

ENERGIA SOLAR

Energias Renováveis

Miguel Centeno Brito

Produção
electricidade
por via
fotovoltaica a
partir de
radiação solar

Radiação solar média em Portugal:

1500 kWh/m²/ano

Com uma eficiência de conversão de 15%:

225 kWh/m²/ano

Consumo electricidade em 2010:

5.0 x10¹⁰ kWh/ano

Área total necessária para produzir 100% da
electricidade consumida em 2010:

220 km² 22m²/pessoa

Radiação solar média em Portugal:

Comprimento estradas em Portugal:

90000 km

Assumindo 10m de largura:

$$900 \text{ km}^2 = 9 \times 10^{2+6} = 9 \times 10^8 \text{ m}^2$$

Por habitante:

$$9 \times 10^8 / 10^7 = 90 \text{ m}^2 \text{ de asfalto per capita}$$

Área total necessária para produzir 100% da
electricidade consumida em 2010:

220 km²

22m²/pessoa

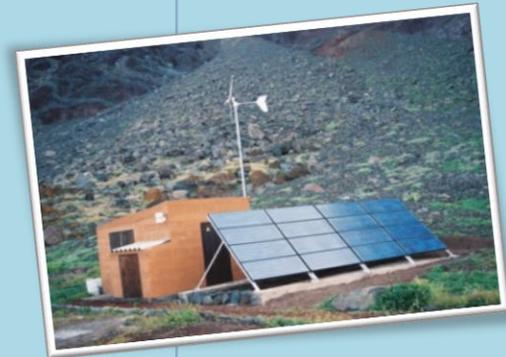
SOLARIA





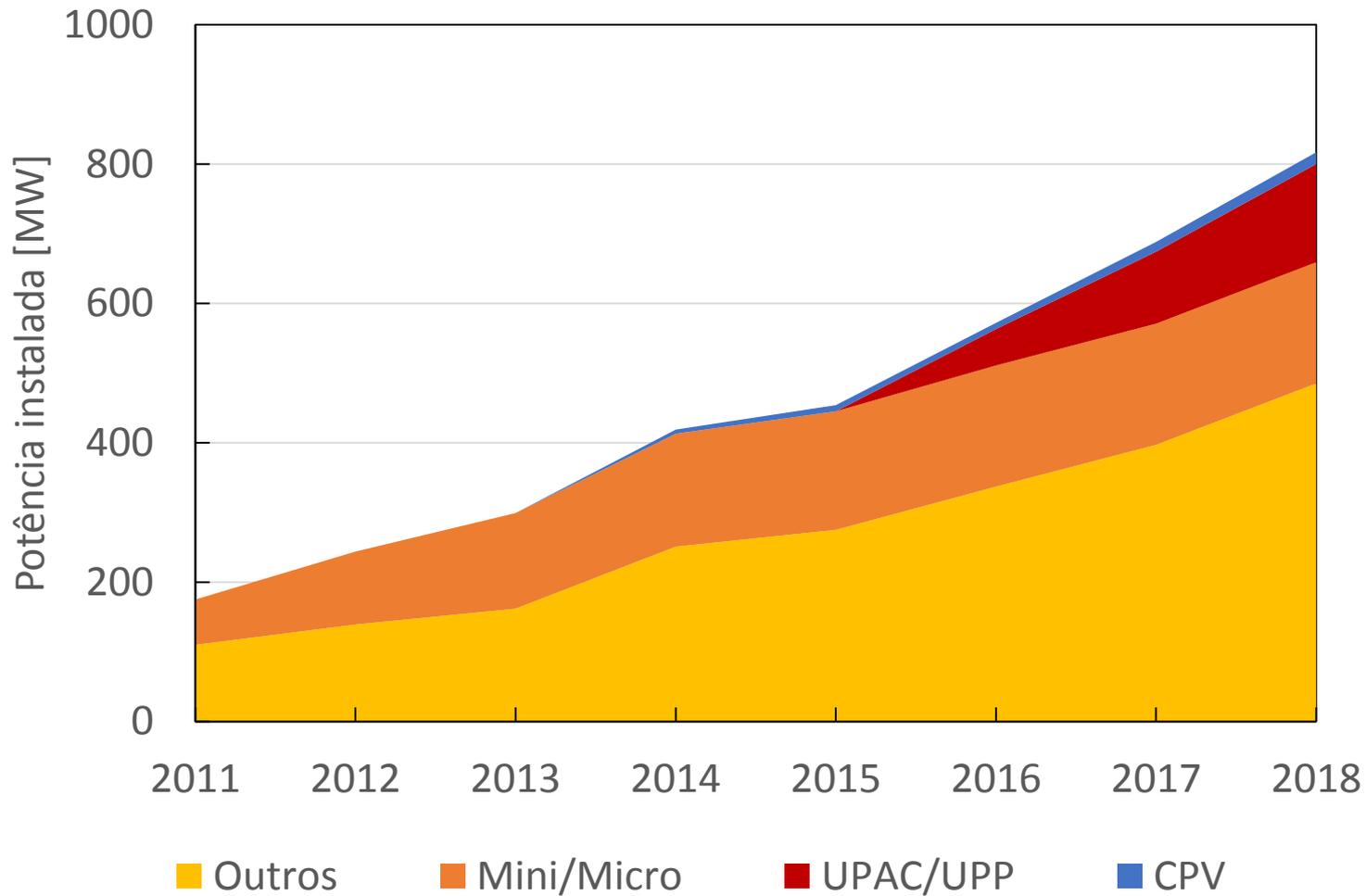


Oceano Atlântico
Atlantic Ocean









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

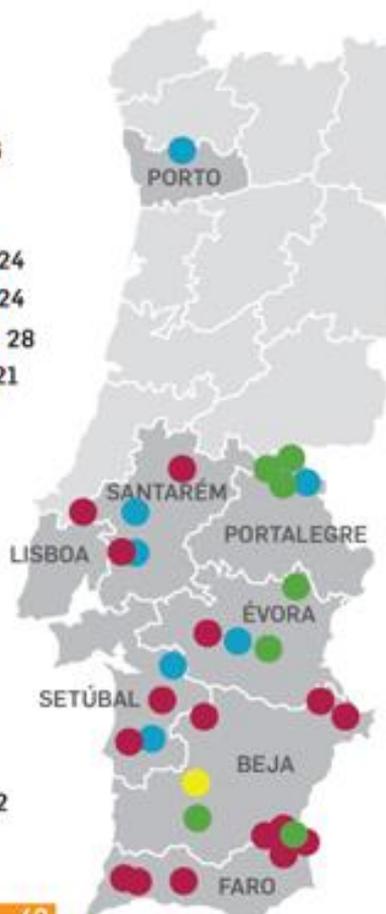
Évora 3	Expoentfokus	29
Montes Novos	Contrate o Sol	3
Vale de Moura	Hyperion	29

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

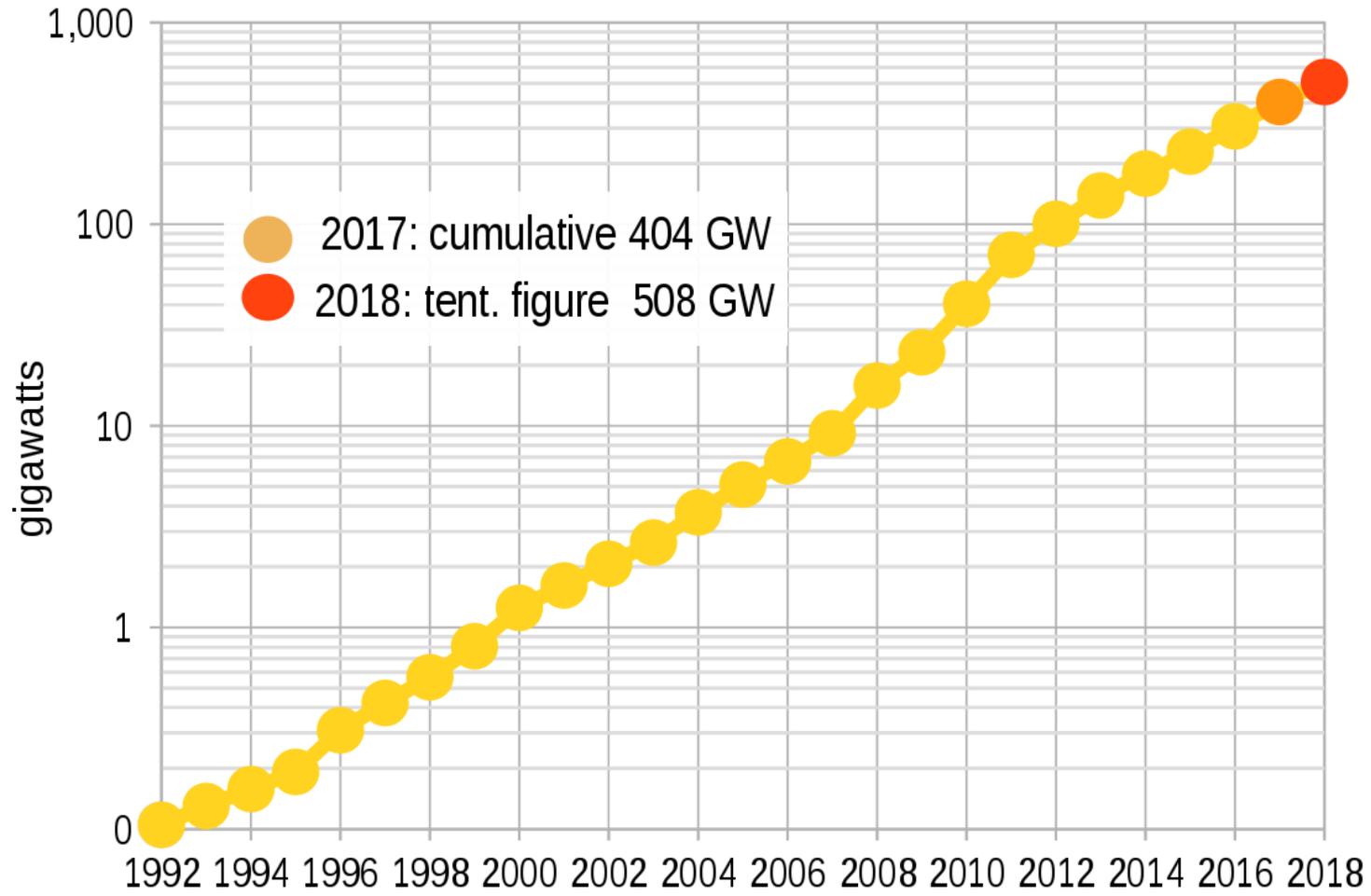
BEJA

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

FARO

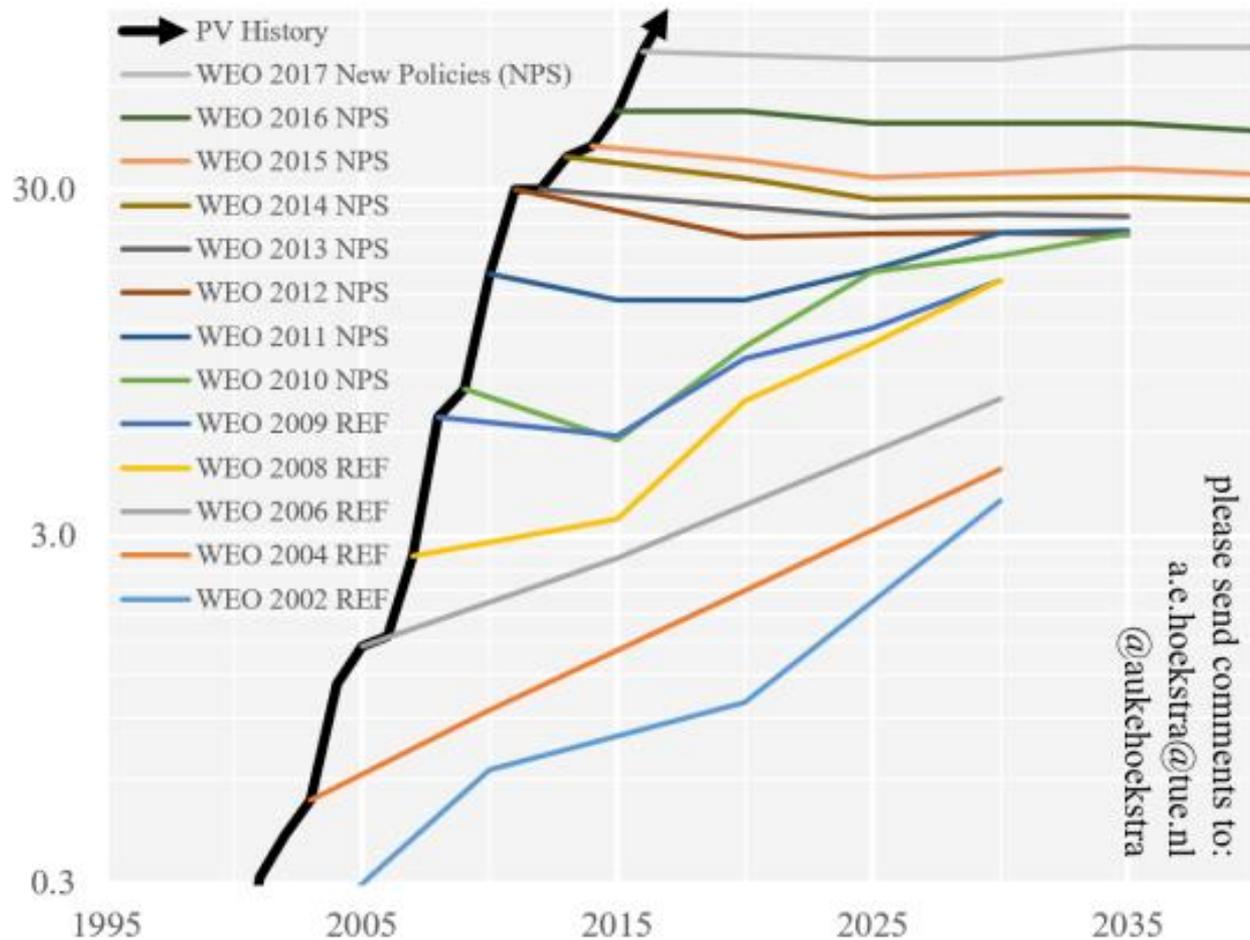
Solara 4	Solara 4	221
Cotovio	Goldiport Solar	49
Viçoso	Goldnalco	48
Lagos	Hyperion	27
Albercas	Muki Solar	28
Pereiro	Muki Solar	29
S. Marcos	Muki Solar	49
Lagos	Lagos Solar Power	21

Exponential Growth of Solar PV (in GW)

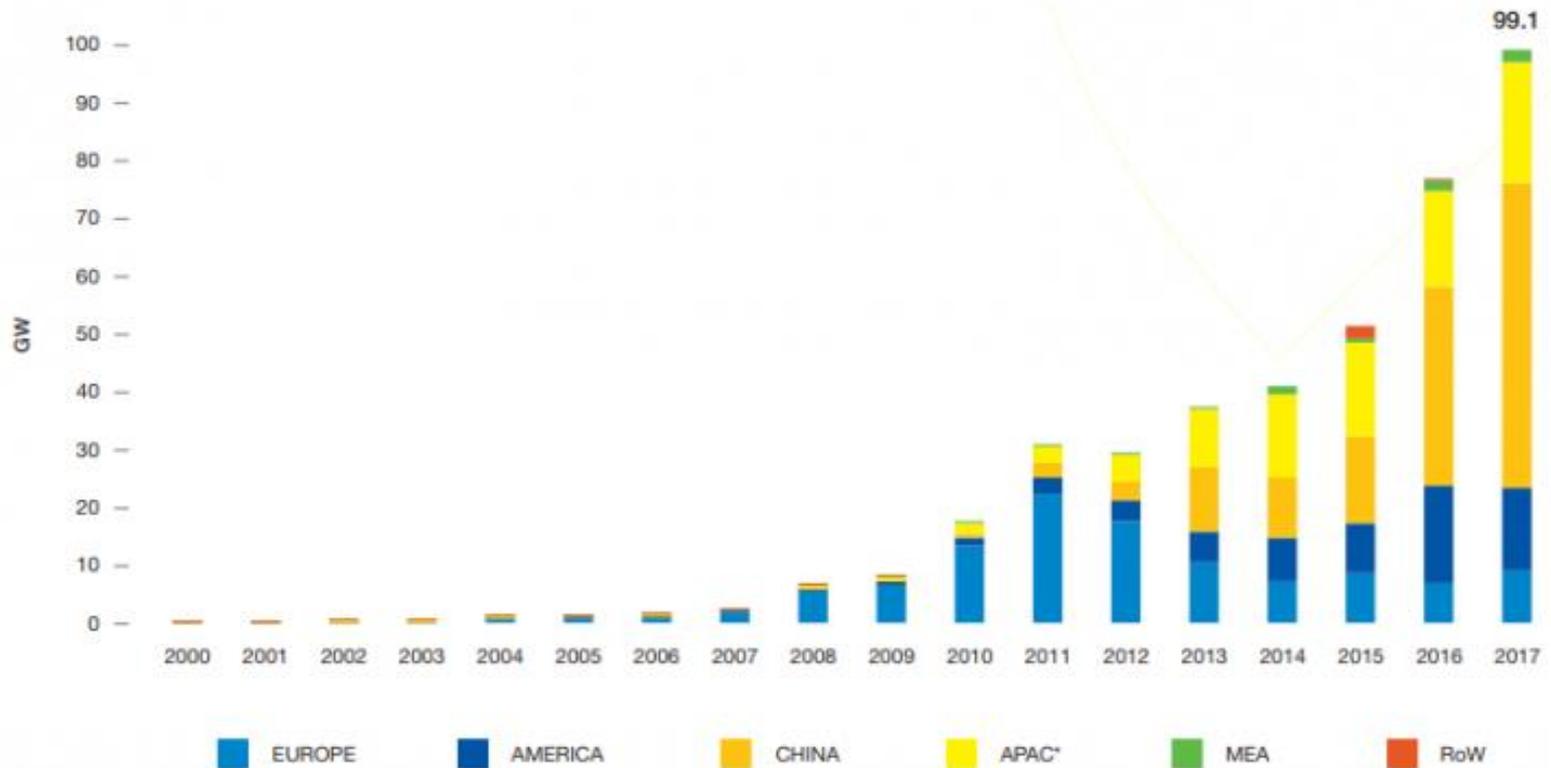


Annual PV additions: historic data vs IEA WEO predictions

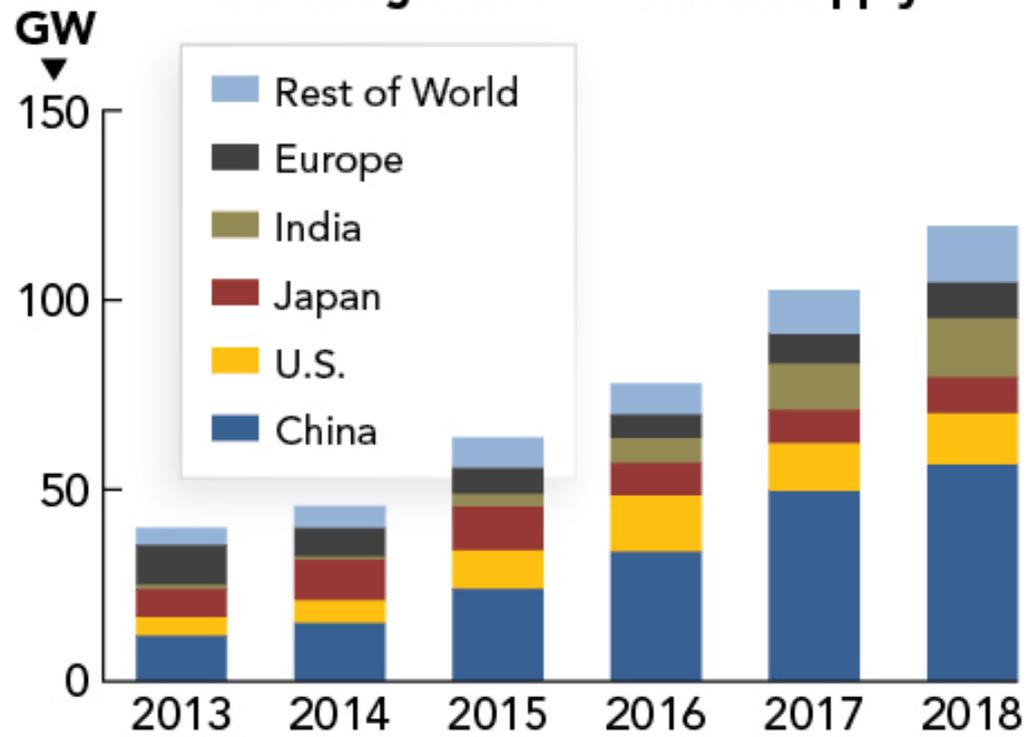
In GW of added capacity per year - source International Energy Agency - World Energy Outlook

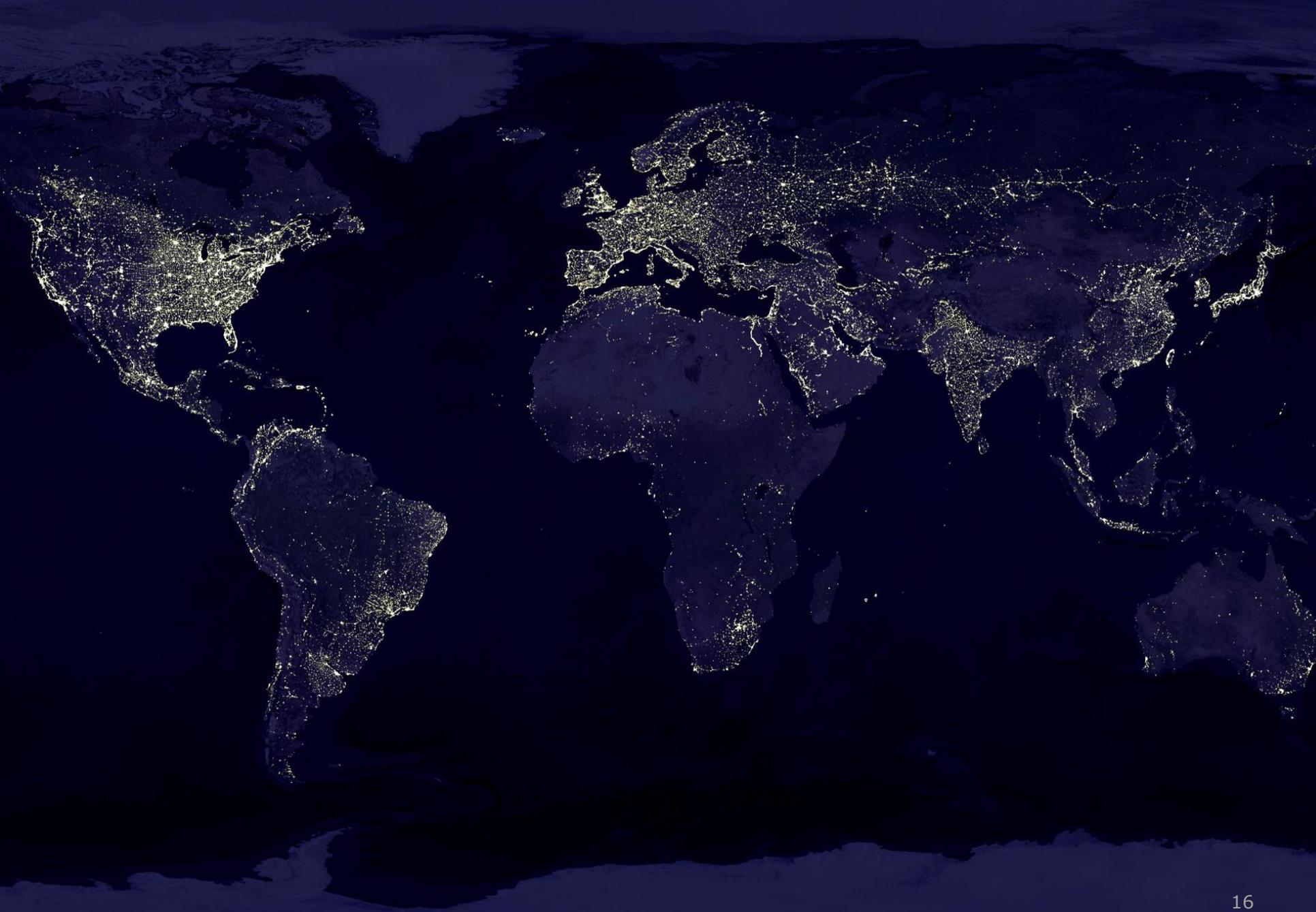


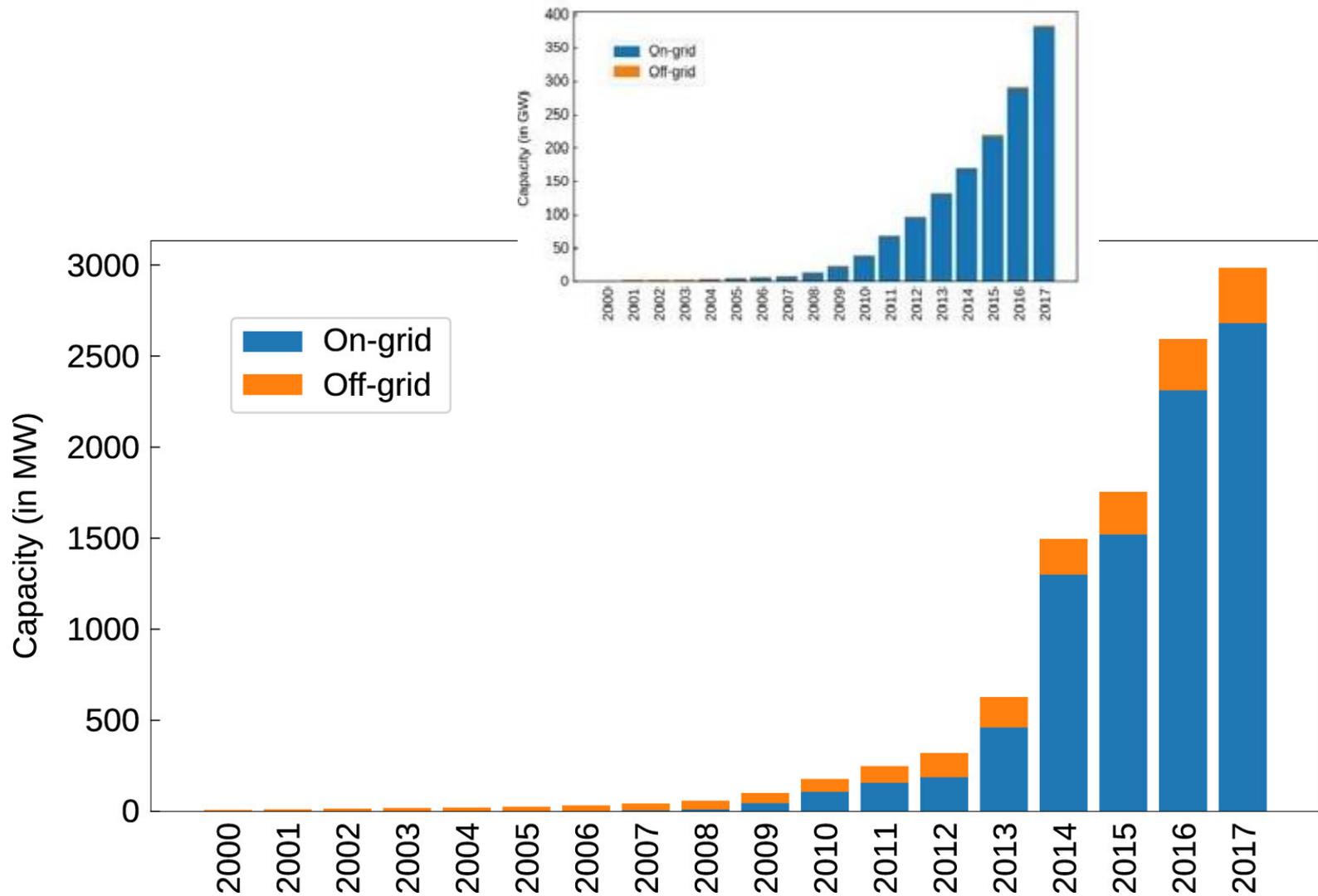
EVOLUTION OF GLOBAL ANNUAL SOLAR PV INSTALLED CAPACITY 2000-2017



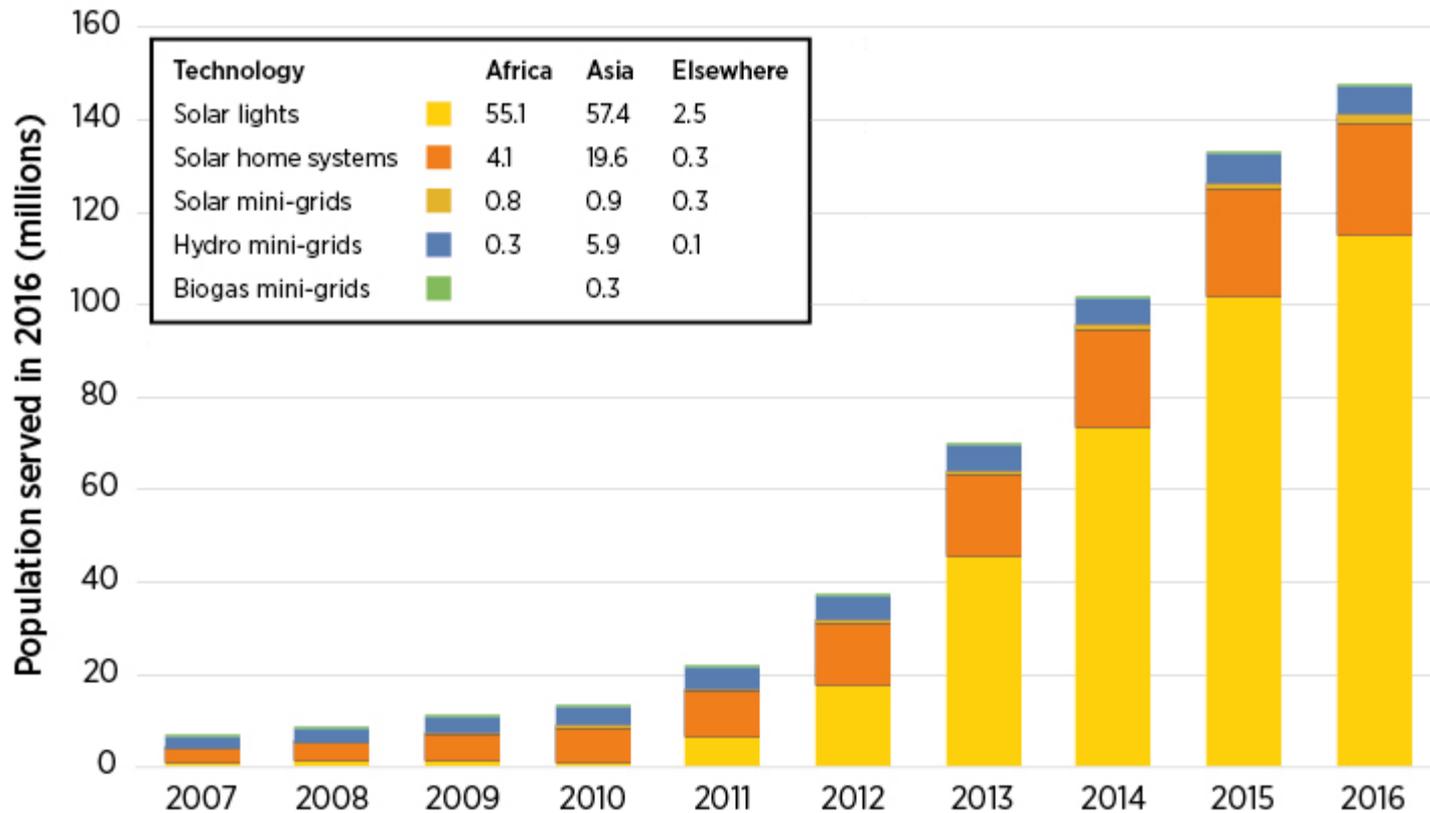
Annual global PV module supply



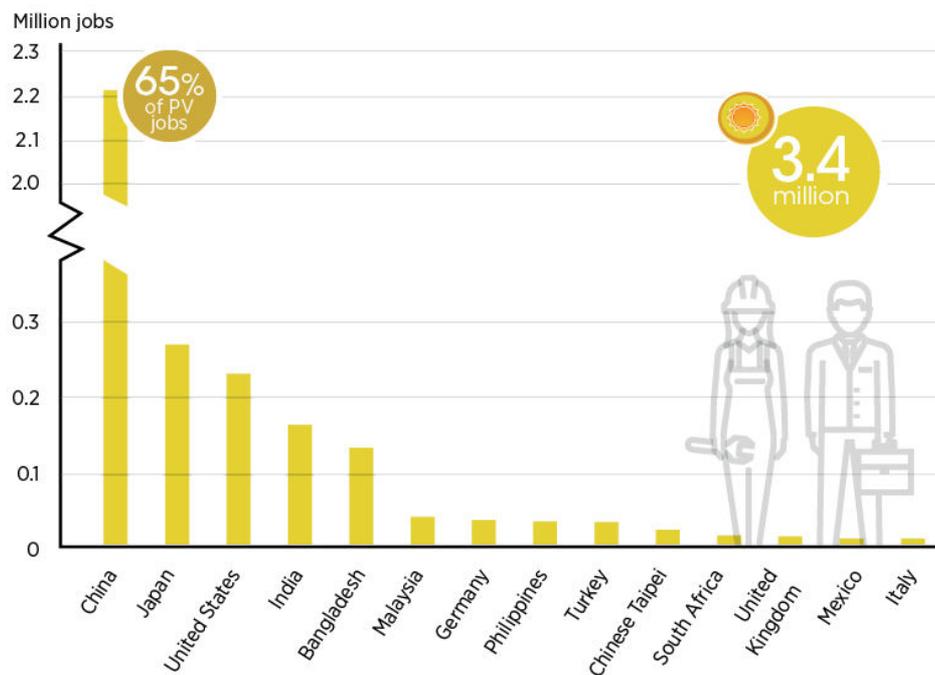




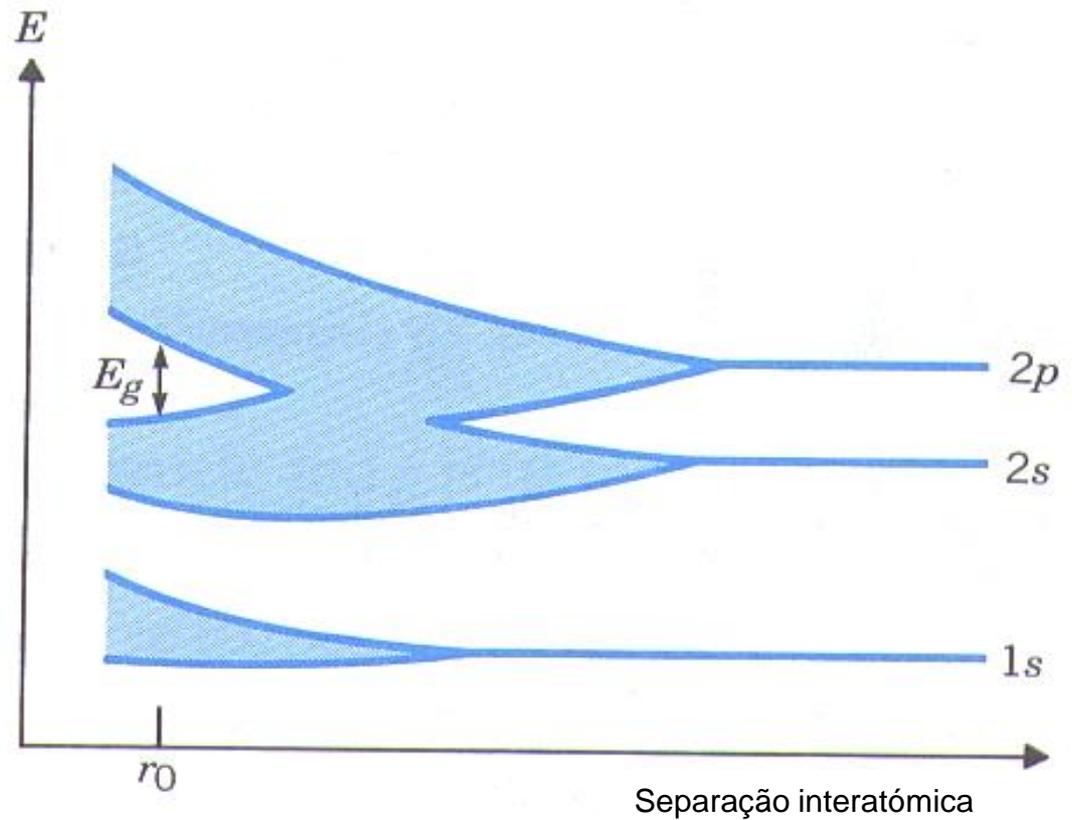
Trends in cumulative PV capacity installed in the world and Sub-Saharan Africa since 2000 ¹⁷



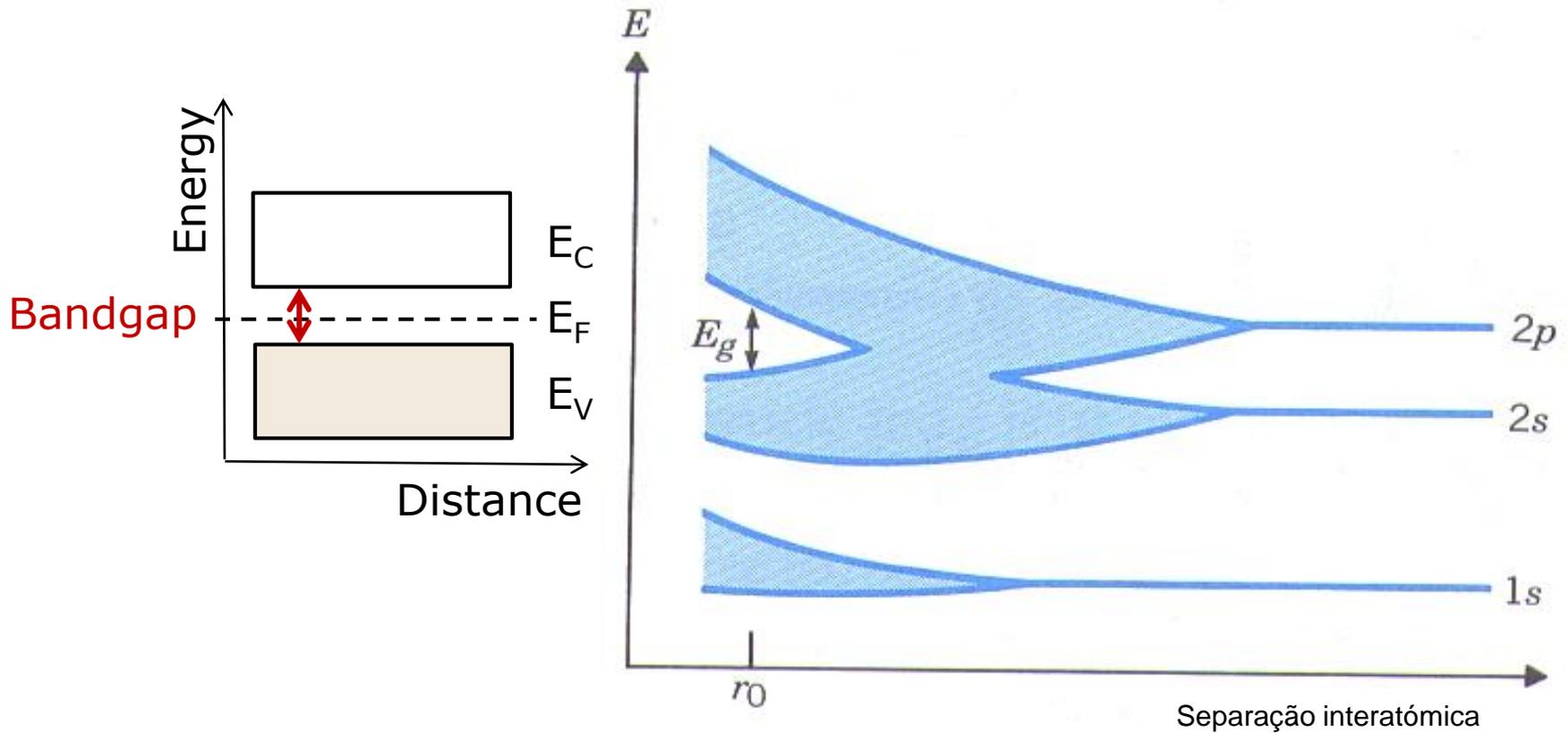
Solar PV was the largest renewable energy employer in 2017 with almost 3.4 million jobs — up 9% from 2016.



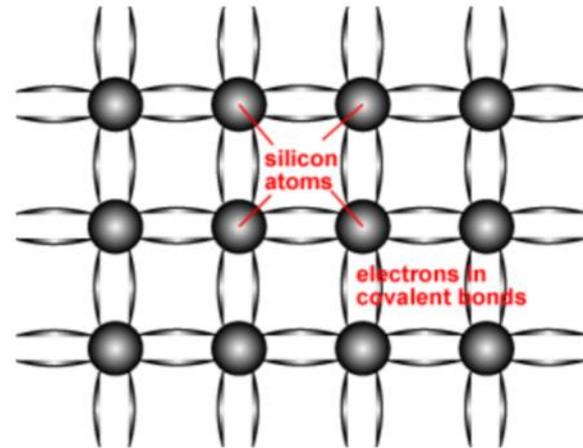
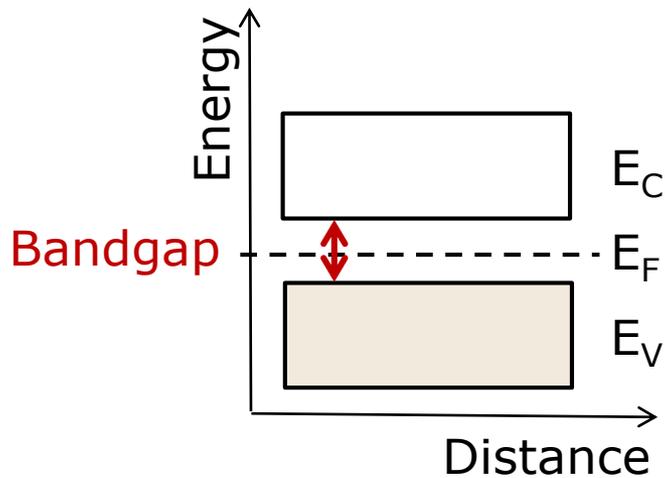
- Bandas de energia permitidas
- Bandas de valência e condução



- Bandas de energia permitidas
- Bandas de valência e condução
- Nível de Fermi



- Bandas de energia permitidas
- Bandas de valência e condução
- Nível de Fermi



- **Absorção da luz**

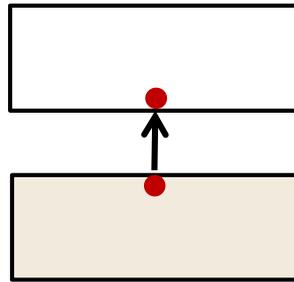
depende da energia do fóton incidente

$$E_{\text{ph}} = E_{\text{g}}$$



$$E = \frac{hc}{\lambda}$$

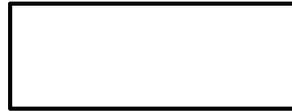
$$E(\text{eV}) = \frac{1.24}{\lambda(\mu\text{m})}$$



- **Absorção da luz**

depende da energia do fóton incidente

$$E_{\text{ph}} < E_g$$



$$E = \frac{hc}{\lambda}$$

$$E(\text{eV}) = \frac{1.24}{\lambda(\mu\text{m})}$$

- **Absorção da luz**

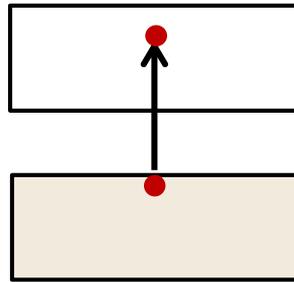
depende da energia do fóton incidente

$$E_{ph} > E_g$$

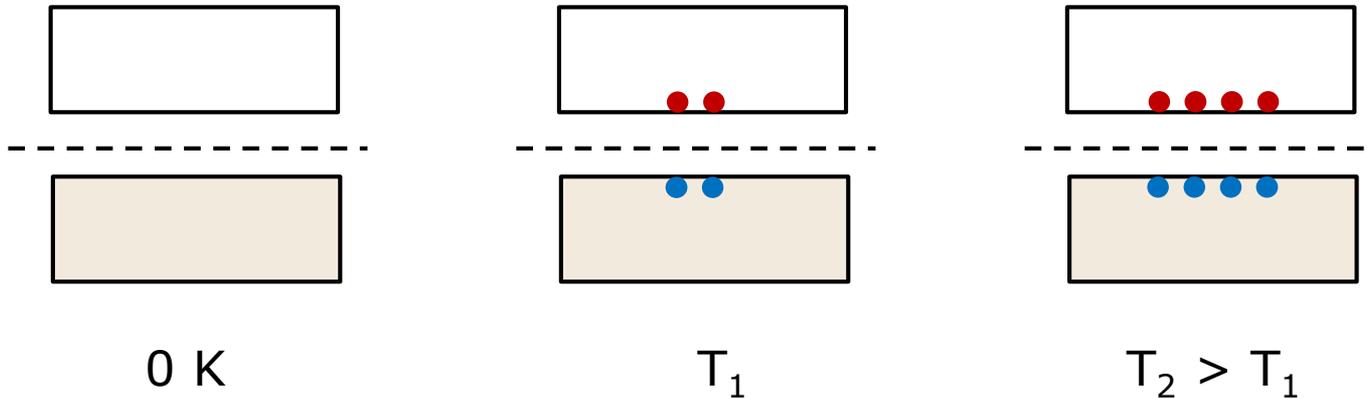


$$E = \frac{hc}{\lambda}$$

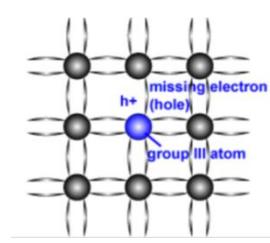
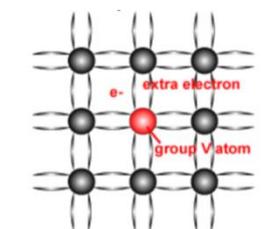
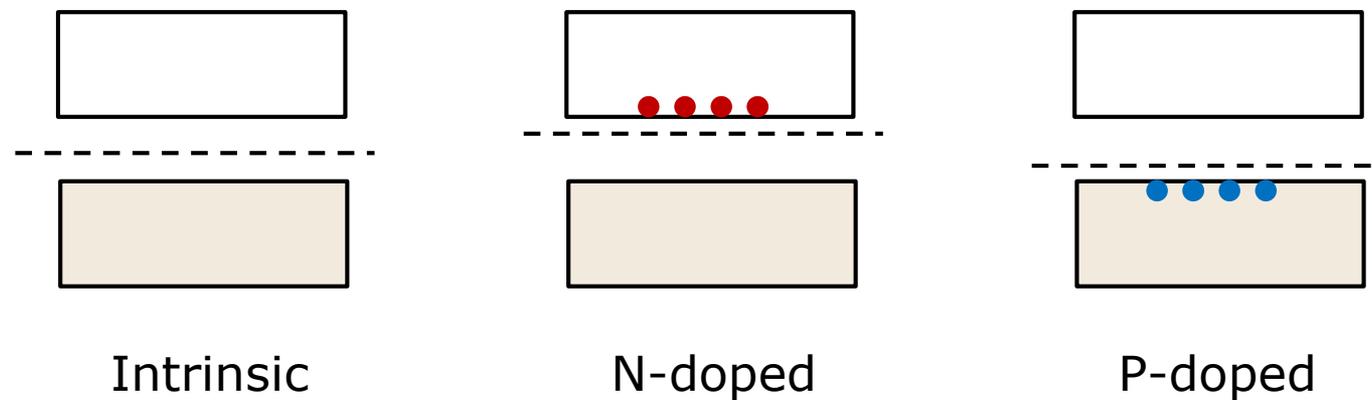
$$E(eV) = \frac{1.24}{\lambda(\mu m)}$$



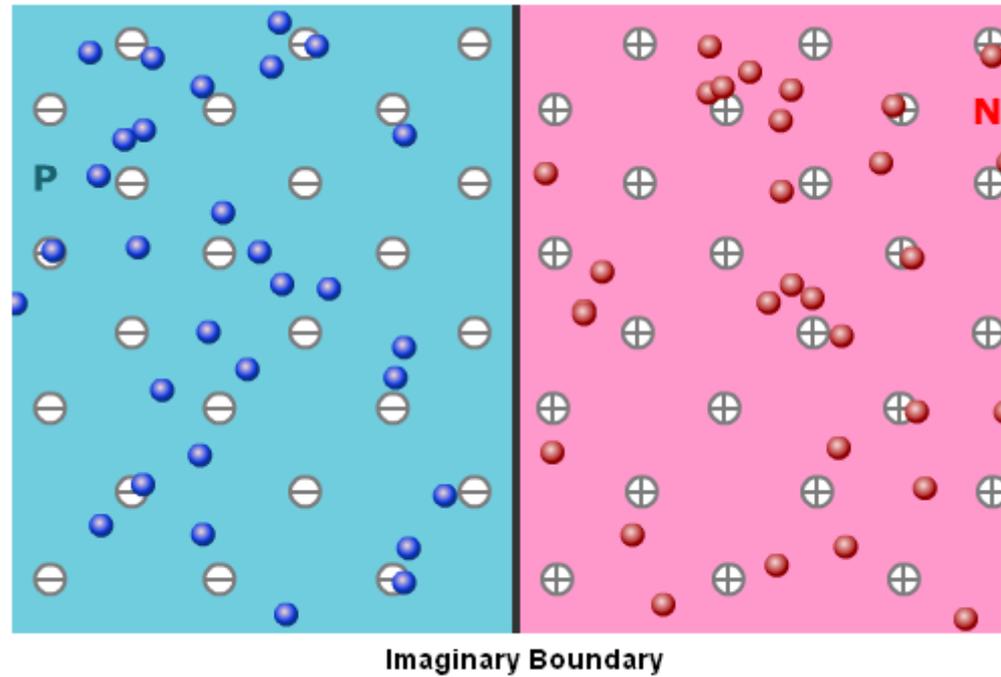
- Efeito da temperatura



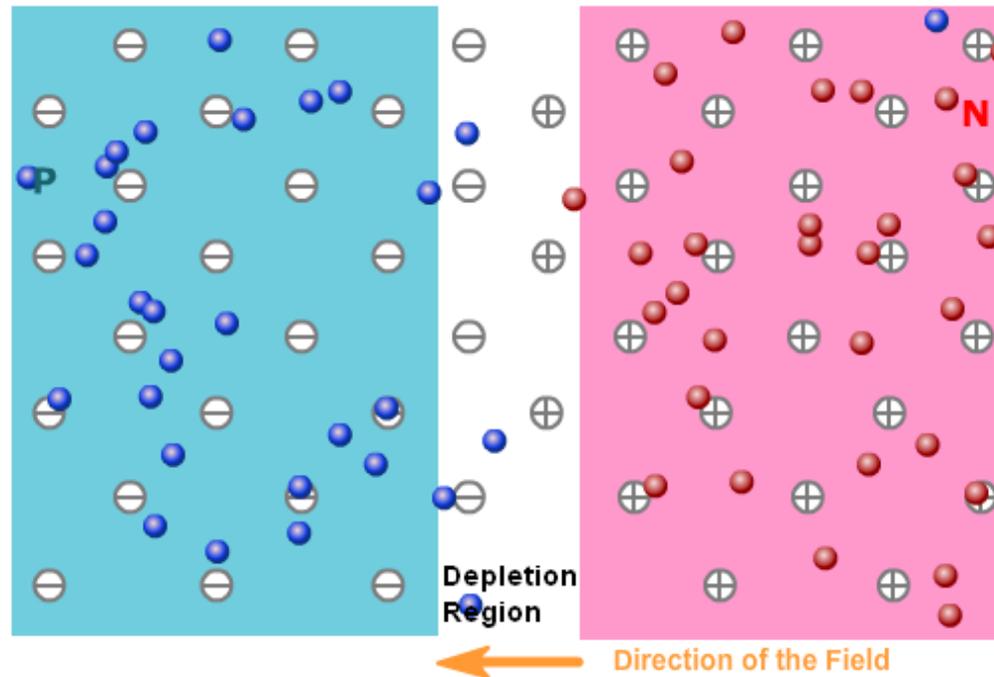
- Efeito da dopagem



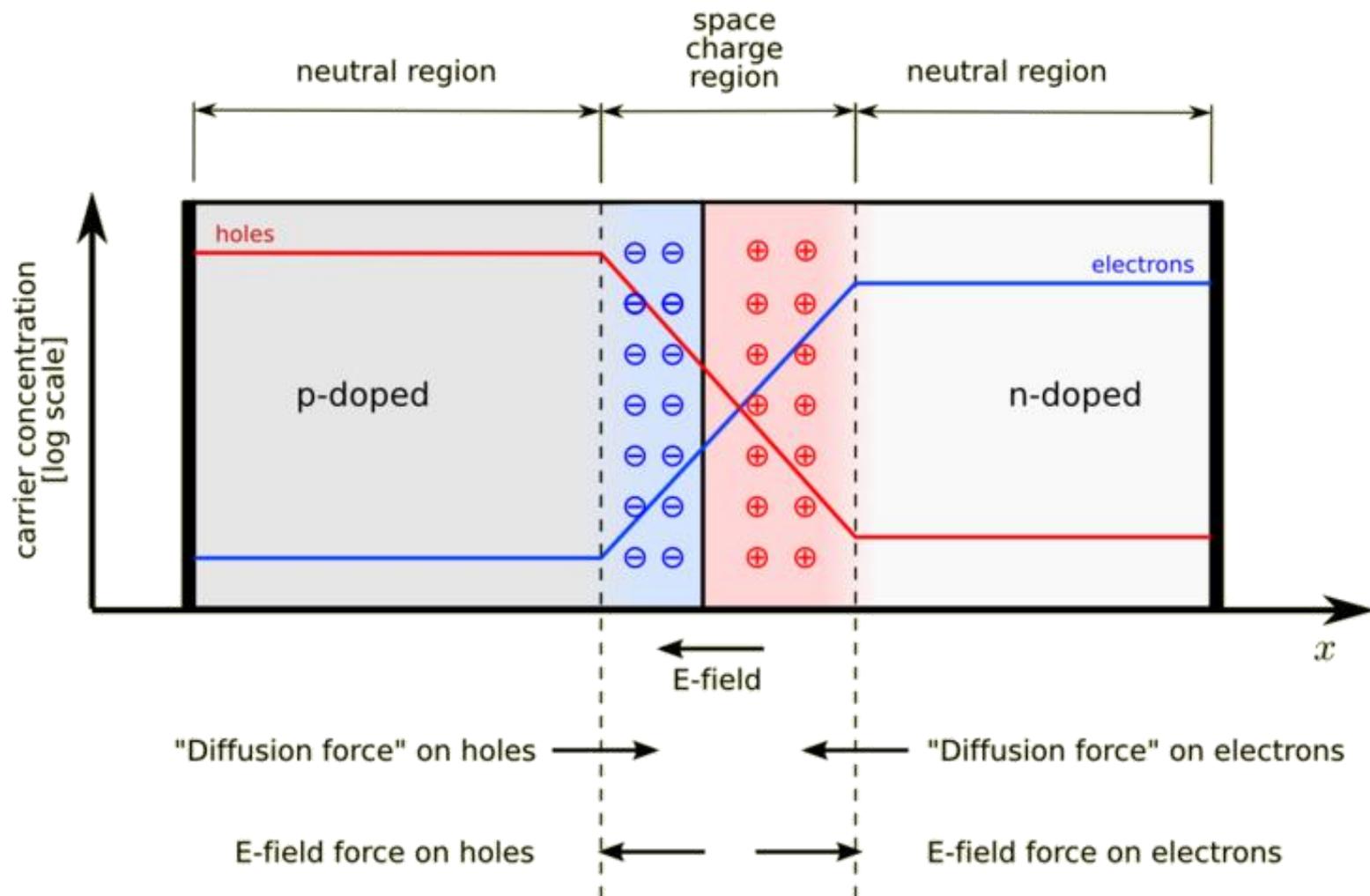
- Junção PN



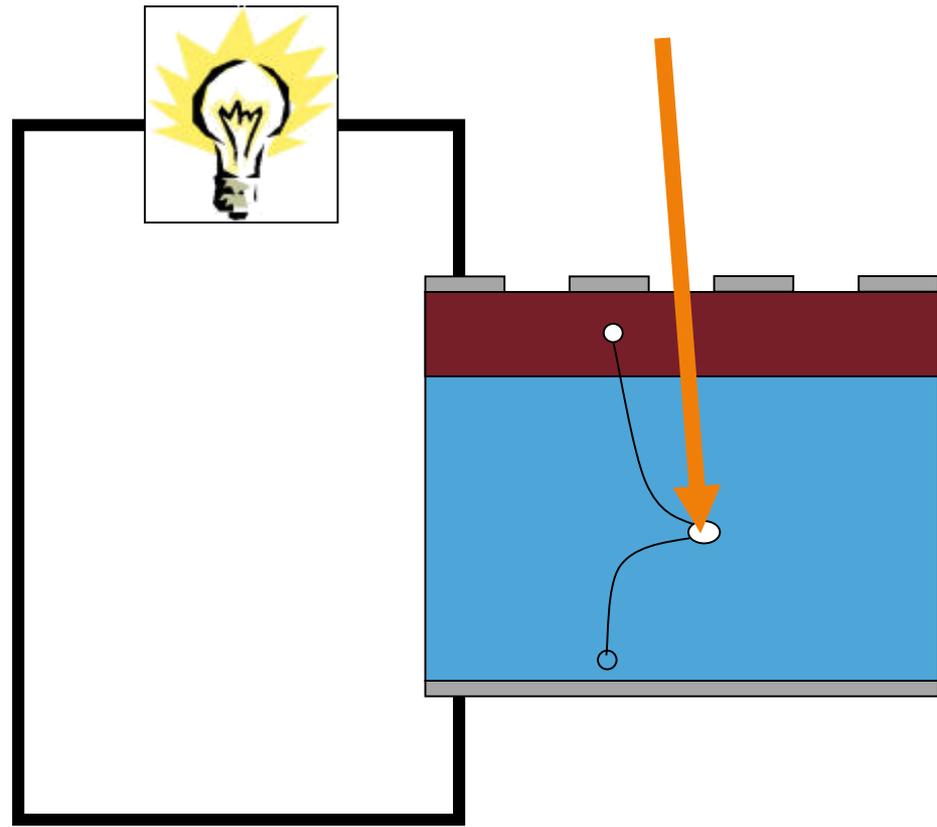
- Junção PN



- Junção PN



- Funcionamento de uma célula fotovoltaica

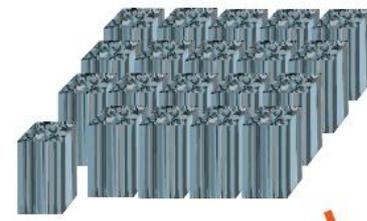




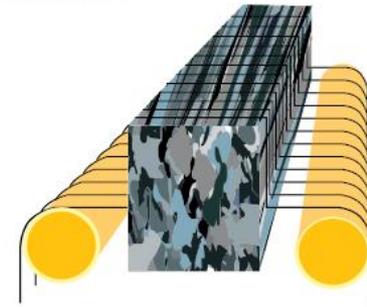
Raw material (Silicon)



Ingot



Ingot squaring



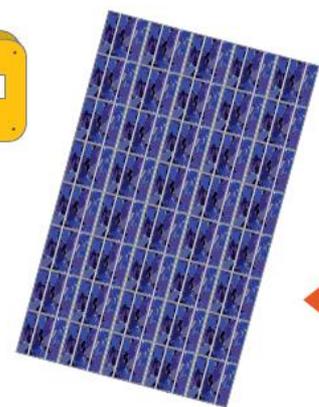
Wafer slicing



Wafer



Cells

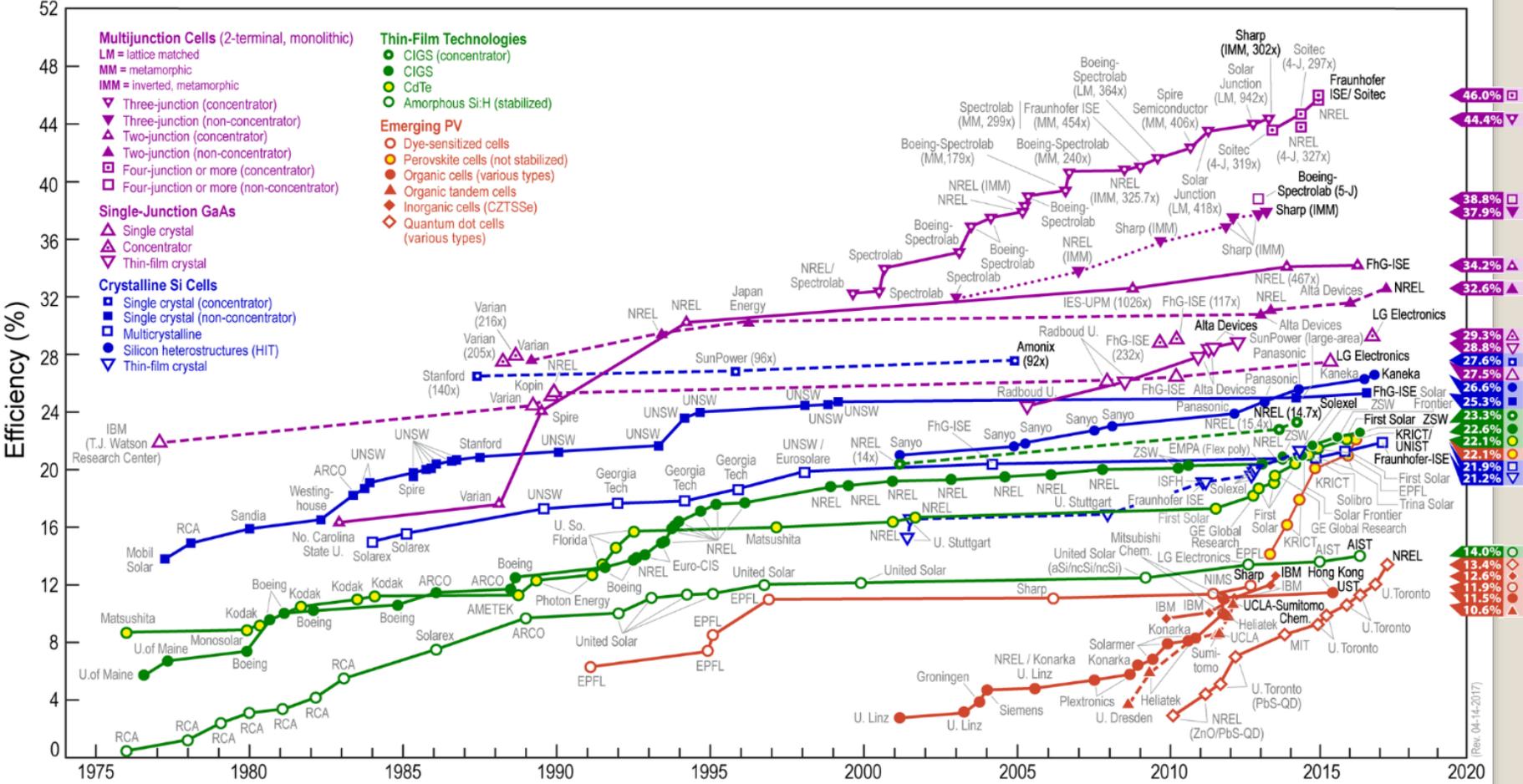


Module



System

Best Research-Cell Efficiencies



Rev. 04-14-2017

- Comparação diferentes tecnologias PV

Custo

Desempenho, durabilidade

Disponibilidade matéria prima

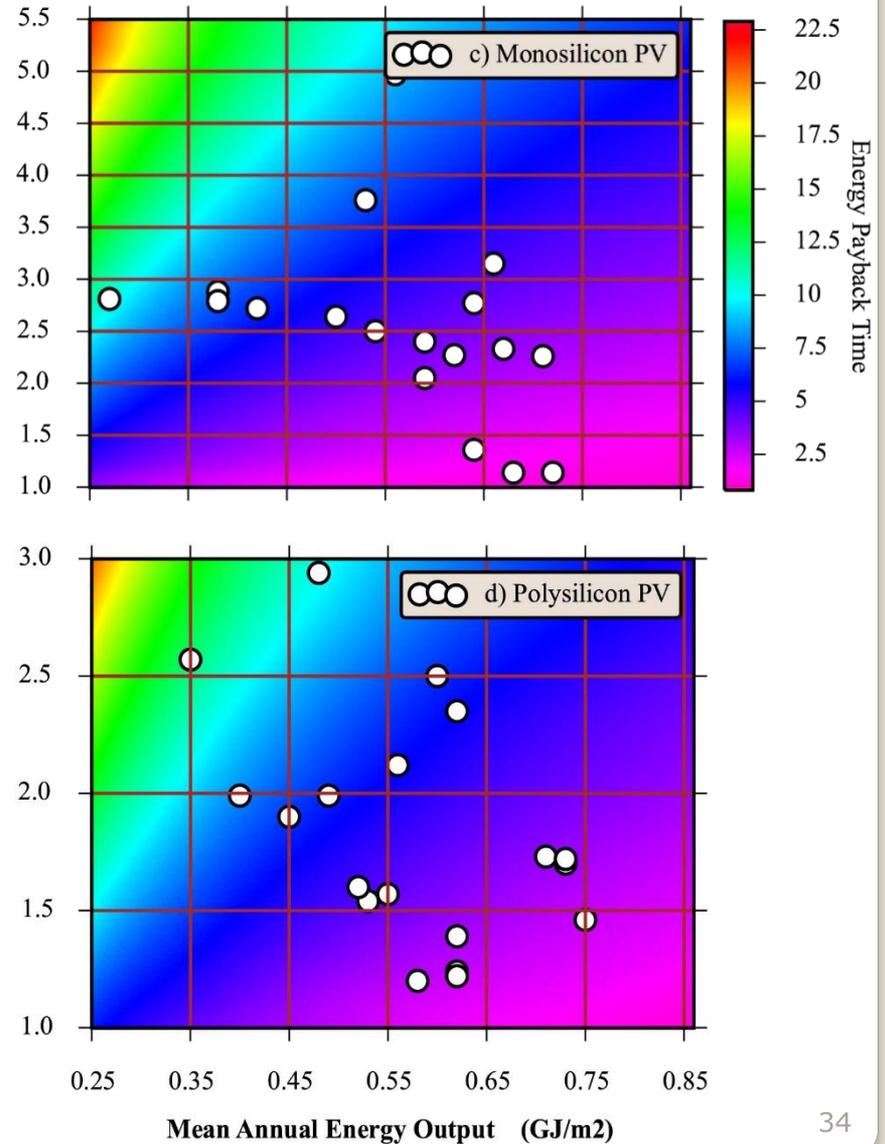
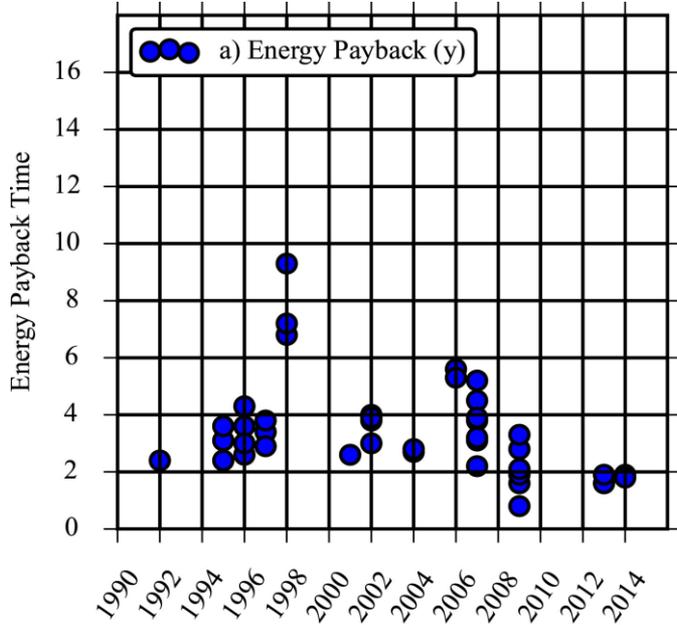
Aspectos ambientais

Maturidade tecnológica

Promotores

Outros

- *Payback time energético*



- *Payback time* energético
- *Energy yield*

$$\text{Energy yield} = \frac{\text{Energy payback time}}{\text{Operational lifetime}}$$

menor *payback time*
mas vida mais longa

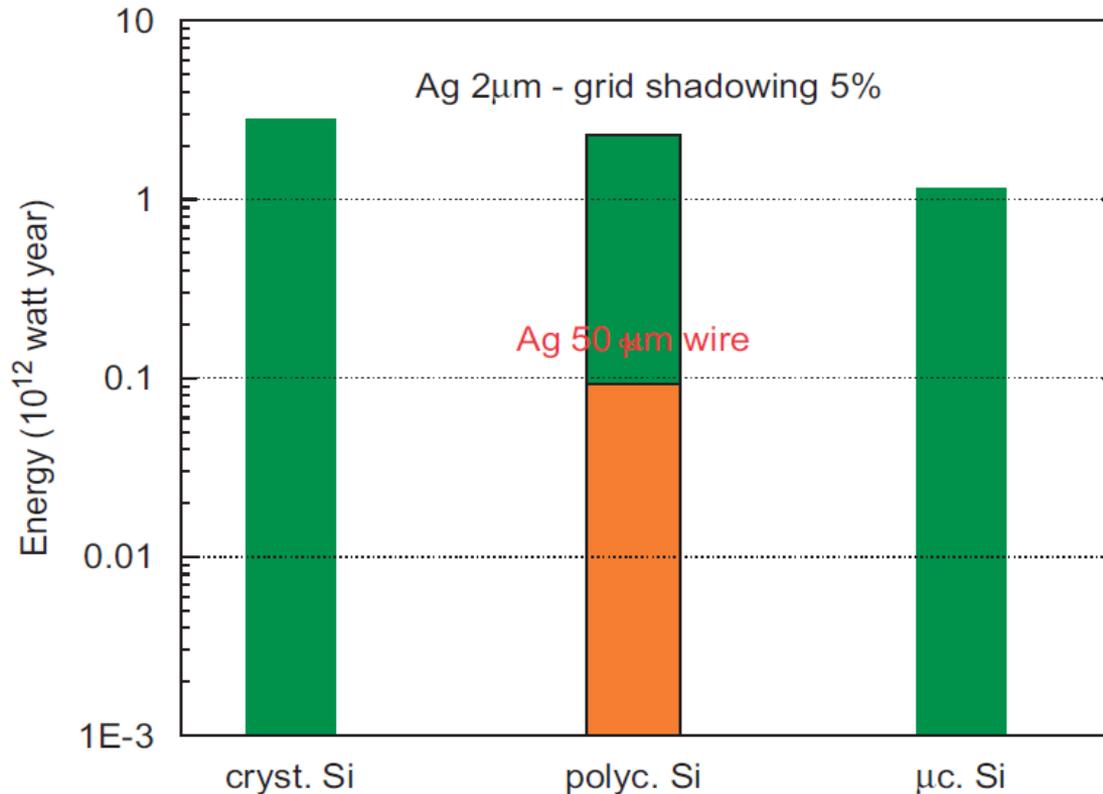
>

menor *payback time*
mas vida mais curta

Valores típicos garantia módulos silício: 25 anos
Centrais com 40 anos de vida com produção 80% valor nominal.

Um painel fotovoltaico produz de 20 a 50x
a energia que foi utilizada para o fabricar!

- Limitações matérias primas



Potential energy limits imposed by global silver (Ag) reserves for bulk-like silicon photovoltaic technologies. The orange shaded area represents limits reached using 50 mm-thick Ag ribbons. The green shaded area represents limits estimated using a 2 mm thick Ag electrodes and 5% grid shadowing.

- Limitações matérias primas

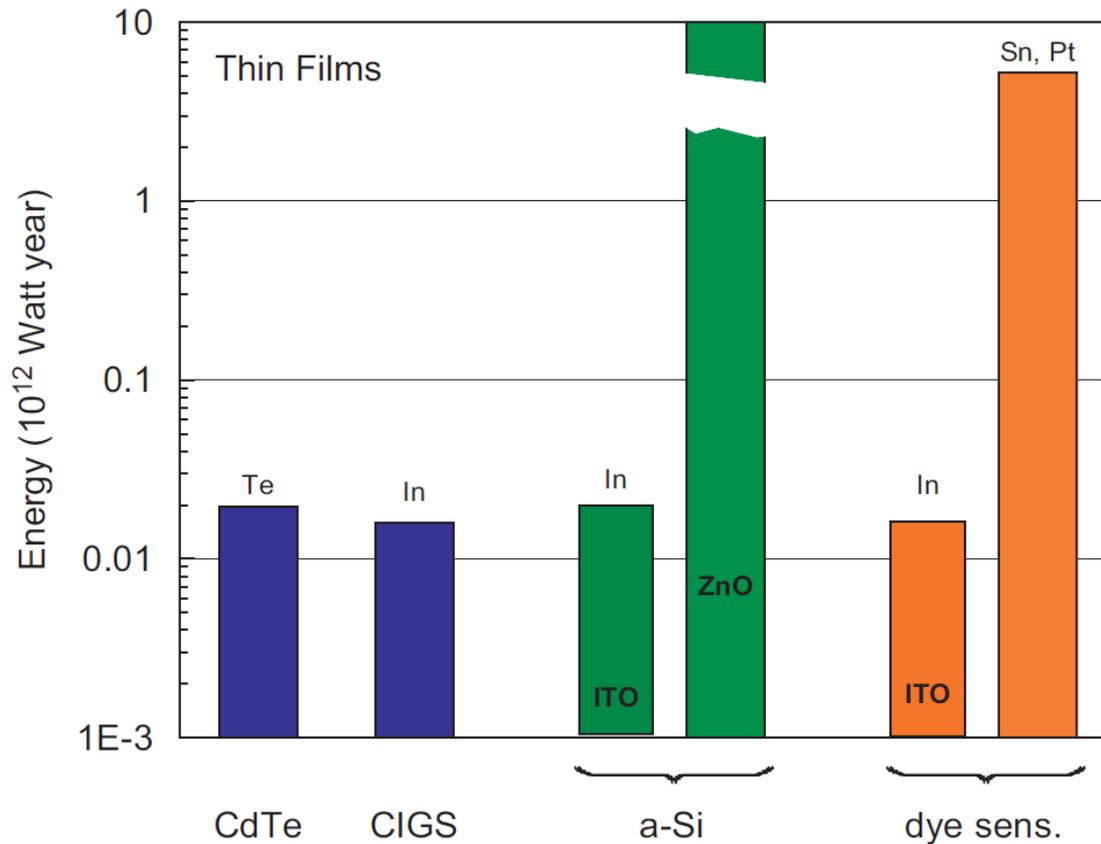


Fig. 4. Potential energy limits imposed for four different thin film photovoltaic technologies.

- Limitações matérias primas

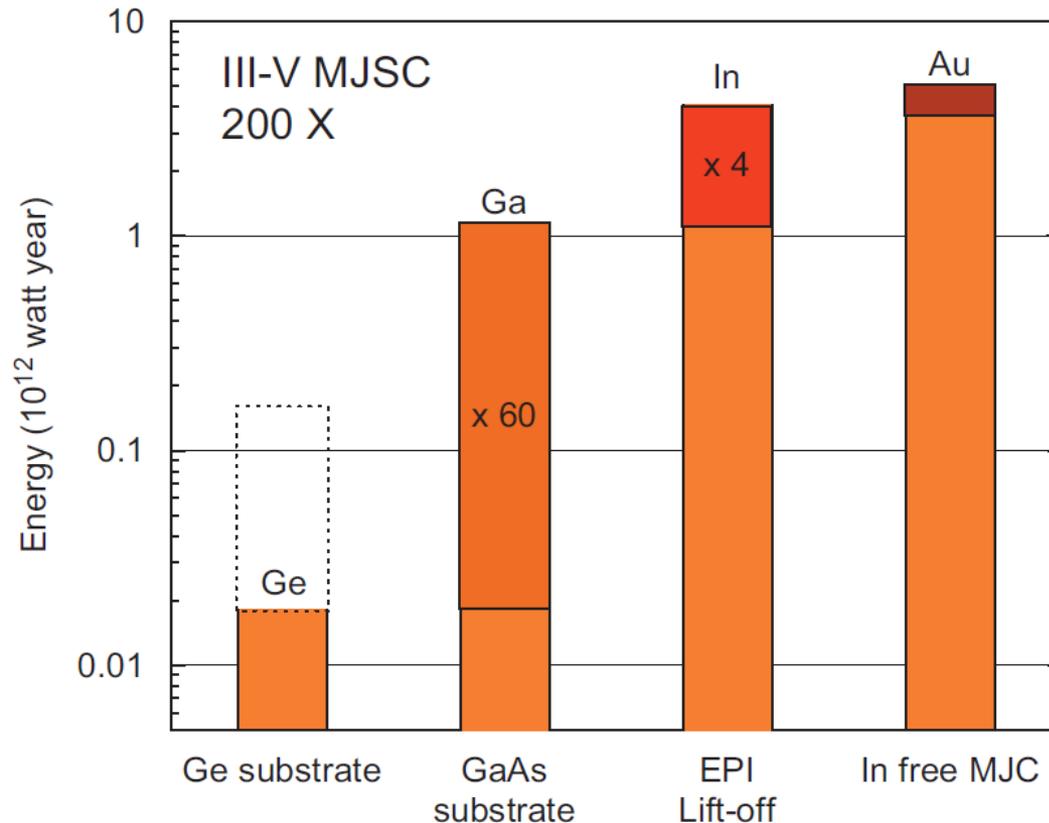
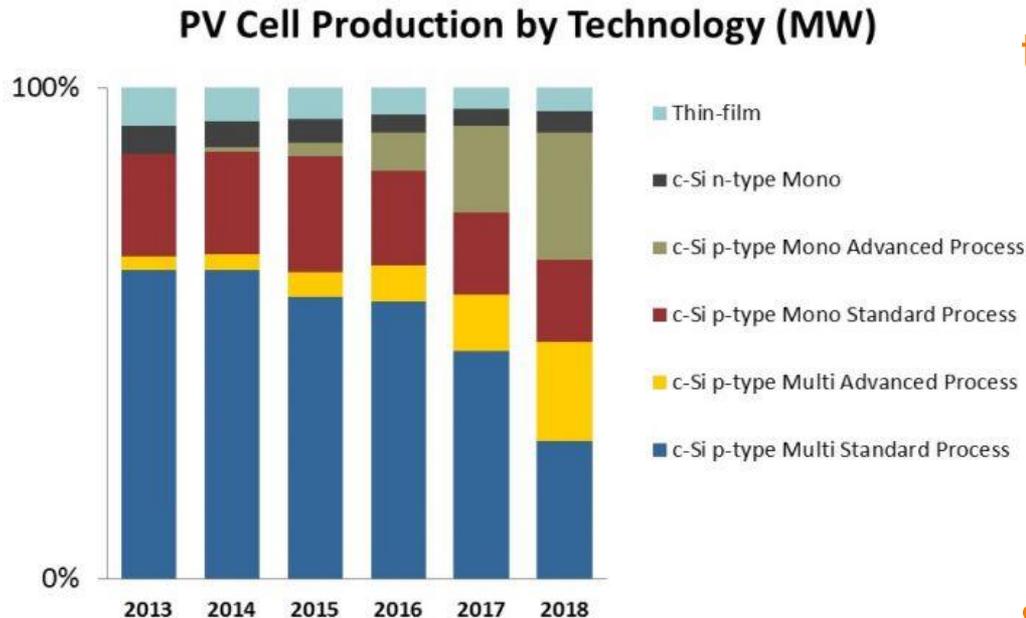


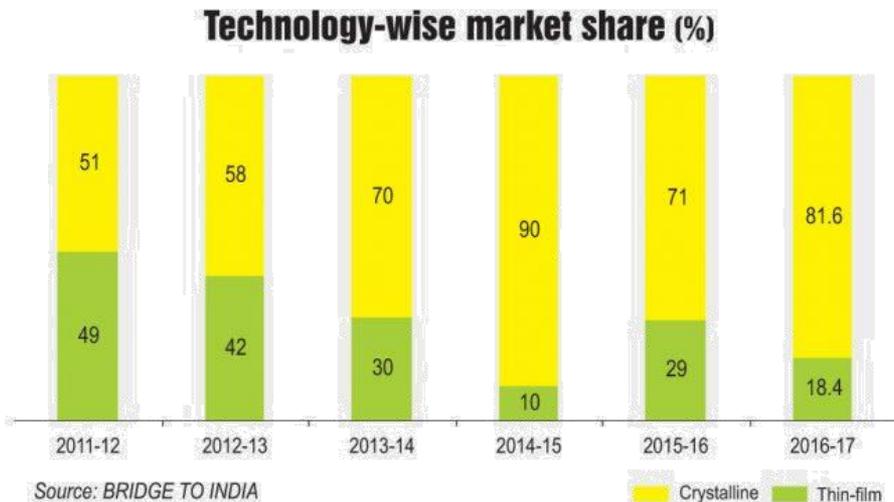
Fig. 5. Potential energy limits imposed to III–V multi-junction cells (200 sun concentrations). The third and fourth columns show the extrapolated potential of this technology if lift-off/cell exfoliation techniques are adopted.

A.Feltrin, A.Freundlich, *Material considerations for TW level deployment of PV*, *Renewable Energy* 33 (2008) 180–185

Comparação entre tecnologias PV diferentes:



- Mercado dominado actualmente por silício cristalino
- Apenas um fabricante relevante de filmes finos (CdTe)
- Tecnologias *emergentes* em desenvolvimento no lab e entusiasmando *Silicon Valley*
- Tecnologias de alta eficiência no nicho da alta concentração

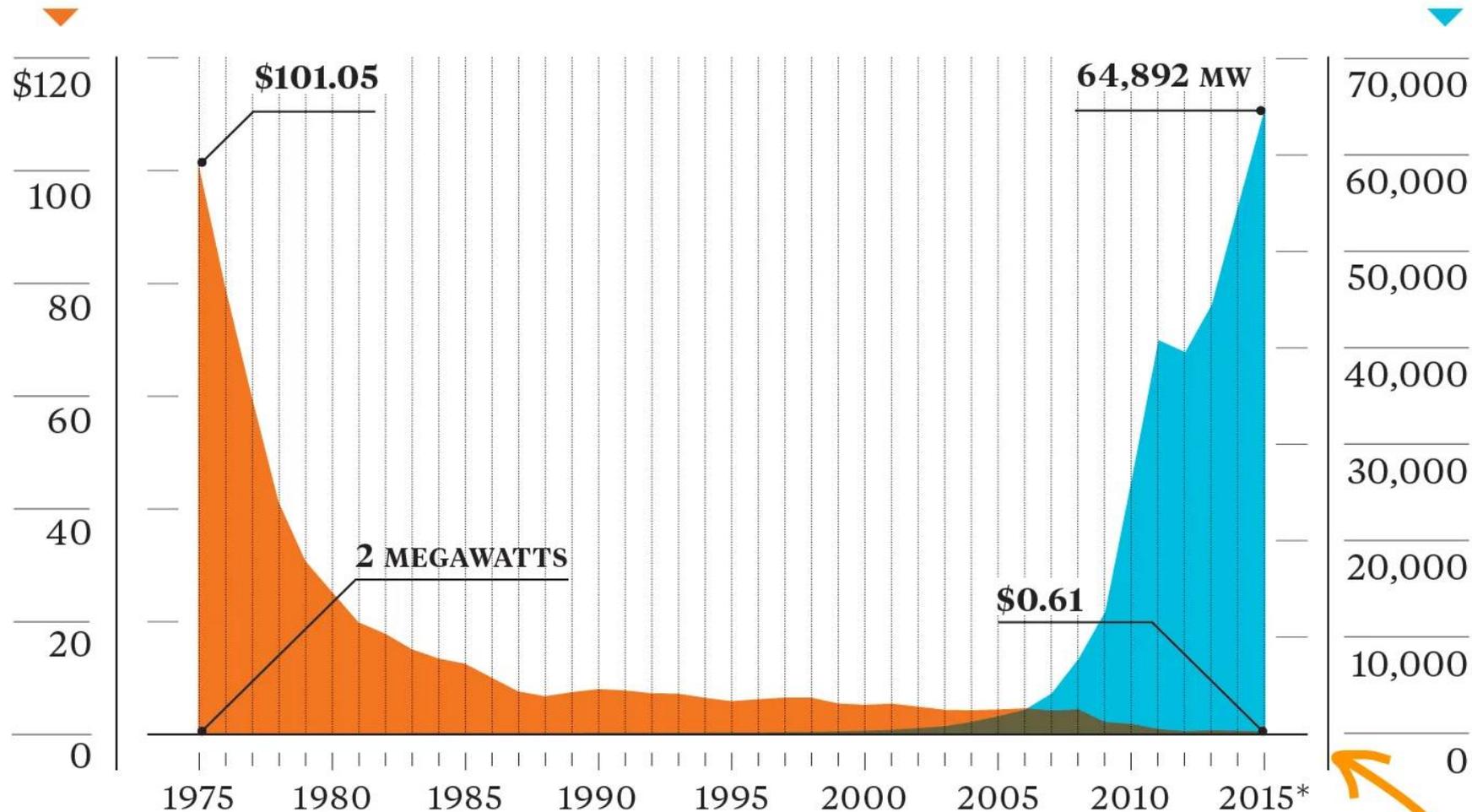


Solar on Fire

As prices have dropped, installations have skyrocketed.

Price of a solar panel per watt

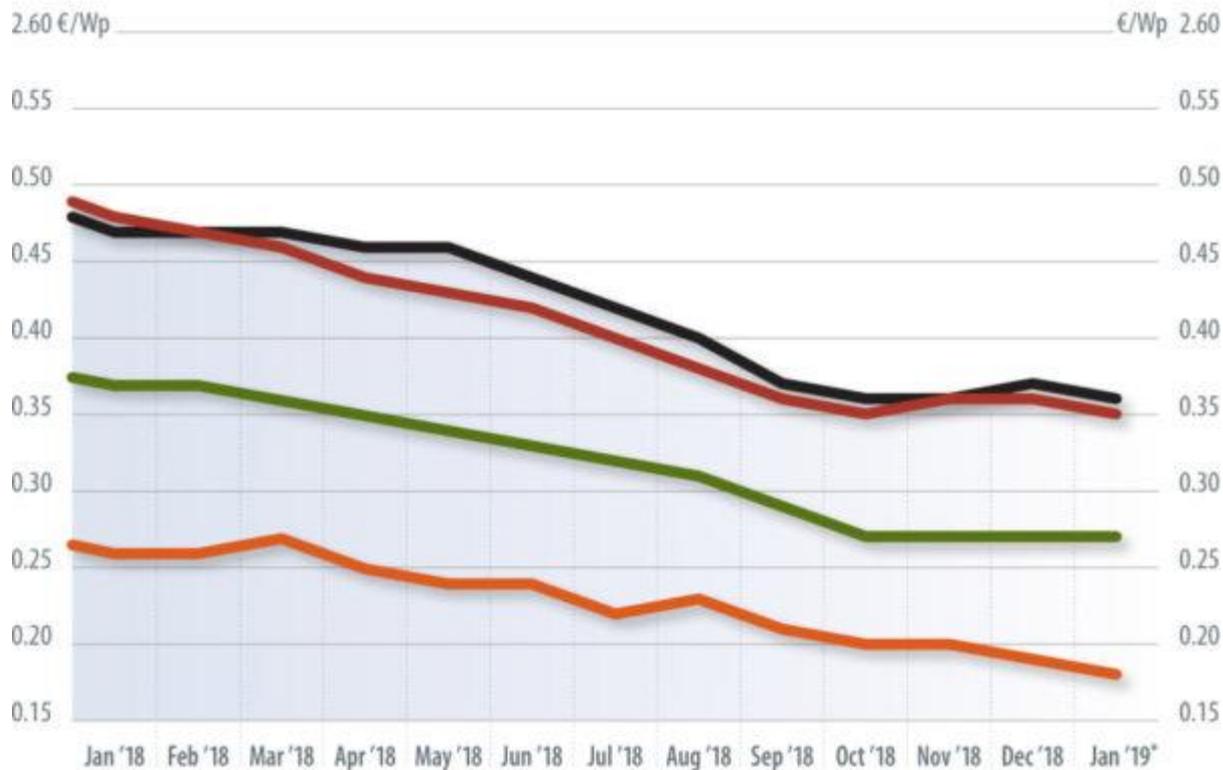
Global solar panel installations



Down to \$0.37 in Late 2017

*Estimate. Sources: Bloomberg, Earth Policy Institute, www.earth-policy.org

EU spot market module prices by technology



Crystalline modules (mono-/poly-Si) average net prices (€/Wp)

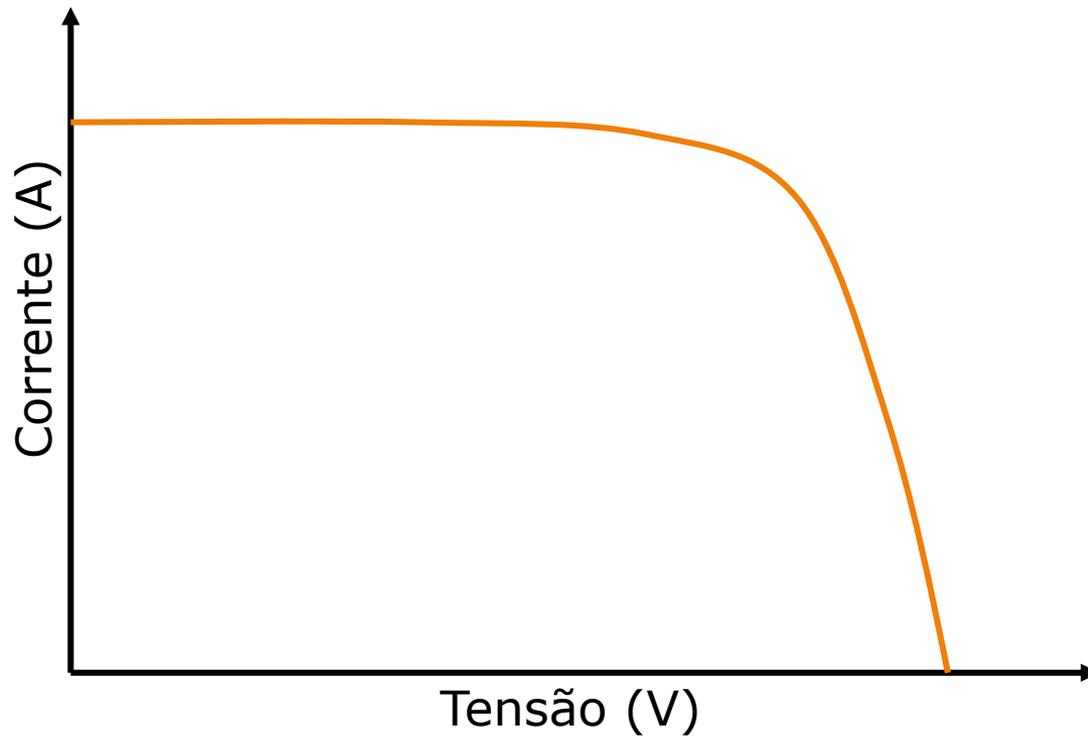
- **High efficiency:** Crystalline modules 290 Wp and above with Cello, PERC, HIT-, n-type – or back-contact cells or combinations thereof
- **Mainstream:** Modules with usually 60 cells, standard aluminum frames, white backing and 260 Wp to 285 Wp – the majority of modules on the market
- **All black:** Module types with black backsheets, black frames and rated outputs of between 200 Wp and 320 Wp
- **Low cost:** Reduced-capacity modules, factory seconds, insolvency goods, used modules (crystalline), products with limited or no guarantee

* Data up to January 17, 2019

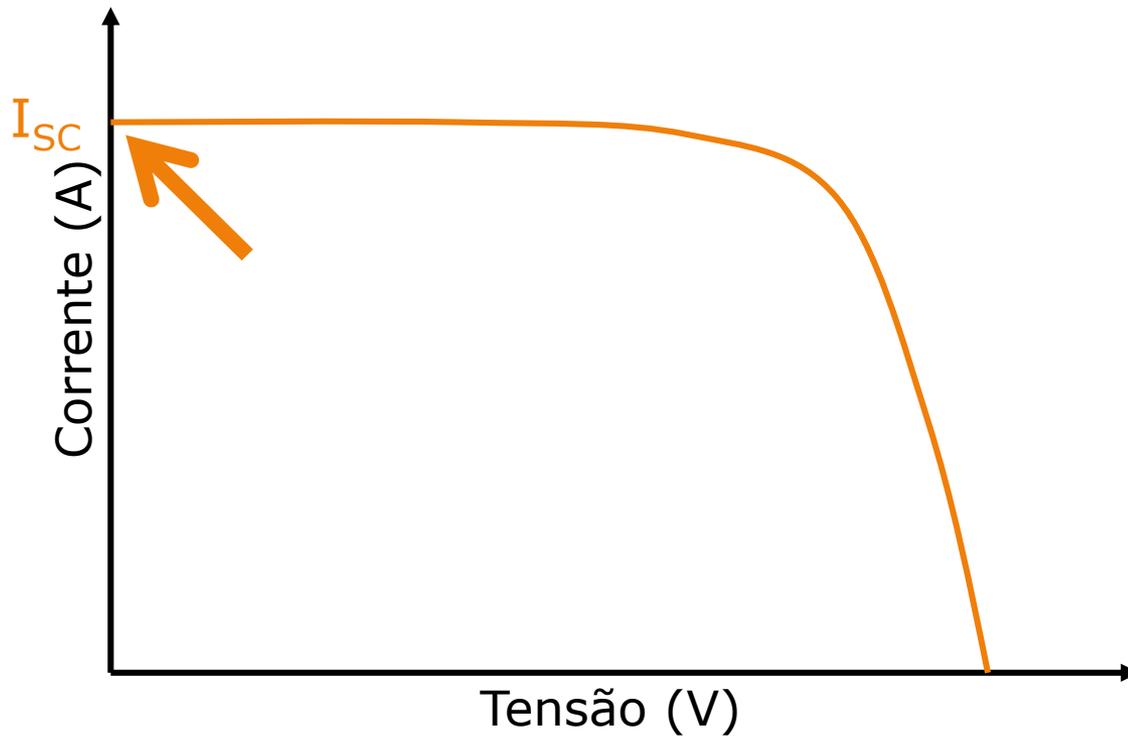
More information: www.pvXchange.com

- Característica IV de uma célula solar

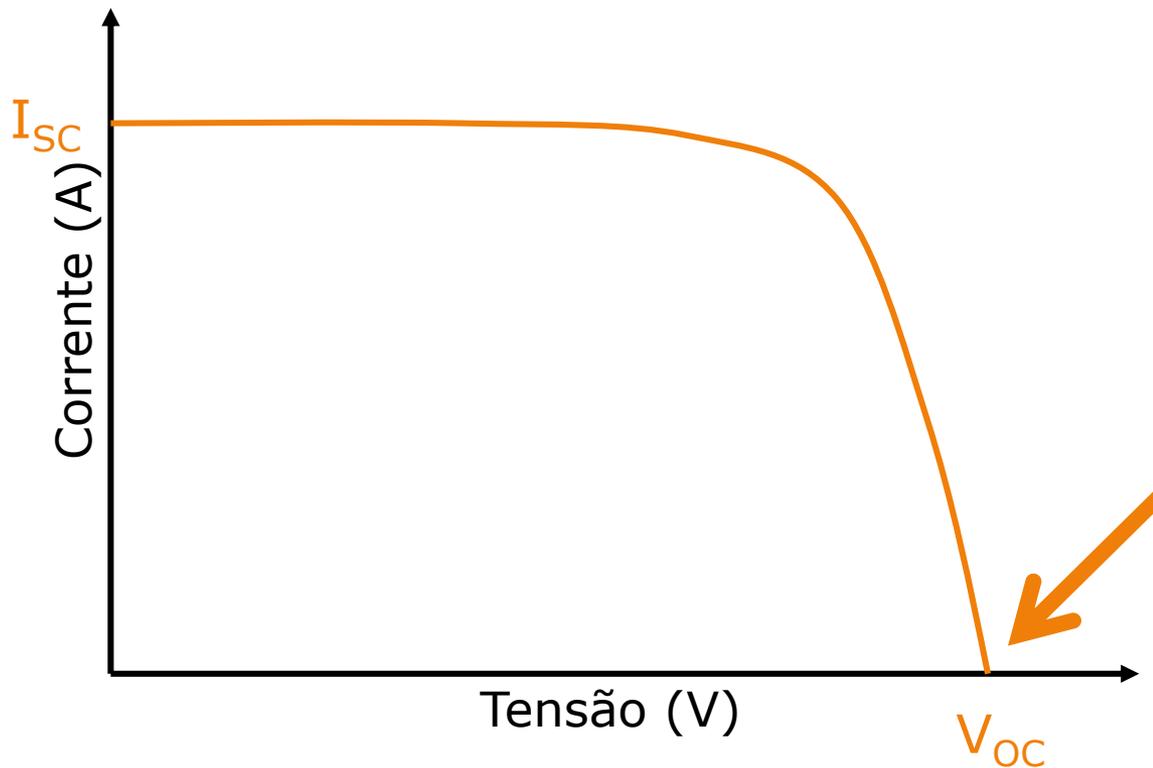
$$I = I_L - I_o \left(e^{\frac{qV}{nkT}} - 1 \right) \quad = \text{um díodo} + \text{corrente fotogerada}$$



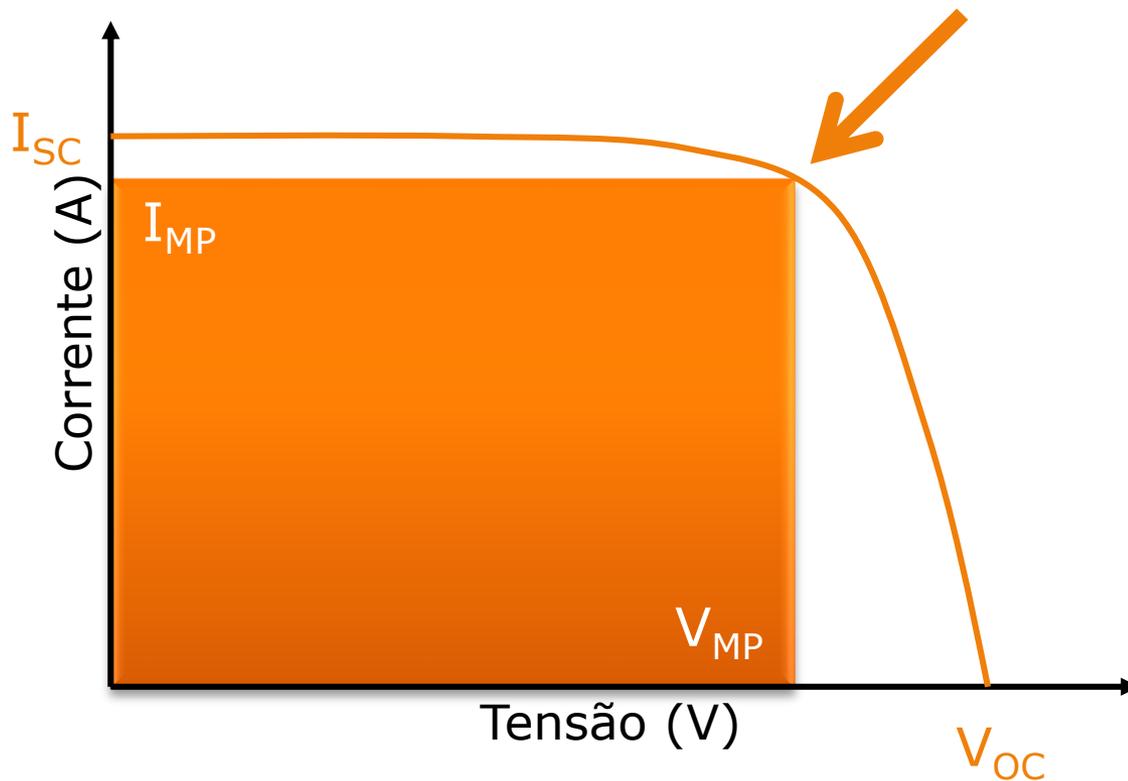
- Característica IV de uma célula solar
Corrente de curto circuito I_{sc}



- Característica IV de uma célula solar
Tensão de circuito aberto V_{oc}



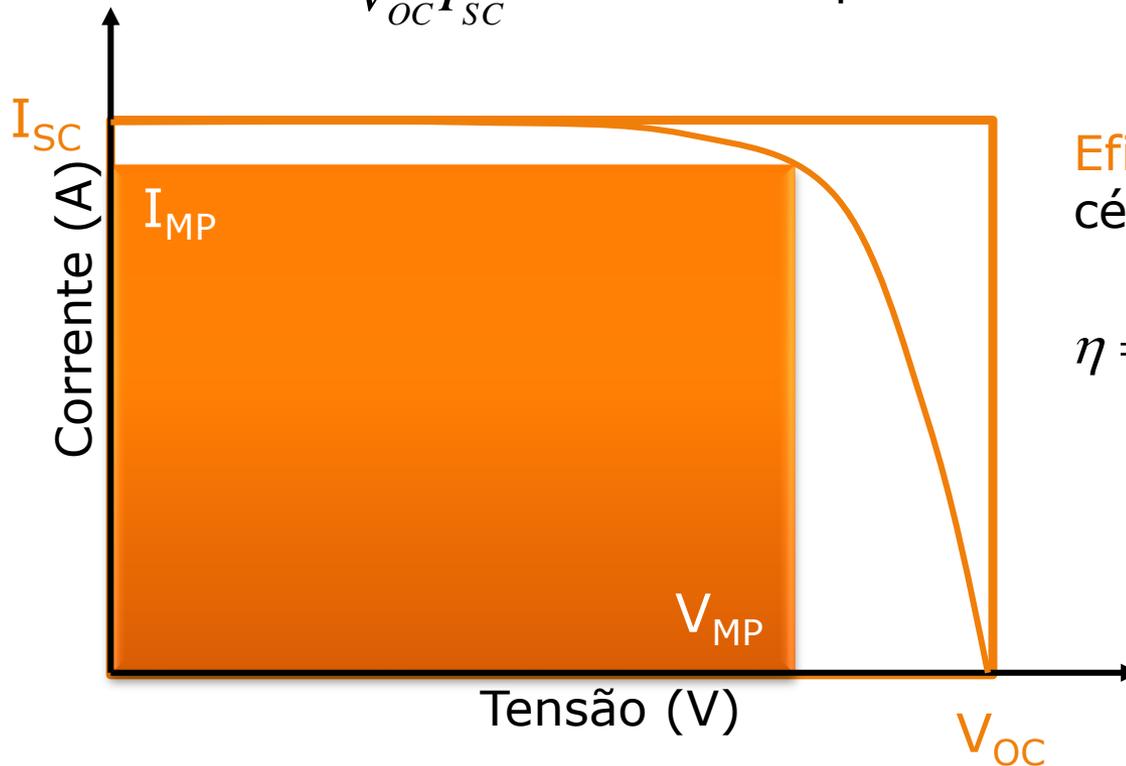
- Característica IV de uma célula solar
Ponto de potência máxima MPP



- Característica IV de uma célula solar
 Factor de preenchimento FF

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}$$

Seria unidade se célula ideal
 Valor típico 0.7 – 0.8

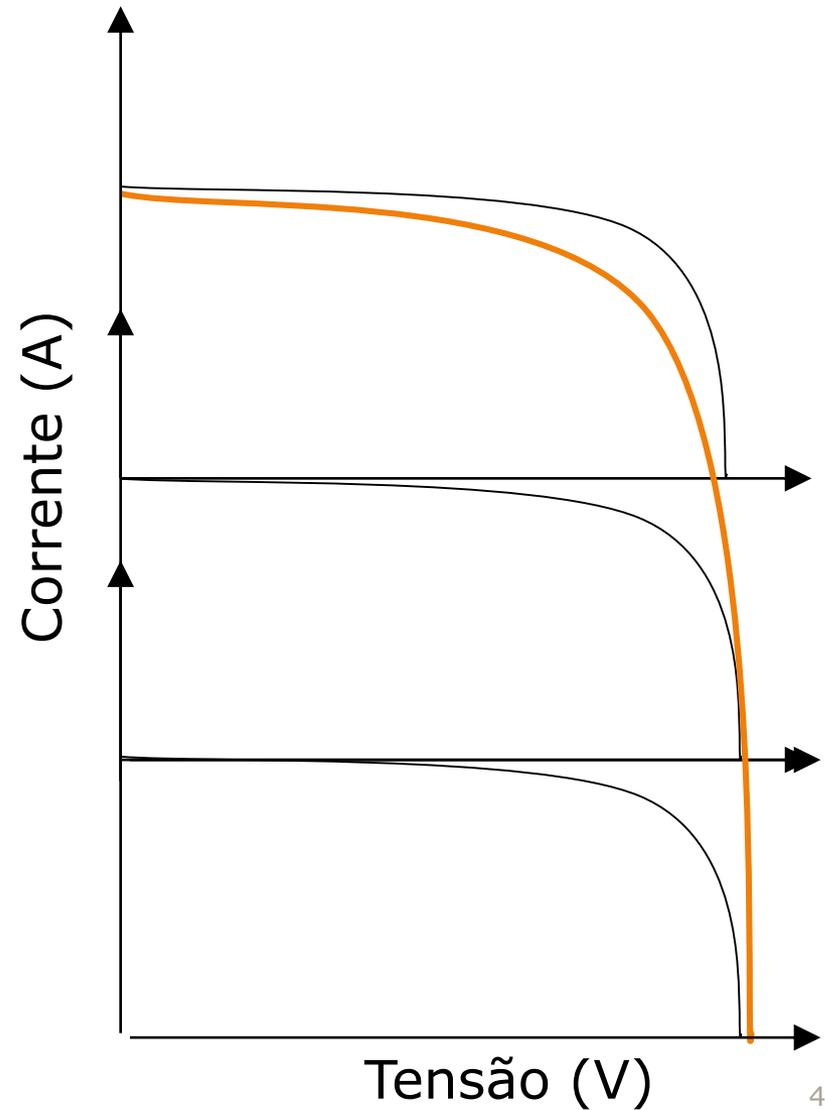
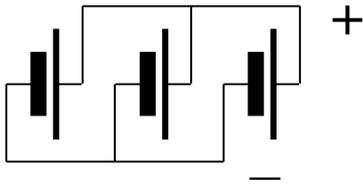


Eficiência de uma célula solar:

$$\eta = \frac{P_{\max}}{Q_{in}} = \frac{FF V_{OC} I_{SC}}{Q_{in}}$$

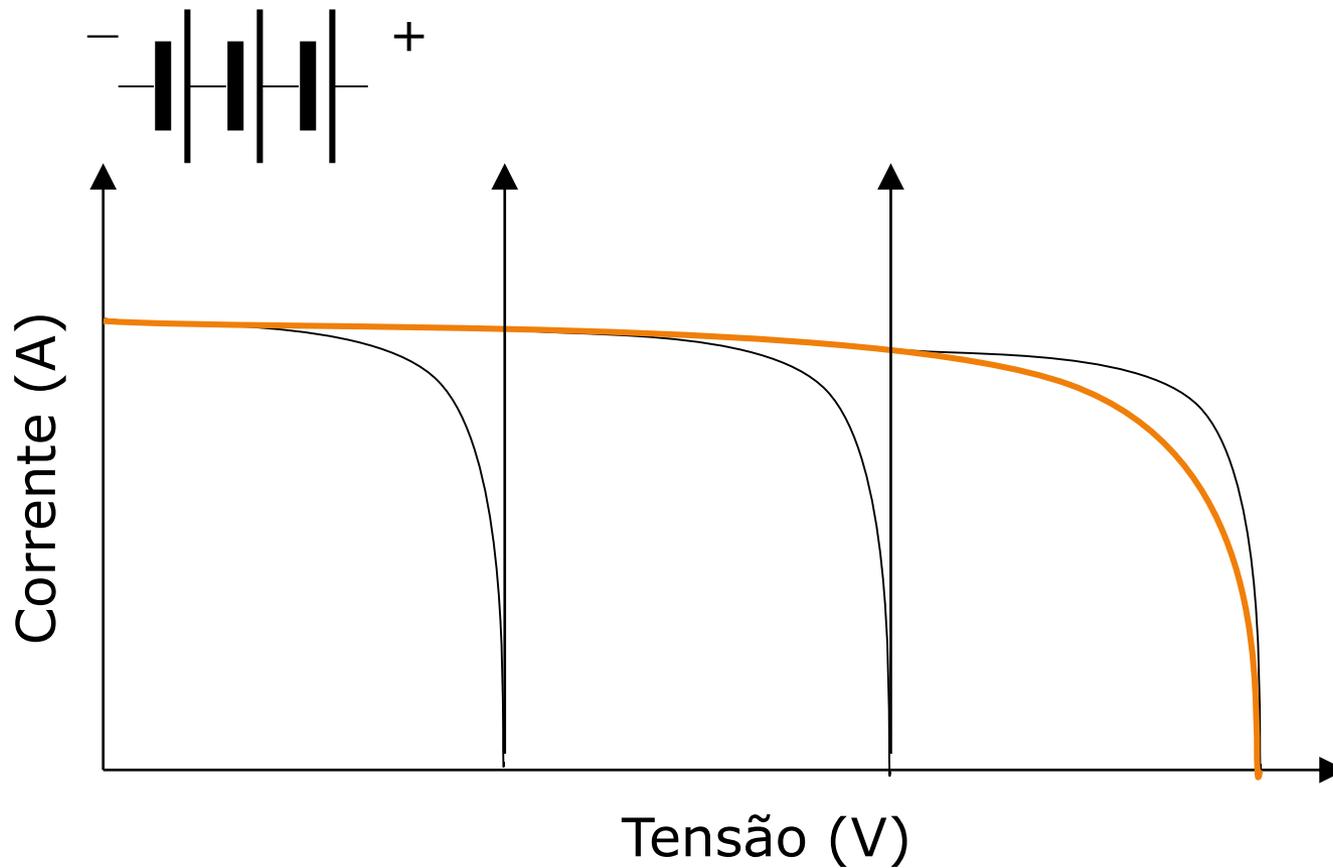
- Ligação células solares

PARALELO

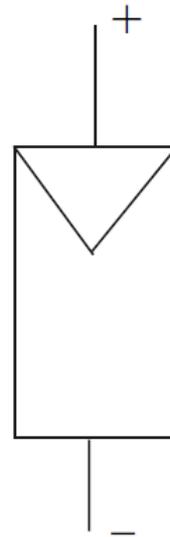


- Ligação células solares

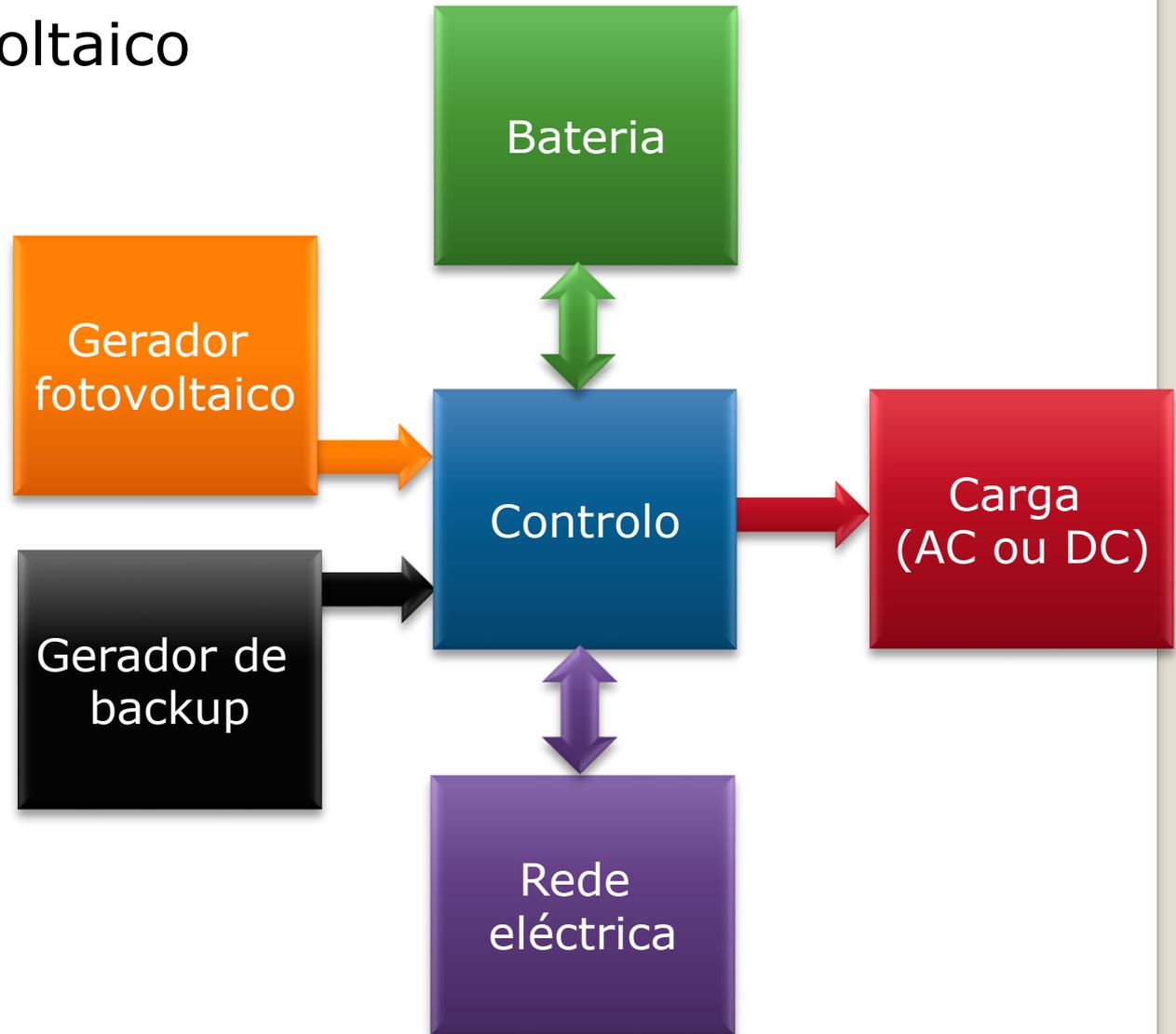
SÉRIE



- Módulos solar



- Sistema fotovoltaico



- Sistema fotovoltaico

Bateria

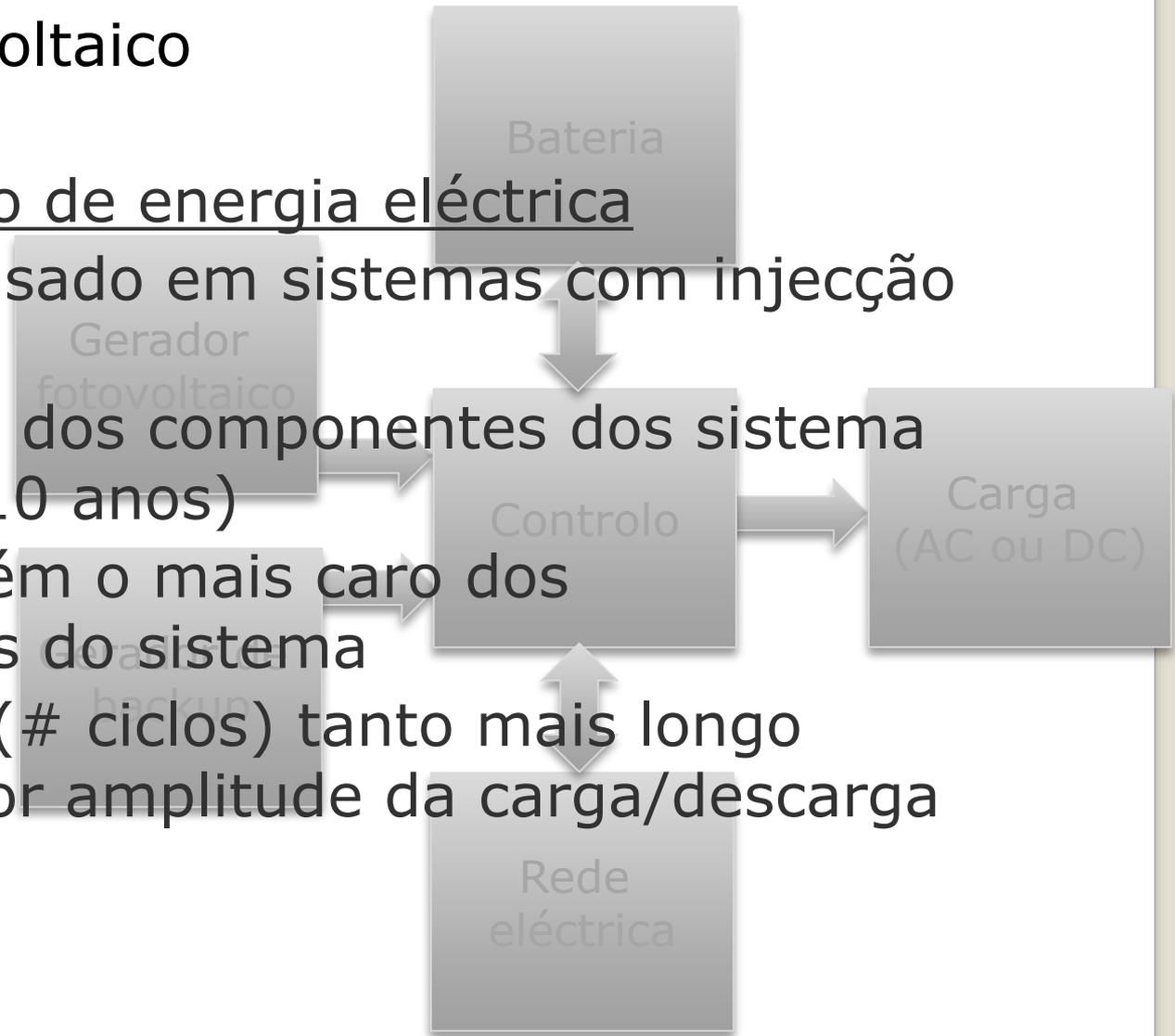
Armazenamento de energia eléctrica

Pode ser dispensado em sistemas com injeccção na rede

O mais sensível dos componentes dos sistema (vida útil 5-10 anos)

Cada vez também o mais caro dos componentes do sistema

Tempo de vida (# ciclos) tanto mais longo quanto menor amplitude da carga/descarga



- Sistema fotovoltaico

Bateria

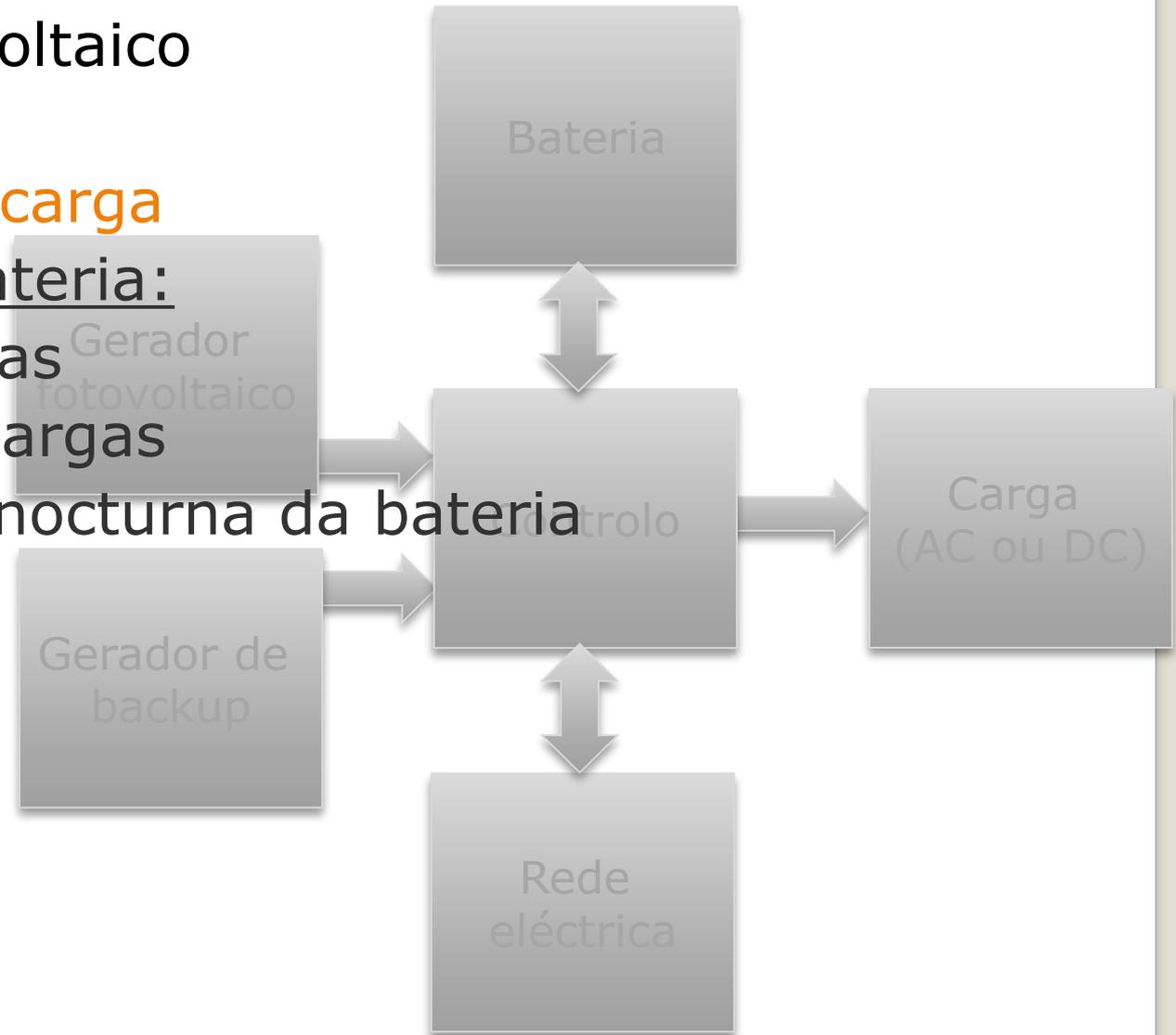
Controlador de carga

Protecção da bateria:

Evita sobrecargas

Evita sobredescargas

Evita descarga nocturna da bateria



- Sistema fotovoltaico

Bateria

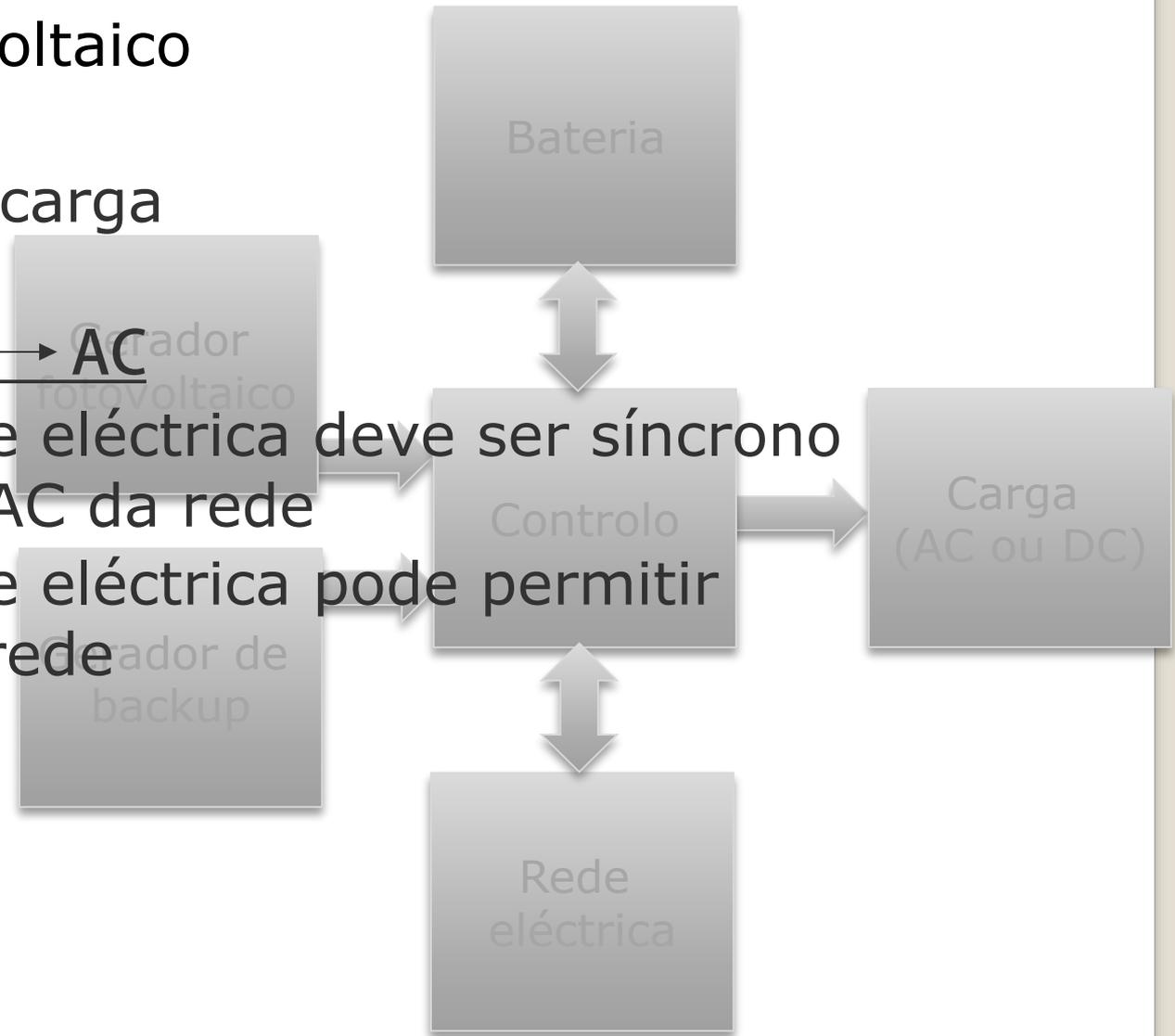
Controlador de carga

Inversor

Transforma DC → AC

Se ligado à rede eléctrica deve ser síncrono com o sinal AC da rede

Se ligado à rede eléctrica pode permitir injeccão na rede



Impactos ambientais

- Consumo de energia durante o processo de fabrico

Impactos ambientais

- Consumo de energia durante o processo de fabrico
- Eventuais acidentes industriais durante o processo de fabrico

washingtonpost.com > business

POST BUSINESS Japan tsunami spares major economic zones

Solar Energy Firms Leave Waste Behind in China

By Ariana Eunjung Cha
Washington Post Foreign Service
Sunday, March 9, 2008

GAOLONG, China -- The first time Li Gengxuan saw the dump trucks from the nearby factory pull into his village, he couldn't believe what happened. Stopping between the cornfields and the primary school playground, the workers dumped buckets of bubbling white liquid onto the ground. Then they turned around and drove right back through the gates of their compound without a word.

This ritual has been going on almost every day for nine months, Li and other villagers said.

PHOTOS [Previous](#) [Next](#)



"It's poison air. Sometimes it gets so bad you can't sit outside. You have to close all the doors and windows," says Qiao Shi Peng, 28, shown in front of a dumping site in his village, who worries about his 1-year-old son's health. (Zhang Quanfeng - Photo By Zhang Quanfeng)

Impactos ambientais

- Consumo de energia durante o processo de fabrico
- Eventuais acidentes industriais durante o processo de fabrico
- Libertação de Cd em caso de incêndio ou se não recolhido para reciclagem no final de vida



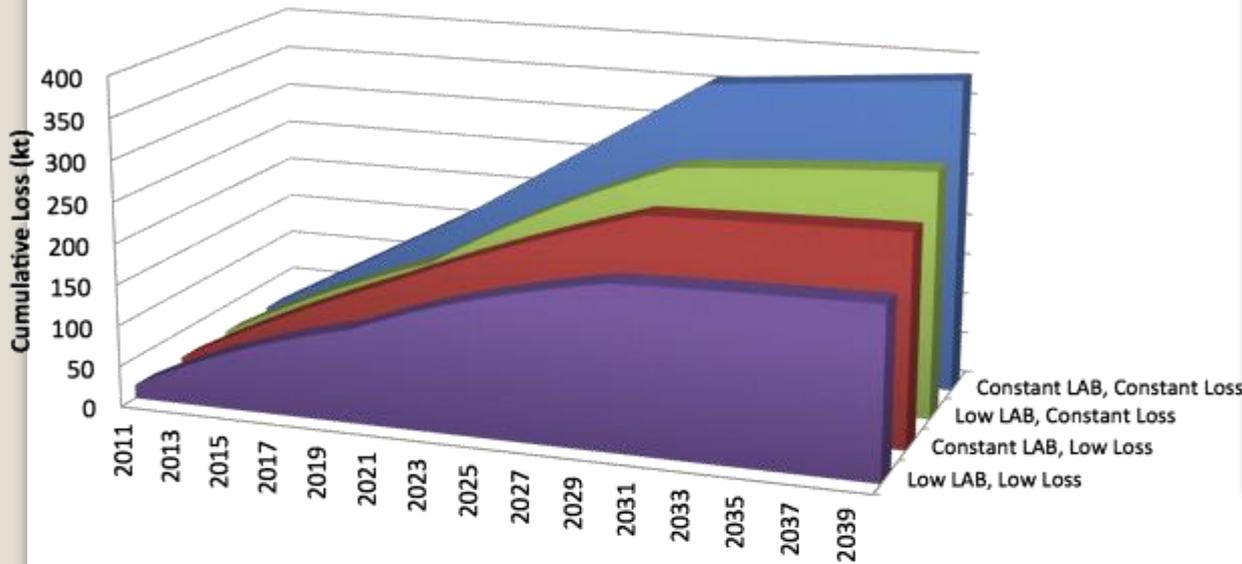
Impactos ambientais

- Consumo de energia durante o processo de fabrico
- Eventuais acidentes industriais durante o processo de fabrico
- Libertação de Cd em caso de incêndio ou se não recolhido para reciclagem no final de vida
- Promoção de baterias de chumbo particularmente em regiões remotas

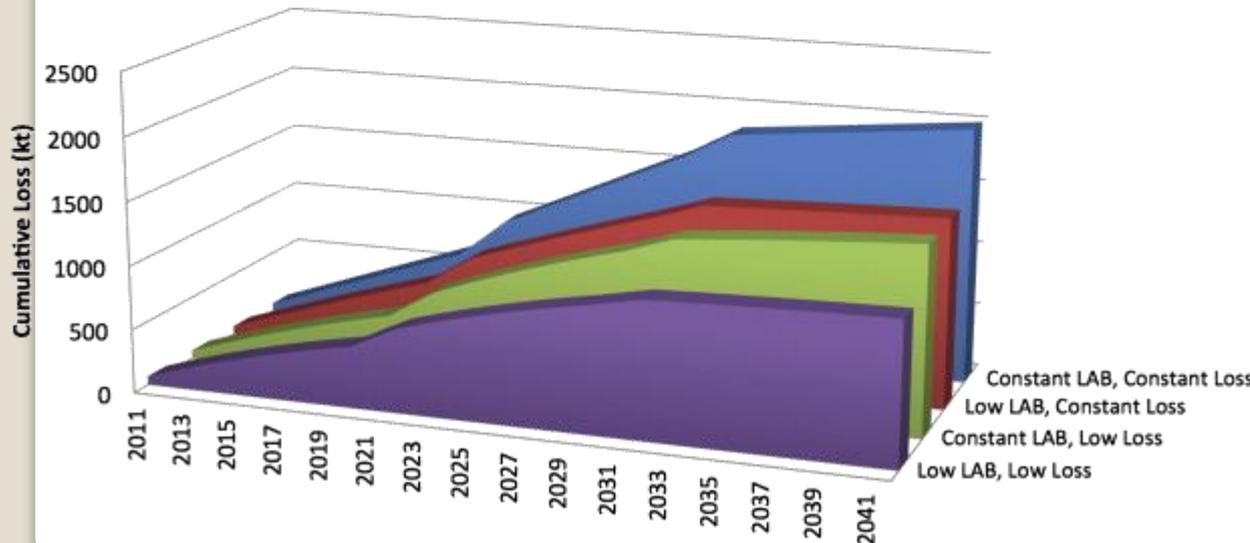
Base and alternative lead emission scenarios for solar PV systems.

Constant LAB: current LAB intensity (kWh LAB per kW PV) throughout system life cycle,
Low LAB: LAB intensity decreases by 5% per year throughout timeline,
Low Loss: ongoing annual improvement (5% China, 4% India) in mining and smelting, manufacturing, and recycling efficiency.

China

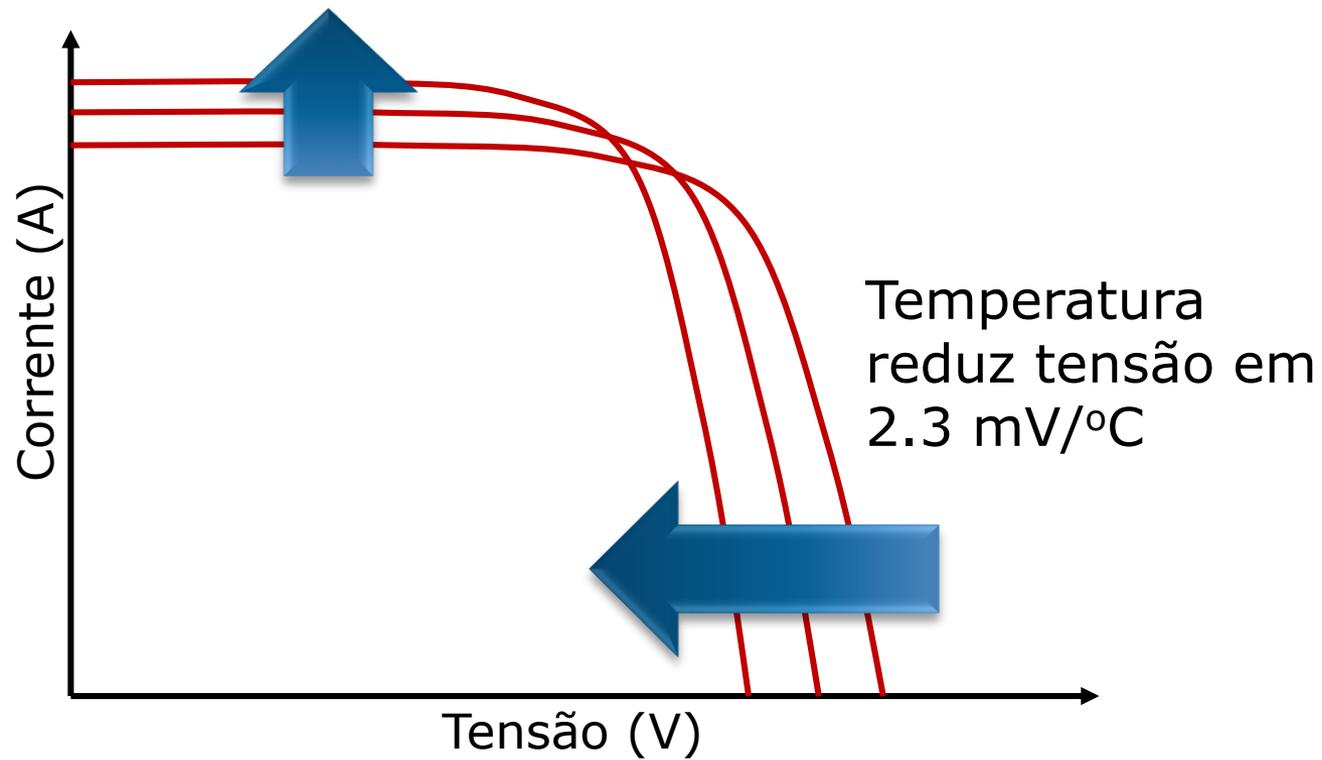


India

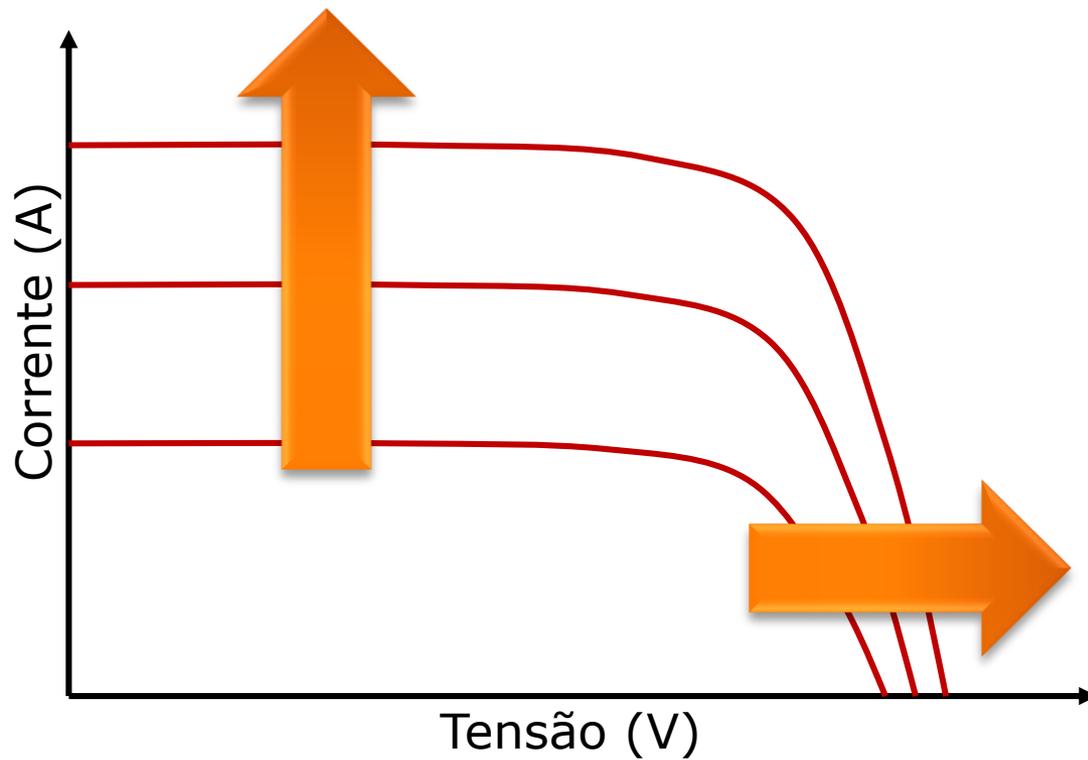


P. Gottesfeld, C.R. Cherry, *Lead emissions from solar photovoltaic energy systems in China and India*, Energy Policy **39** (2011)4939–4946³⁸

- Efeito da temperatura

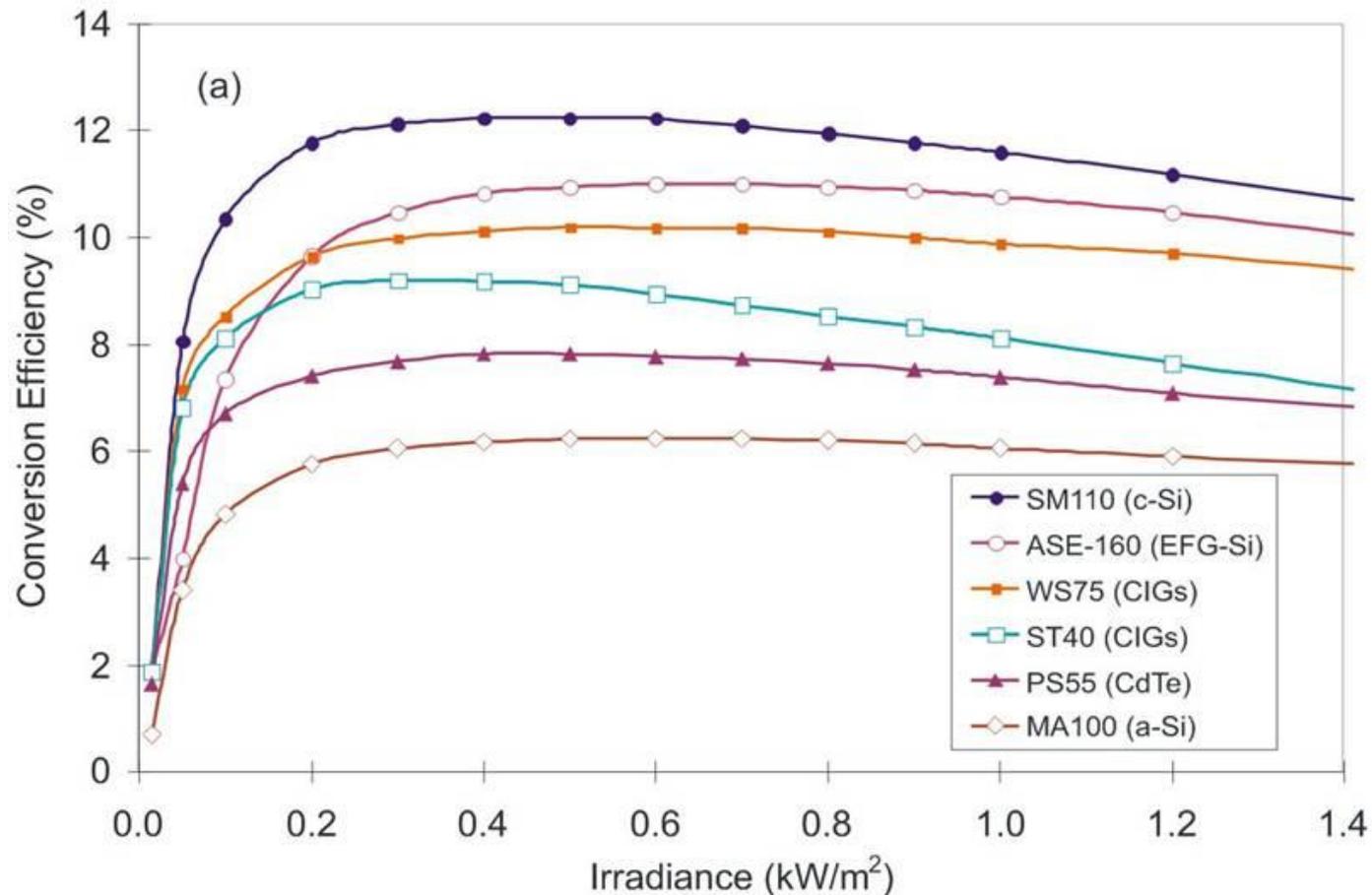


- Efeito da radiação



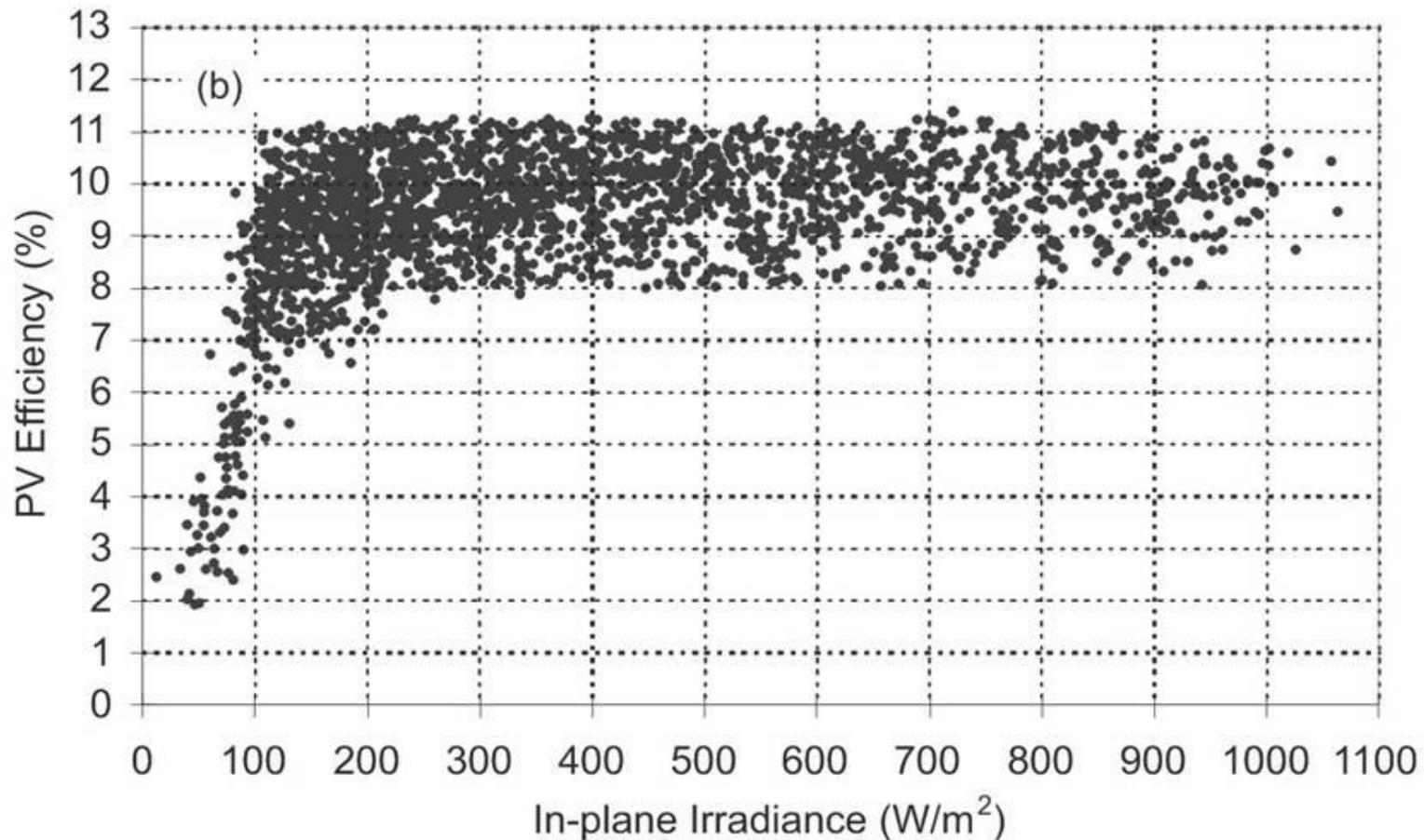
Parametros que determinam desempenho célula solar

- Irradiância
- Temperatura



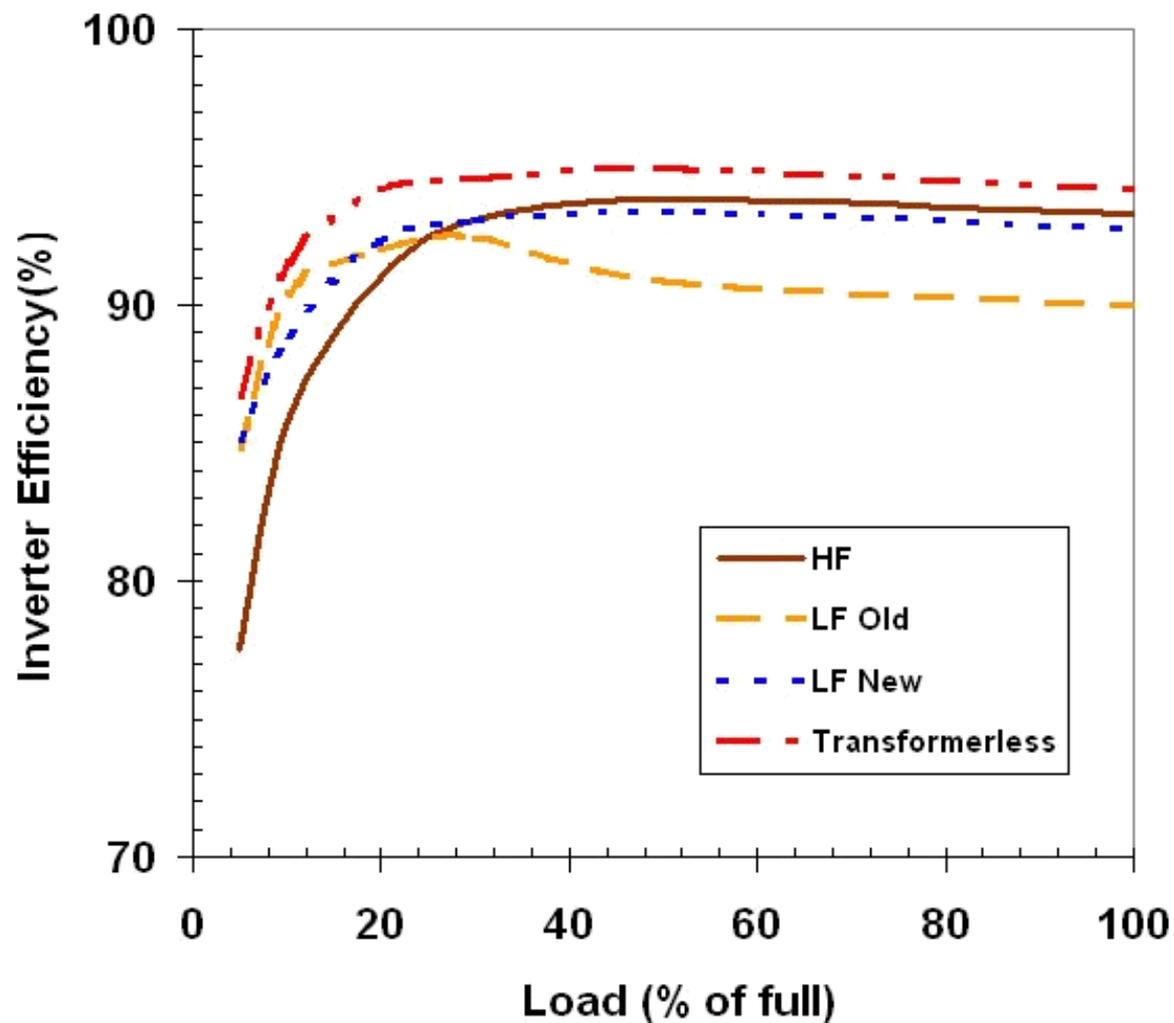
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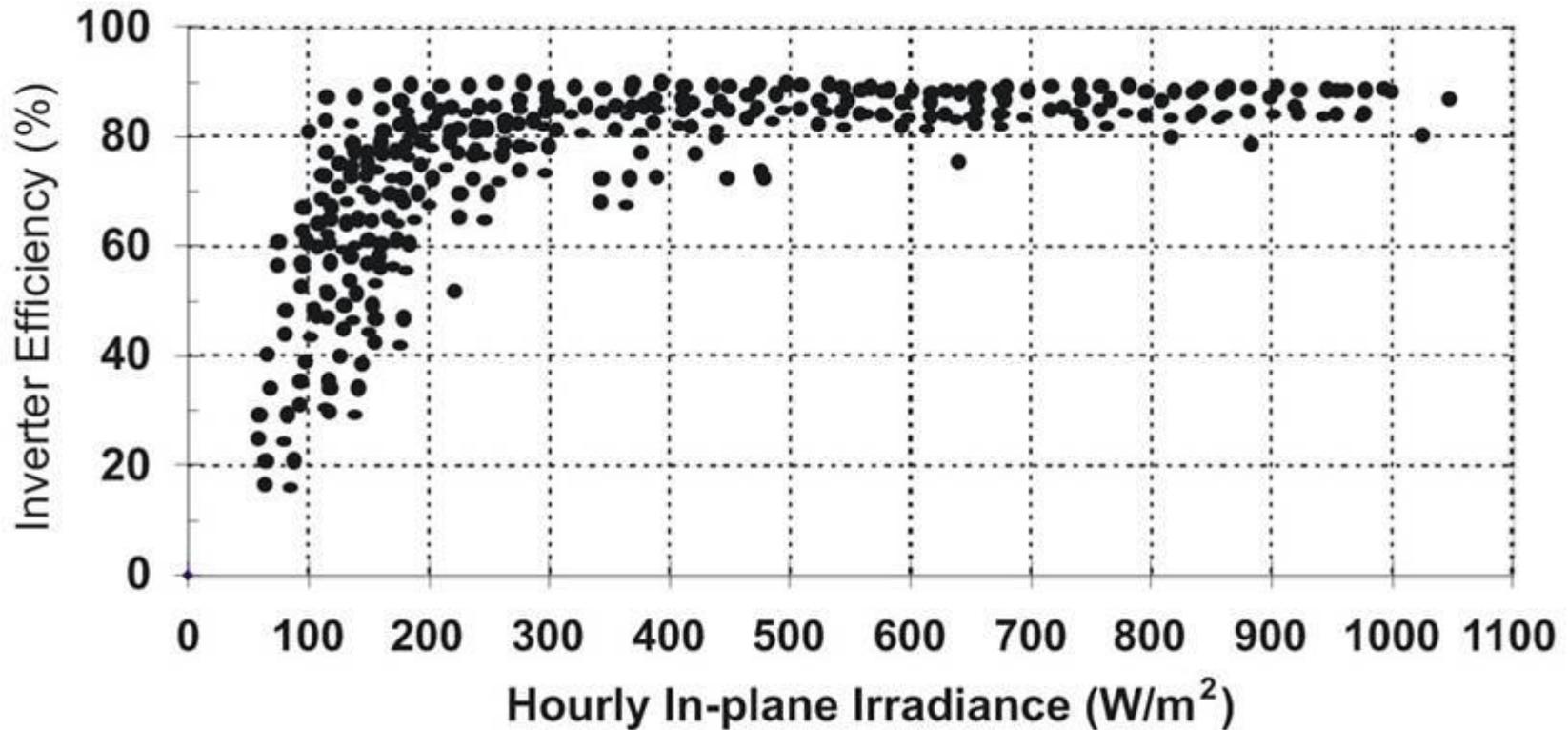
Parametros que determinam desempenho sistema solar

- eficiência dos componentes a jusante: inversor



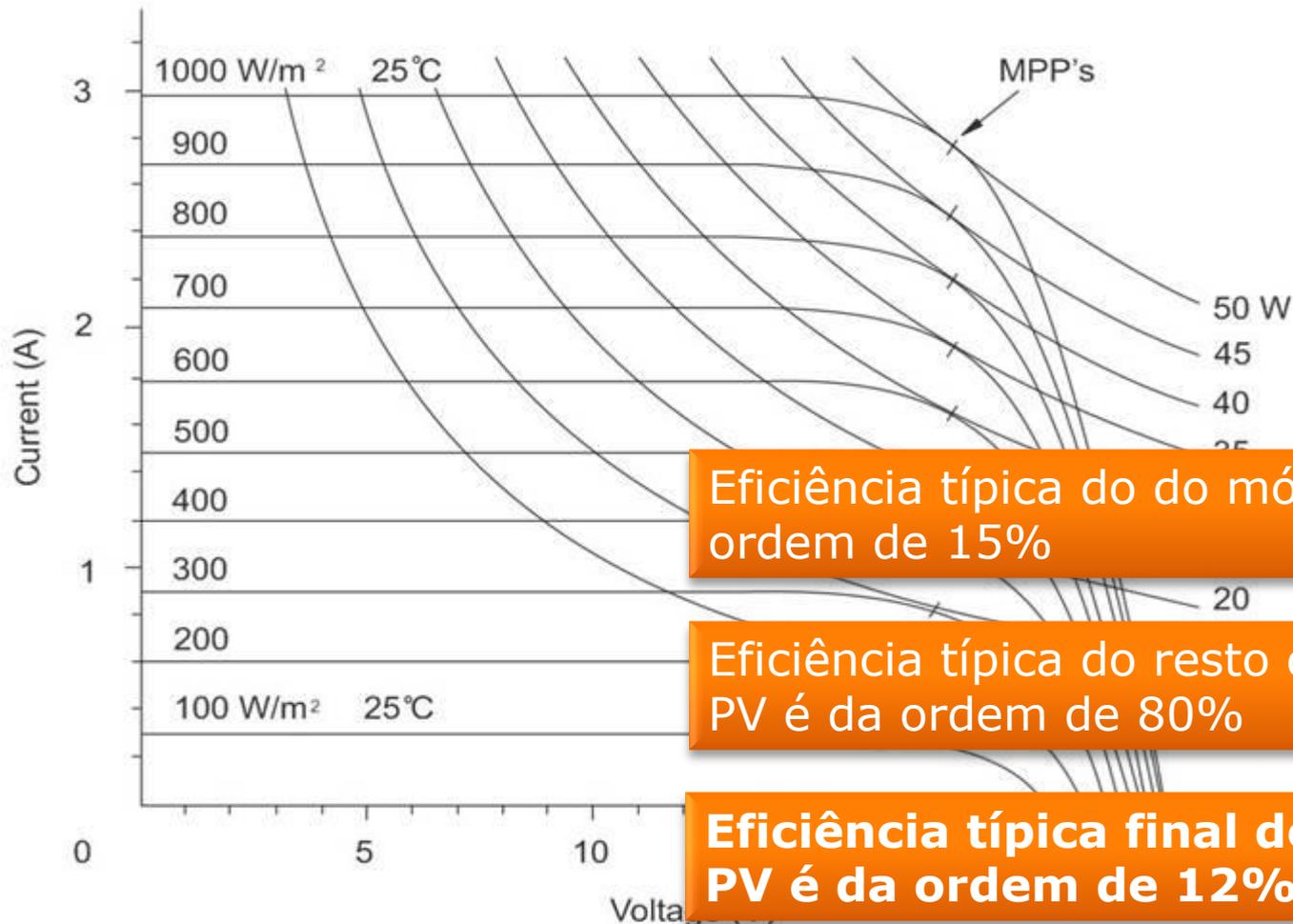
Parametros que determinam desempenho sistema solar

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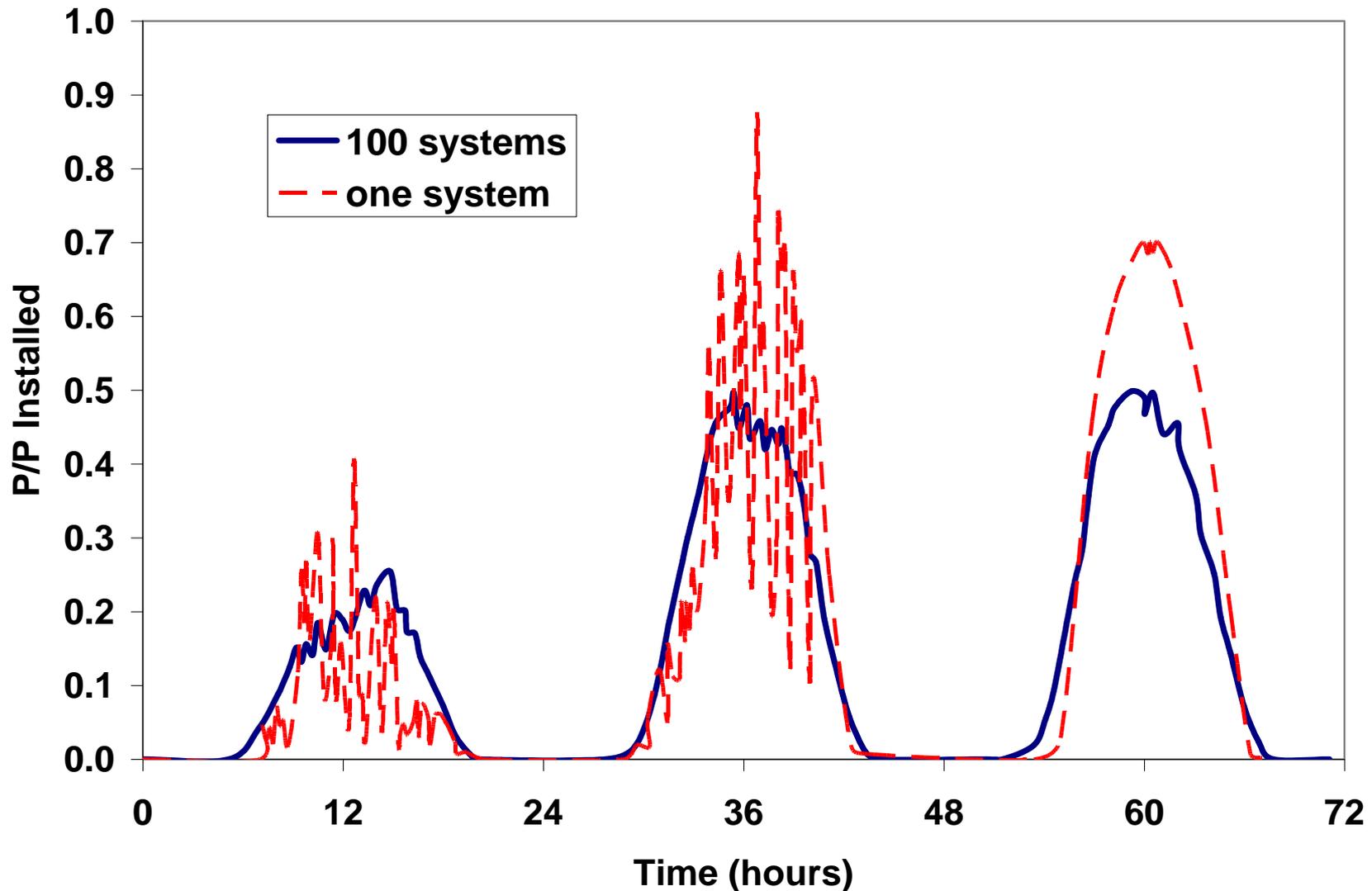


Parâmetros que determinam desempenho sistema solar

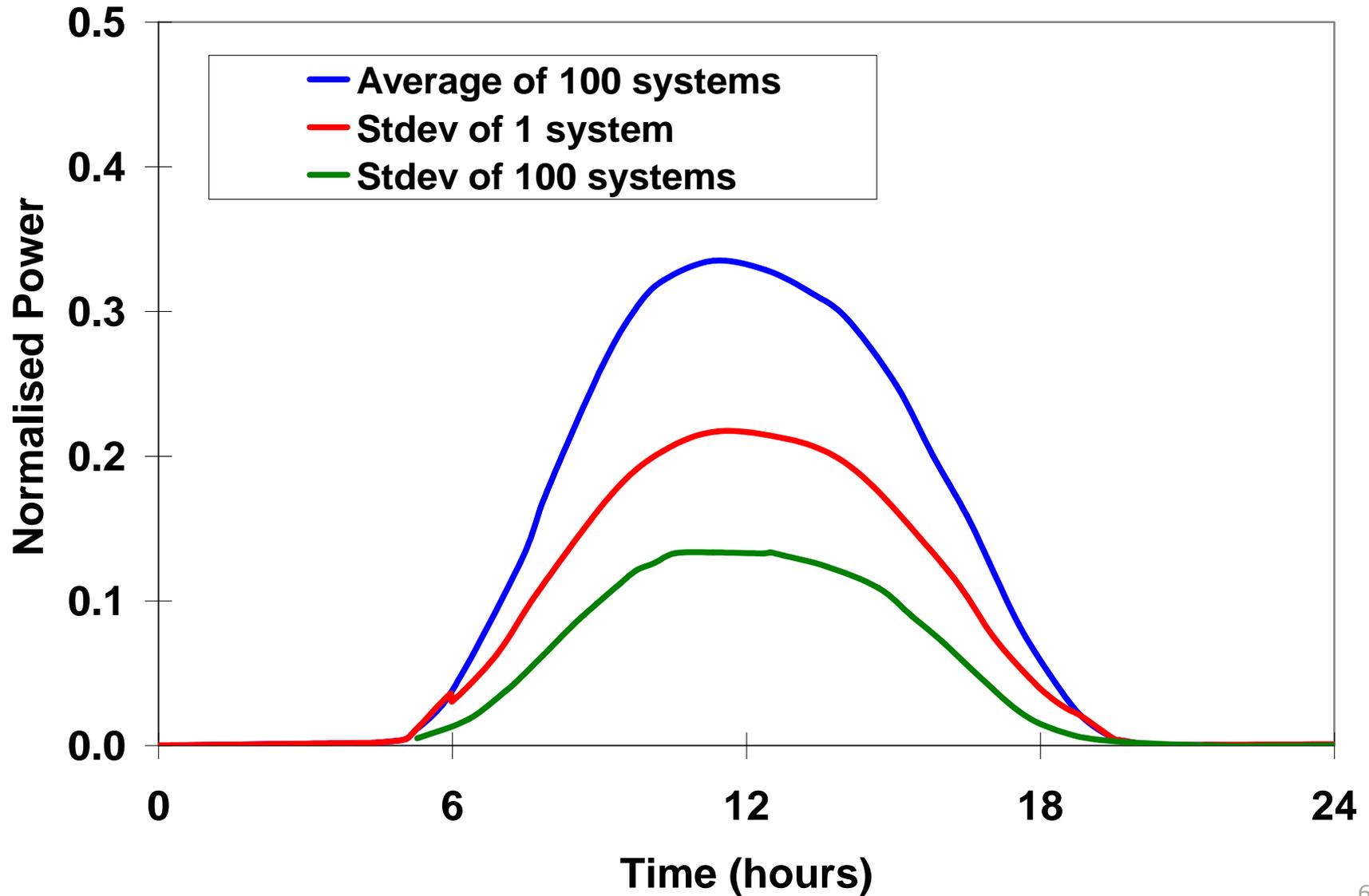
- eficiência dos componentes a jusante: MPP



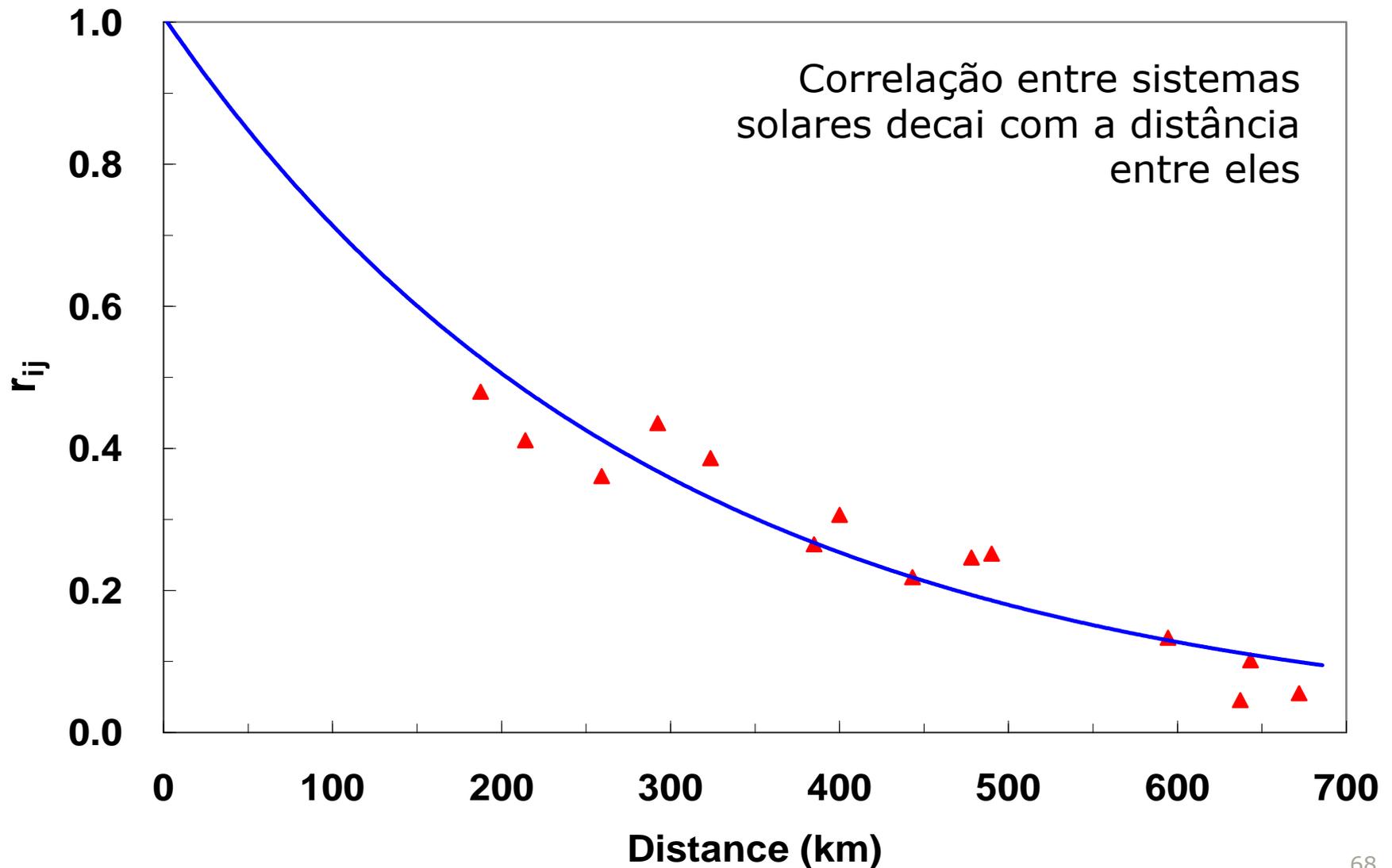
Variabilidade (e não intermitência!)



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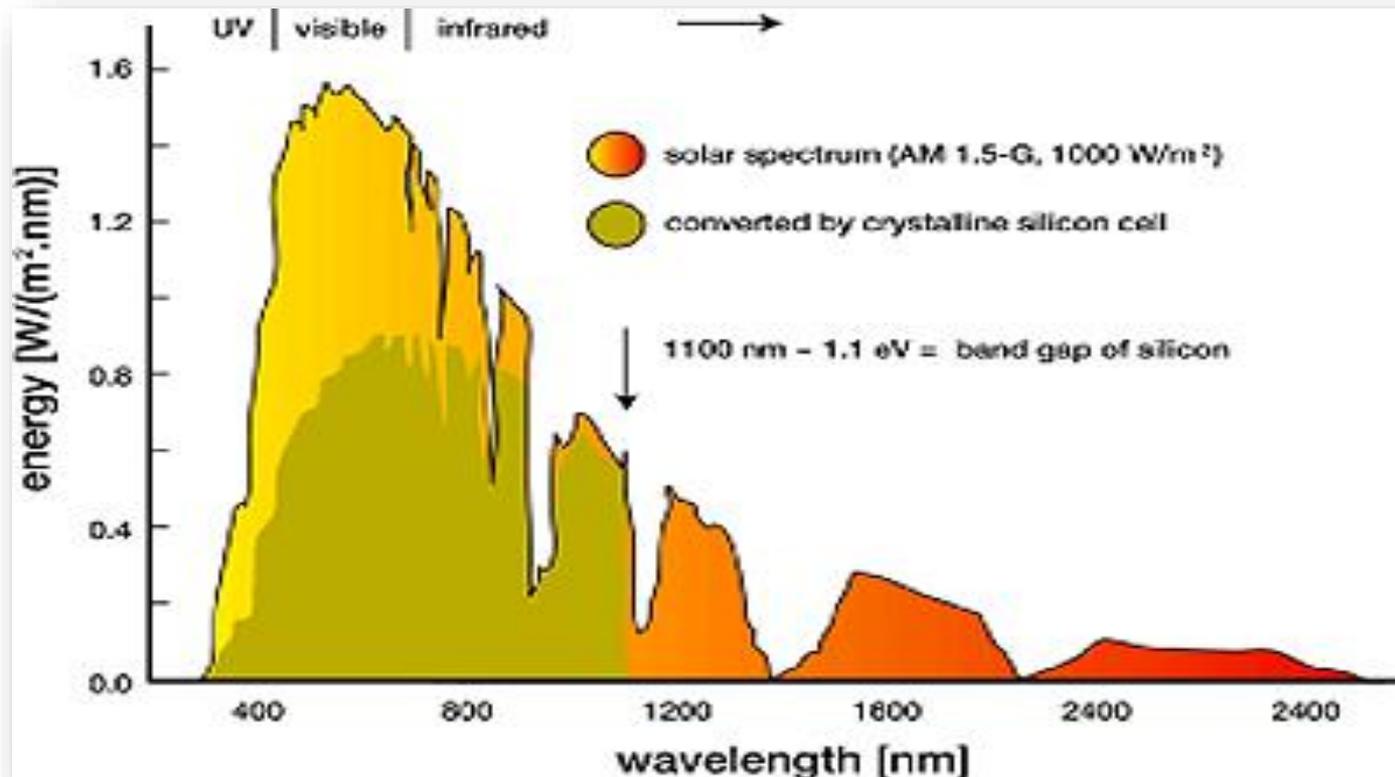
Variabilidade (e não intermitência!)



O que limita a eficiência de uma célula solar?

Razões fundamentais

- Fótons que não têm energia para criar uma carga no silício
- Fótons com mais energia do que a energia do hiato



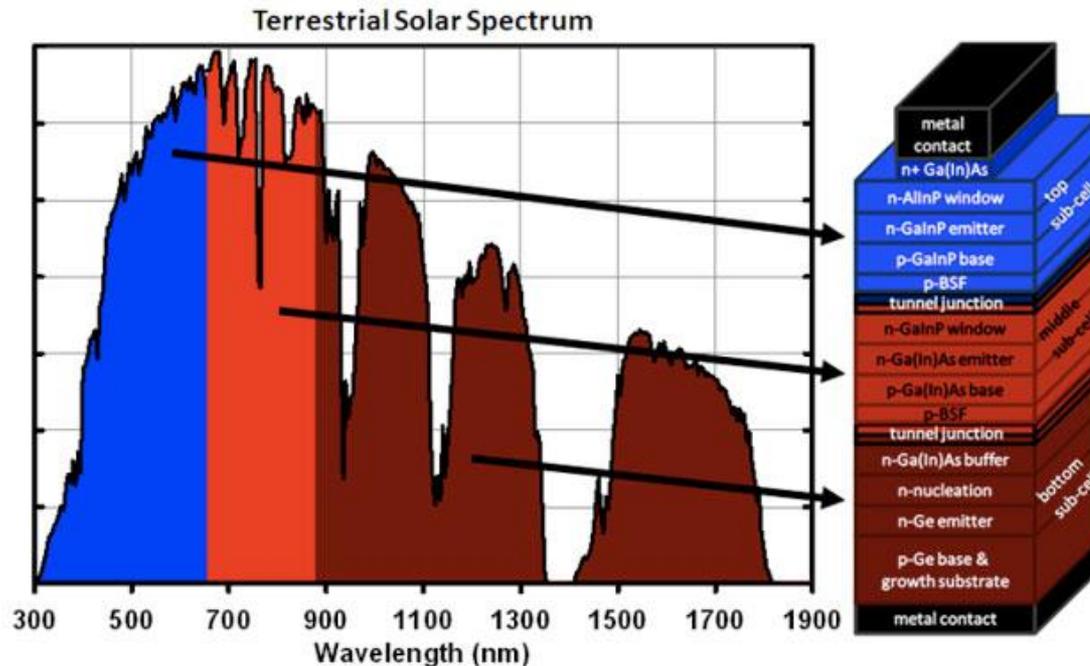
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O que podemos fazer?

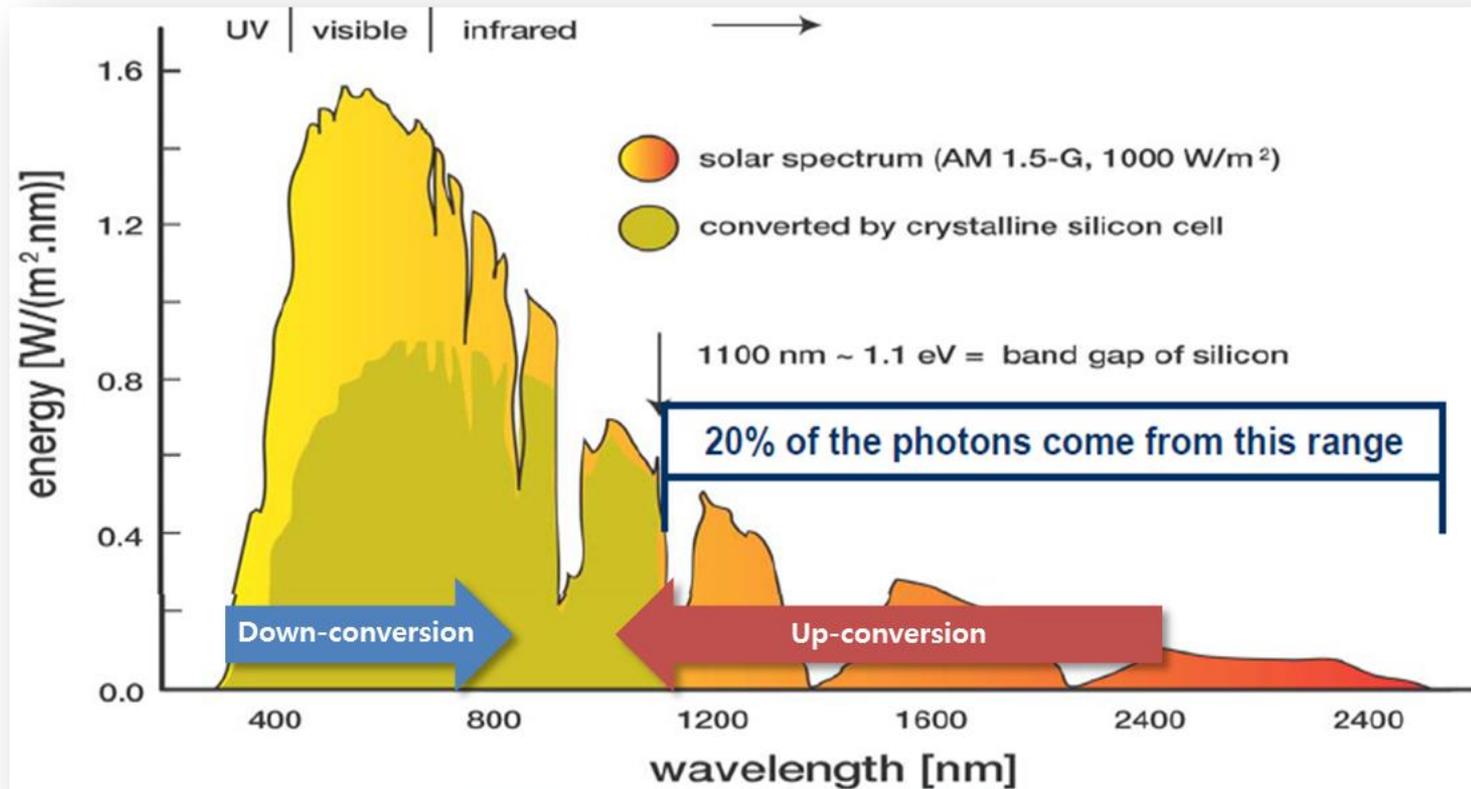
Células com vários hiatos diferentes: células multijunção



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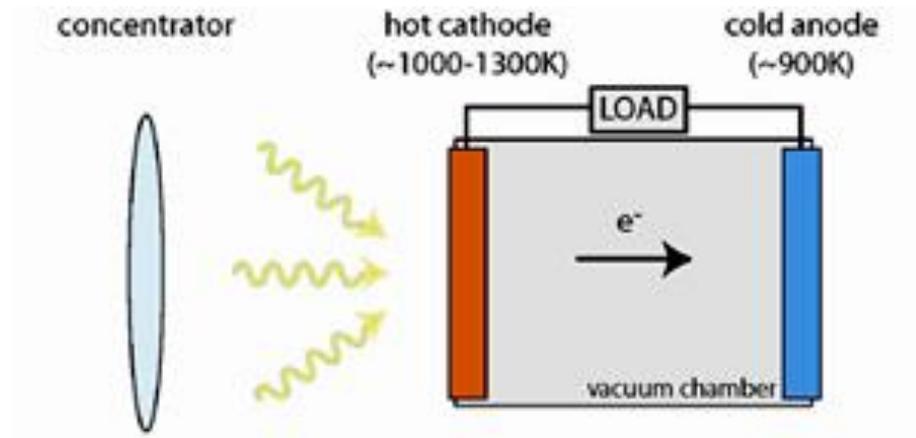
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O que podemos fazer?

Células com vários hiatos diferentes: células multijunção

Alterar a energia dos fótons incidentes



O que limita a eficiência de uma célula solar?

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Razões tecnológicas

Perdas ópticas (luz reflectida na superfície e/ou nos contactos, fótons que atravessam o material sem ser absorvido, etc)

Recombinação das cargas antes de chegarem aos contactos

Perdas resistivas

Etc.

Podem ser reduzidas significativamente, mas encarecem processo de fabrico pelo que é necessário um compromisso entre eficiência e custo. O que conta é €/kWh!