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:

5.0×10^{10} 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:

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

Por habitante:

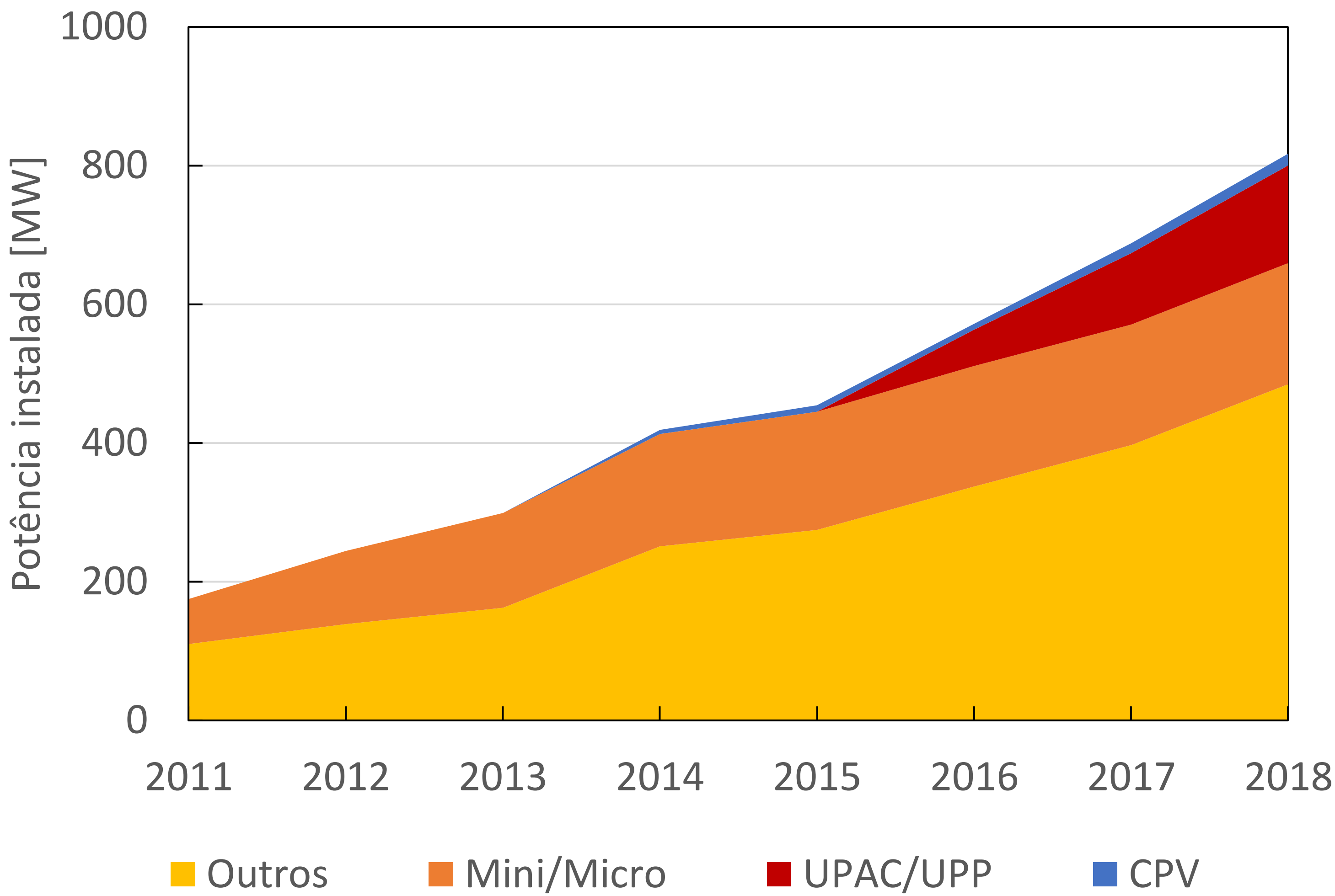
$9 \times 10^8 / 10^7 = 90\ m^2$ de asfalto per capita

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

$220\ km^2$ $22 m^2$/pessoa


SOLARIA

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 da Atalaia
Enseada das Pedreiras
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
Selvagem Pequena
Ponta de Oeste
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


1000
800
600
400
200
0
Potência instalada [MW]
2011
2012
2013
2014
2015
2016
2017
2018
Outros
Mini/Micro
UPAC/UPP
CPV

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

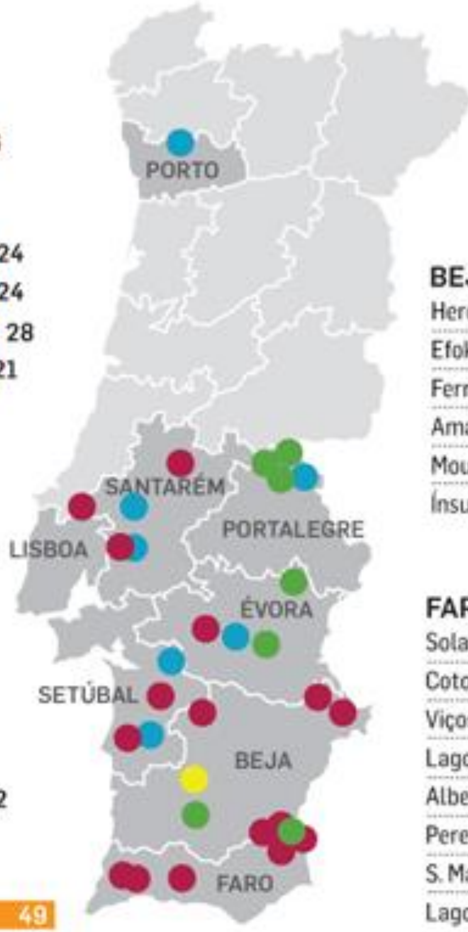
Évora 3	Expoentfokus	29
Montes Novos	Contrate o Sol	3
Vale de Moura	Hyperion	29

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

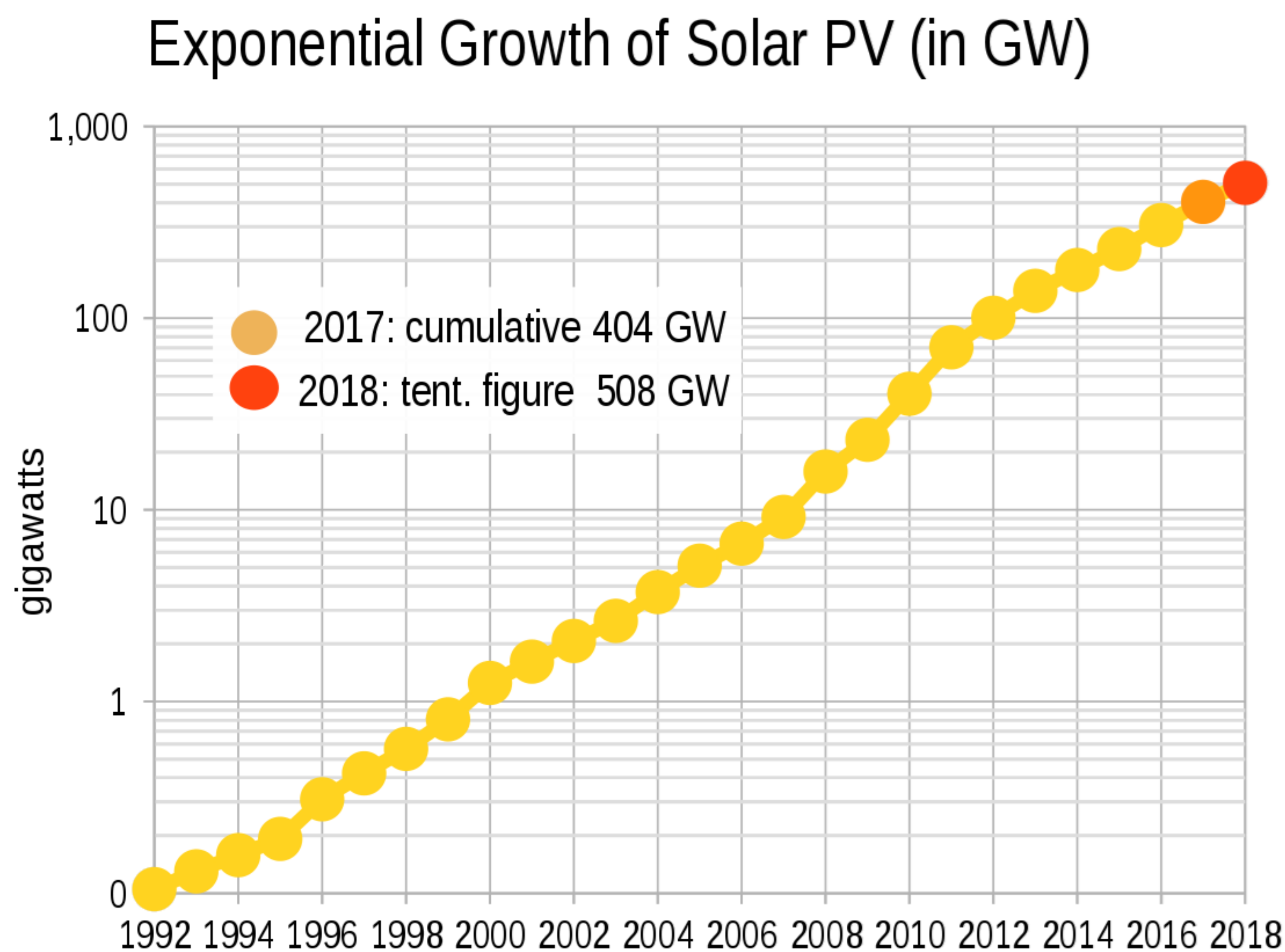
Falagueira I	Expoentfokus	16
Falagueira II	Expoentfokus	15
Falagueira III	Expoentfokus	21
Tendeiros	C. Solar de Tendeiros	24

BEJA

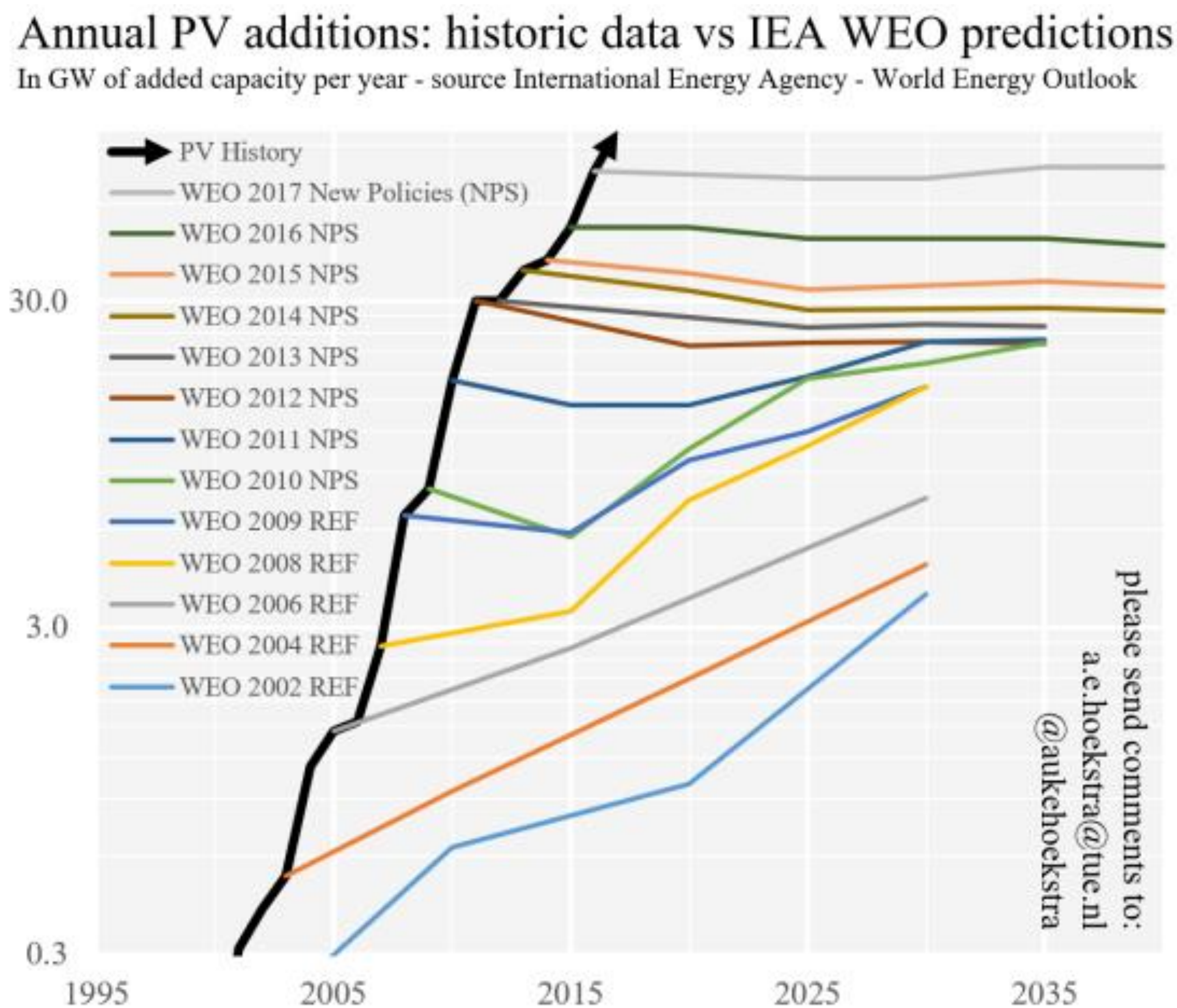
Herdade dos Murzelos	Morning Chapter	46
Efokus Ourique	Expoentfokus	49
Ferreira do Alentejo	Hyperion	42
Amareleja	Hyperion	16
Moura	Hyperion	48
Ínsua	Goldalqueva	49

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

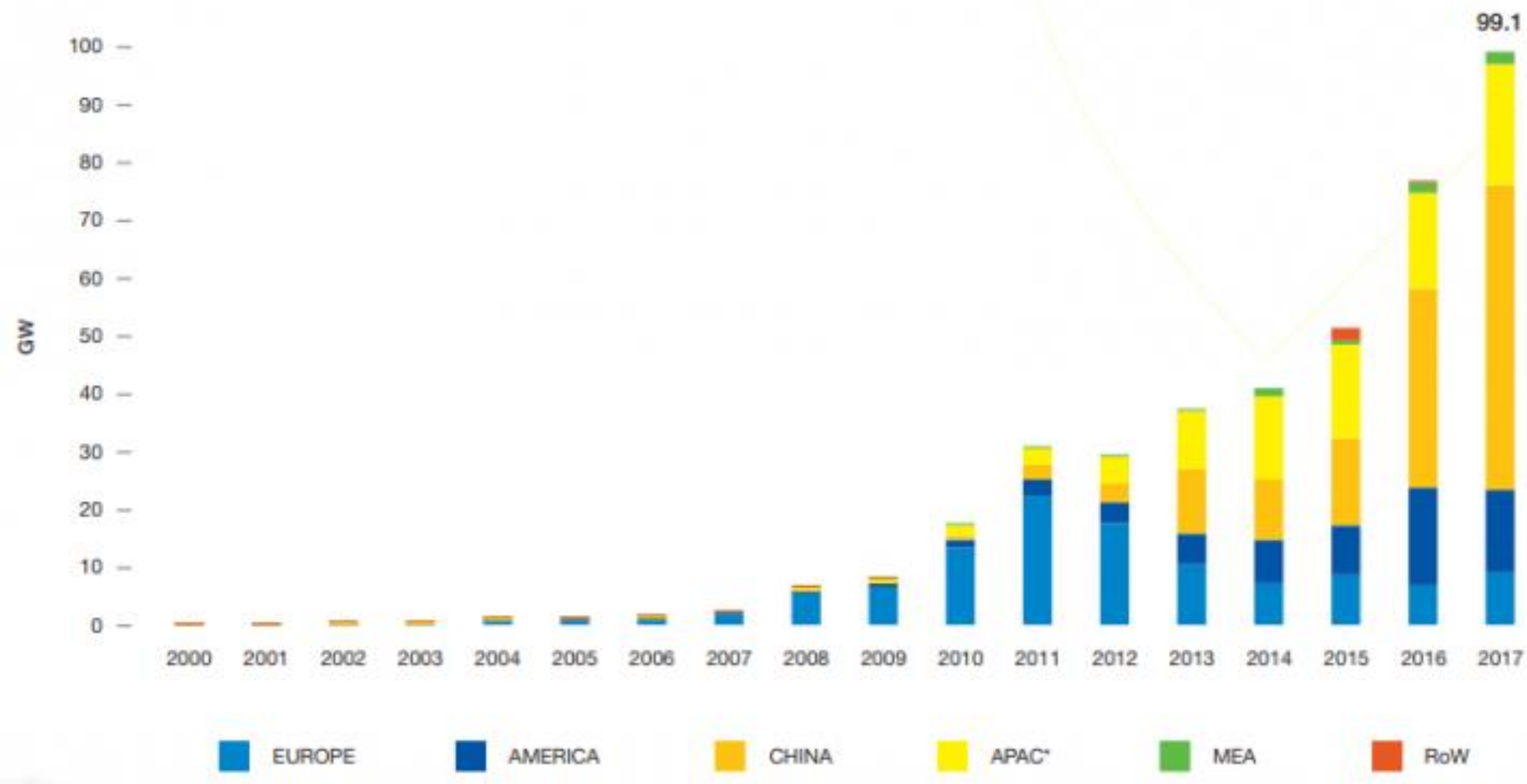


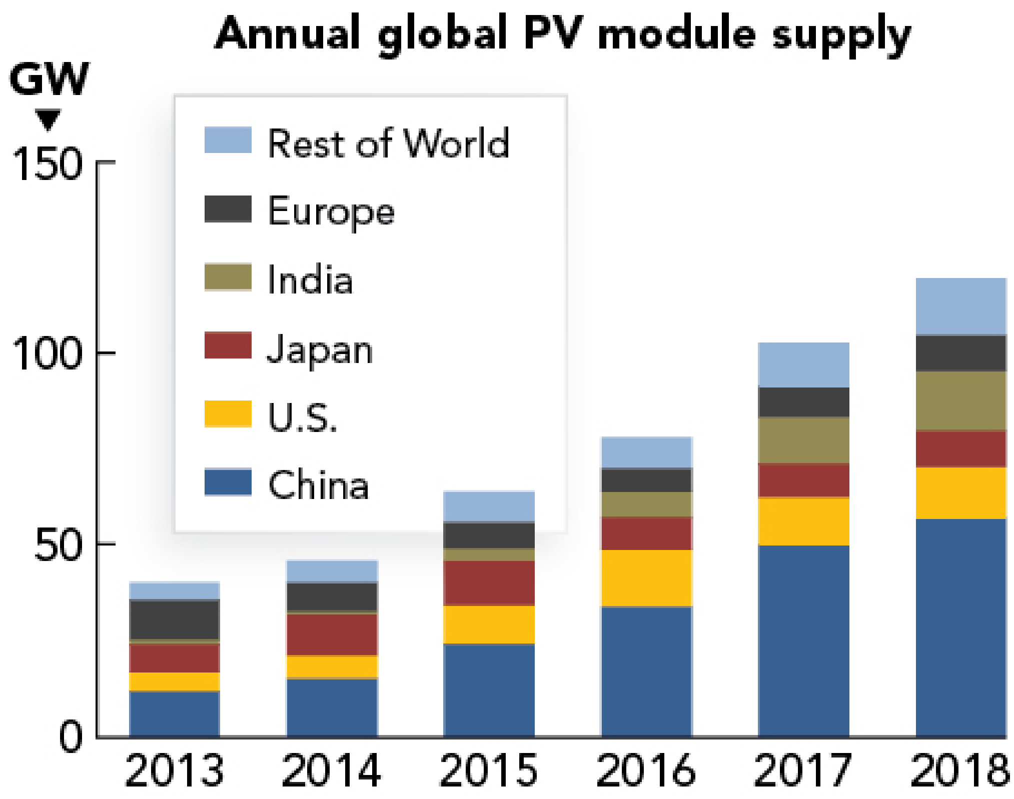
Exponential Growth of Solar PV (in GW)
1,000
100
10
1
0
gigawatts
2017: cumulative 404 GW
2018: tent. figure 508 GW
1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018

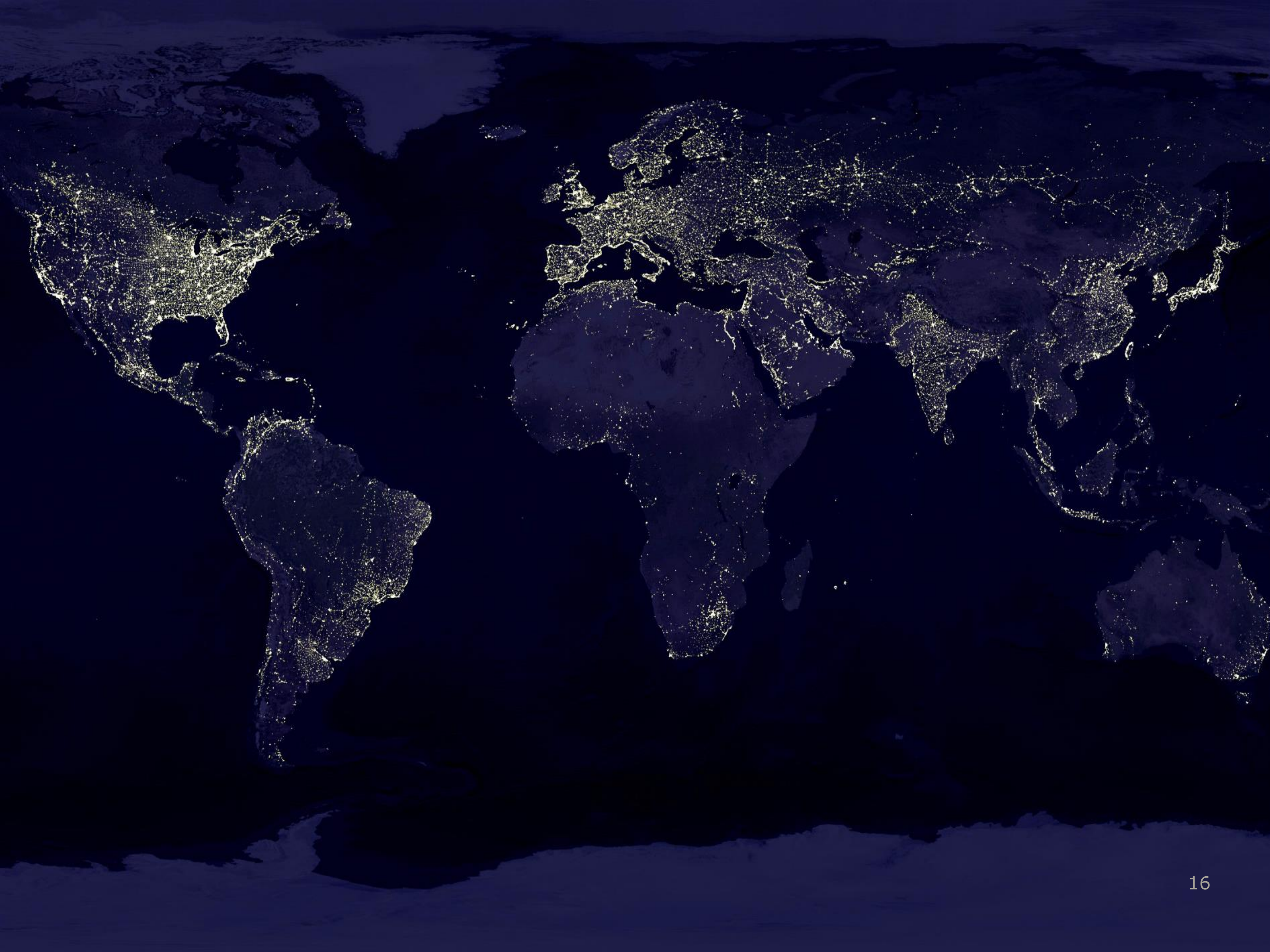


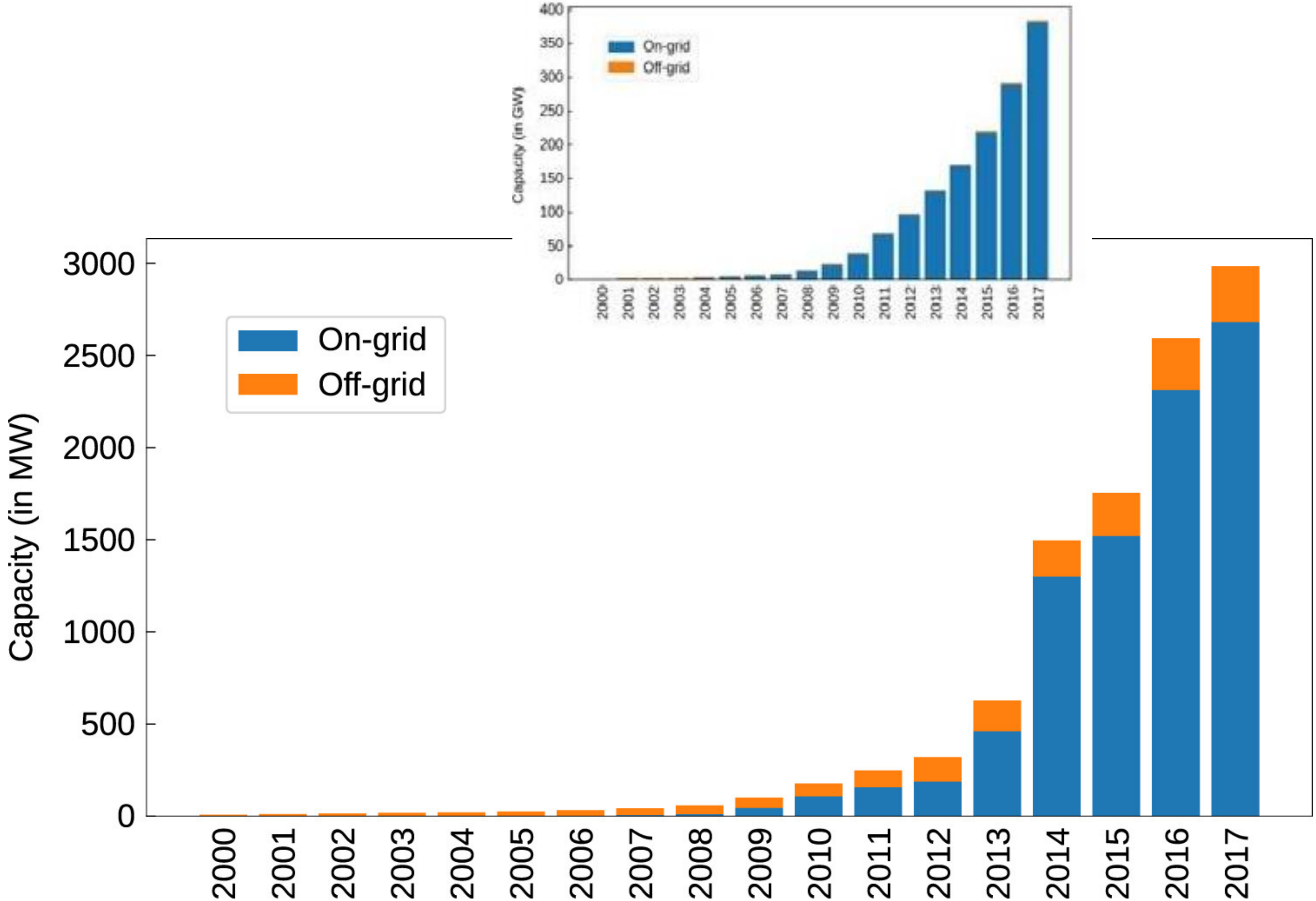
Annual PV additions: historic data vs IEA WEO predictions
In GW of added capacity per year - source International Energy Agency - World Energy Outlook
PV History
WEO 2017 New Policies (NPS)
WEO 2016 NPS
WEO 2015 NPS
WEO 2014 NPS
WEO 2013 NPS
WEO 2012 NPS
WEO 2011 NPS
WEO 2010 NPS
WEO 2009 REF
WEO 2008 REF
WEO 2006 REF
WEO 2004 REF
WEO 2002 REF
30.0
3.0
0.3
1995
2005
2015
2025
2035
please send comments to:
a.e.hoekstra@tue.nl
@aukehoekstra

EVOLUTION OF GLOBAL ANNUAL SOLAR PV INSTALLED CAPACITY 2000-2017

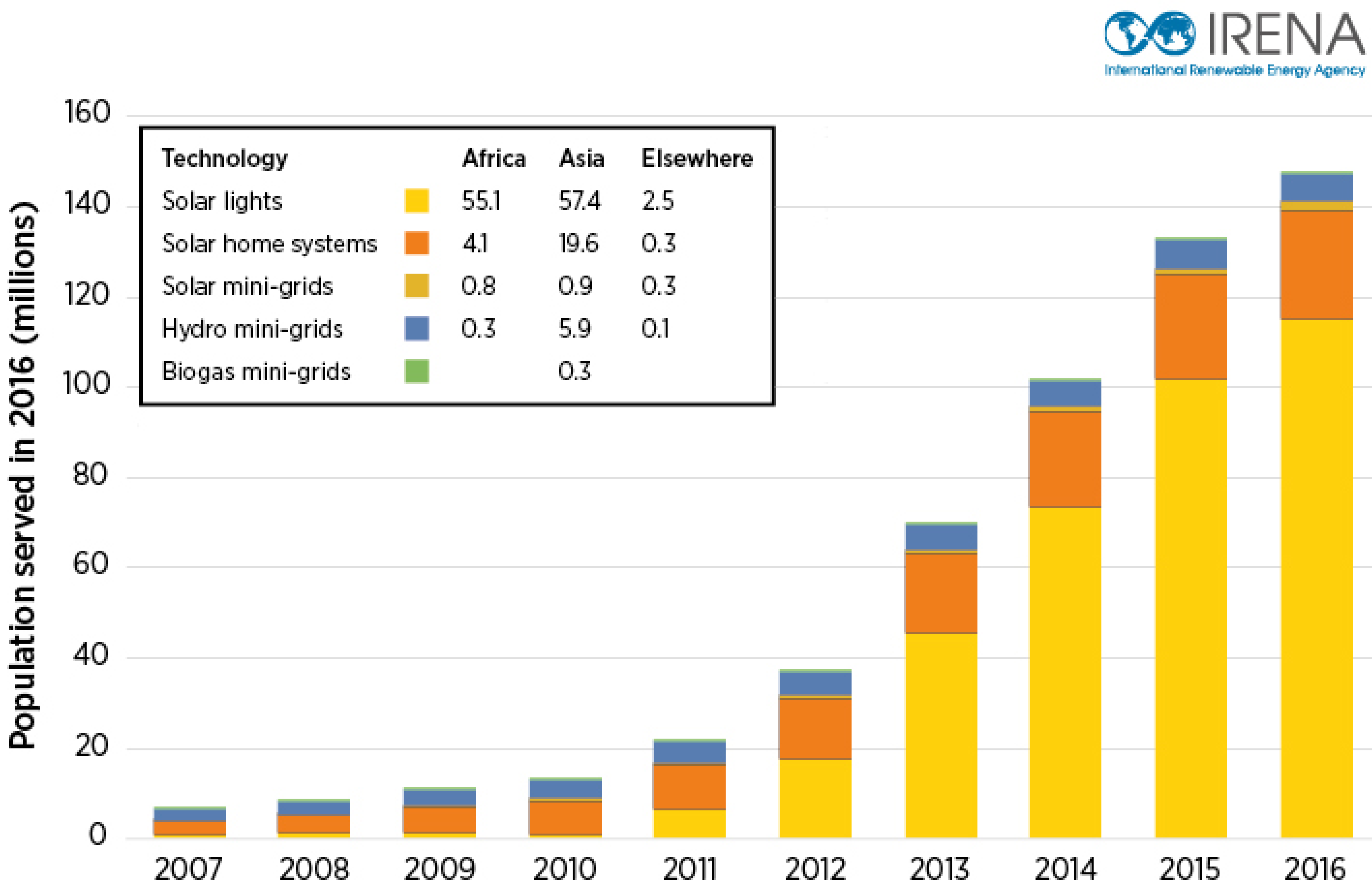



Annual global PV module supply
GW
150
100
50
0
Rest of World
Europe
India
Japan
U.S.
China
2013
2014
2015
2016
2017
2018



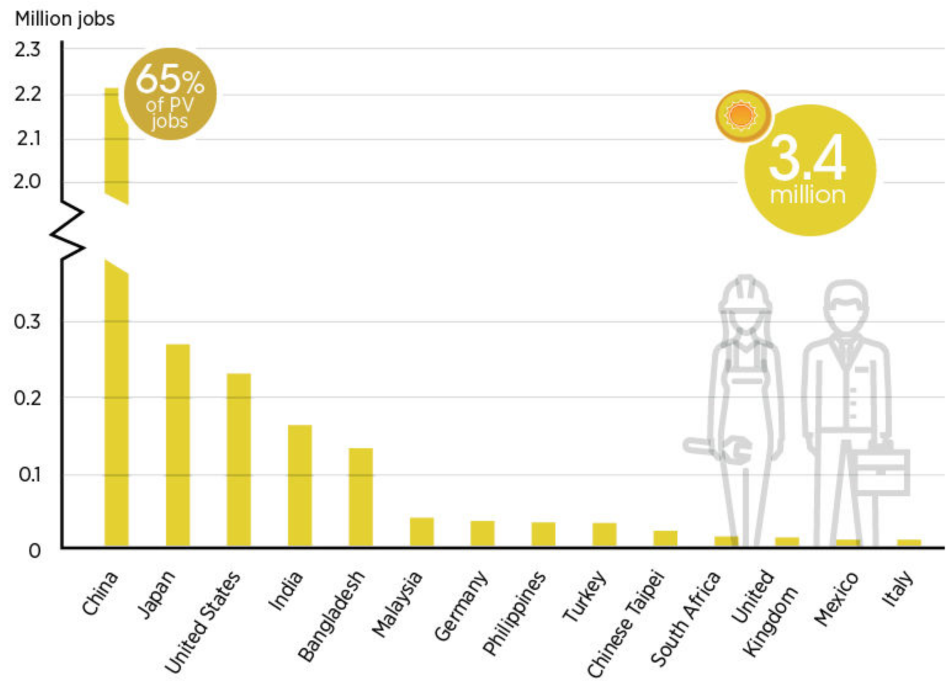


Trends in cumulative PV capacity installed in the world and Sub-Saharan Africa since 2000

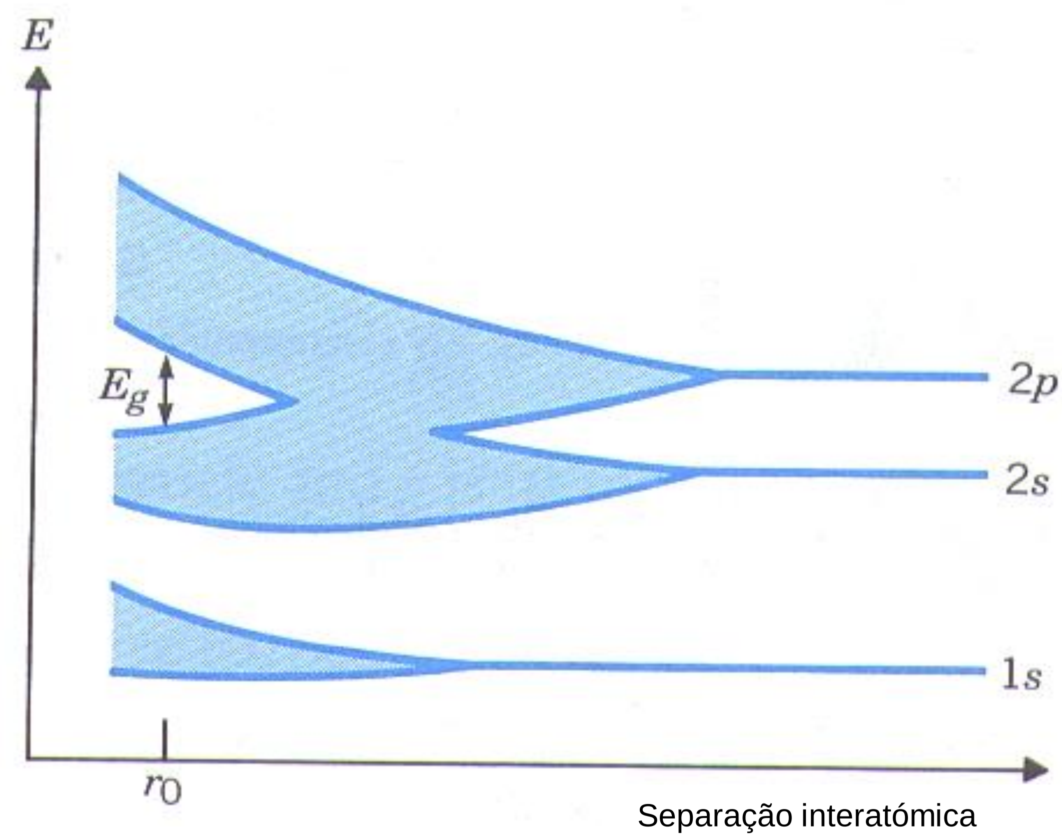

IRENA
International Renewable Energy Agency
Population served in 2016 (millions)
0
20
40
60
80
100
120
140
160
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Technology Africa Asia Elsewhere
Solar lights 55.1 57.4 2.5
Solar home systems 4.1 19.6 0.3
Solar mini-grids 0.8 0.9 0.3
Hydro mini-grids 0.3 5.9 0.1
Biogas mini-grids 0.3

IRENA International Renewable Energy Agency

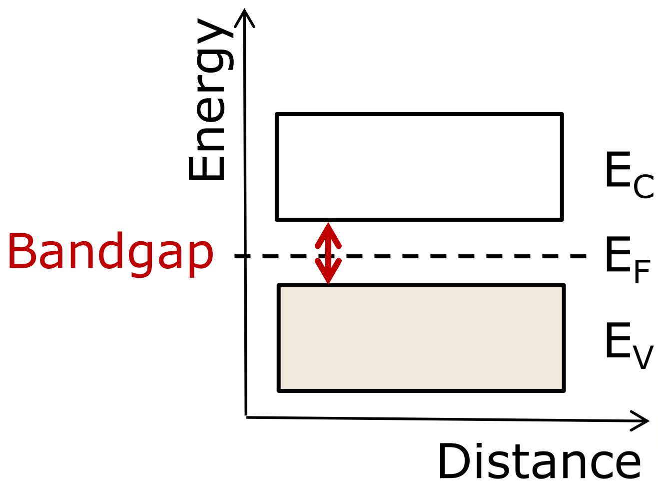
Solar PV was the largest renewable energy employer in 2017 with almost 3.4 million jobs — up 9% from 2016.

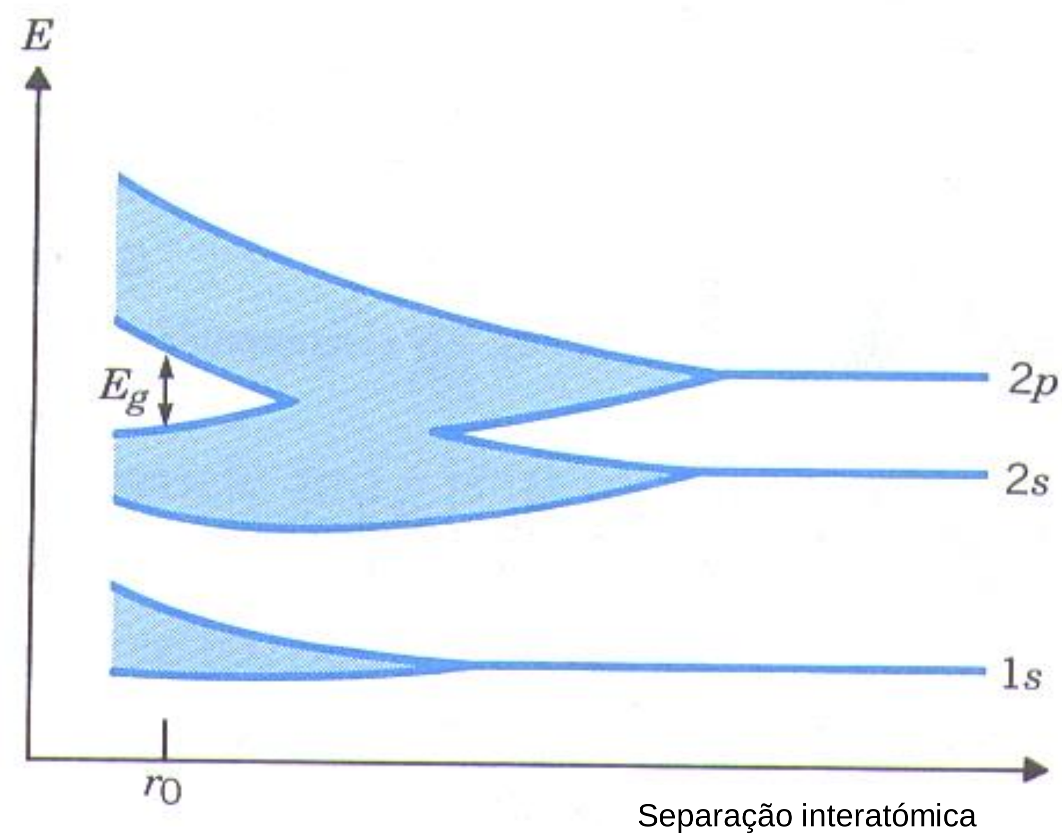


- Bandas de energia permitidas
- Bandas de valência e condução



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





- Bandas de energia permitidas
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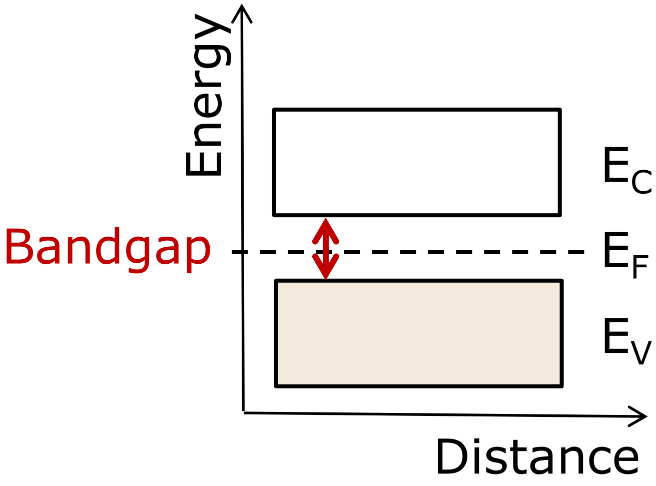
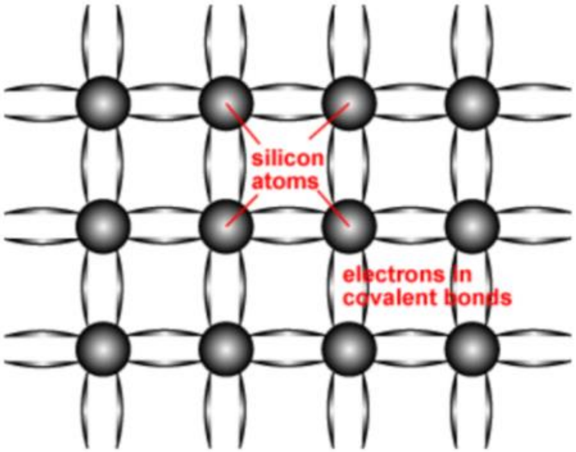
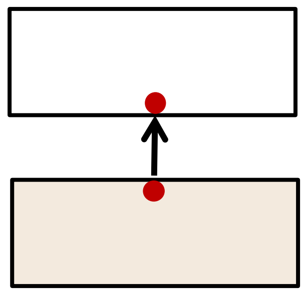




- **Absorção da luz**
  depende da energia do fotão incidente

$E_{ph} = E_g$

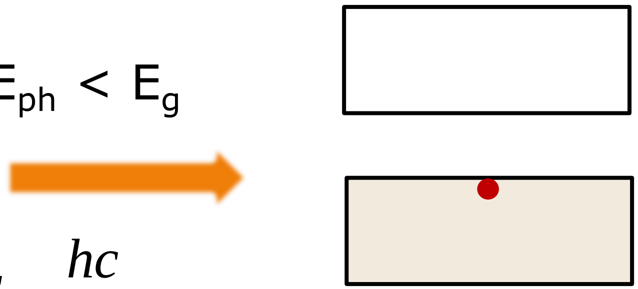


$$E = \frac{hc}{\lambda}$$

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

- **Absorção da luz**
  depende da energia do fotão incidente

$E_{ph} < E_g$



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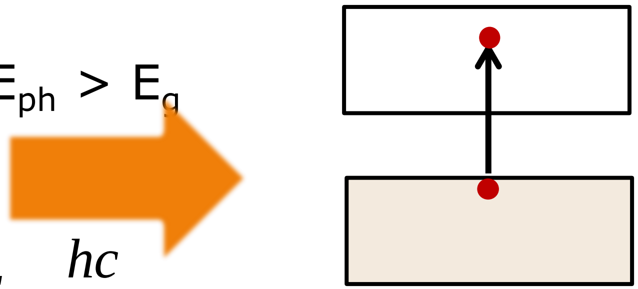
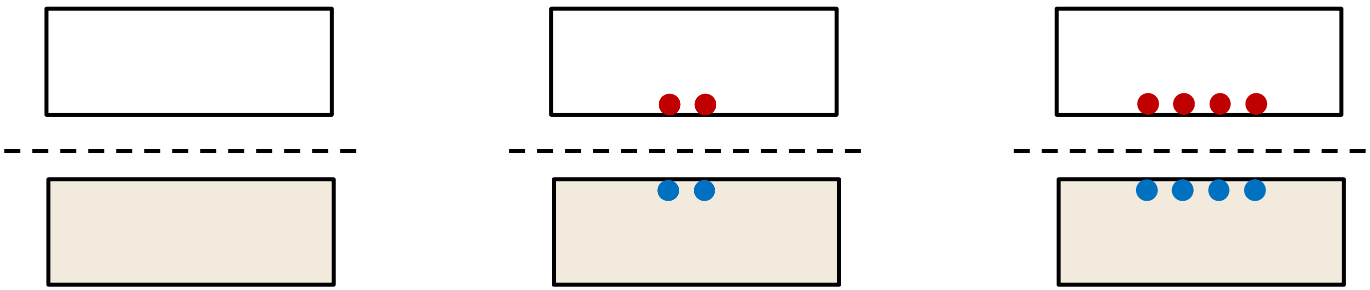


$$E = \frac{hc}{\lambda}$$

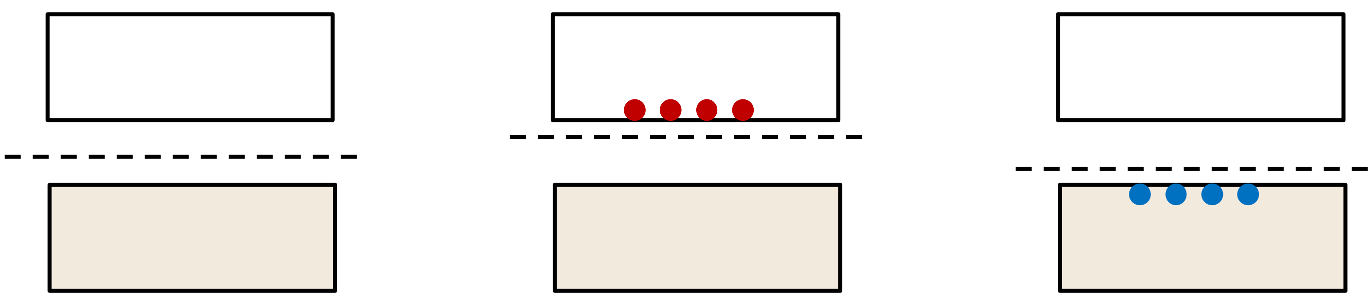
$$E(eV) = \frac{1.24}{\lambda(\mu m)}$$

- Efeito da temperatura

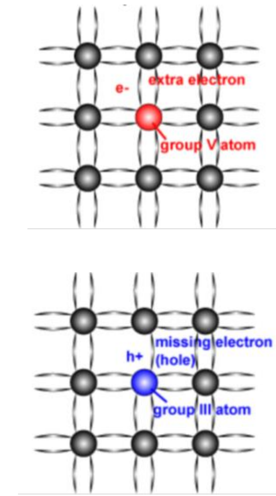


0 K | T_1 | $T_2 > T_1$

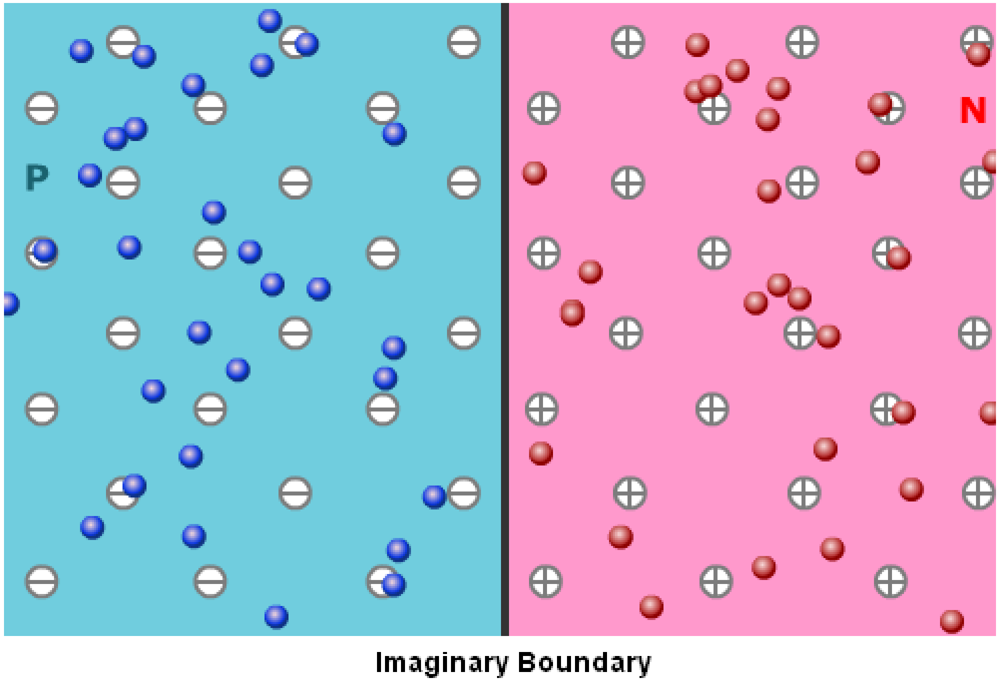
- Efeito da dopagem



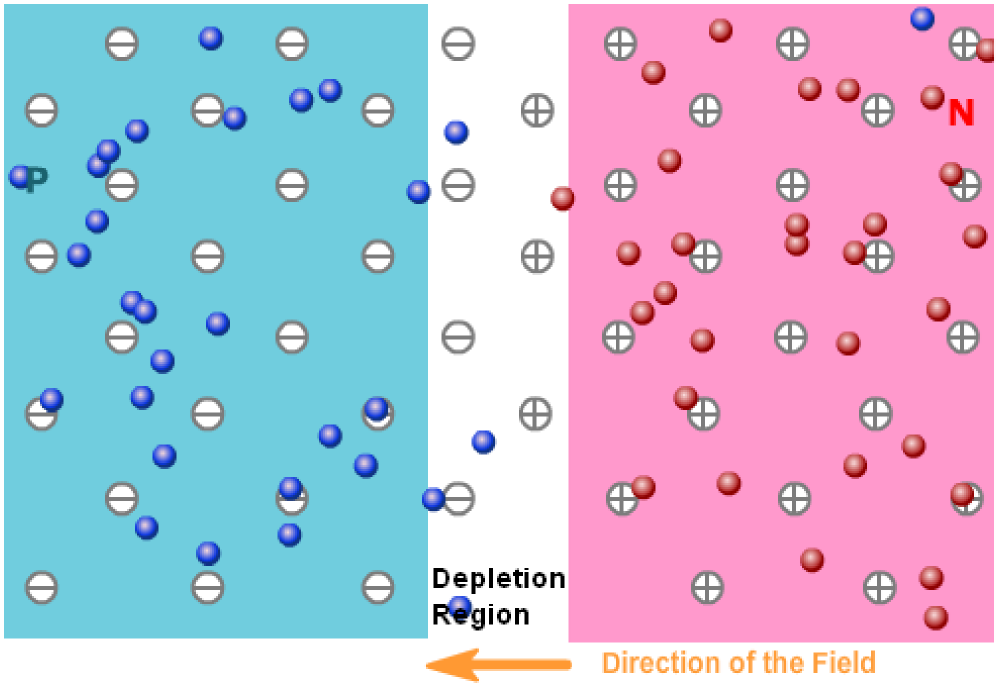
Intrinsic | N-doped | P-doped



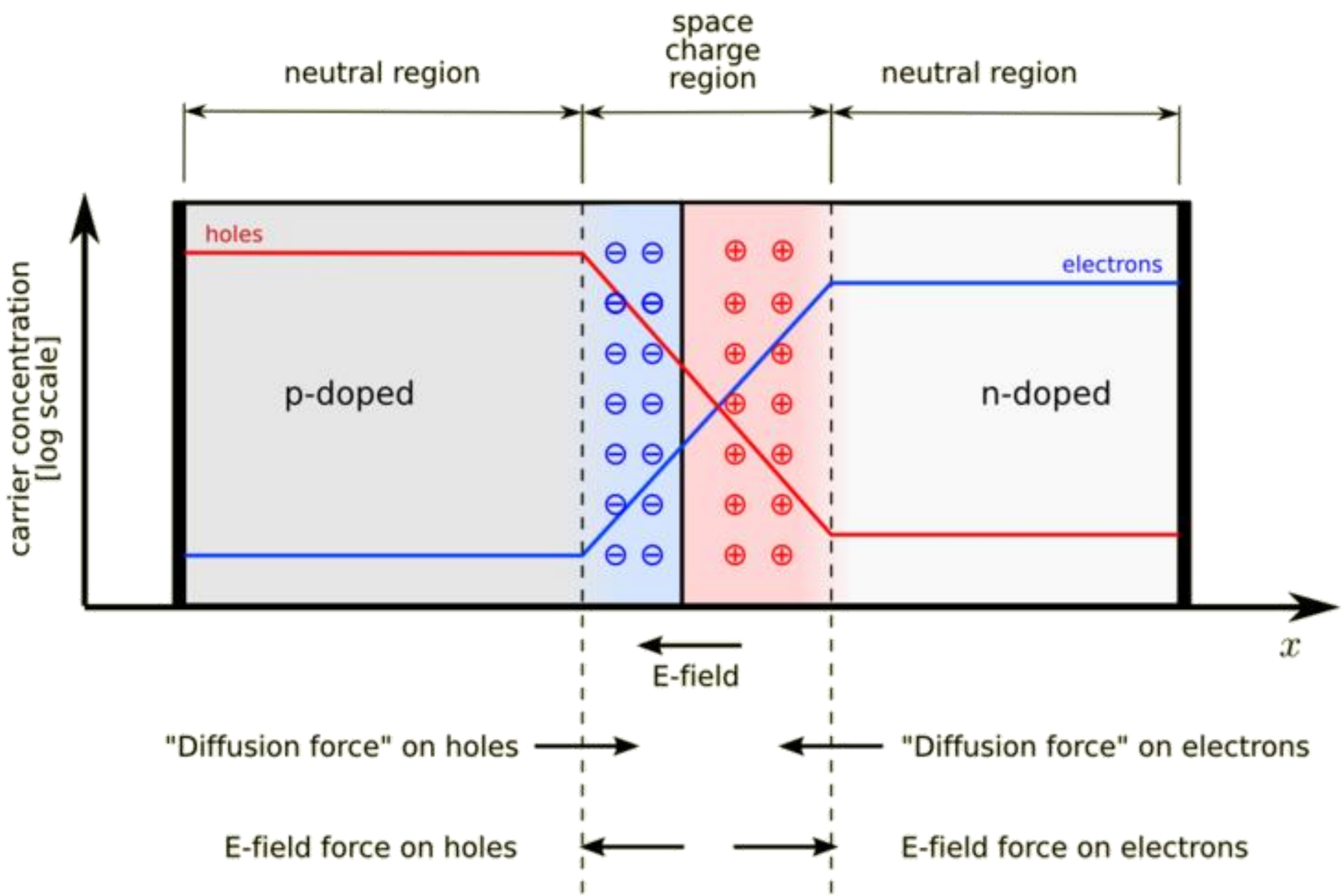
- Junção PN



- Junção PN

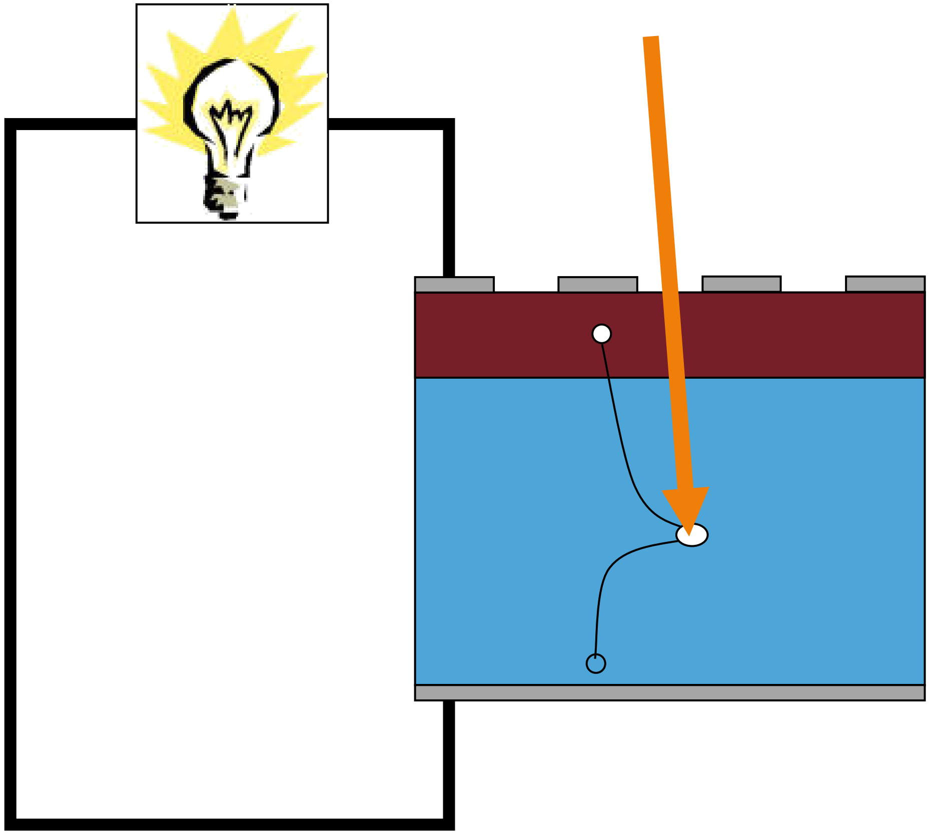


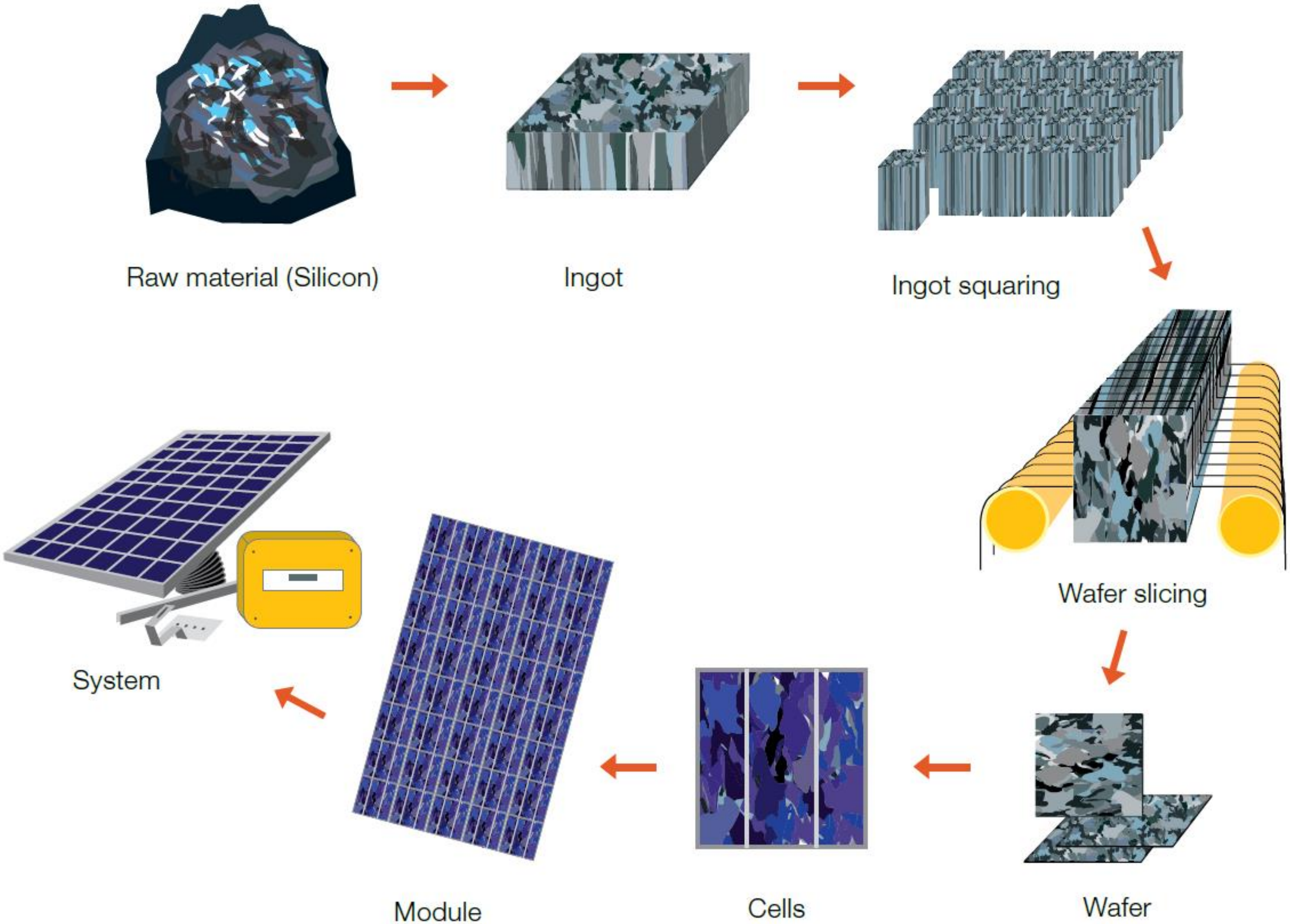
- Junção PN



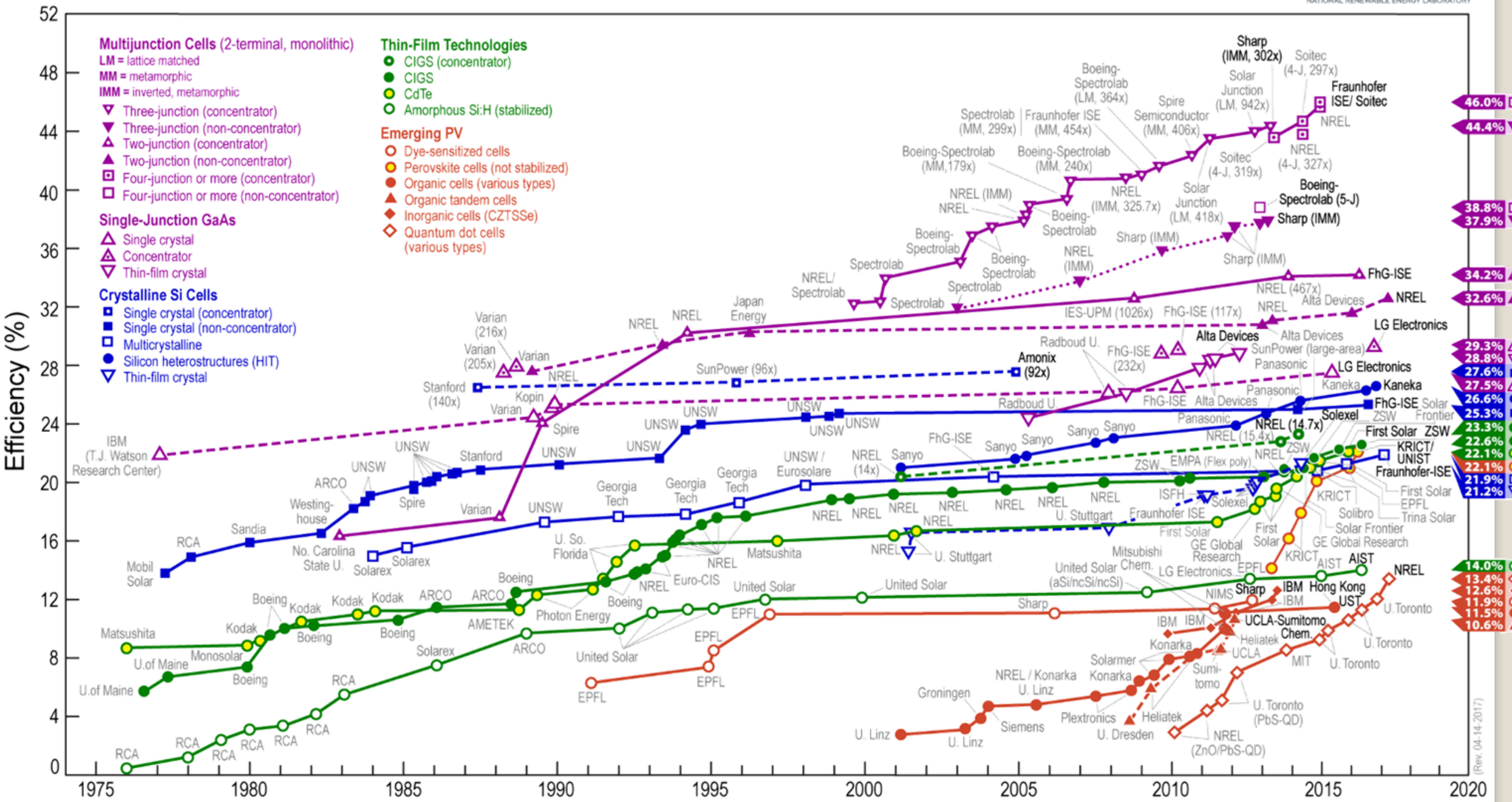
space
charge
region
neutral region
neutral region
carrier concentration
[log scale]
holes
electrons
p-doped
n-doped
x
E-field
"Diffusion force" on holes
"Diffusion force" on electrons
E-field force on holes
E-field force on electrons

- Funcionamento de uma célula fotovoltaica



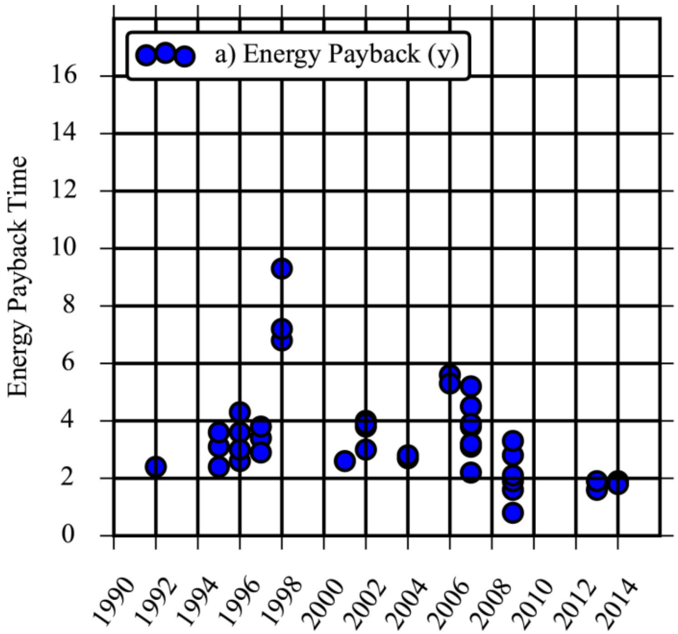

Raw material (Silicon)
Ingot
Ingot squaring
Wafer slicing
Wafer
Cells
Module
System

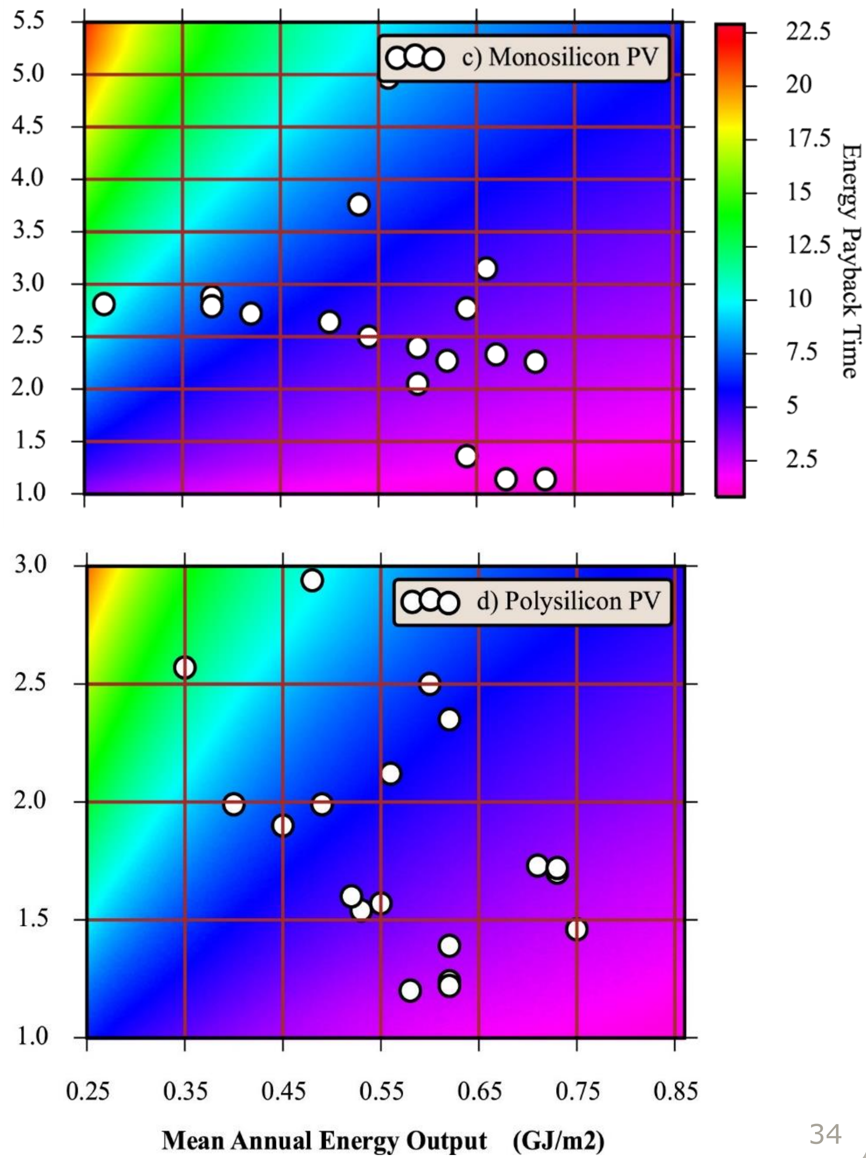
Best Research-Cell Efficiencies



- Comparação diferentes tecnologias PV
  - Custo
  - Desempenho, durabilidade
  - Disponibilidade matéria prima
  - Aspectos ambientais
  - Maturidade tecnológica
  - Promotores
  - Outros

- *Payback time* energético





- *Payback time* energético
- *Energy yield*

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

menor *payback time*
mas vida mais longa

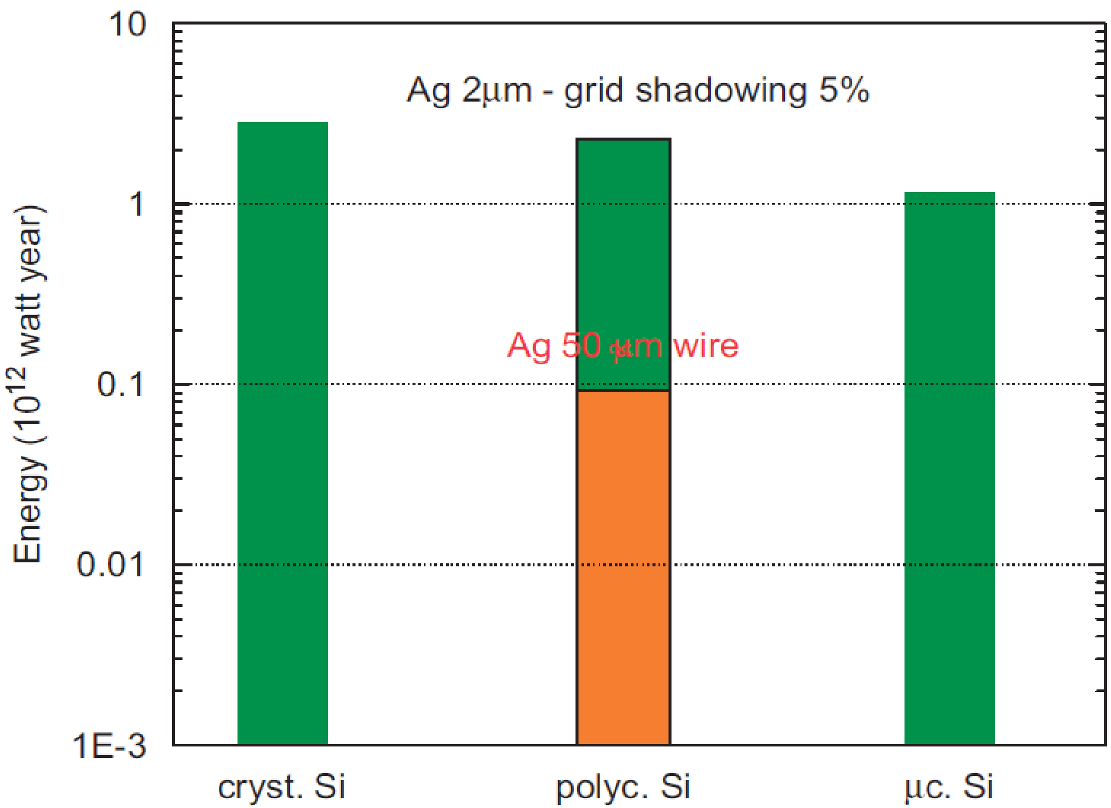
>

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.

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

- Limitações matérias primas

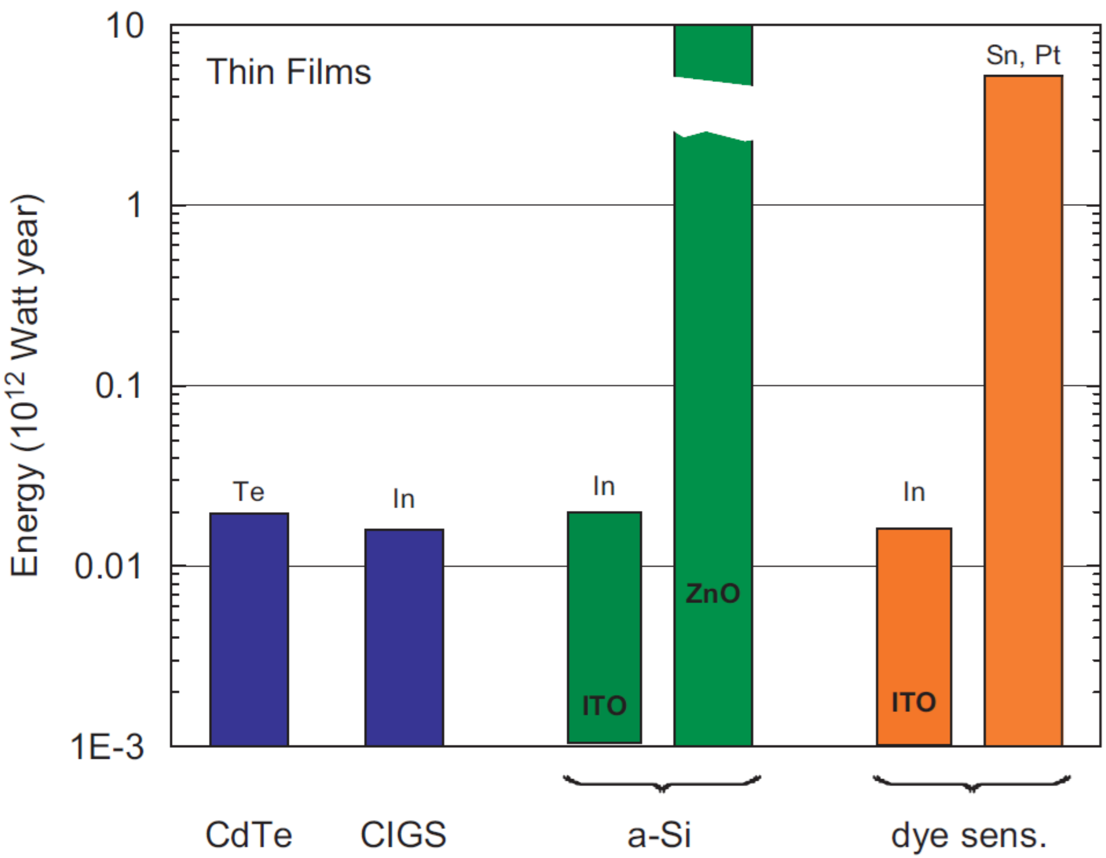


Fig. 4. Potential energy limits imposed for four different thin film photovoltaic technologies.

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

- Limitações matérias primas

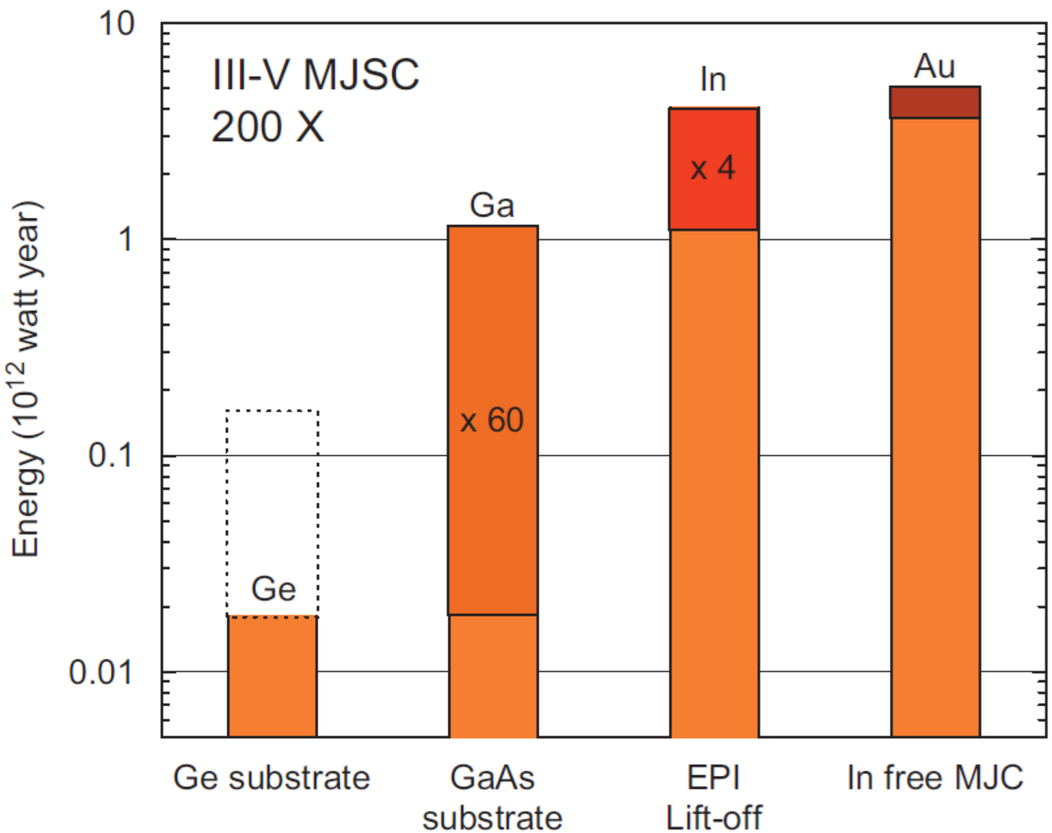
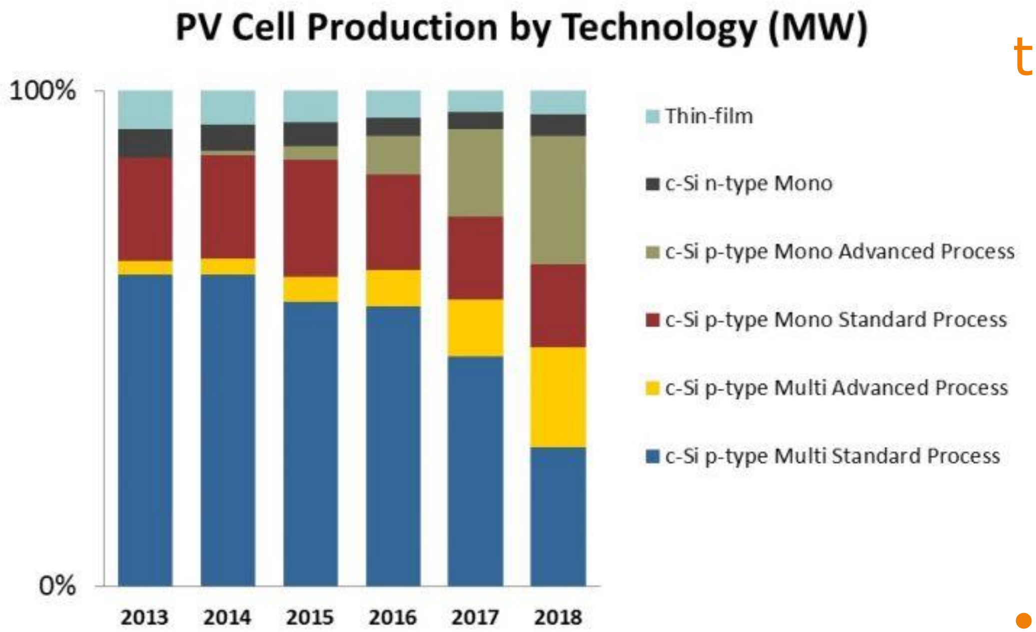
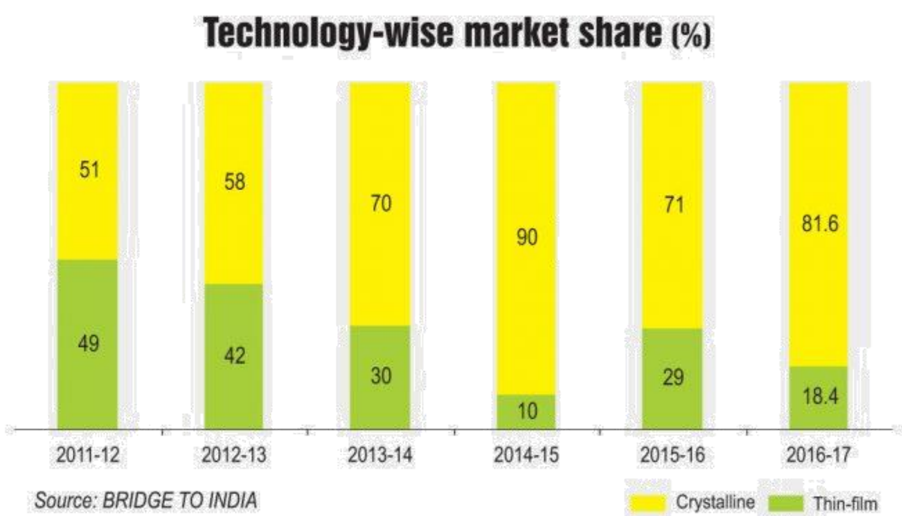


Fig. 5. Potential energy limits imposed to III–V multi-junction cells (200 sun concentrations). The third and fourth columns show the extrapolated potential of this technology if lift-off/cell exfoliation techniques are adopted.

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

Comparação entre tecnologias PV diferentes:

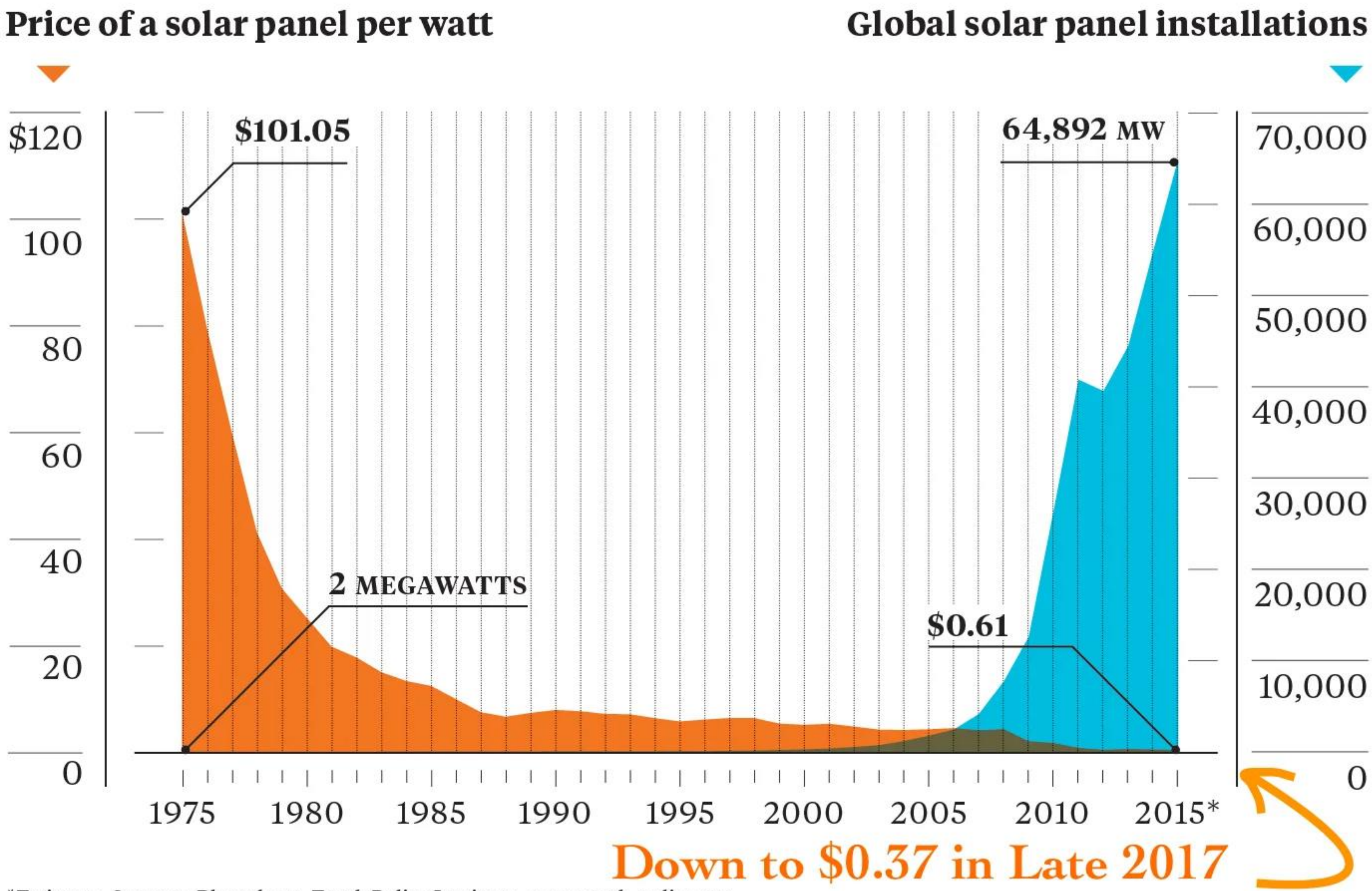




- Mercado dominado actualmente por silício cristalino
- Apenas um fabricante relevante de filmes finos (CdTe)
- Tecnologias *emergentes* em desenvolvimento no lab e entusiasmando *Silicon Valley*
- Tecnologias de alta eficiência no nicho da alta concentração

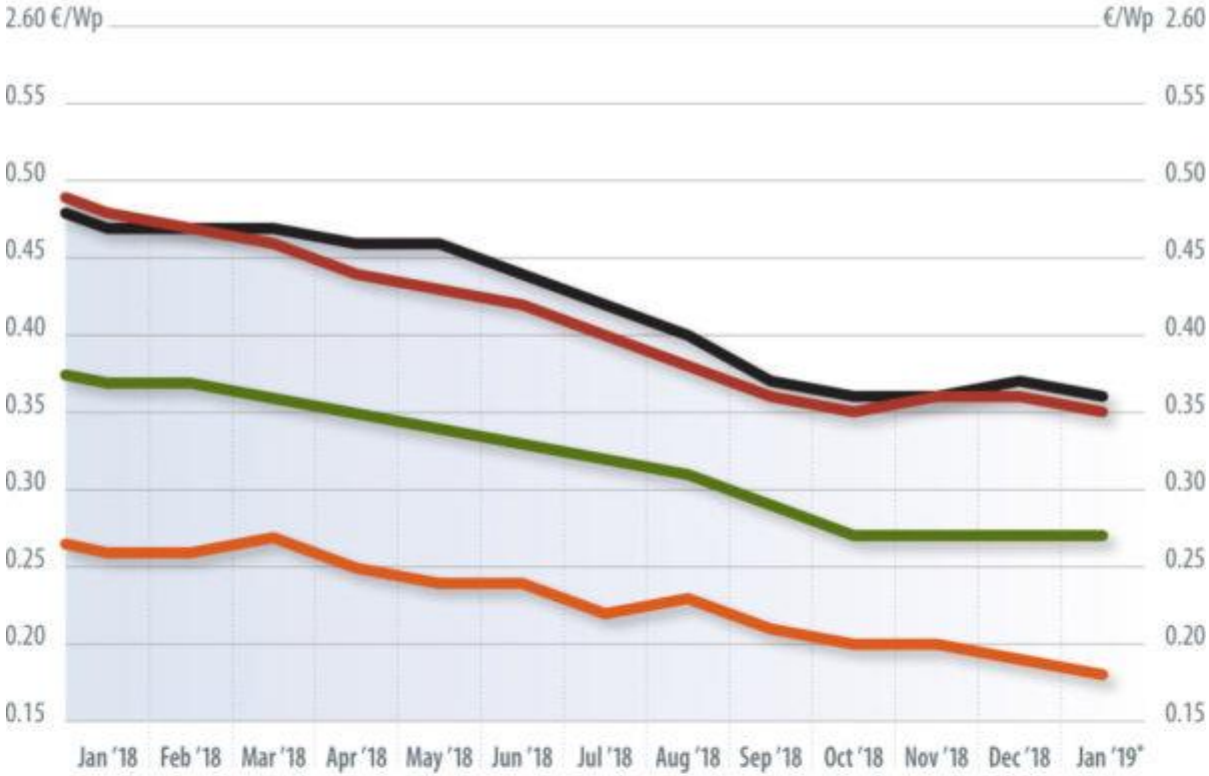
Solar on Fire

As prices have dropped, installations have skyrocketed.



*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
- All black: Module types with black backsheets, black frames and rated outputs of between **200 Wp and 320 Wp**
- Mainstream: Modules with usually 60 cells, standard aluminum frames, white backing and **260 Wp to 285 Wp** – the majority of modules on the market
- Low cost: Reduced-capacity modules, factory seconds, insolvency goods, used modules (crystalline), products with limited or no guarantee

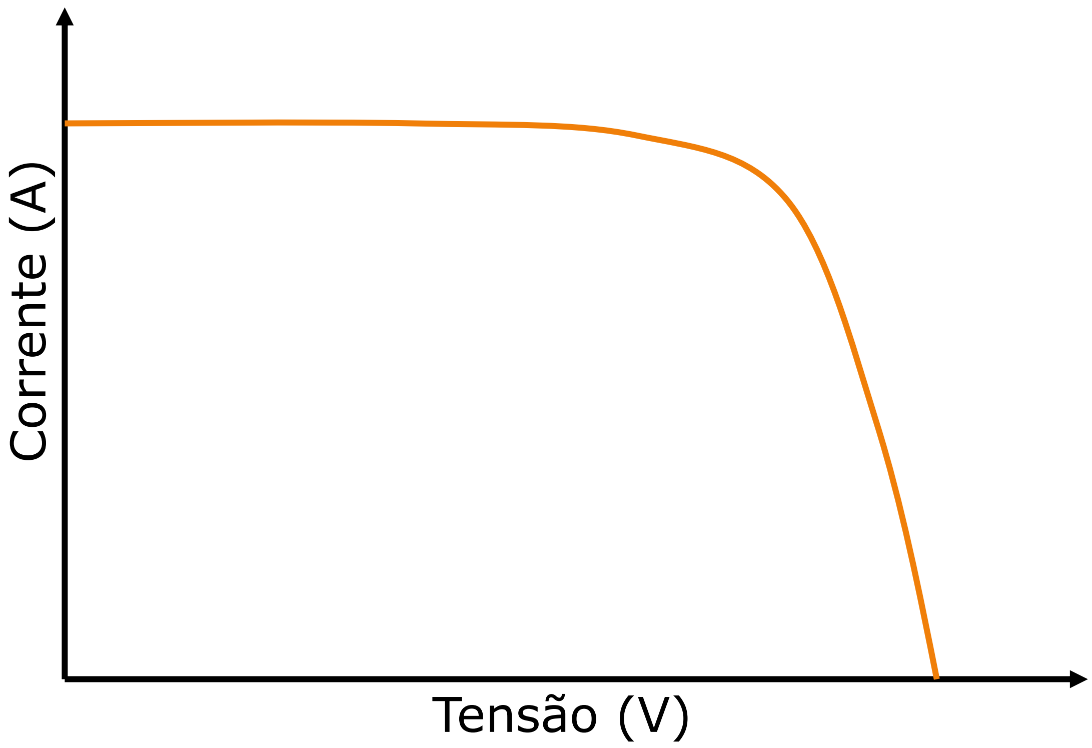
* Data up to January 17, 2019

More information: www.pvXchange.com

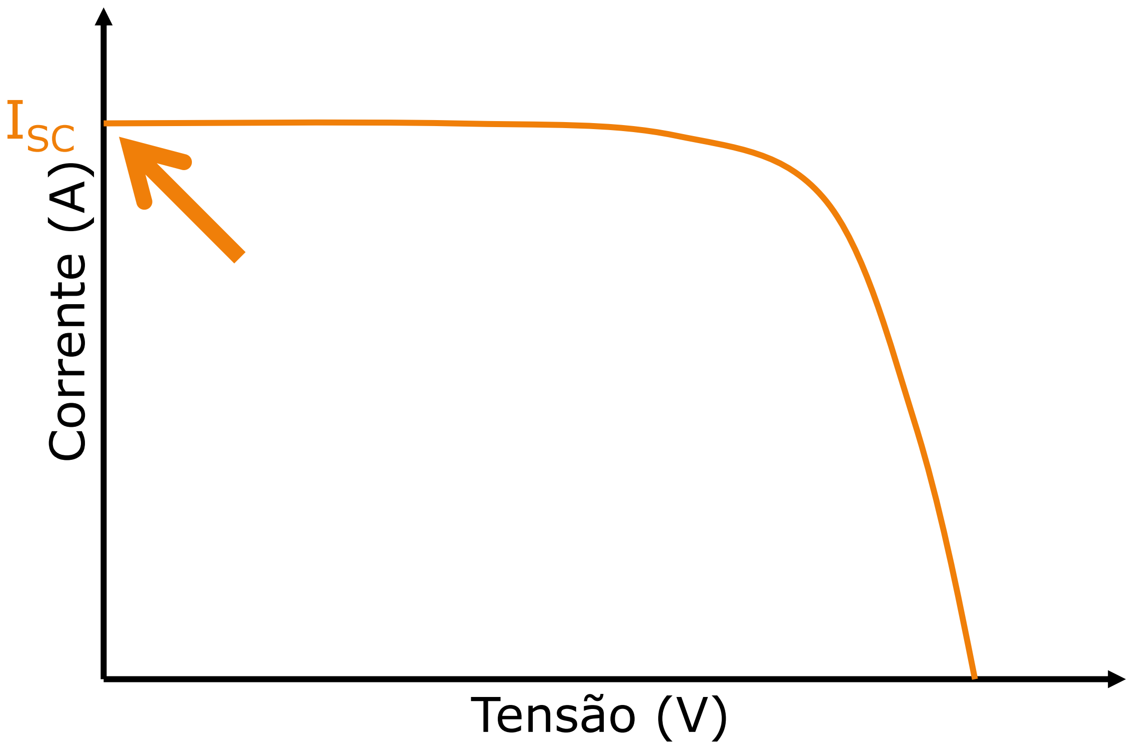
- Característica IV de uma célula solar

$$I = I_L - I_o\left(e^{\frac{qV}{nkT}} - 1\right)$$

=um díodo + corrente fotogerada

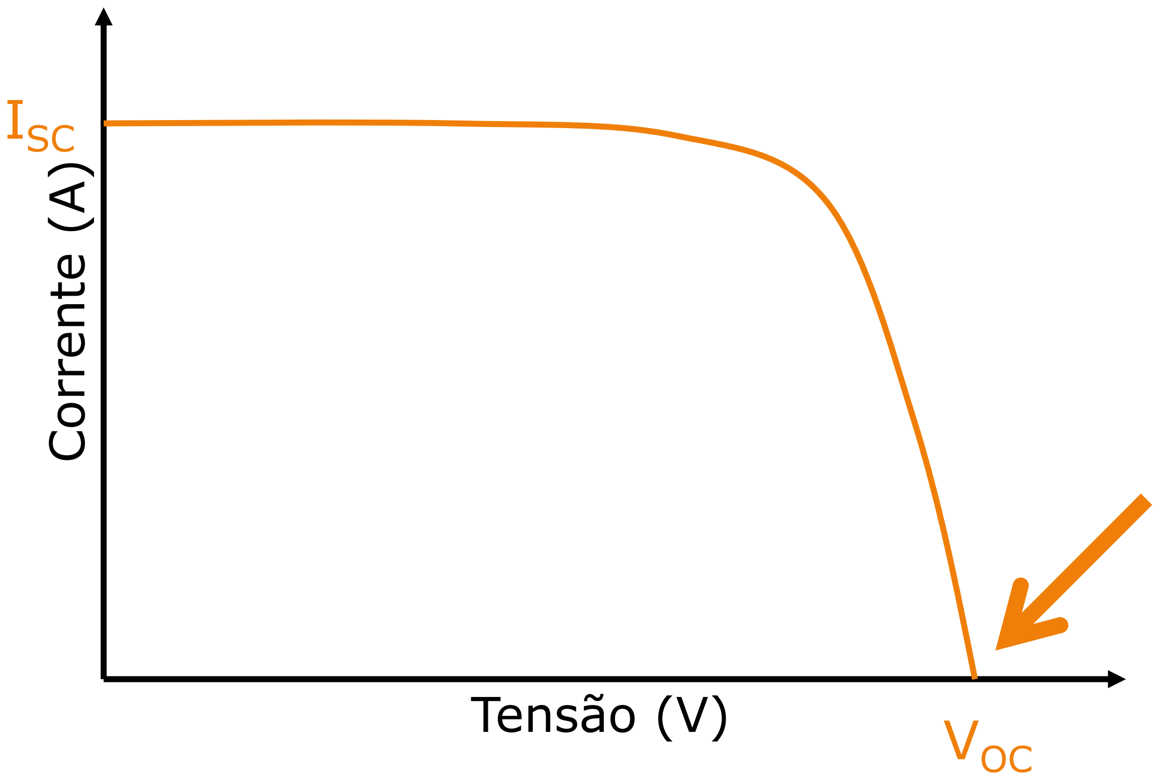


- Característica IV de uma célula solar
  Corrente de curto circuito Isc

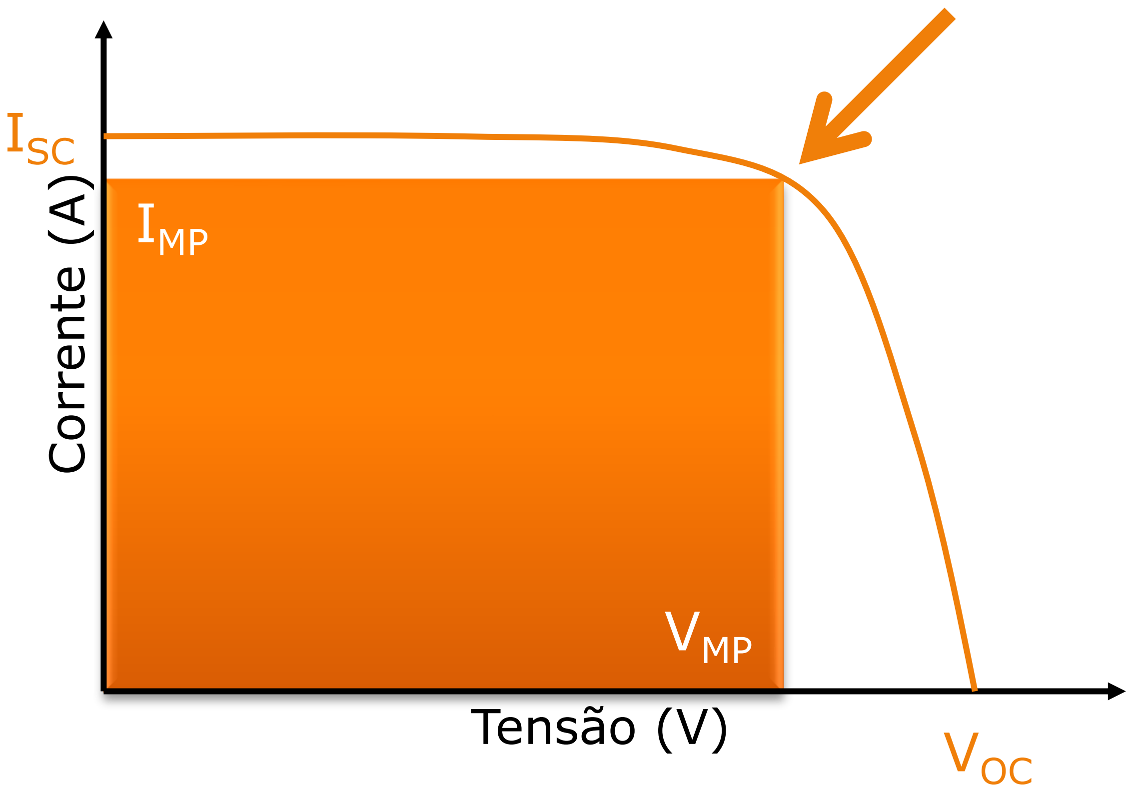


- Característica IV de uma célula solar

  Tensão de circuito aberto Voc



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

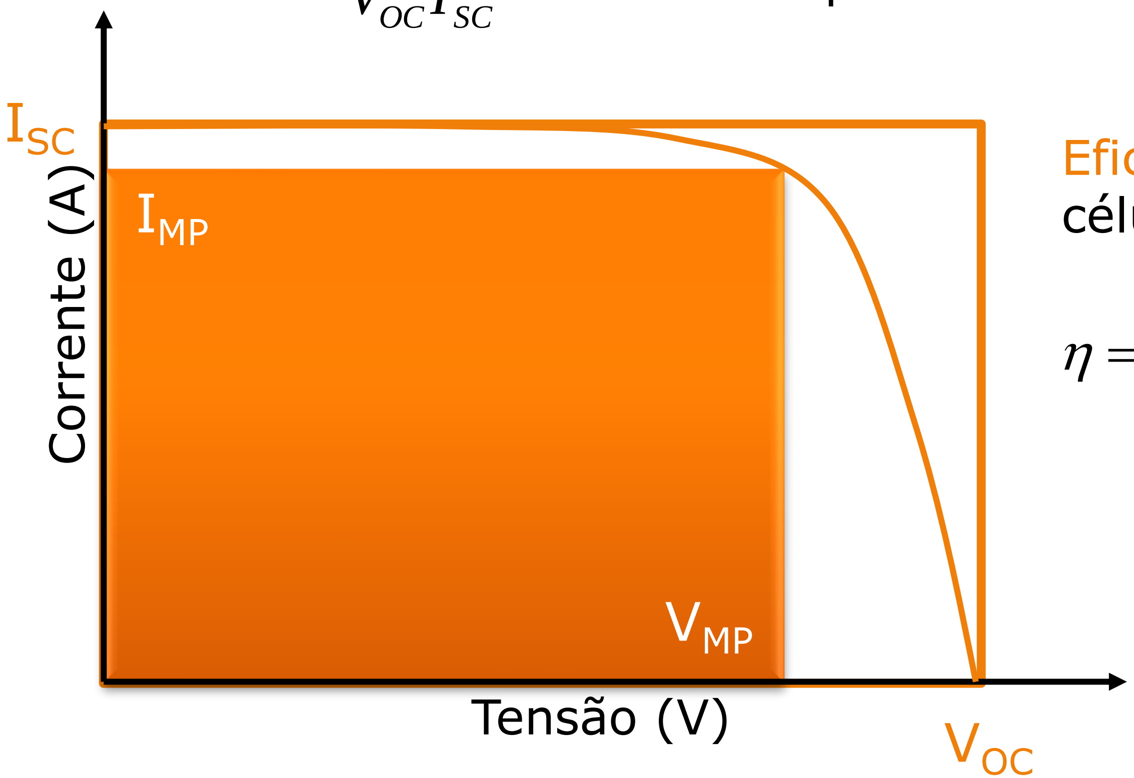


- Característica IV de uma célula solar

Factor de preenchimento FF

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

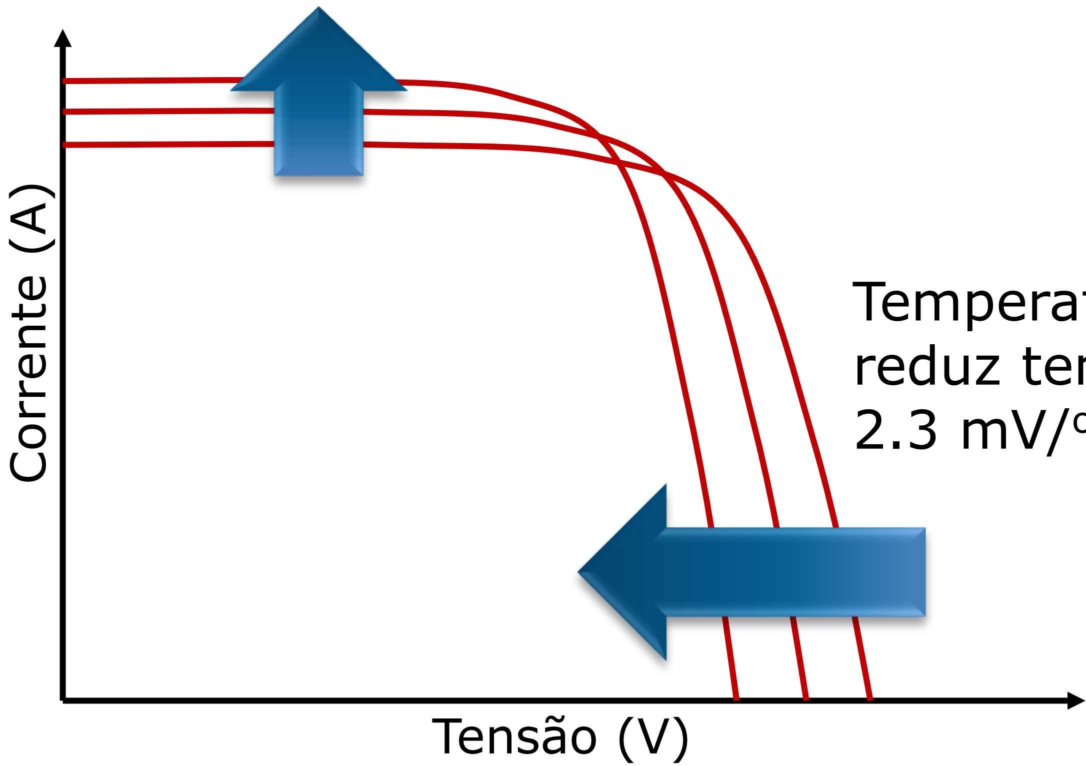
Seria unidade se célula ideal
Valor típico 0.7 – 0.8



Eficiência de uma célula solar:

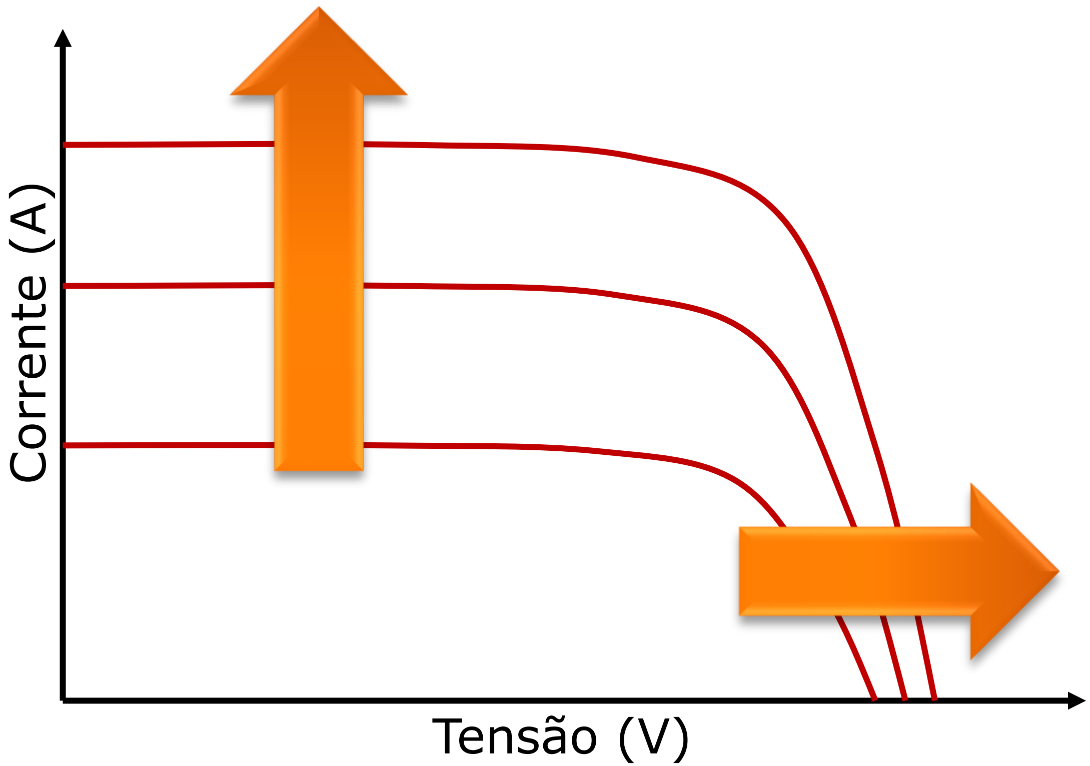
$$\eta = \frac{P_{max}}{Q_{in}} = \frac{FF\, V_{OC} I_{SC}}{Q_{in}}$$

- Efeito da temperatura



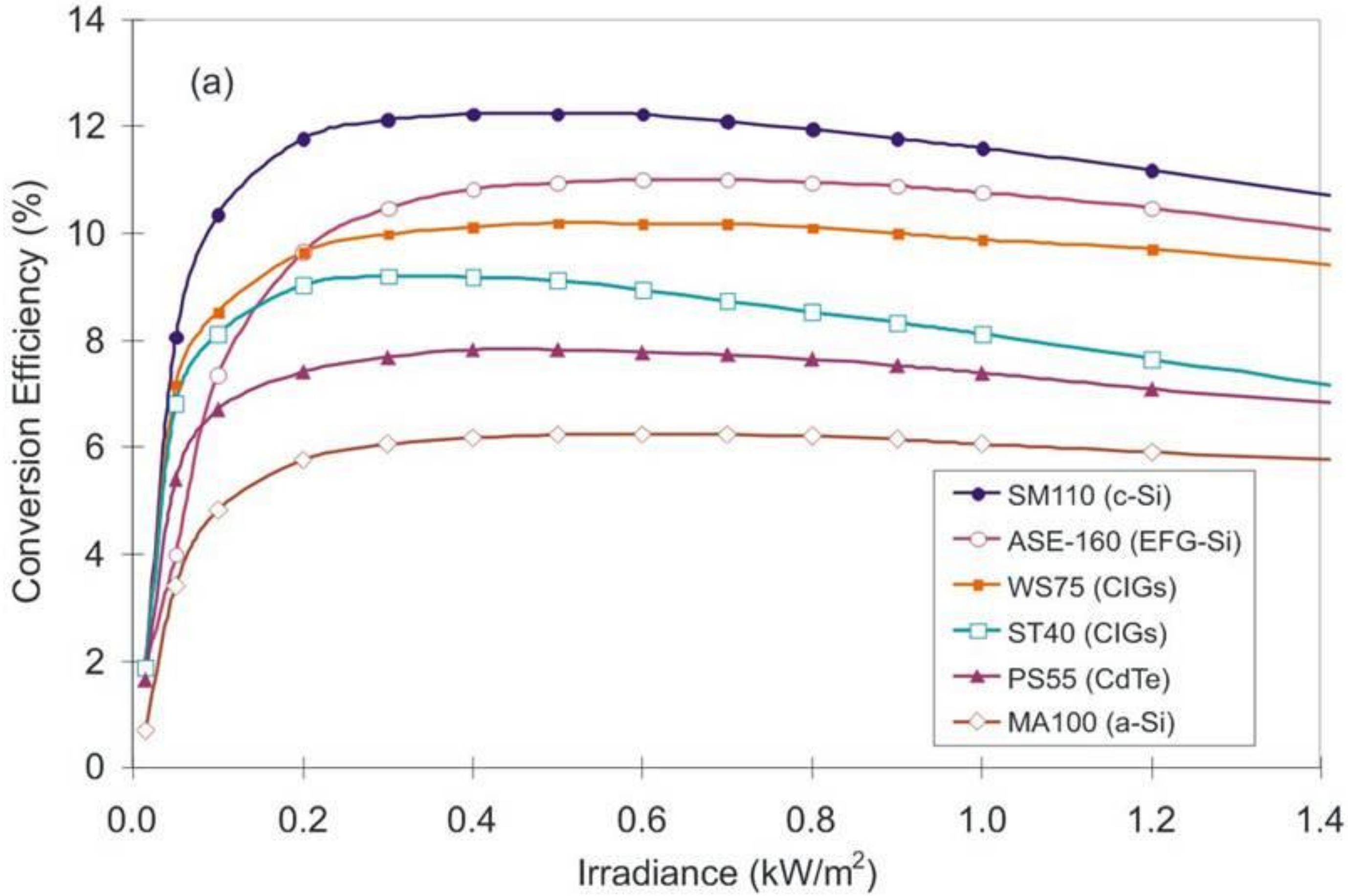
Temperatura reduz tensão em 2.3 mV/ºC

- Efeito da radiação



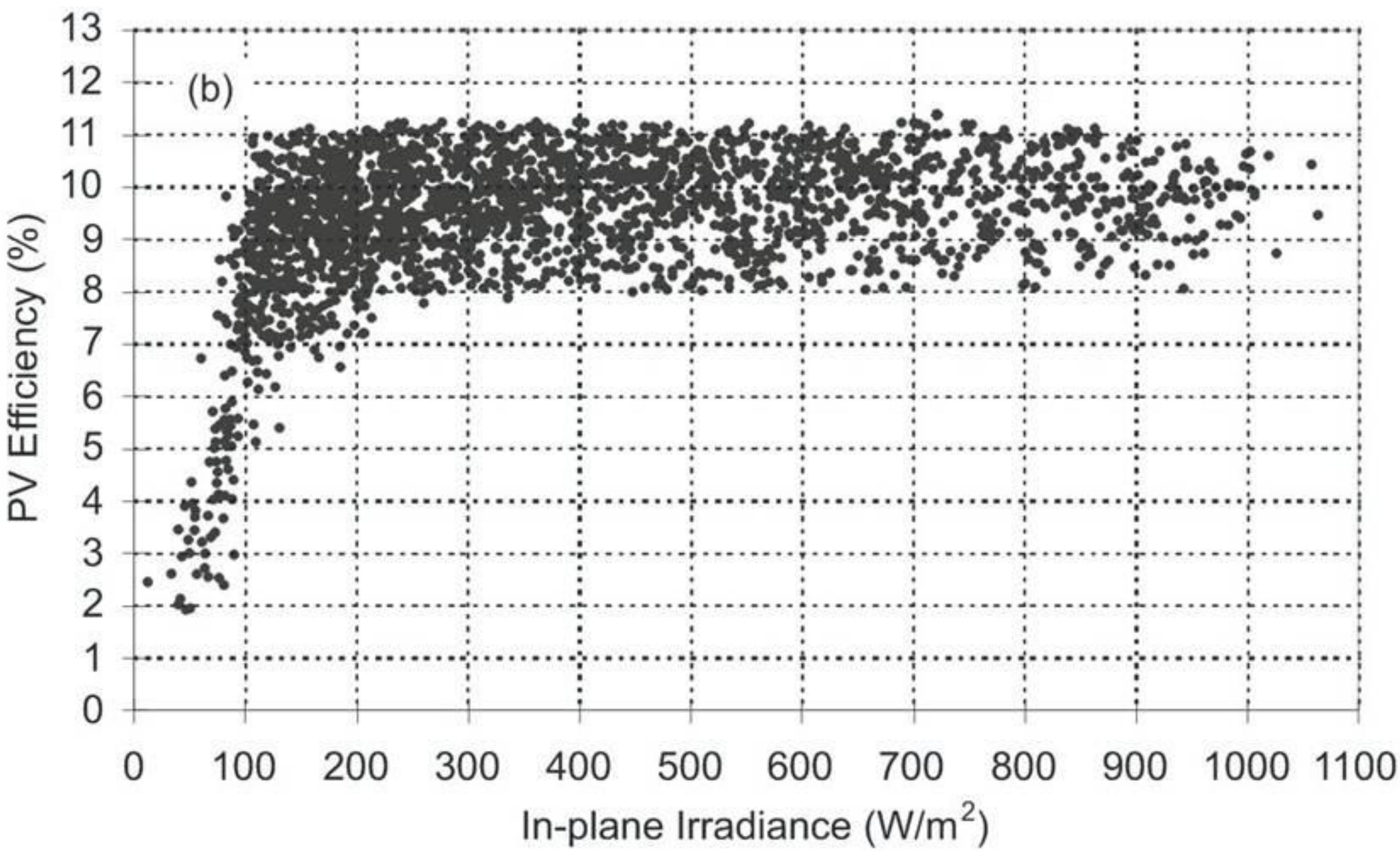
Parametros que determinam desempenho célula solar

- Irradiância
- Temperatura



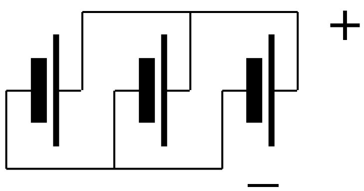
Parametros que determinam desempenho célula solar

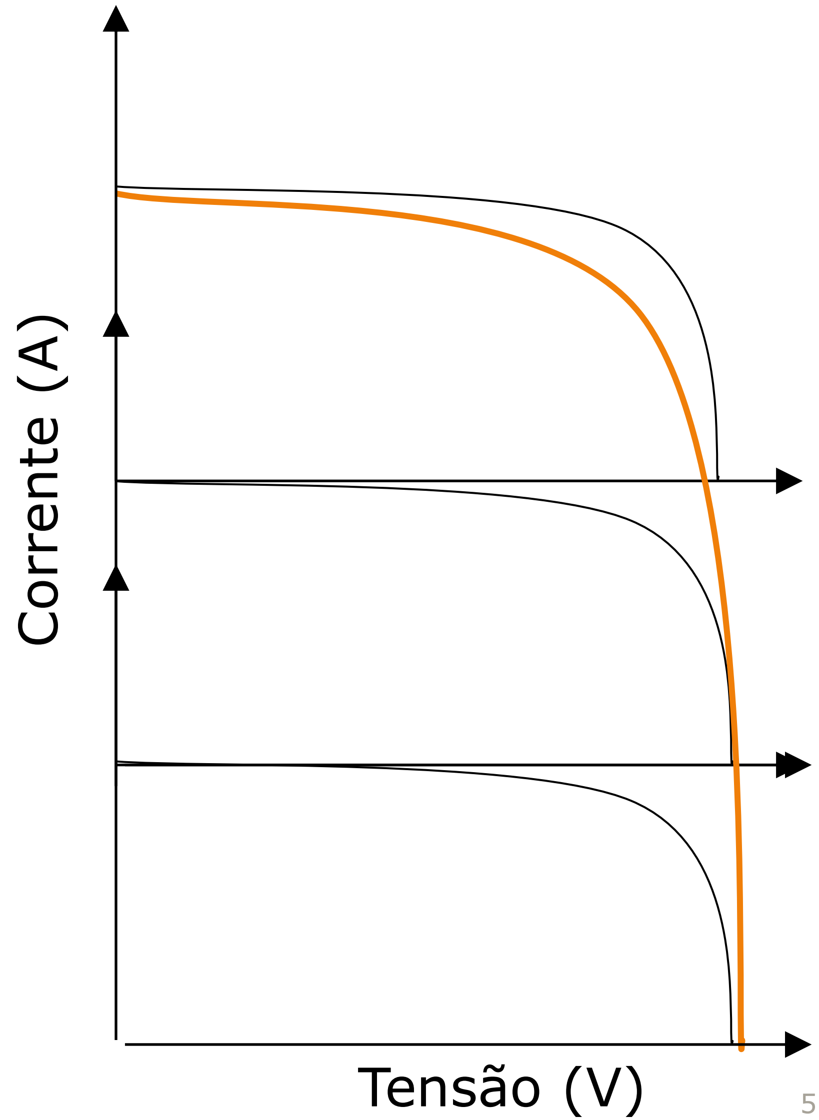
- Irradiância
- Temperatura



- Ligação células solares

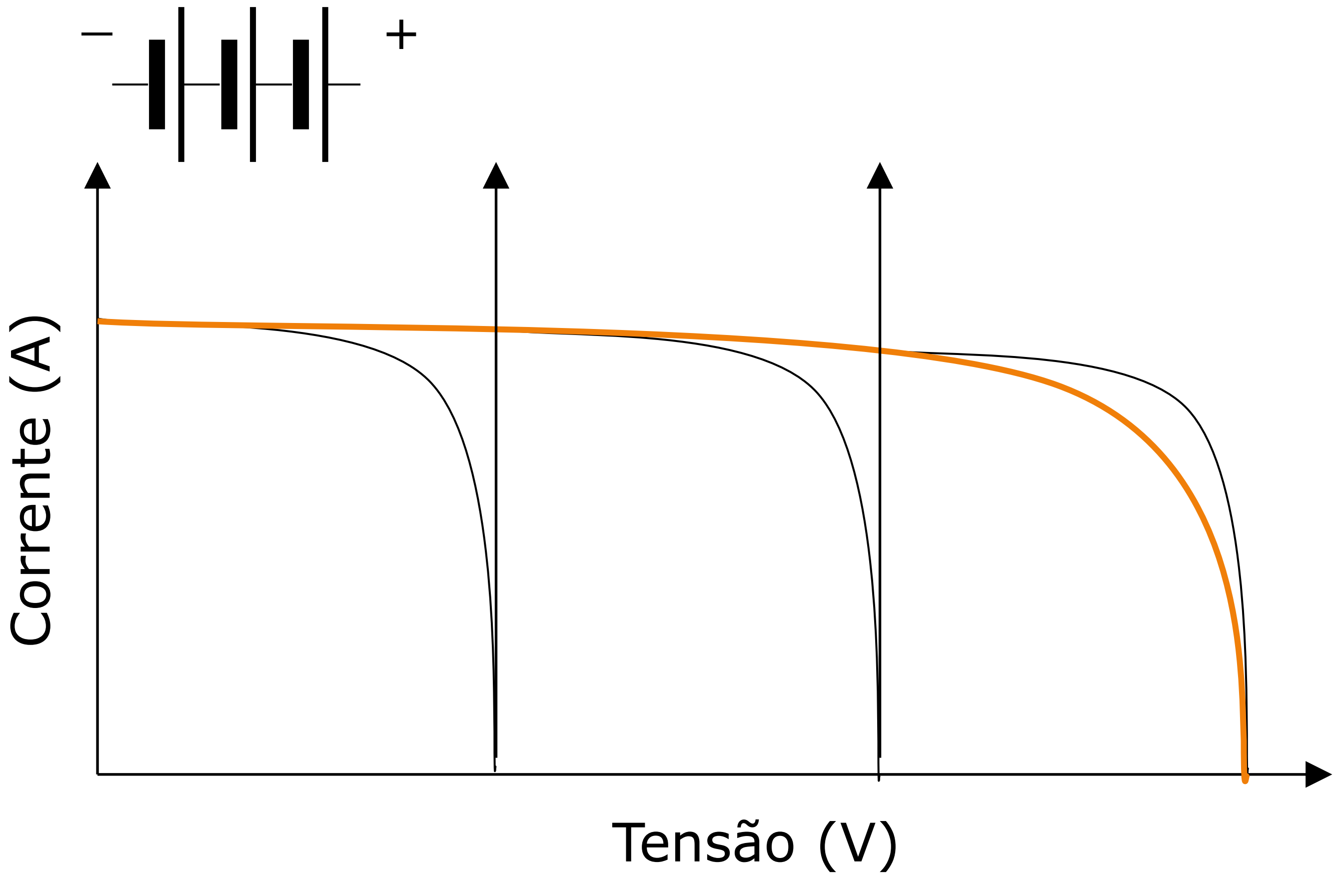
PARALELO



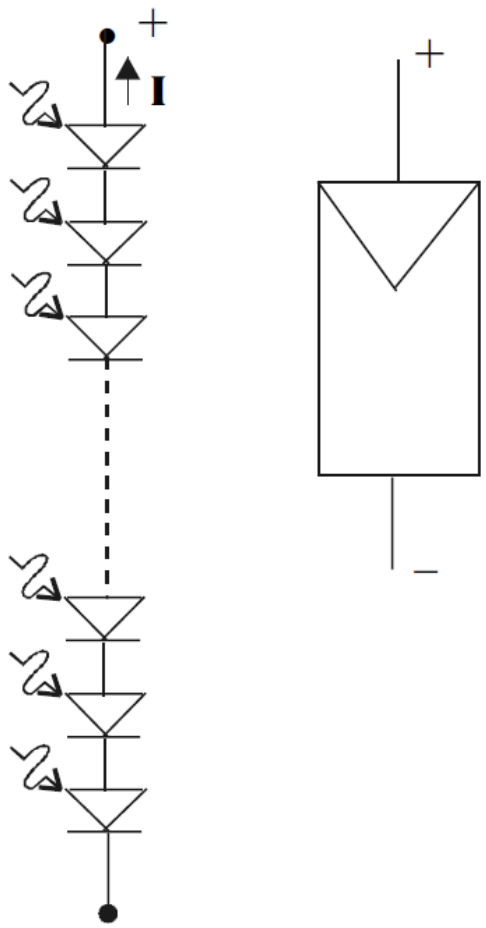


- Ligação células solares

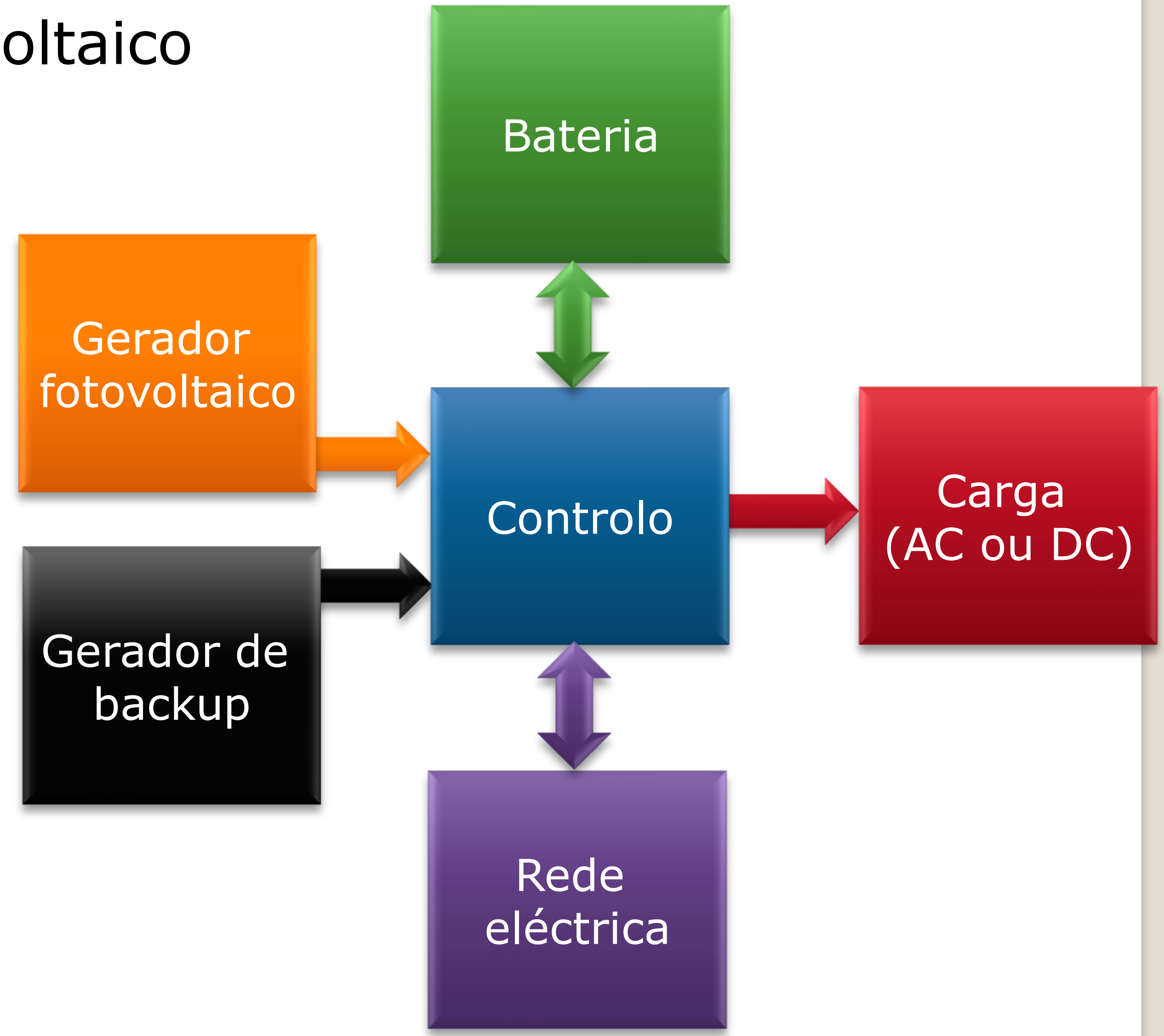
SÉRIE



- Módulos solar



- Sistema fotovoltaico



- Sistema fotovoltaico

Bateria

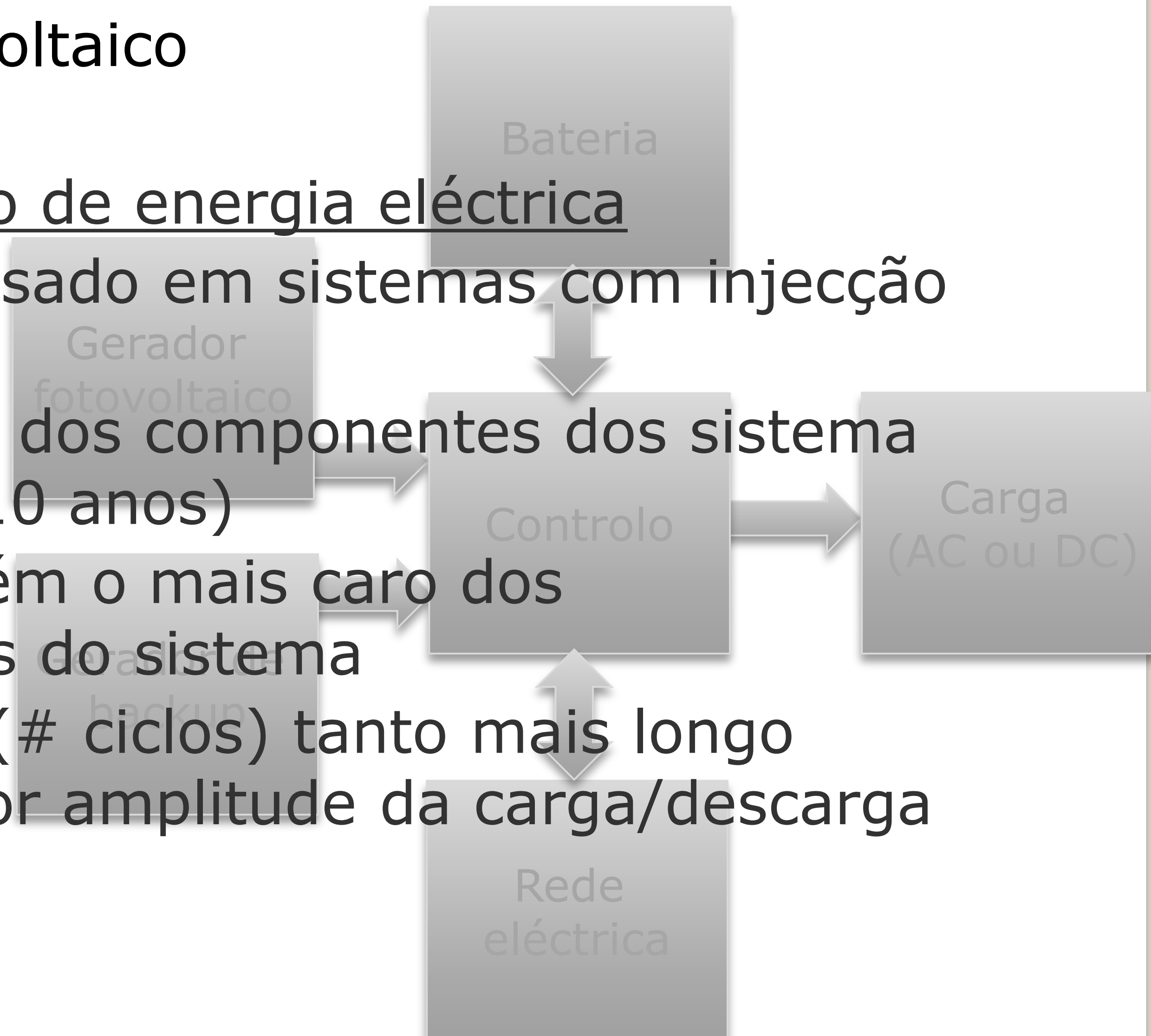
<u>Armazenamento de energia eléctrica</u>

Pode ser dispensado em sistemas com injecção 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

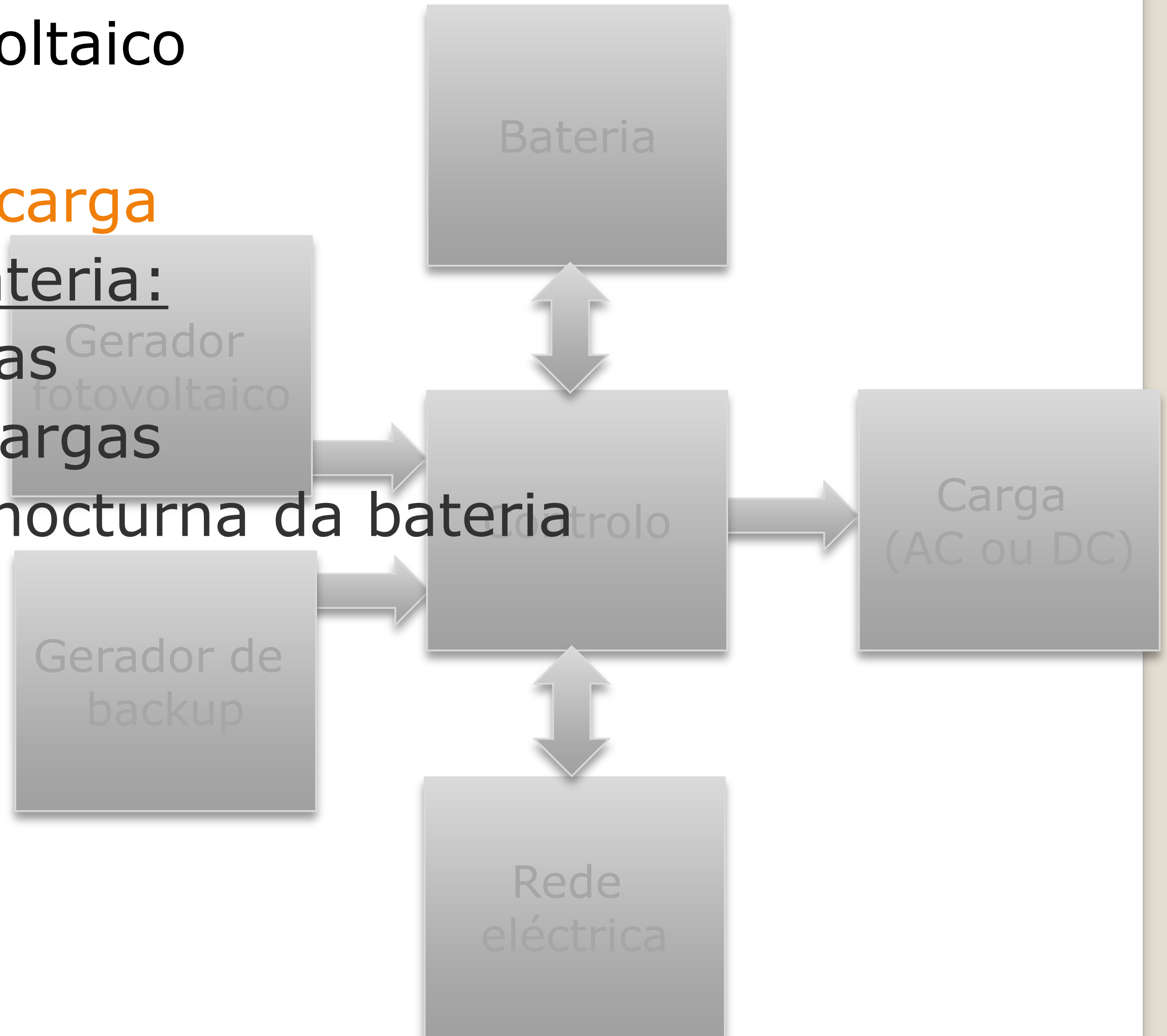
Controlador de carga

Protecção da bateria:

Evita sobrecargas

Evita sobredescargas

Evita descarga nocturna da bateria



- Sistema fotovoltaico

Bateria

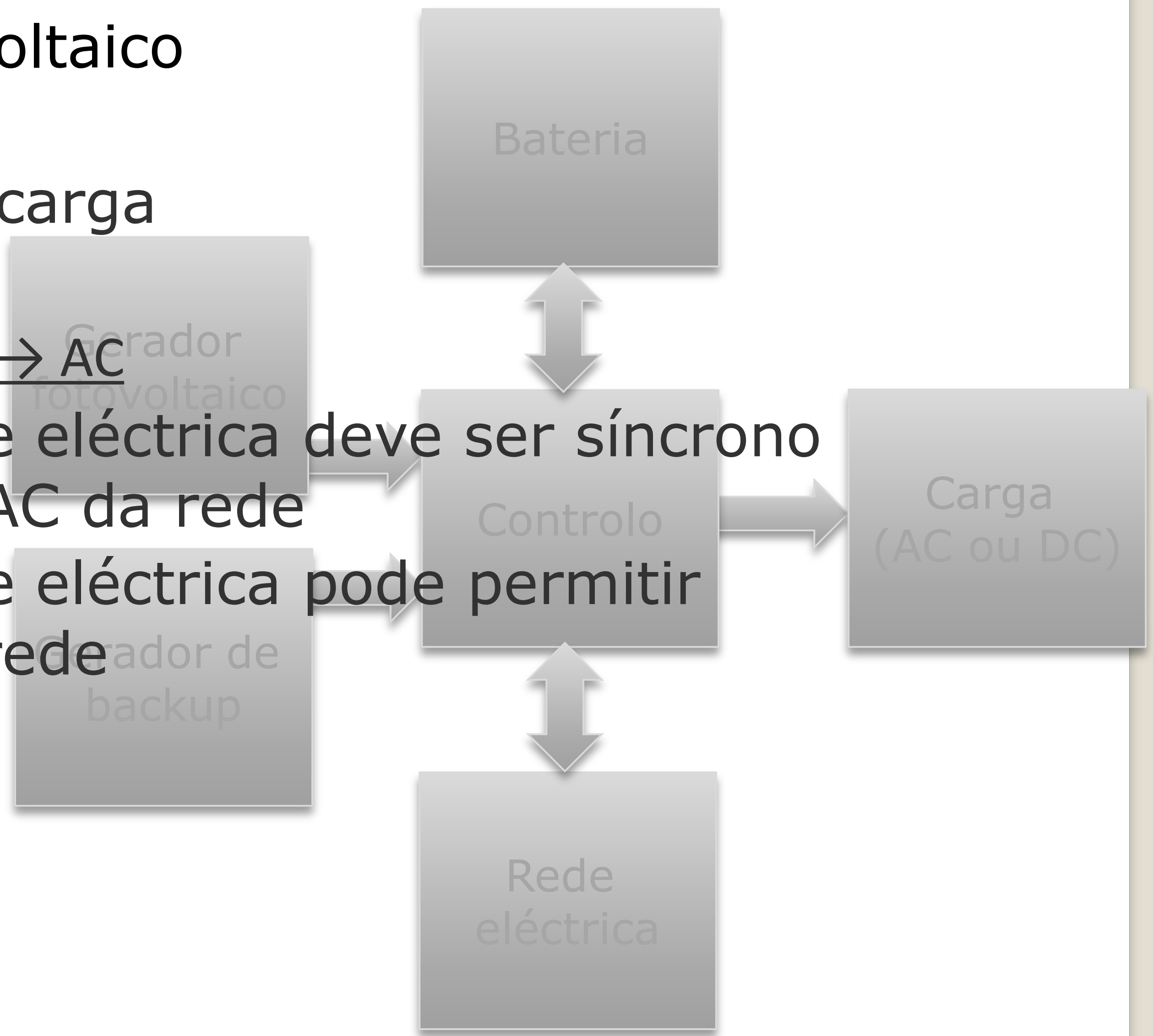
Controlador de carga

Inversor

Transforma DC → AC

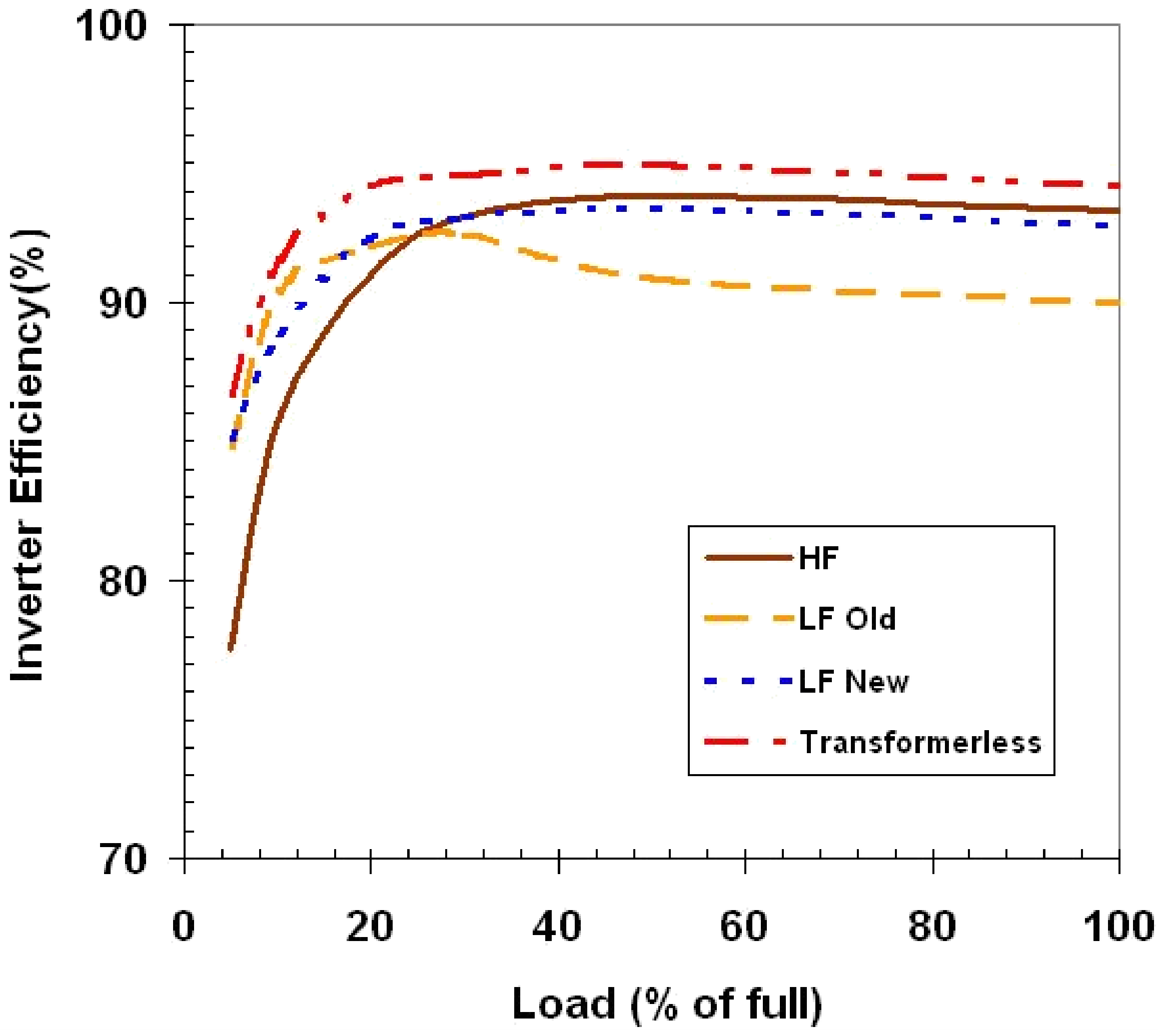
Se ligado à rede eléctrica deve ser síncrono com o sinal AC da rede

Se ligado à rede eléctrica pode permitir injecção na rede



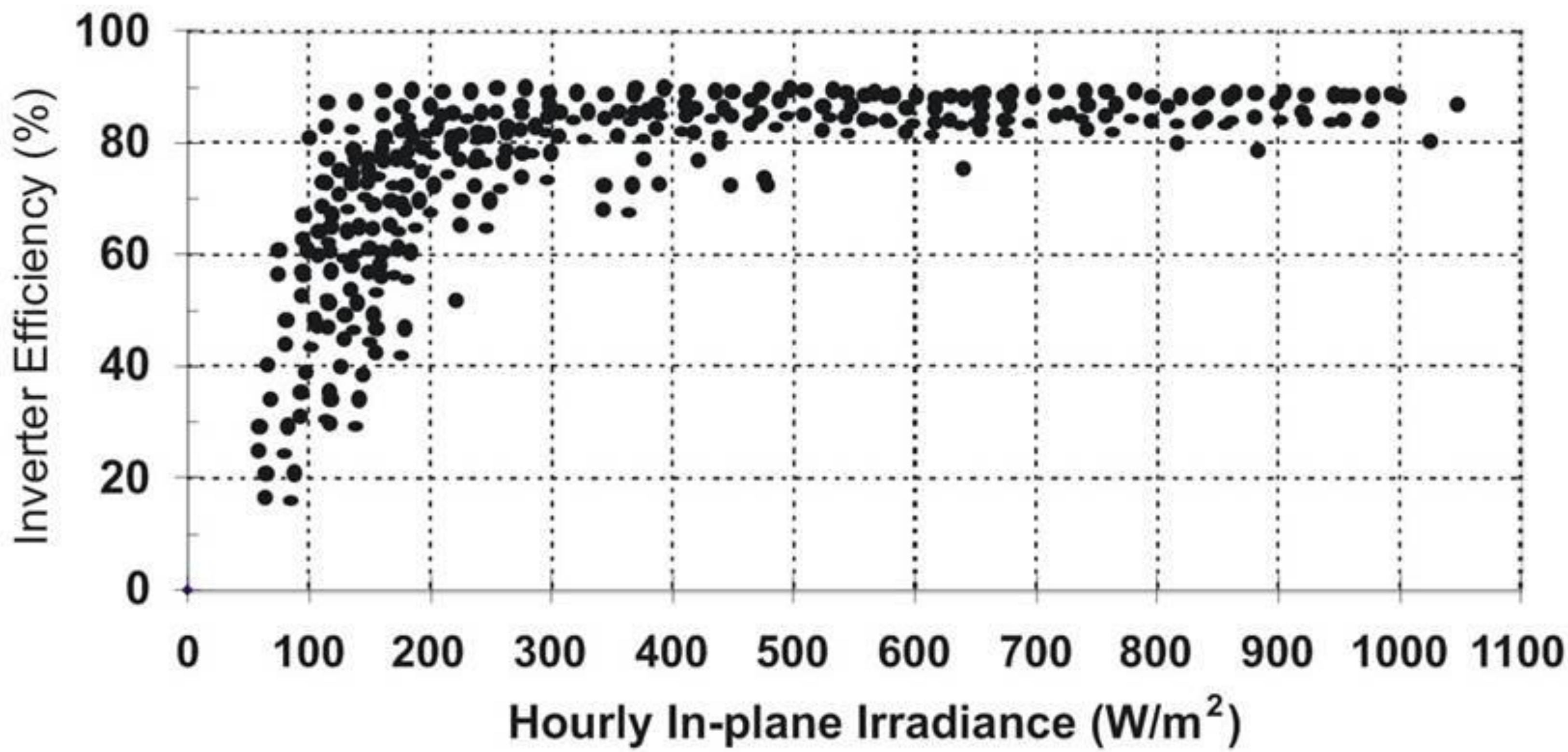
Parametros que determinam desempenho sistema solar

- eficiência dos componentes a jusante: inversor



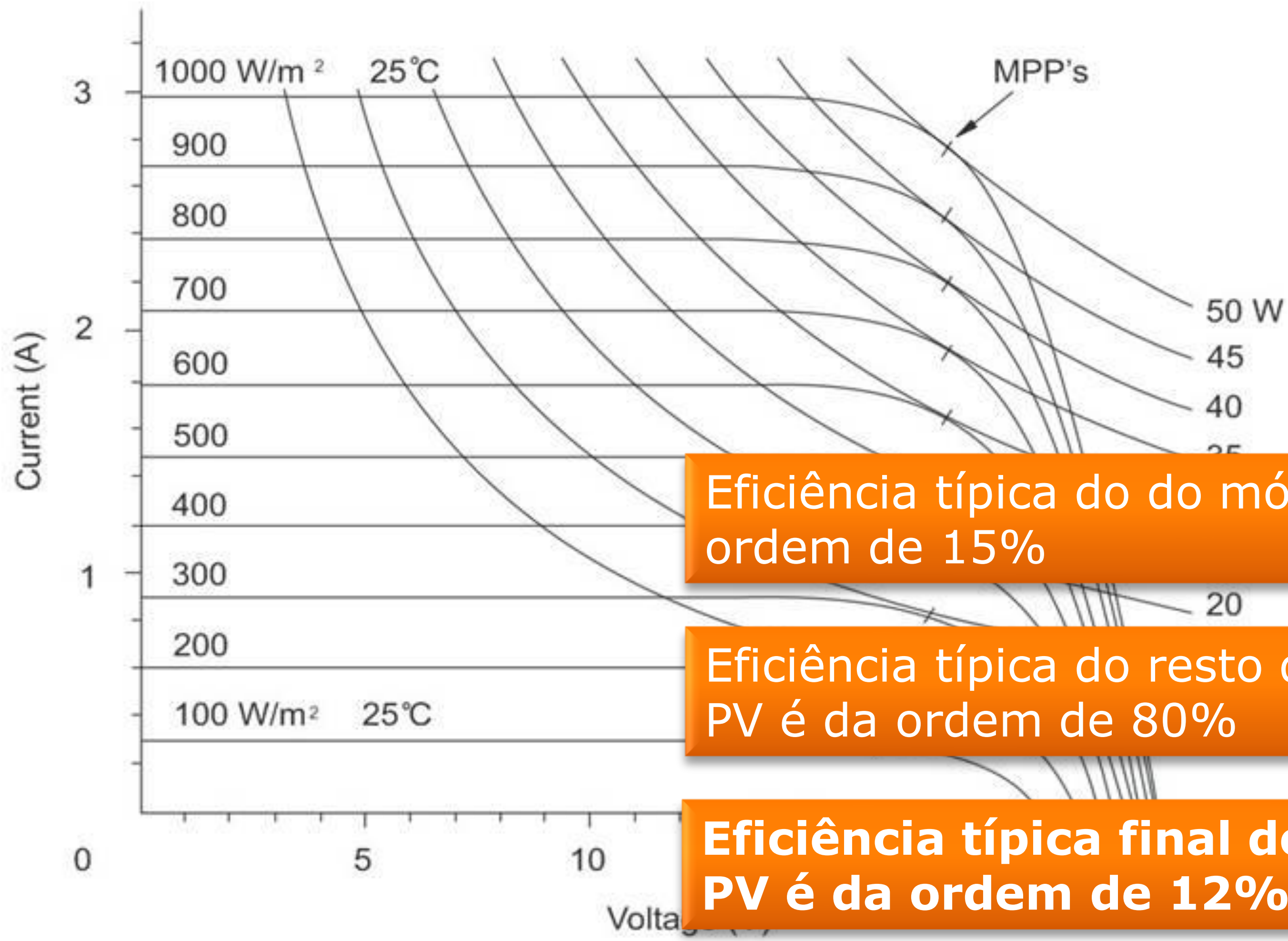
Parametros que determinam desempenho sistema solar

- eficiência dos componentes a jusante: inversor



Parametros que determinam desempenho sistema solar

- eficiência dos componentes a jusante: MPP

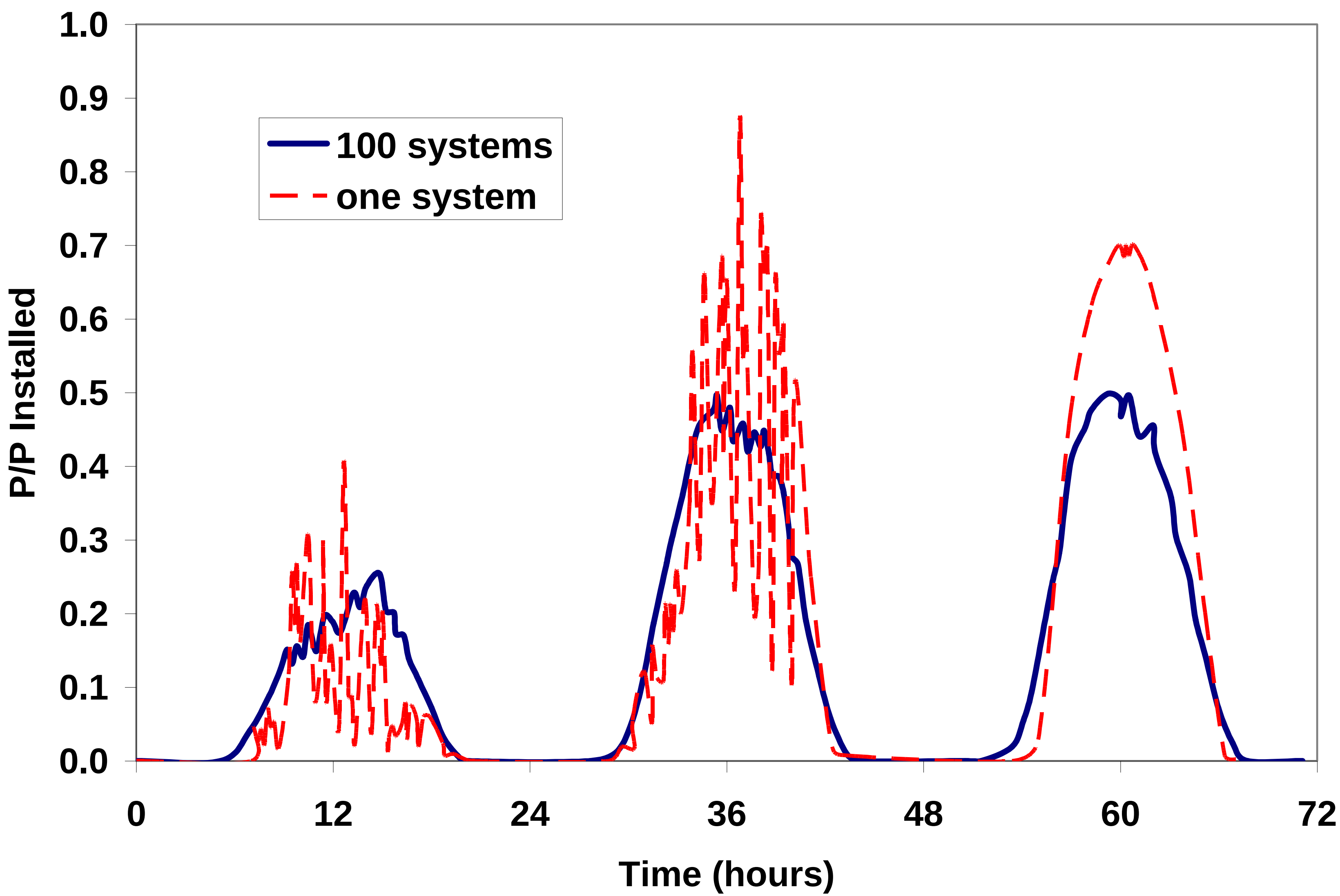


Eficiência típica do do módulo PV é da ordem de 15%

Eficiência típica do resto do sistema PV é da ordem de 80%

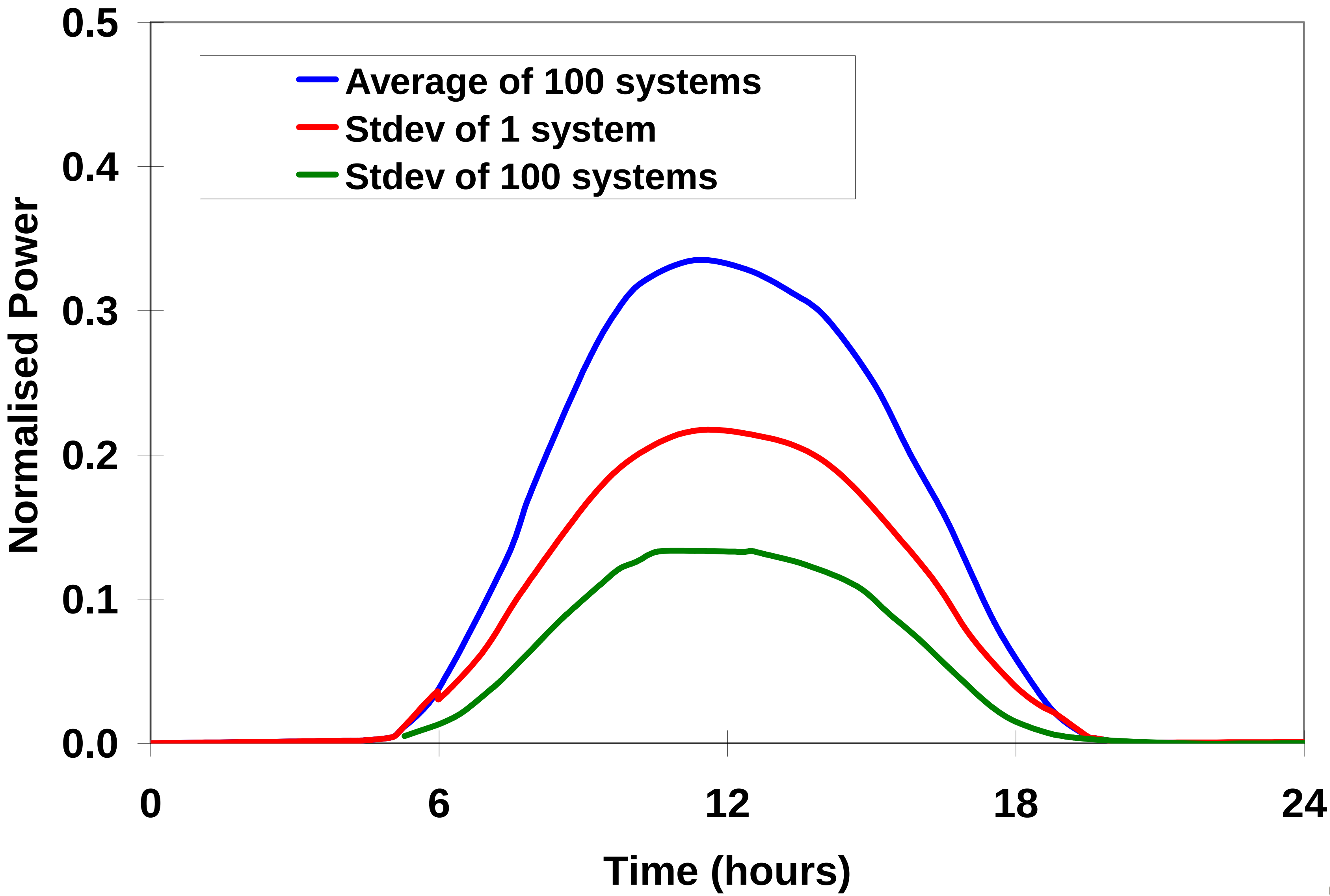
Eficiência típica final do sistema PV é da ordem de 12%

Variabilidade (e não intermitência!)



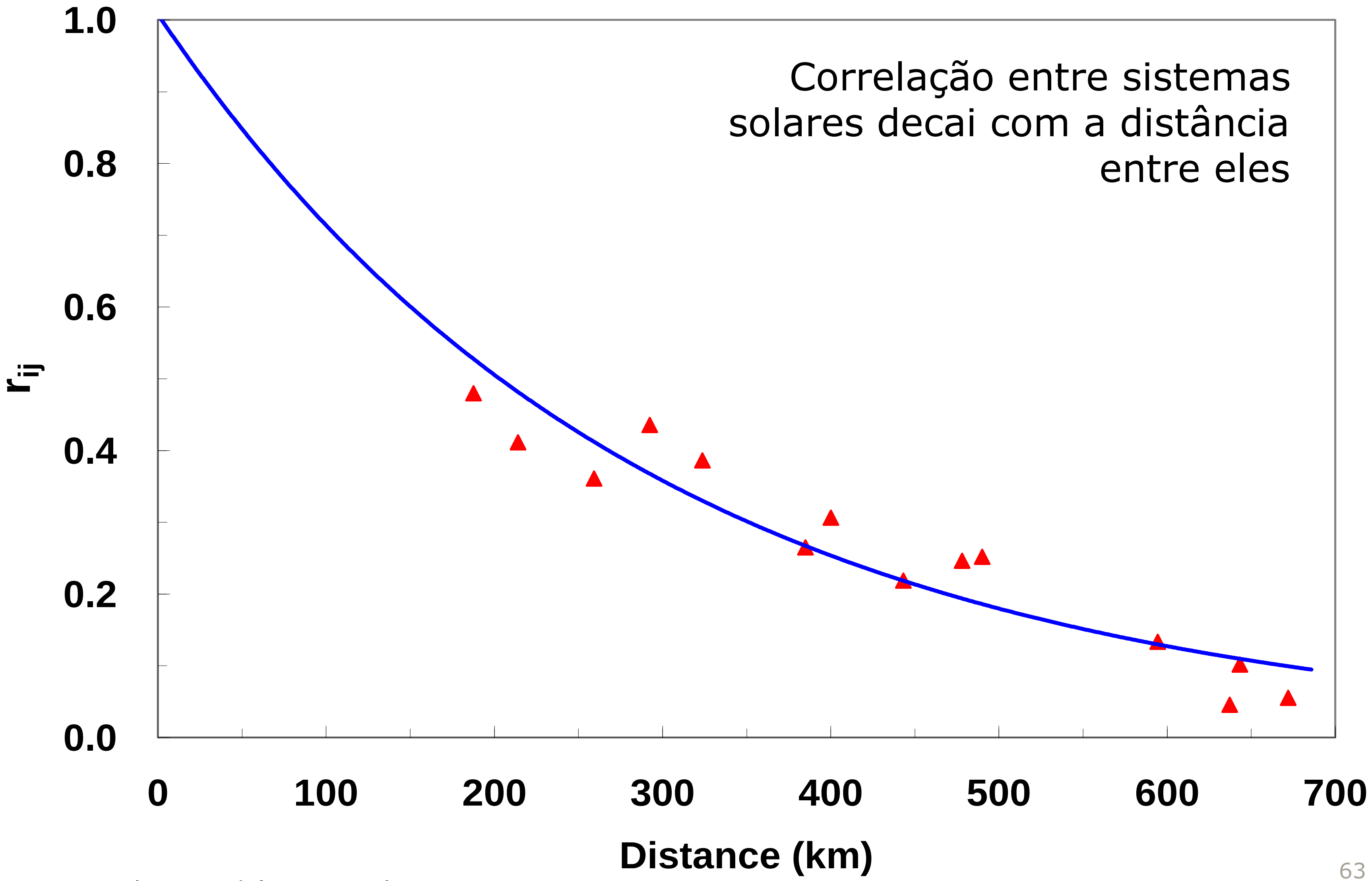
Source: Wiemken et al (2001, *Solar Energy* 70, 6, 513–518, http://www.sciencedirect.com/science/journal/0038092X)

Variabilidade (e não intermitência!)



Source: Wiemken et al (2001, *Solar Energy* 70, 6, 513–518, http://www.sciencedirect.com/science/journal/0038092X)

Variabilidade (e não intermitência!)



Source: Wiemken et al (2001, *Solar Energy* 70, 6, 513–518, http://www.sciencedirect.com/science/journal/0038092X)

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

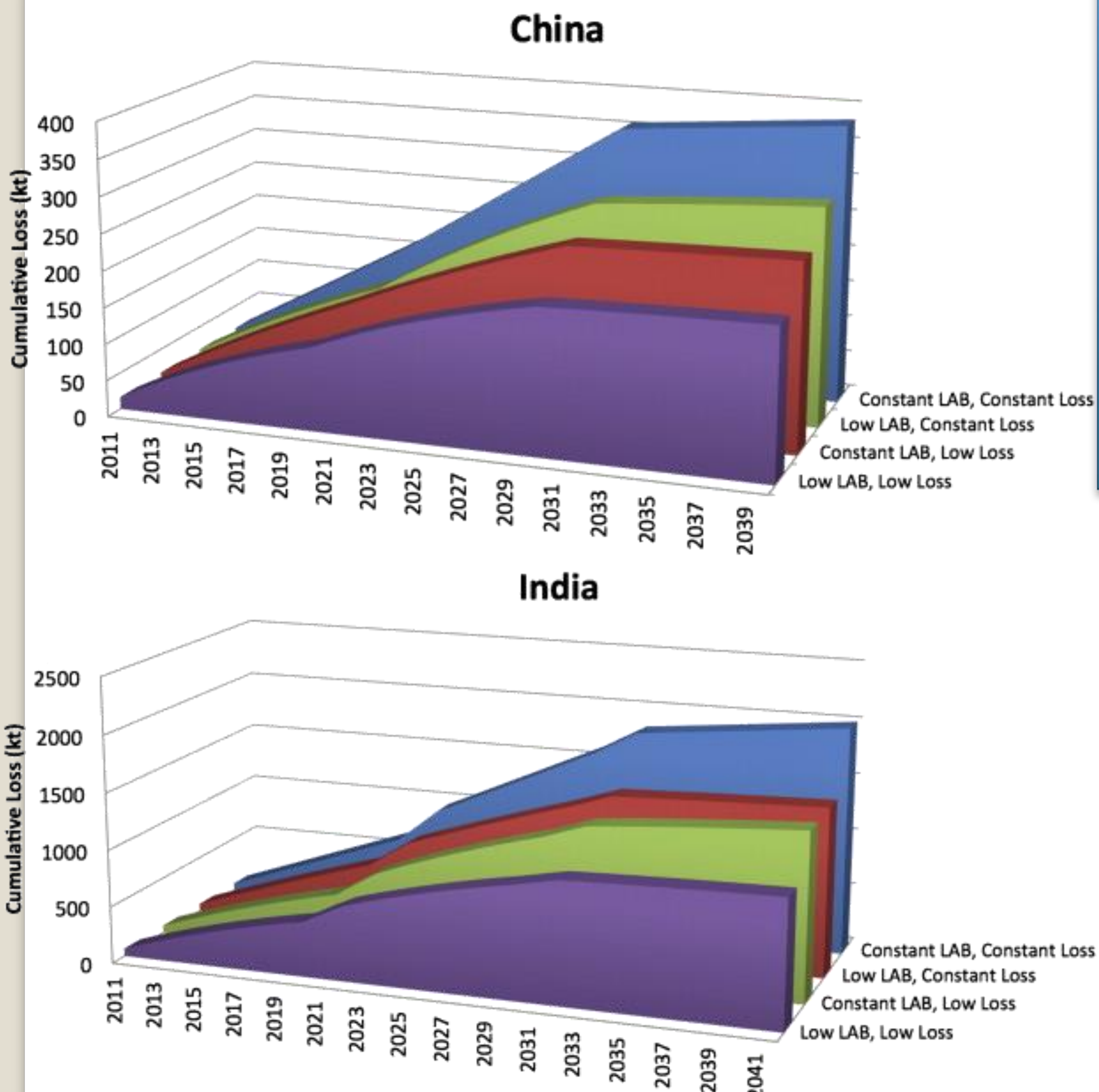
"It's poison air. Sometimes it gets so bad you can't sit outside. You have to close all the doors and windows," says Qiao Shi Peng, 28, shown in front of a dumping site in his village, who worries about his 1-year-old son's health. (Zhang Quanfeng - Photo By Zhang Quanfeng)

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.

P. Gottesfeld, C.R. Cherry, *Lead emissions from solar photovoltaic energy systems in China and India*, Energy Policy **39** (2011)4939–4946