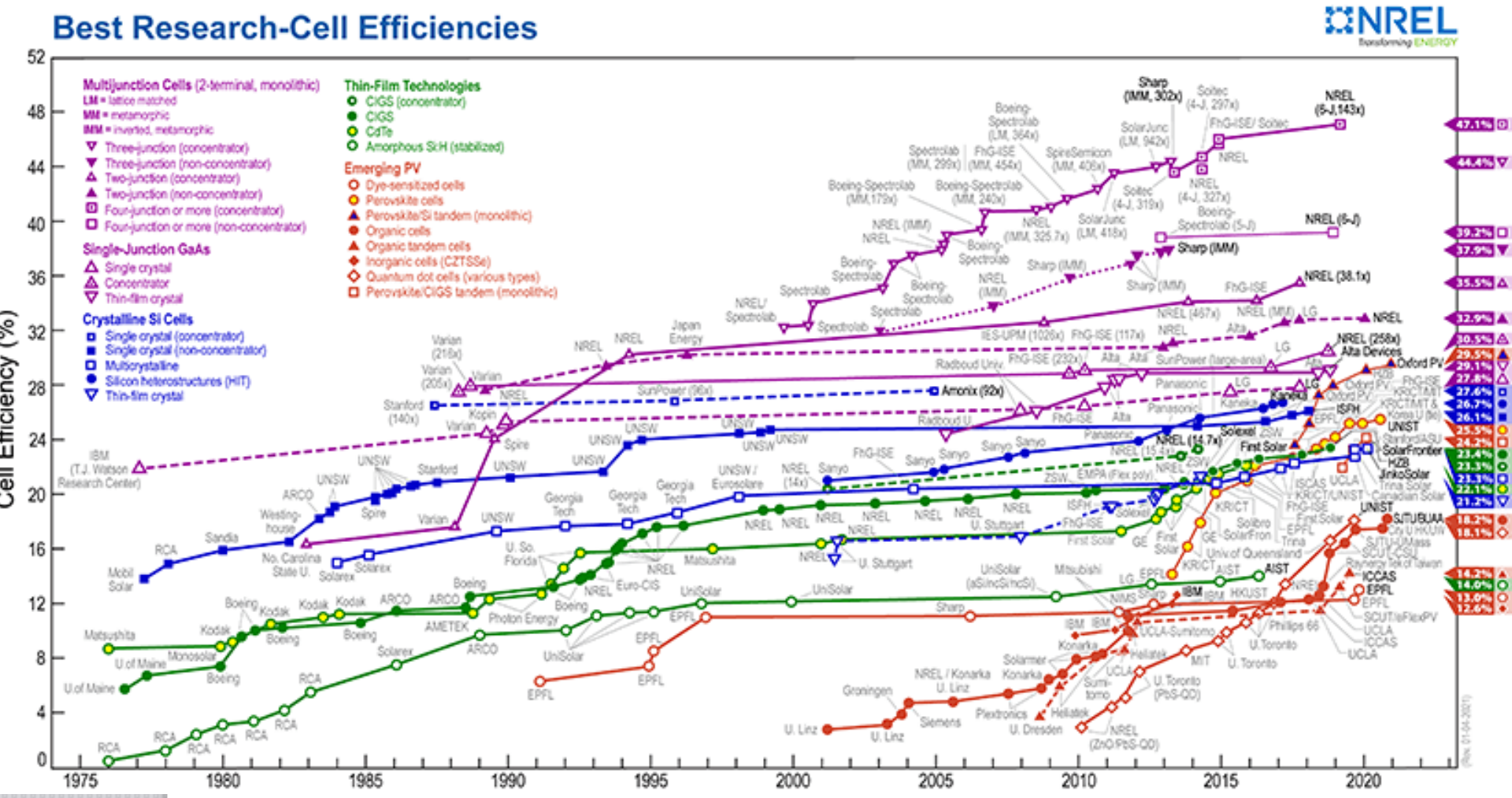
Drivers for cost reduction



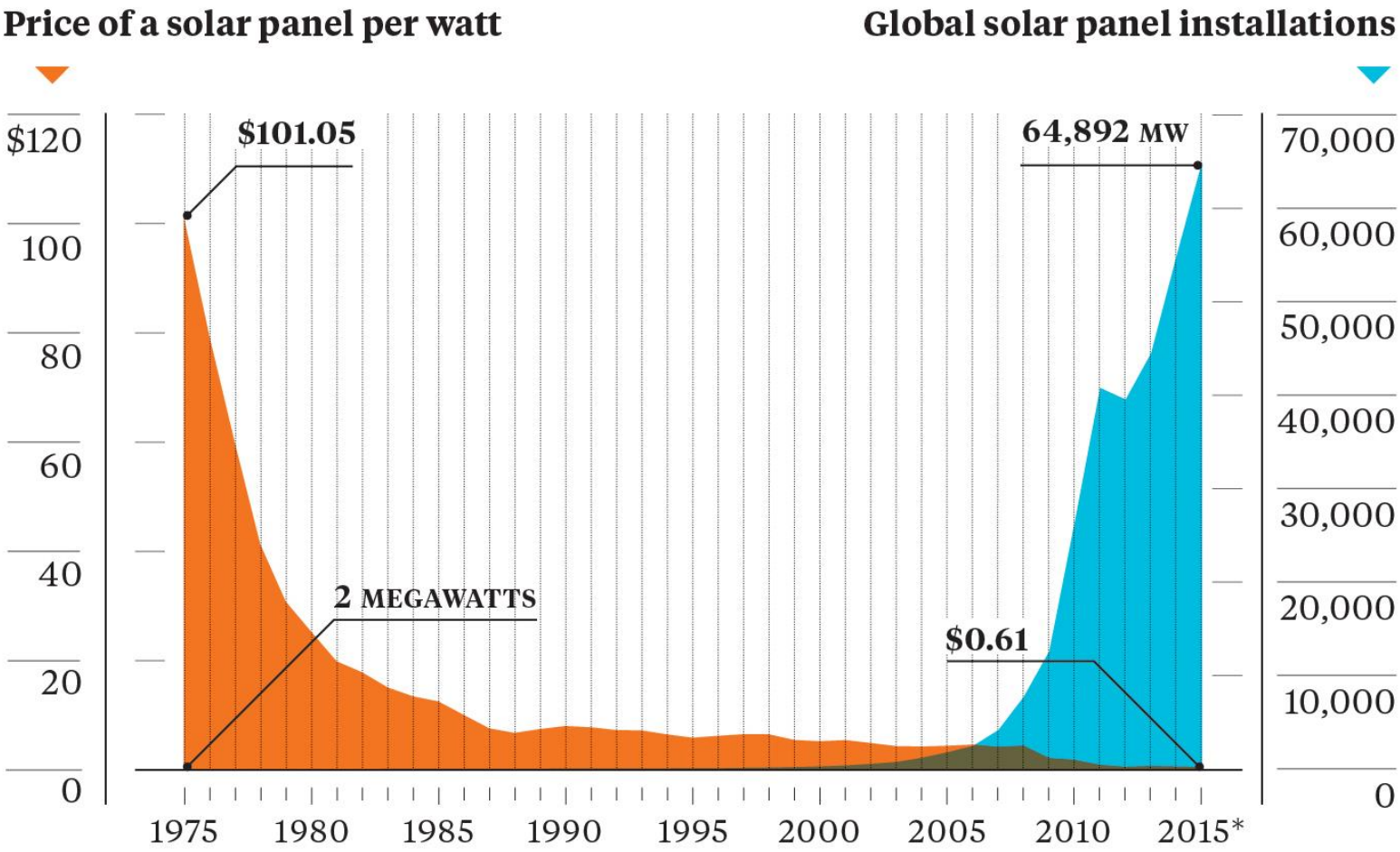


Energy Policy 123 (2018) 700–710; 707

Drivers: technology

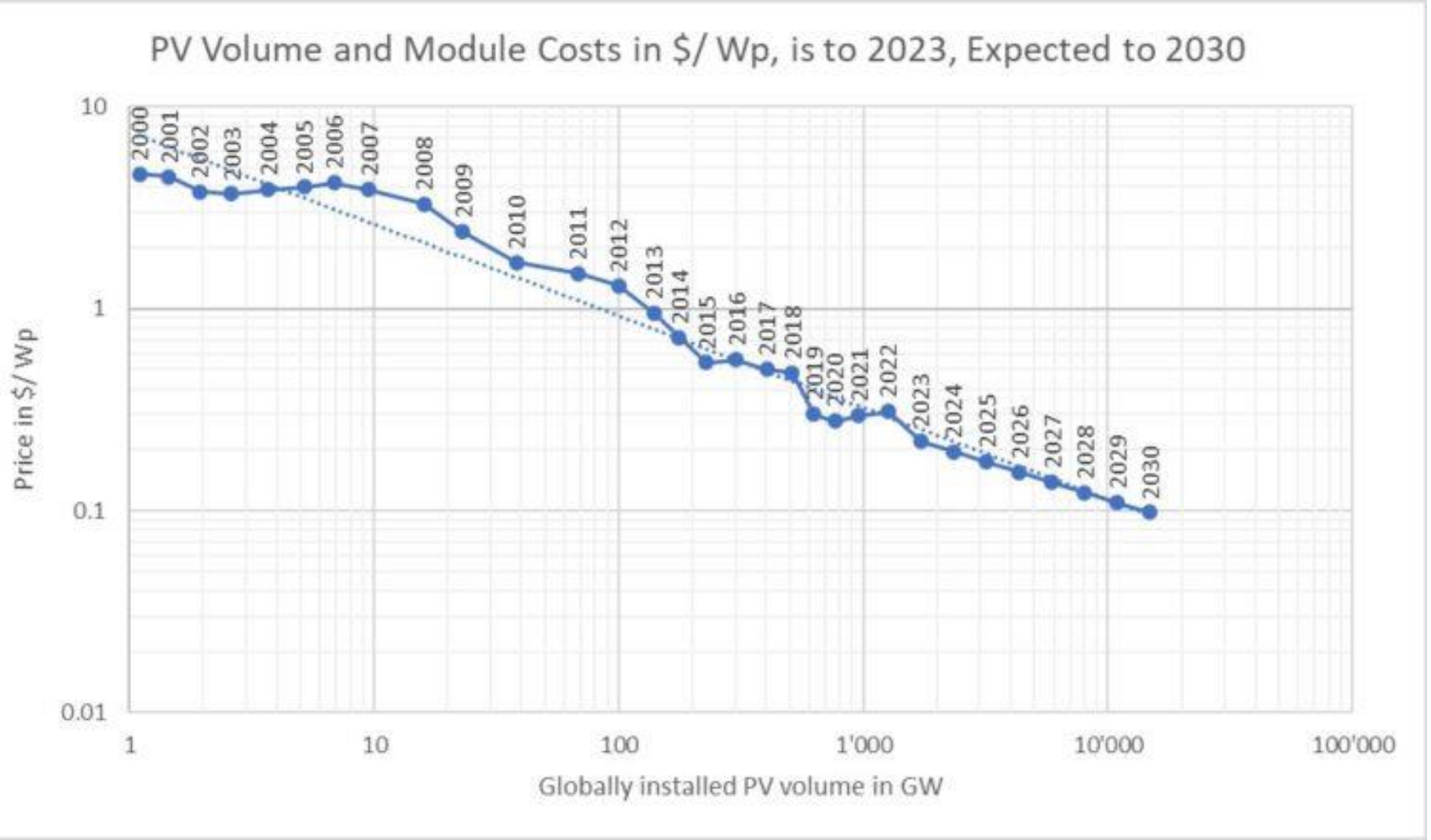


Drivers: economies of scale



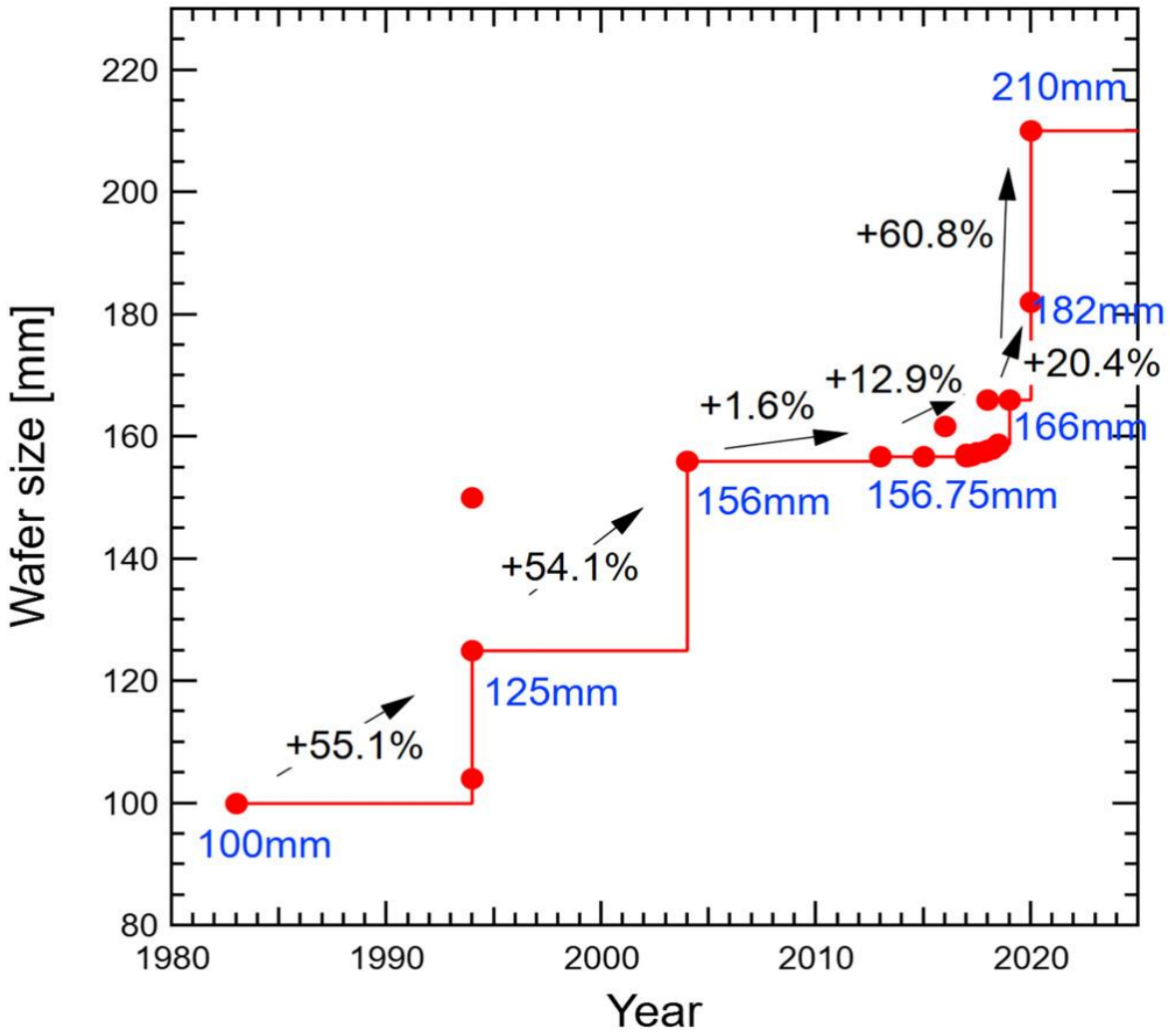
Drivers: economies of scale

PV fast development



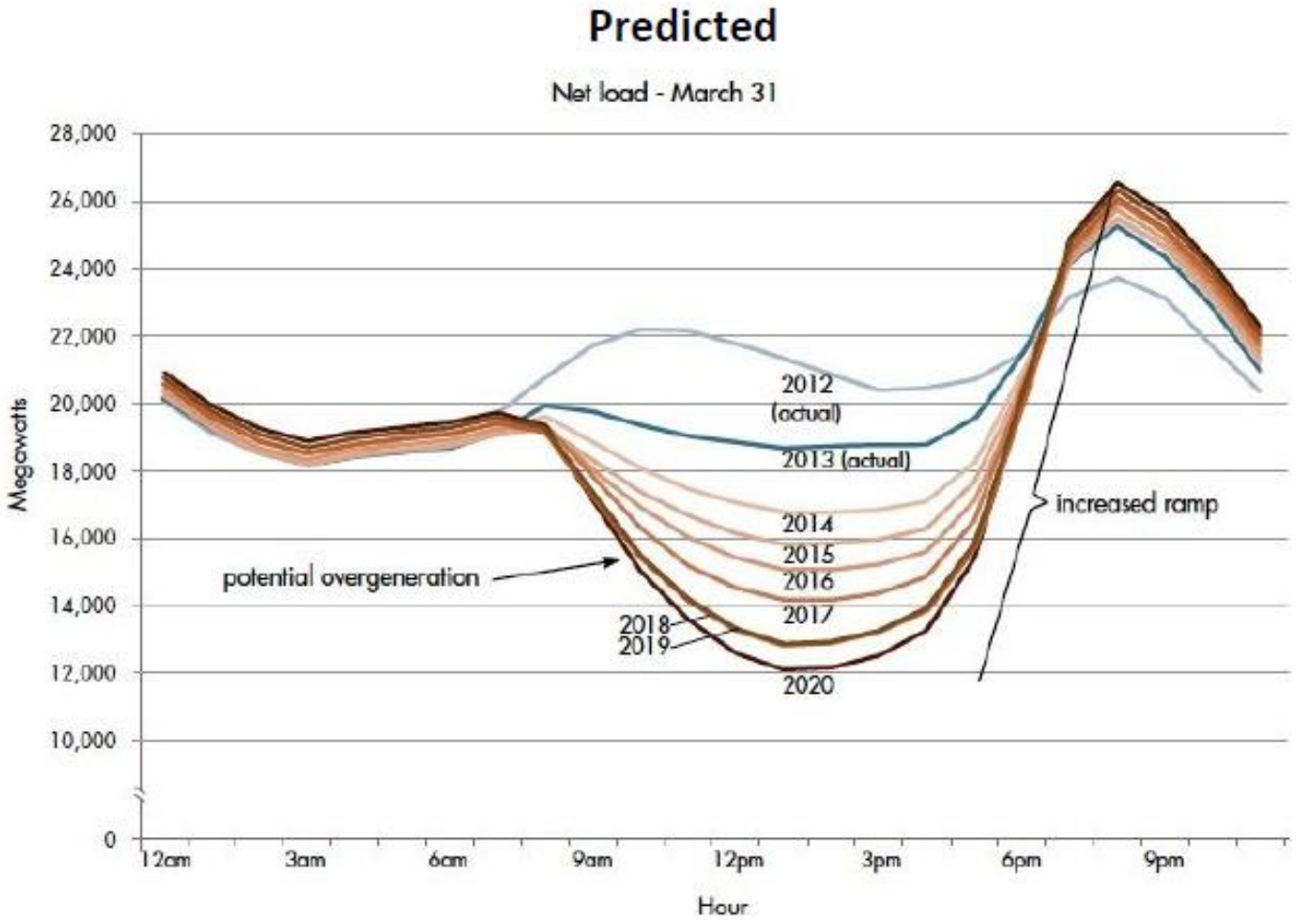
Technology evolution of the photovoltaic industry:
Learning from history and recent progress

Wafer size over time

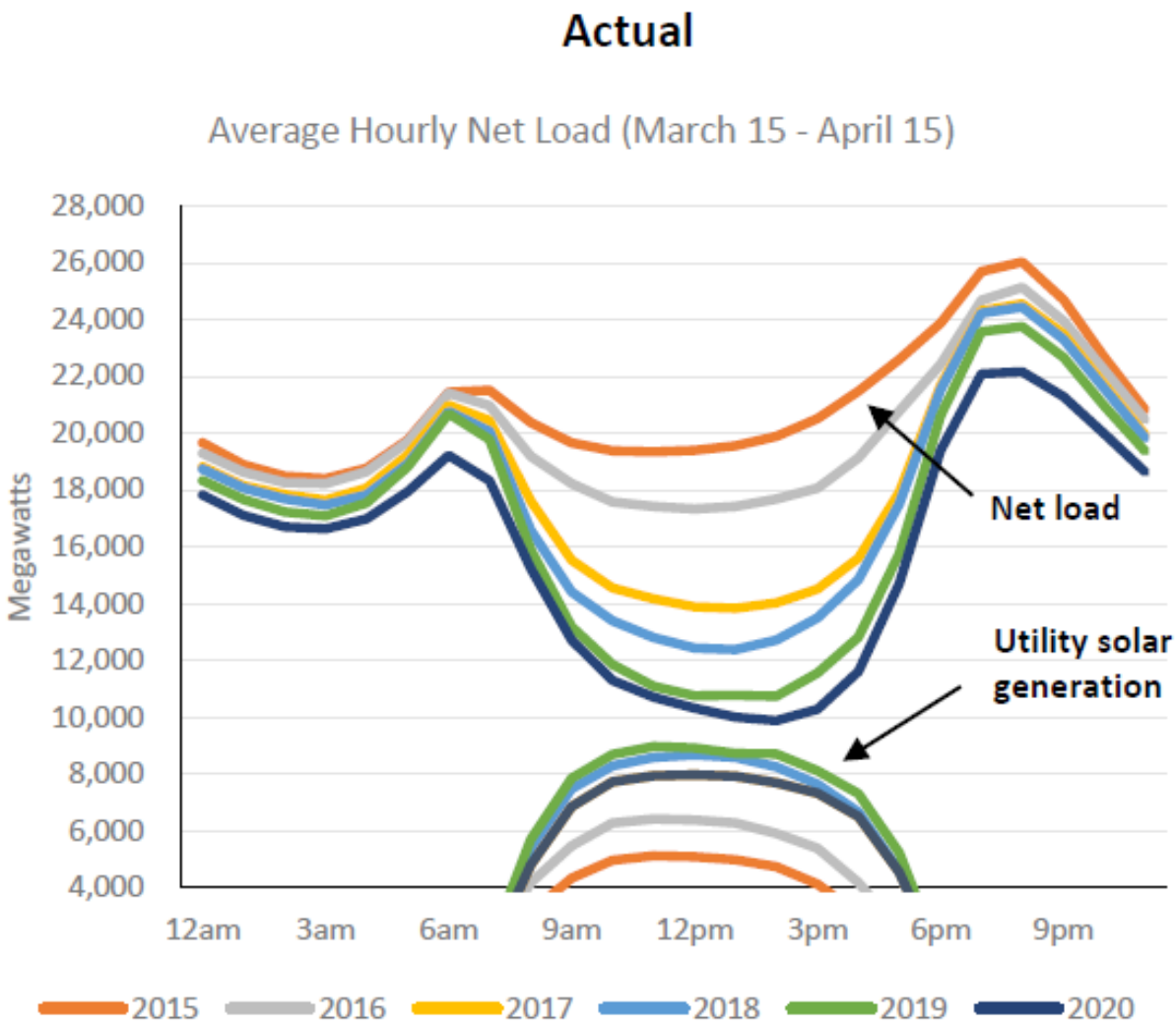


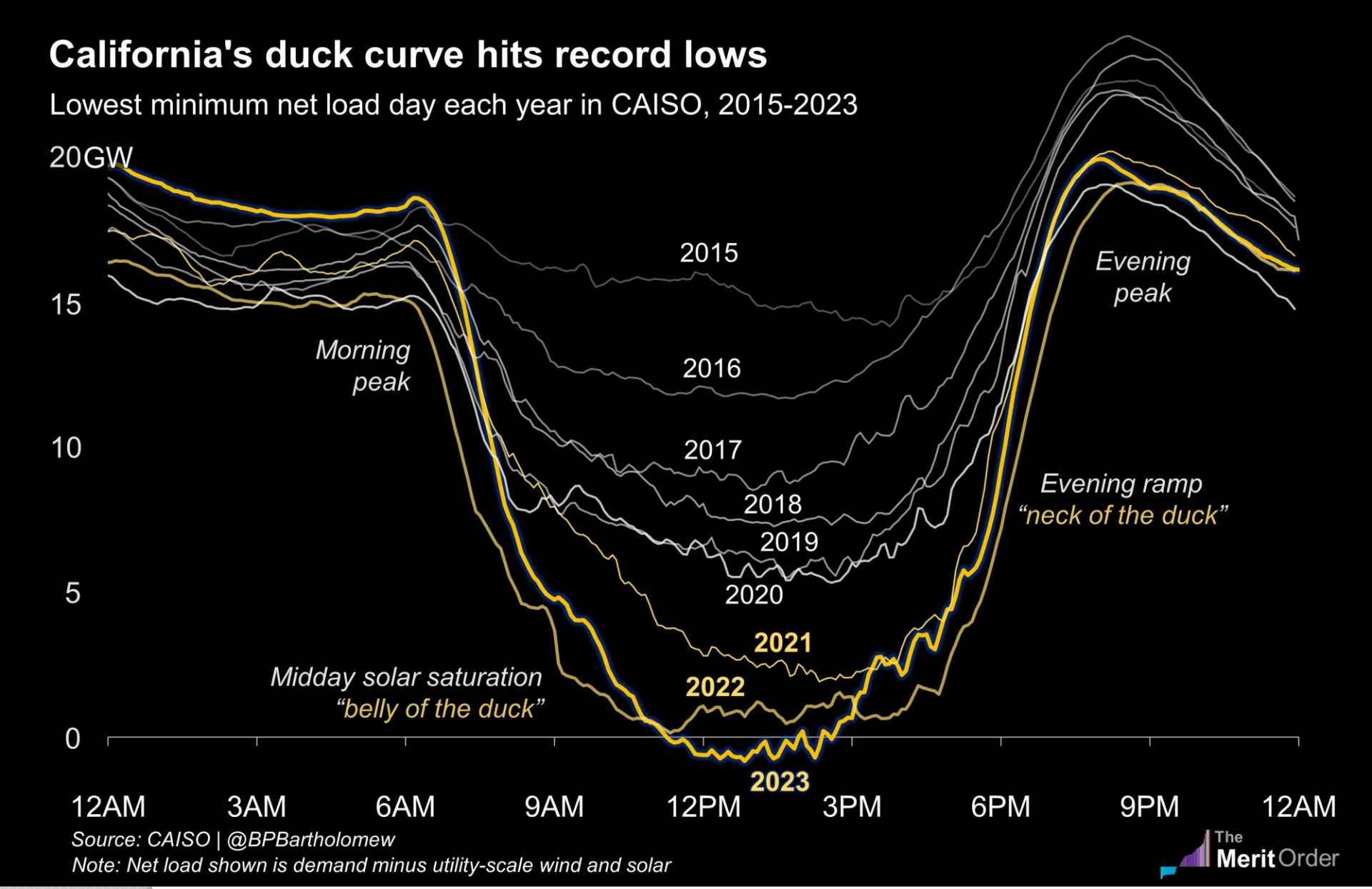
Progress in Photovoltaics, Volume: 31, Issue: 2, Pages: 113-133, First published: 02 August 2022, DOI: (10.1002/pip.3613)

Impacts of lots of PV

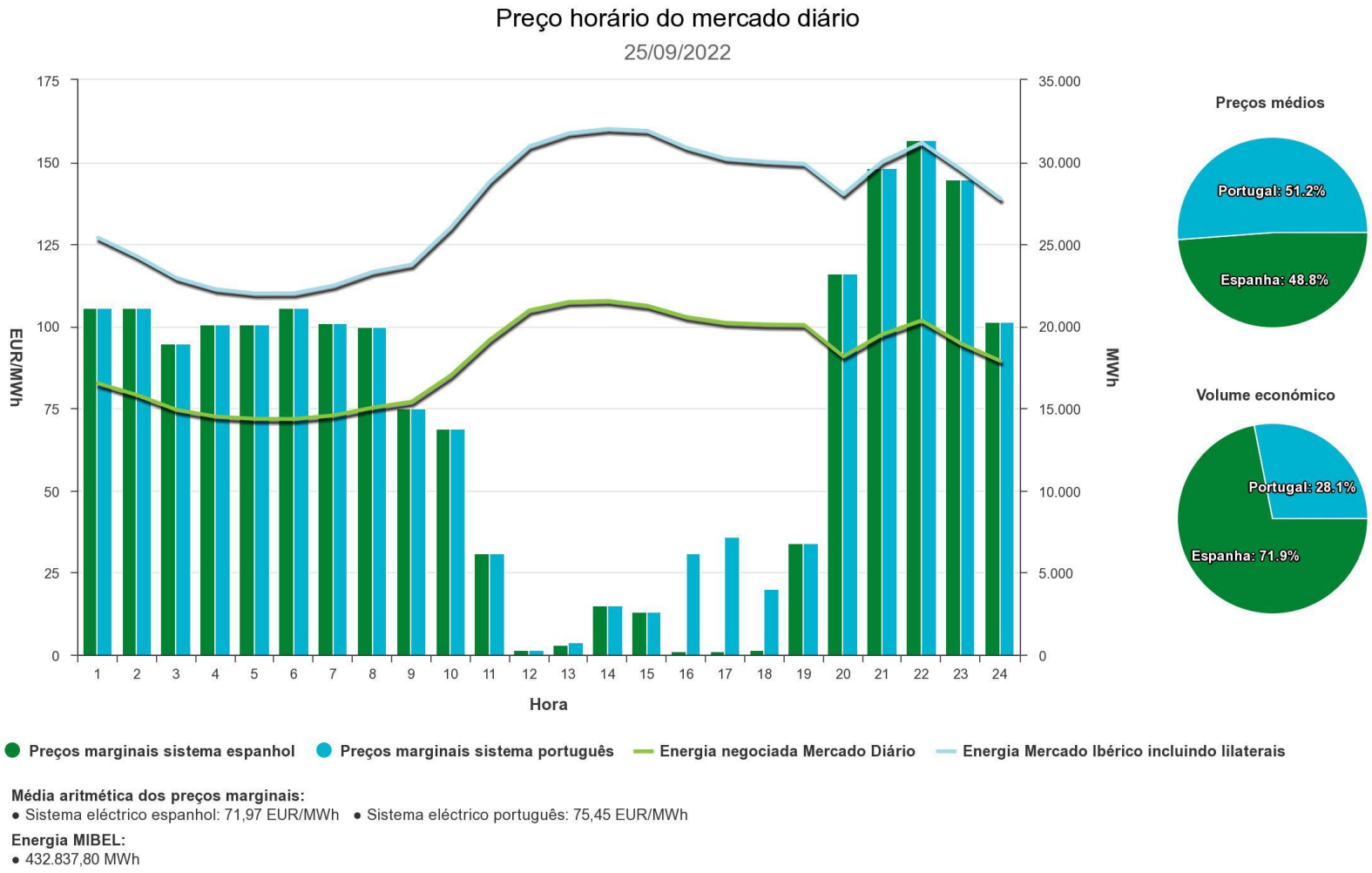


Impacts of lots of PV




California's duck curve hits record lows
Lowest minimum net load day each year in CAISO, 2015-2023
20GW
15
10
5
0
2015
2016
2017
2018
2019
2020
2021
2022
2023
Morning peak
Evening peak
Evening ramp "neck of the duck"
Midday solar saturation "belly of the duck"
12AM
3AM
6AM
9AM
12PM
3PM
6PM
9PM
12AM
Source: CAISO | @BPBartholomew
Note: Net load shown is demand minus utility-scale wind and solar
The Merit Order

Impacts of lots of PV



Média aritmética dos preços marginais:
- Sistema eléctrico espanhol: 71,97 EUR/MWh
- Sistema eléctrico português: 75,45 EUR/MWh

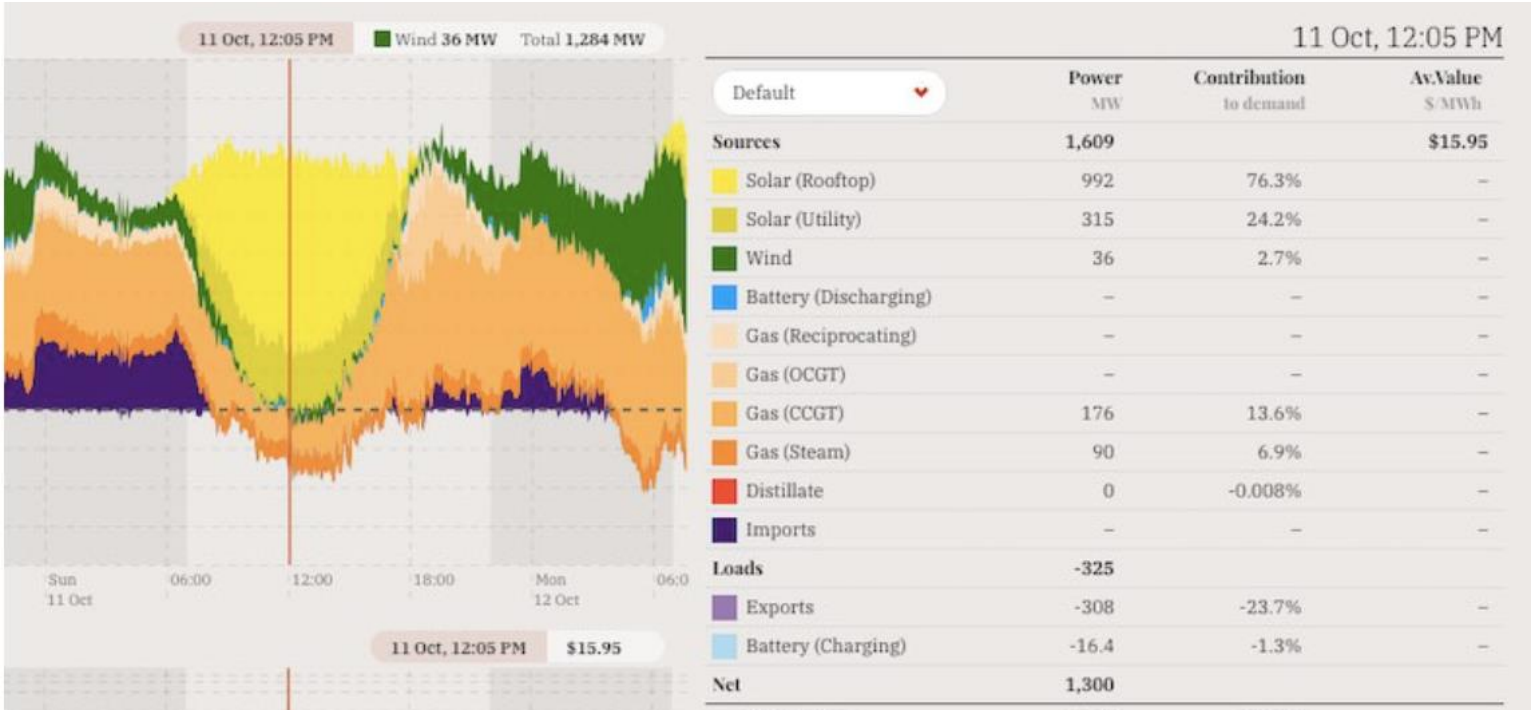
Energia MIBEL:
- 432.837,80 MWh

Impacts of lots of PV

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

Giles Parkinson 12 October 2020 46

Share Tweet 0



Brief history (2): markets

1990's – Japan

- Subsidies to installation

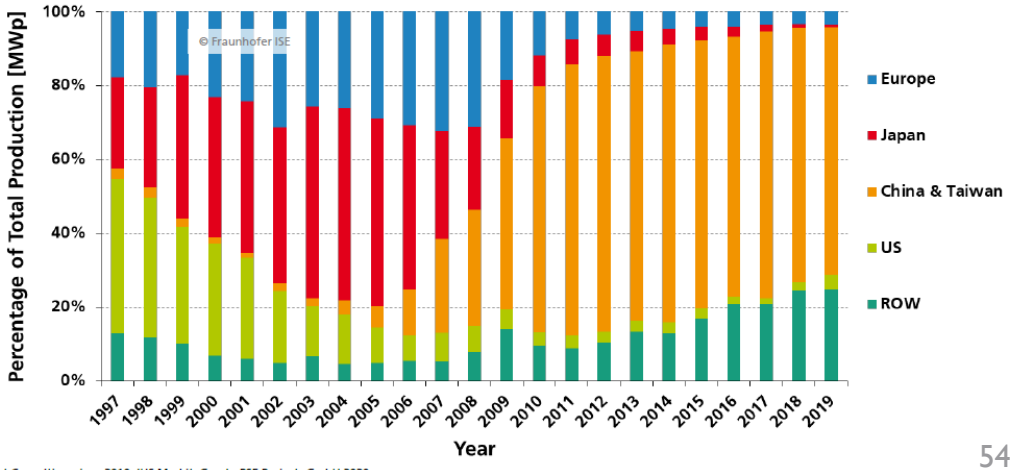
2000's – Germany (and the rest of EU)

- 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)

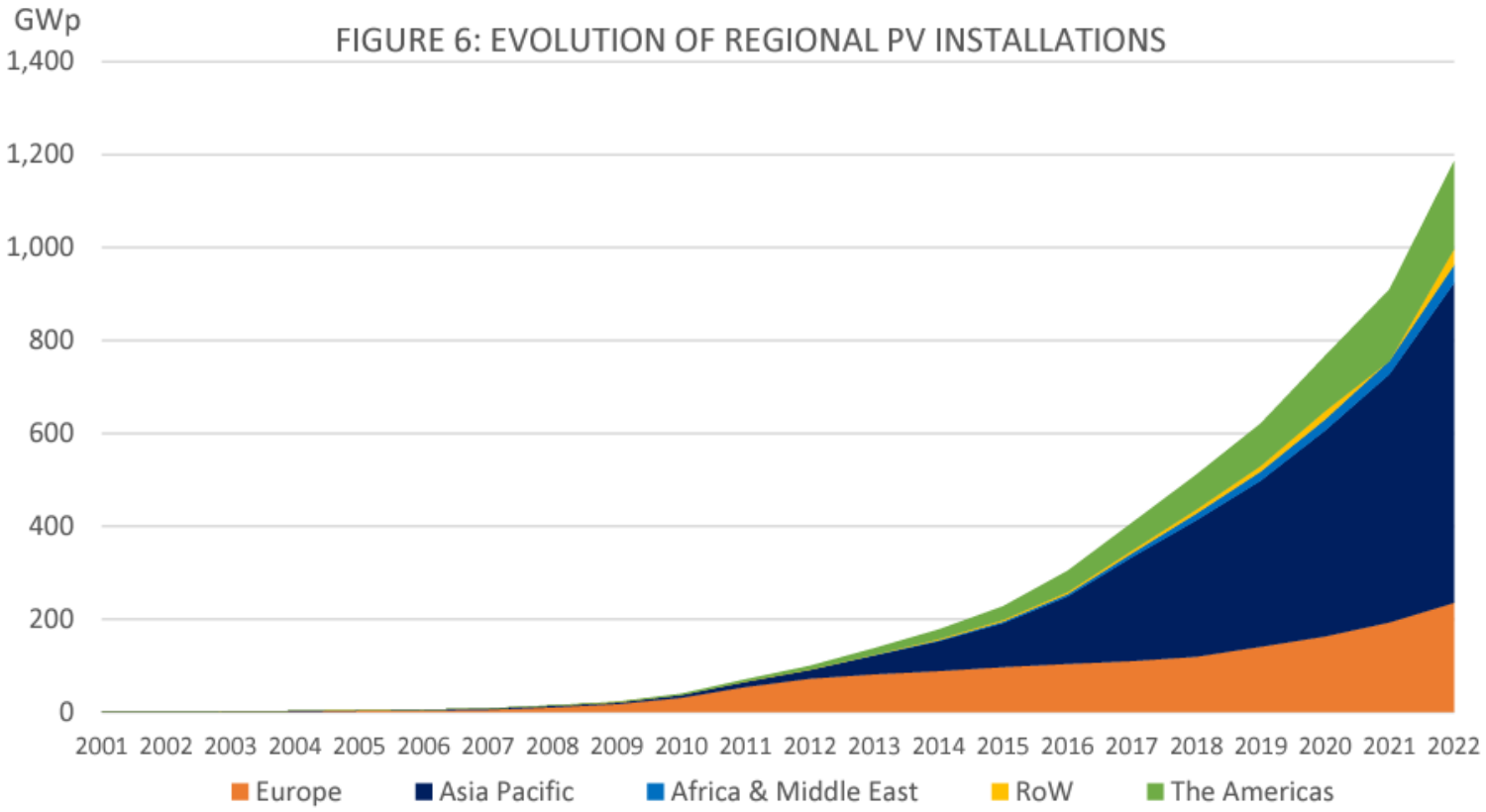
Feedin tariff

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 market

TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2022

FOR ANNUAL INSTALLED CAPACITY				FOR CUMULATIVE CAPACITY			
1		China	106 GW	1		China	414,5 GW
(2)		*European Union*	*38,7 GW*	*(2)*		*European Union*	*209,3 GW*
2		USA	18,6 GW	2		USA	141,6 GW
3		India	18,1 GW	3		Japan	84,9 GW
4		Brazil	9,9 GW	4		India	79,1 GW
5		Spain	8,1 GW	5		Germany	67,2 GW
6		Germany	7,5 GW	6		Australia	30 GW
7		Japan	6,5 GW	7		Spain	26,6 GW
8		Poland	4,9 GW	8		Italy	25 GW
9		Australia	3,9 GW	9		Korea	24,8 GW
10		Netherlands	3,9 GW	10		Brazil	23,6 GW

China is largest producer

FIGURE 4.2: SHARE OF PV POLYSILICON PRODUCTION IN 2019

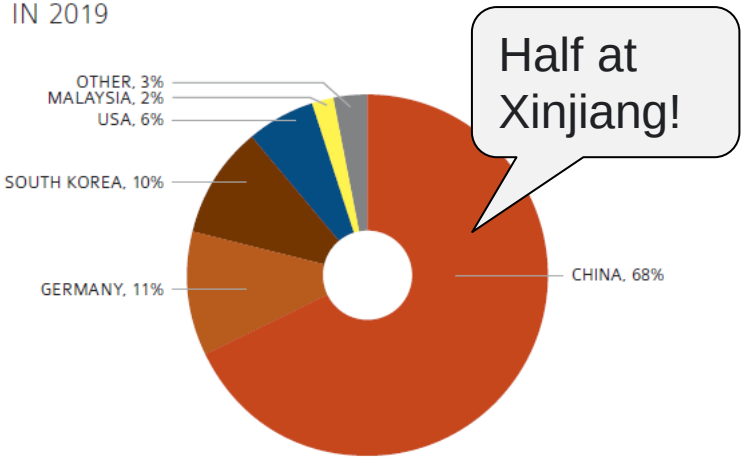


FIGURE 4.3: SHARE OF PV WAFERS PRODUCTION IN 2019

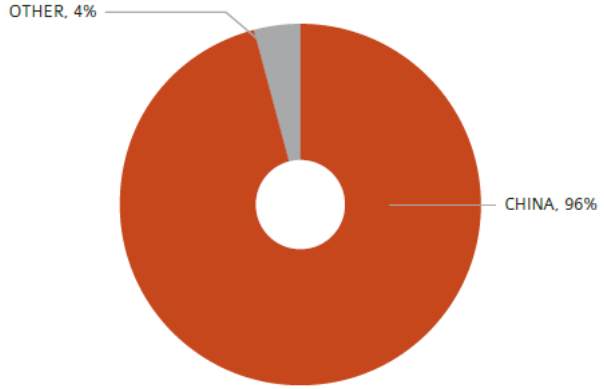


FIGURE 4.4: SHARE OF PV CELLS PRODUCTION IN 2019

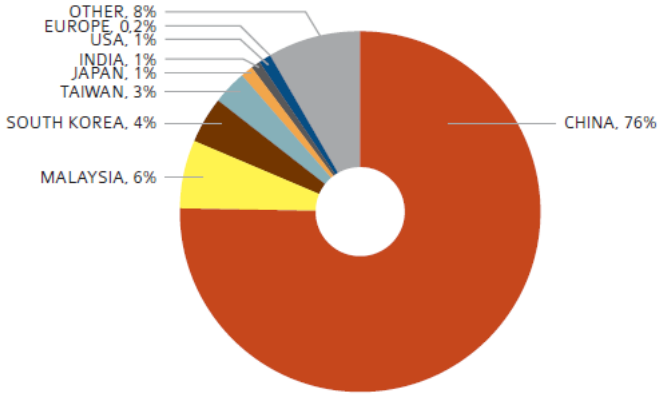
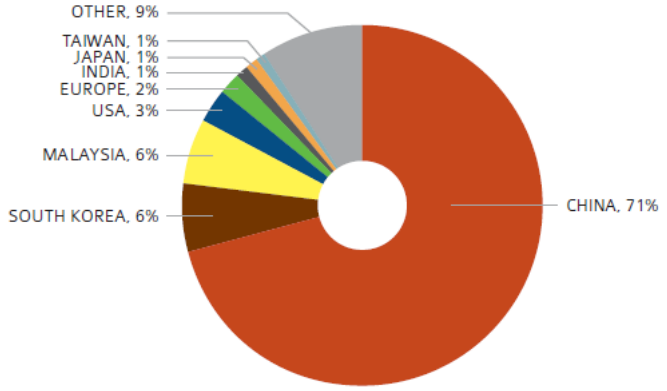
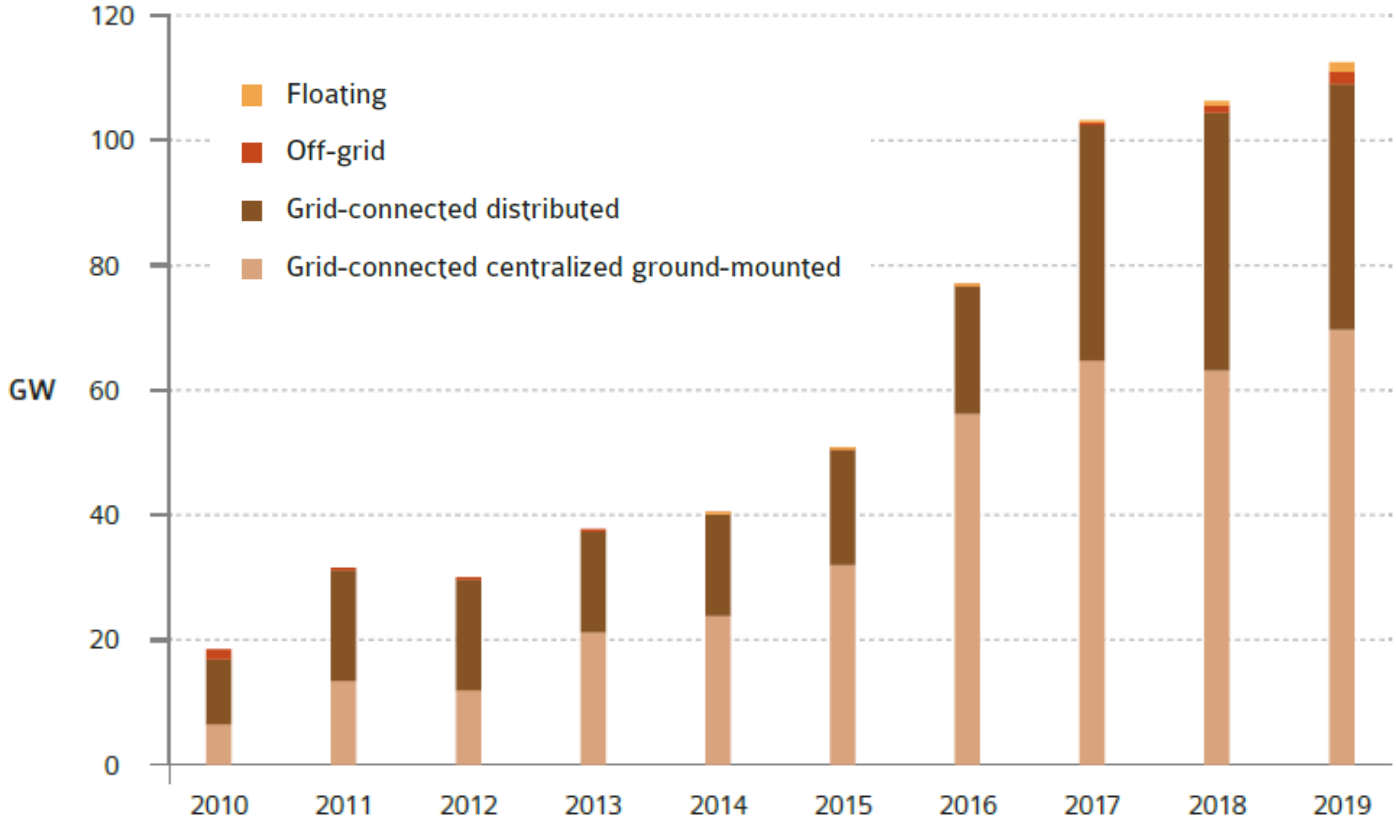


FIGURE 4.5: SHARE OF PV MODULES PRODUCTION IN 2019



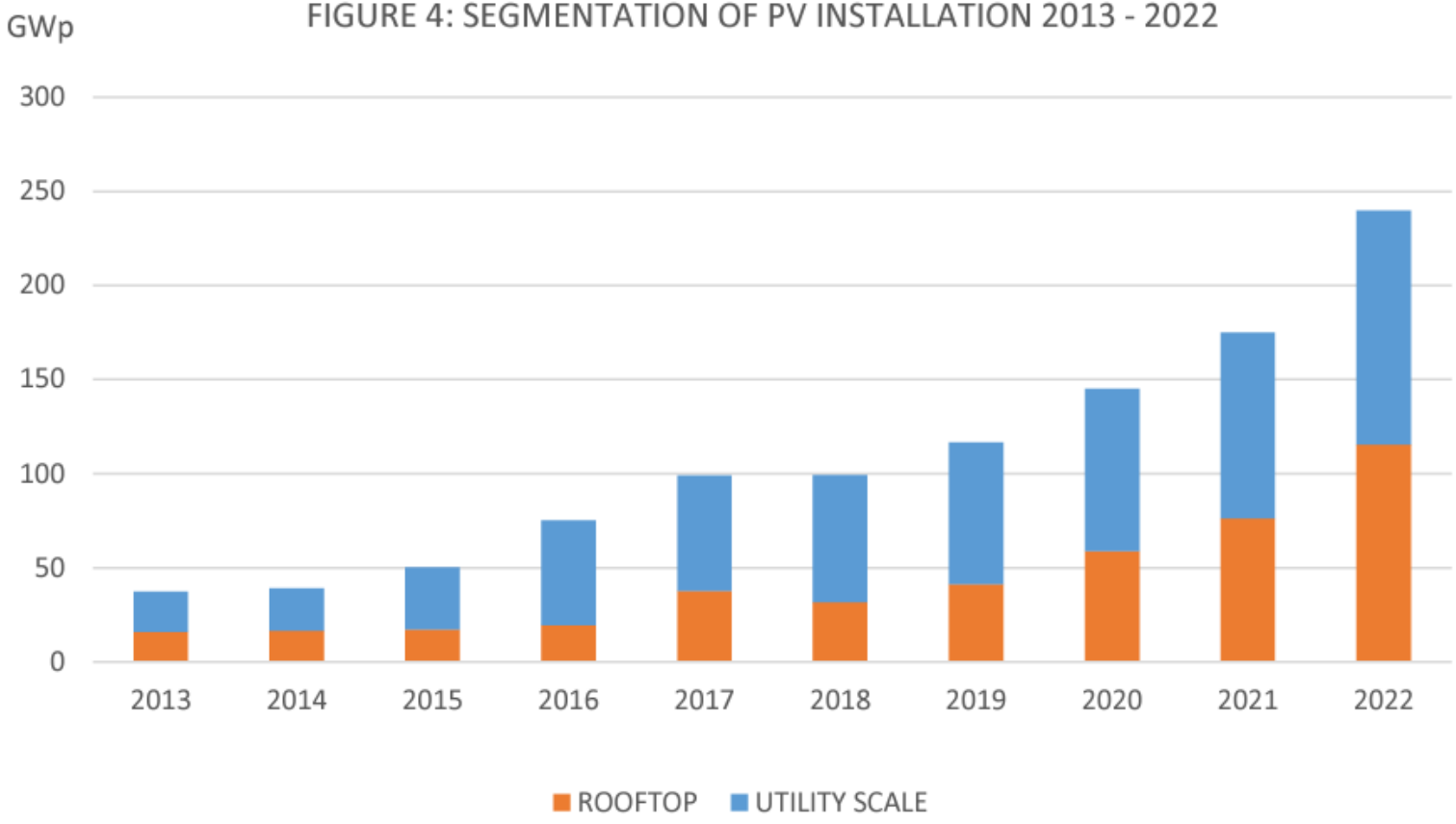
PV market today

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



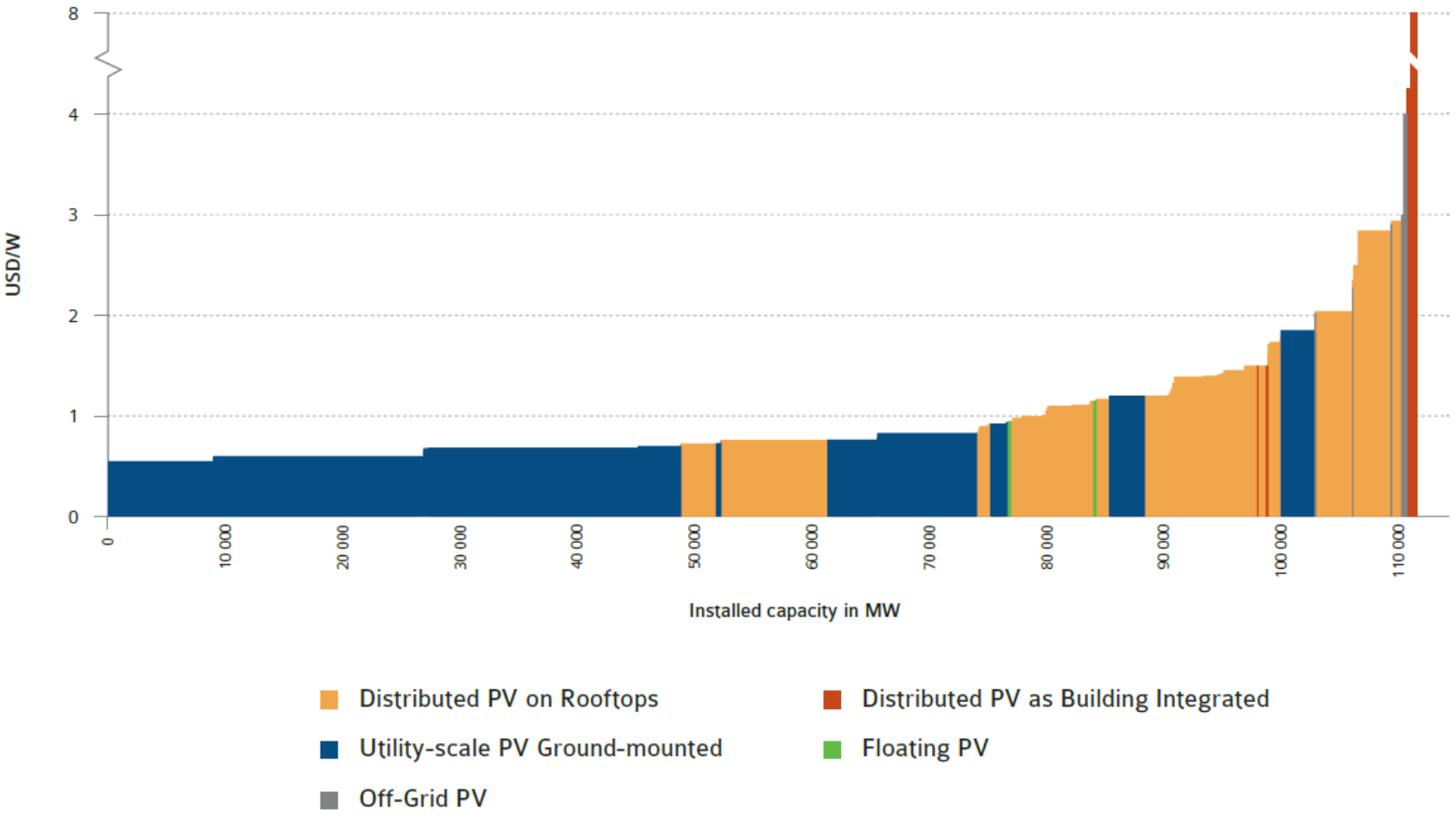
All sectors growing but
Utility scale PV is the largest segment
Off grid solar is almost negligible

FIGURE 4: SEGMENTATION OF PV INSTALLATION 2013 - 2022



PV market today

FIGURE 6.3: 2019 PV MARKET COSTS RANGES



PV market today

FIGURE 6.8: UTILITY-SCALE SYSTEM HARDWARE COST BREAKDOWN

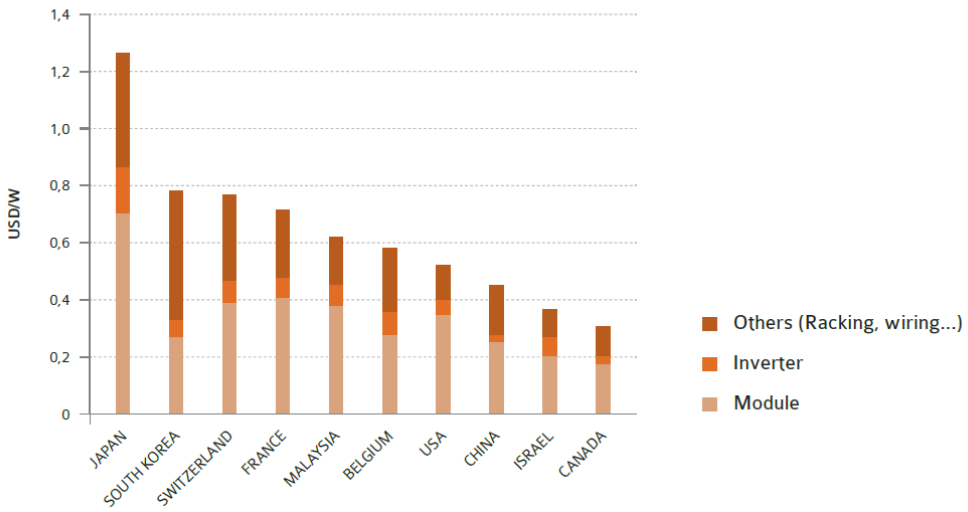
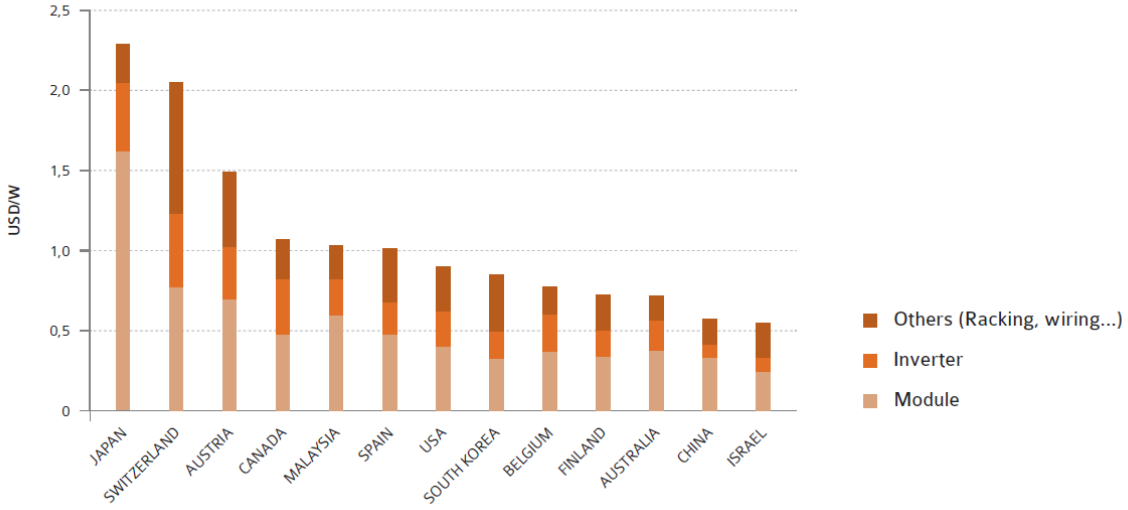
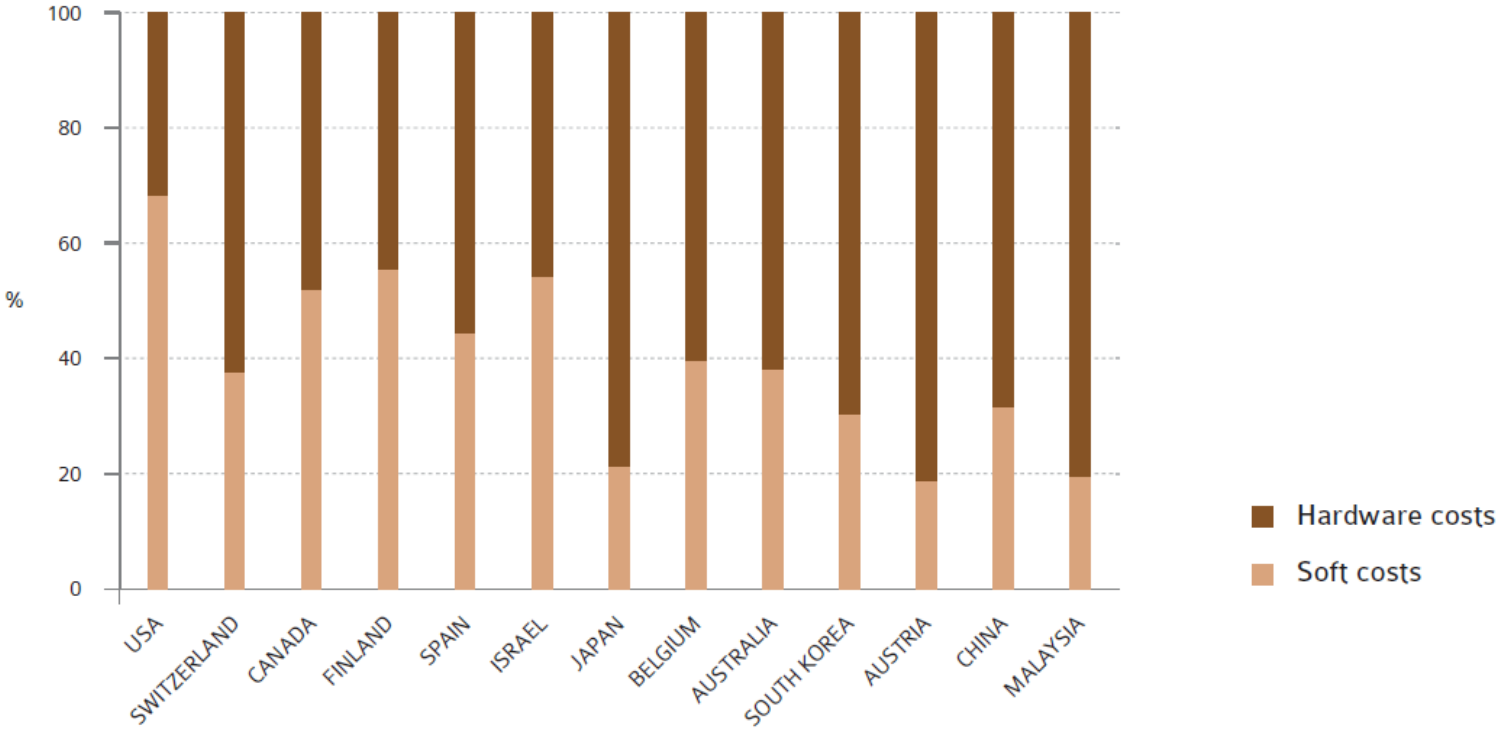


FIGURE 6.6: RESIDENTIAL SYSTEM HARDWARE COST BREAKDOWN



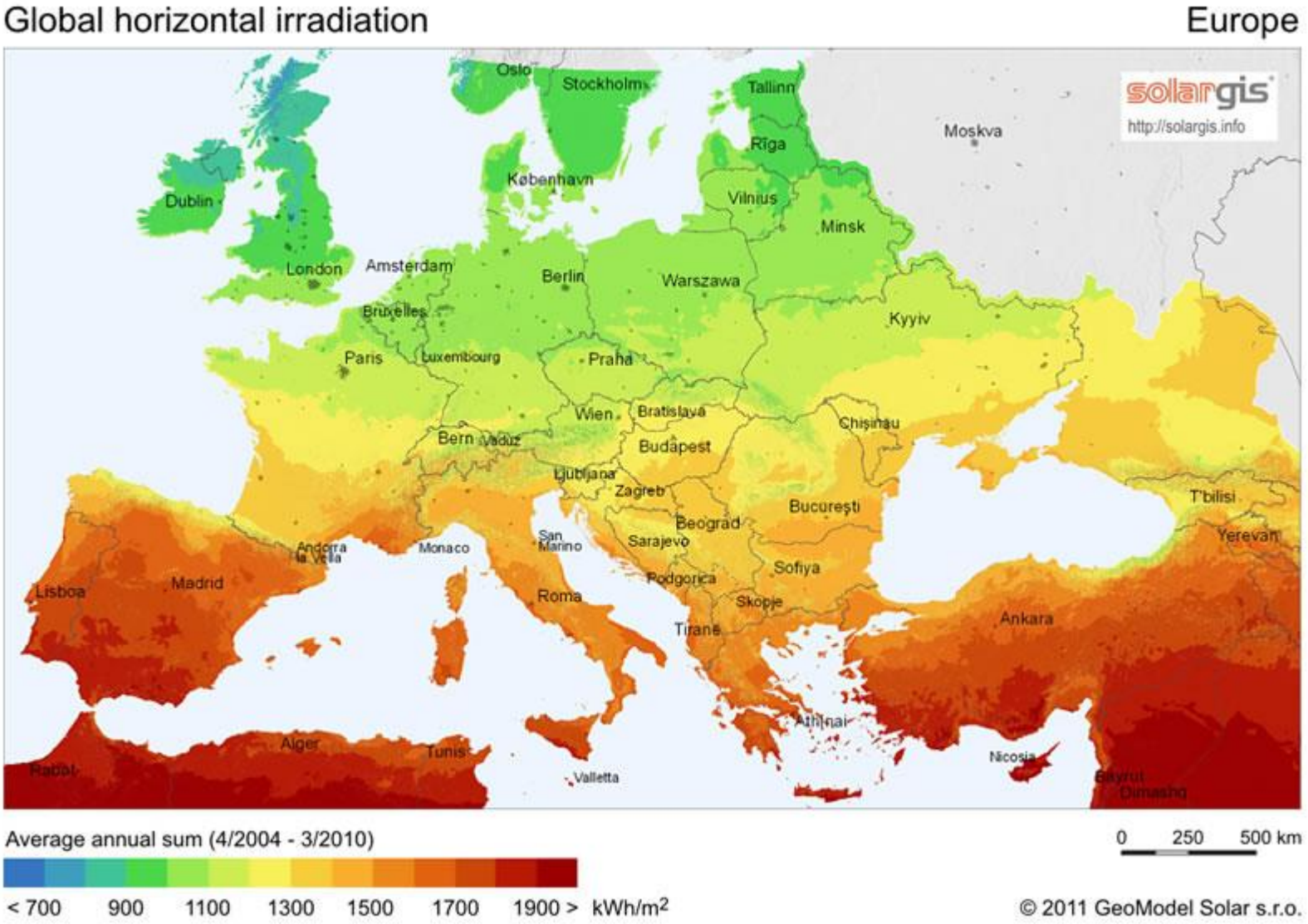
PV market today

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

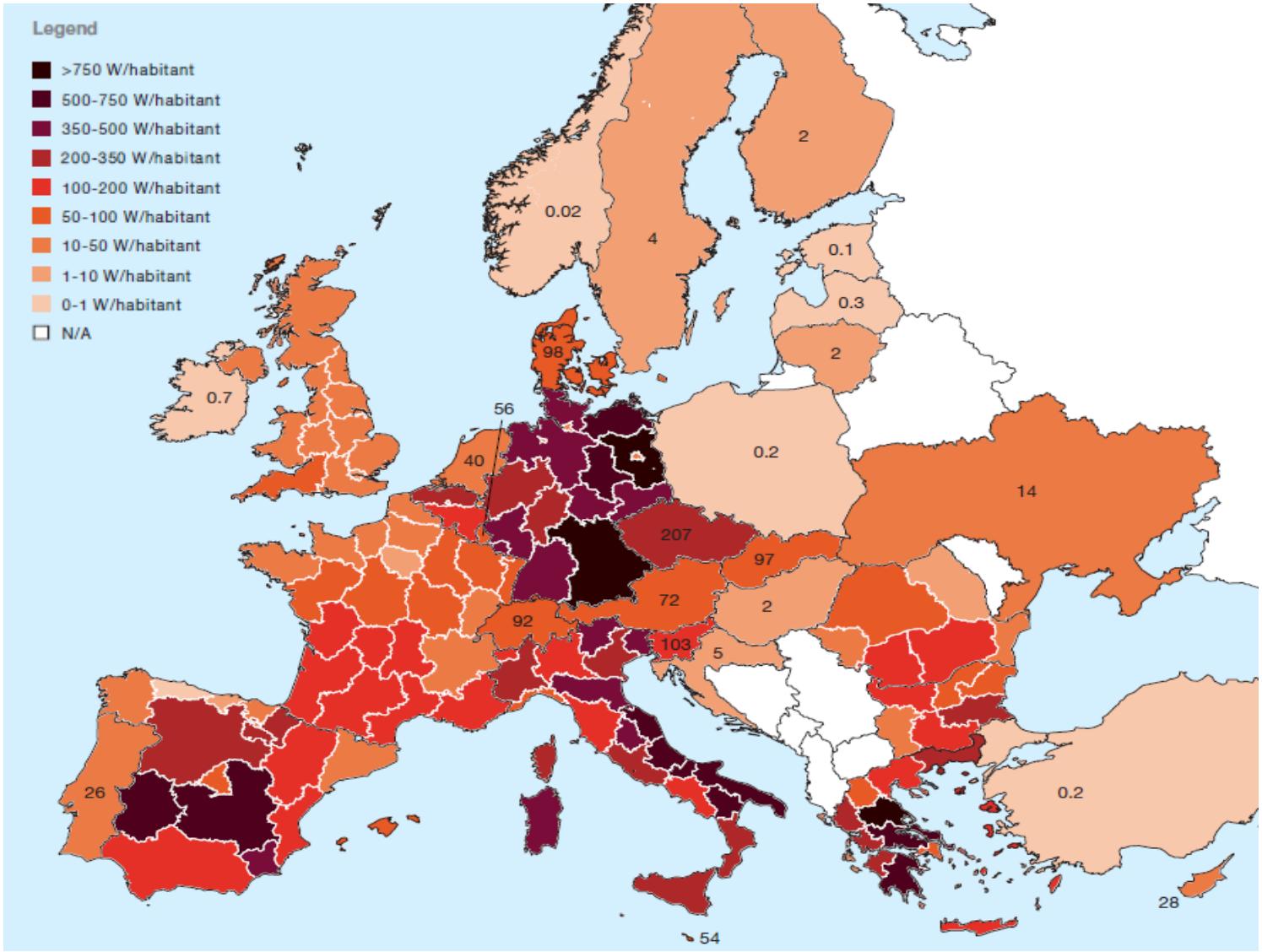


PV in Portugal

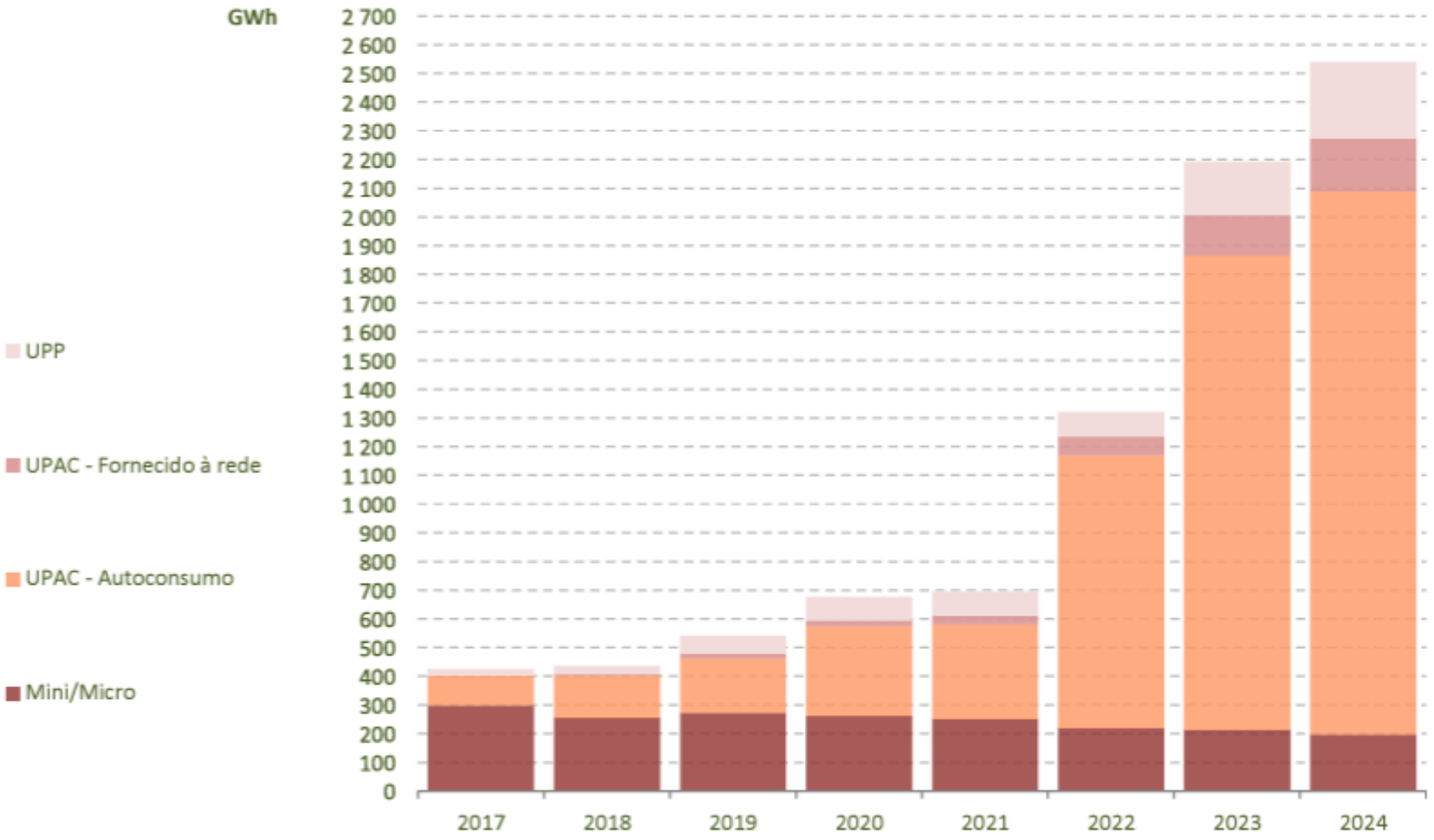
High resource



Low installed capacity

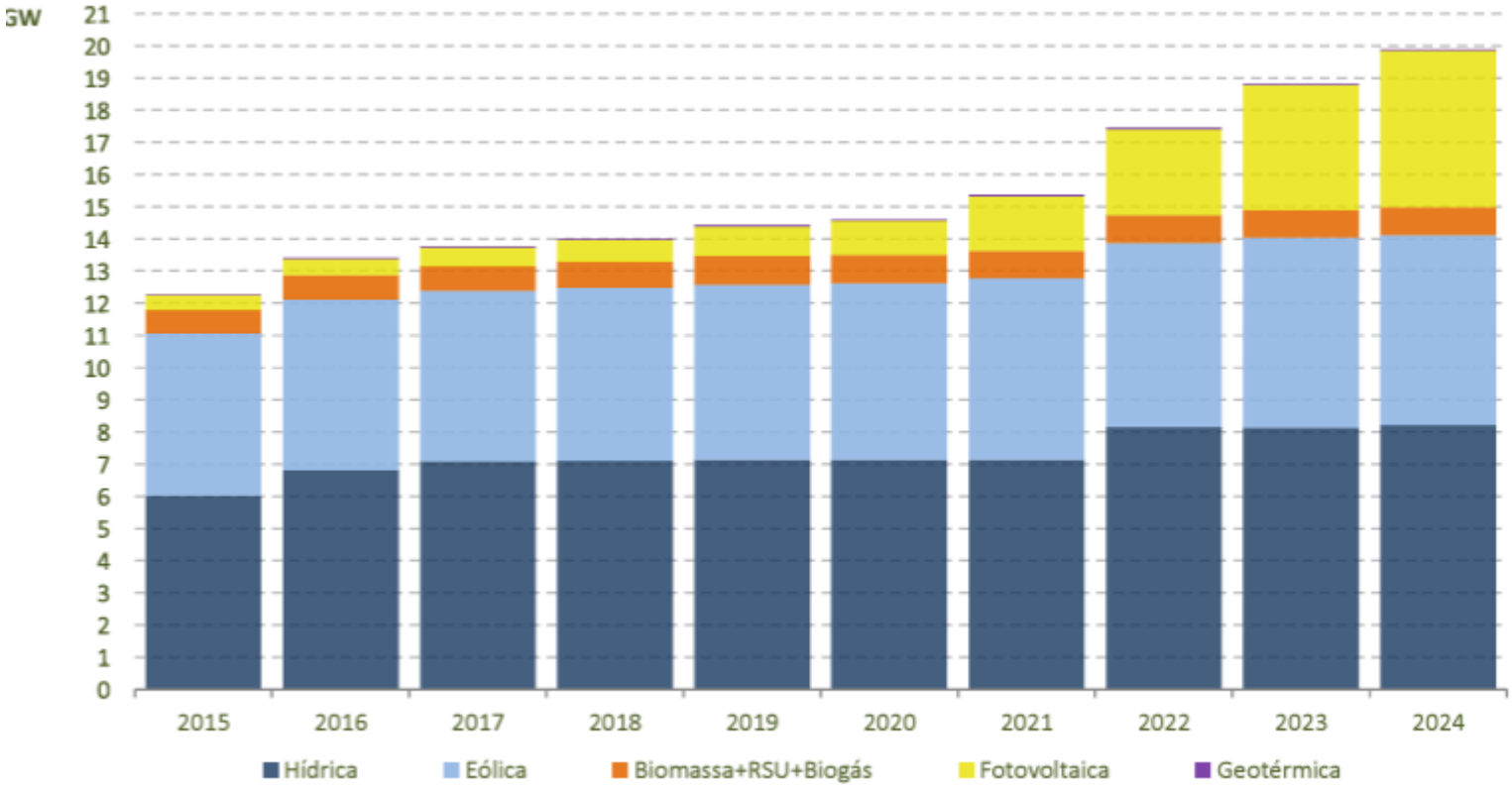


Increasing capacity



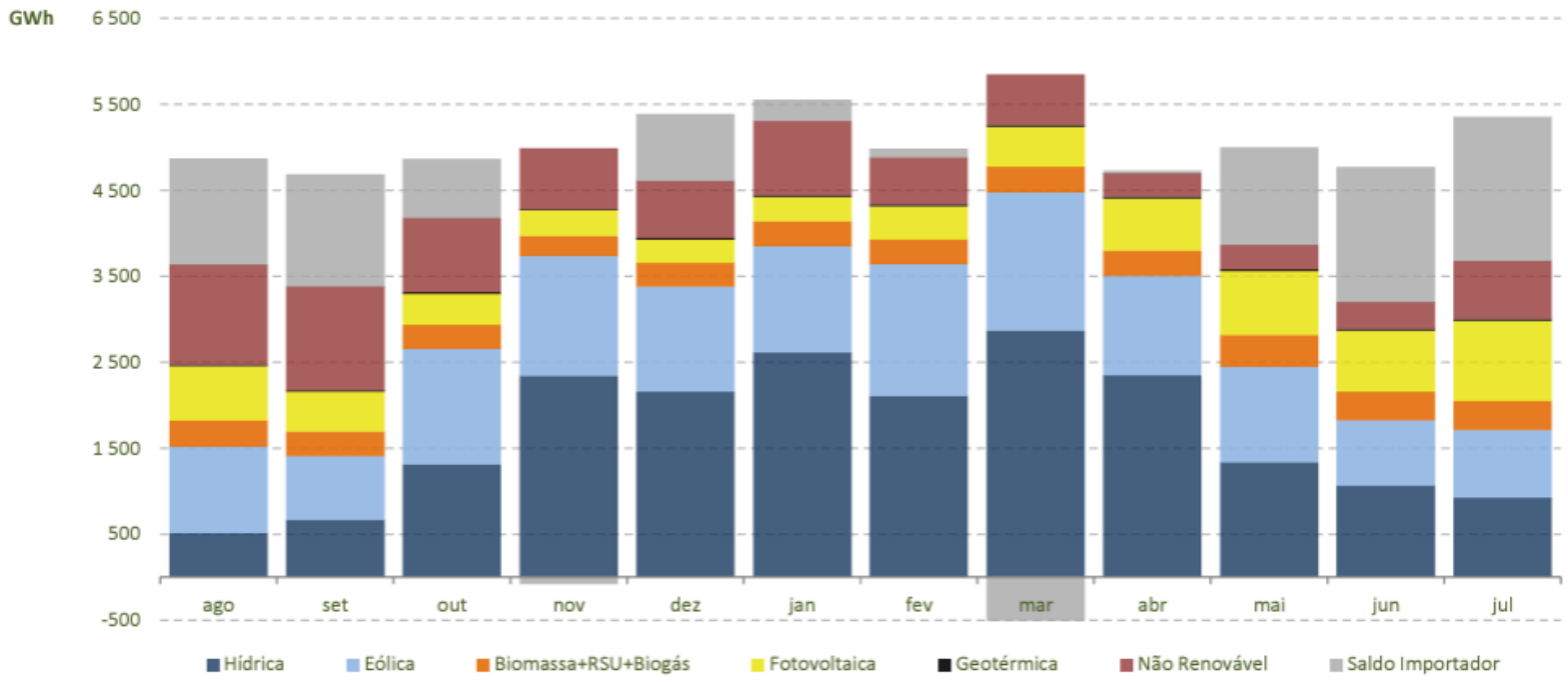
Estatísticas rápidas, DEGEG, Julho 2024

Only a fraction of the RES fleet



Estatísticas rápidas, DEGEG, Julho 2024

Only a fraction of the RES fleet



Estatísticas rápidas, DEGEG, Julho 2020

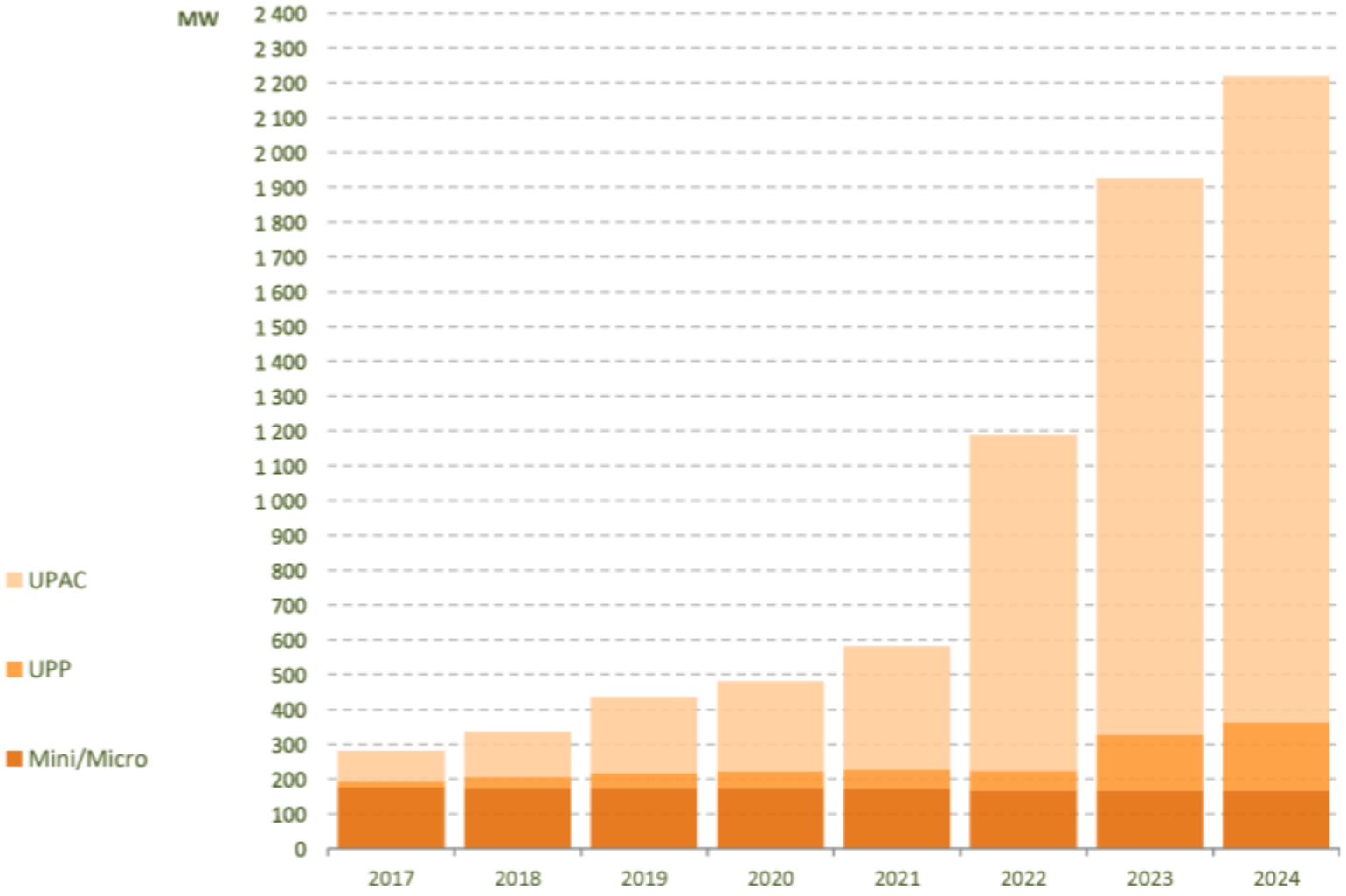
Legal landscape

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



Estatísticas rápidas, DEGEG, Julho 2024

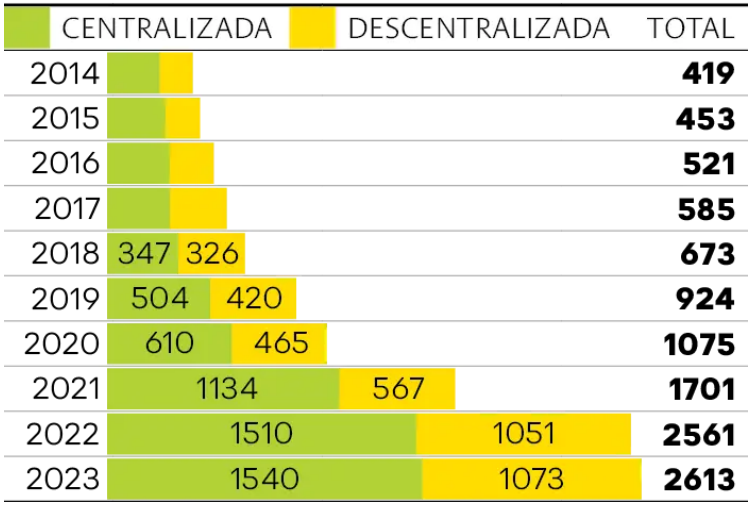
Big PV


Global
Germany
Spain
France
USA
Mexico
Latin America
Australia
India
China
pv magazine
Subscriptions
News
Features
Events
Awards
Partner news
pv magazine test
Print archive
About
Advertise
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
Keep up to date
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.
Email *

Big PV

EVOLUÇÃO DA CAPACIDADE INSTALADA FOTOVOLTAICA

Em megawatts (MW)



MAIORES CENTRAIS SOLARES LICENCIADAS

CENTRAL E MUNICÍPIO	POTÊNCIA (MW)	PESO NO CONSUMO*	ÁREA A OCUPAR (HA)
THSIS (SANTIAGO DO CACÉM)			
	1242	4,26%	1000
S. MIGUEL DO PINHEIRO (MÉRTOLA)			
	558	2%	495
CASAL VALEIRA/VALE PEQUENO (CHAMUSCA)			
	375	1,47%	395
MOGADOURO			
	370	1,67%	620
BARTOLOMEU DIAS (OURIQUE)			
	370	1,53%	440
CERCAL (SANTIAGO DO CACÉM)			
	282	1,18%	323
PAIVA (VILA NOVA DE PAIVA)			
	268	0,98%	548
OURIQUE I			
	250	1,09%	299
ARROCHAIS (MOURA)			
	240	0,84%	270
ESCALABIS (SANTARÉM E CARTAXO)			
	228	0,77%	116
TOTAL A CONSTRUIR	**4183**	**15,79%**	**4506**

* Peso no consumo elétrico nacional anual (valores de 2022)

FONTE: ESTUDOS DE IMPACTO AMBIENTAL/APA

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

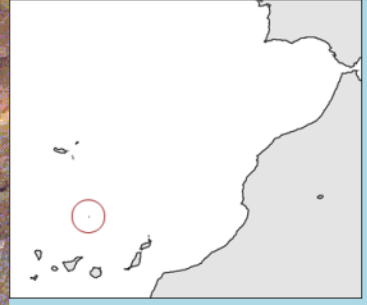
Torre Bela. Abate de animais para construção de central fotovoltaica começou há meses

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".



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
- Huge solar potential
- Large scale utility scale PV 'exploding'
- Main limitation: access to grid
- Distributed PV lagging
- Public acceptance decreasing