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FACULTY OF ELECTRICAL ENGINEERING, COMPUTER SCIENCE AND INFORMATION TECHNOLOGY OSIJEK

Influence of external factors on the performance of PV systems

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Zagreb Energy Congress

Zagreb, 13th – 16th of December 2017

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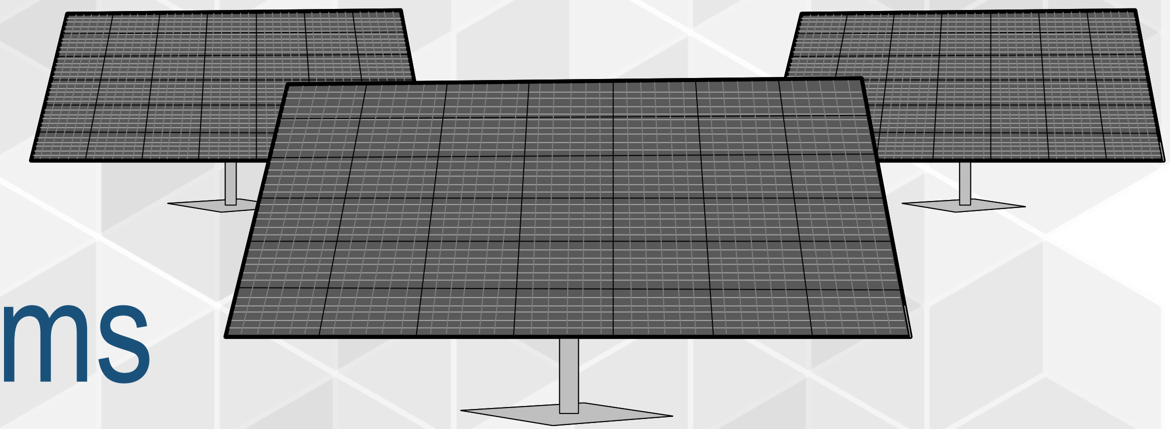
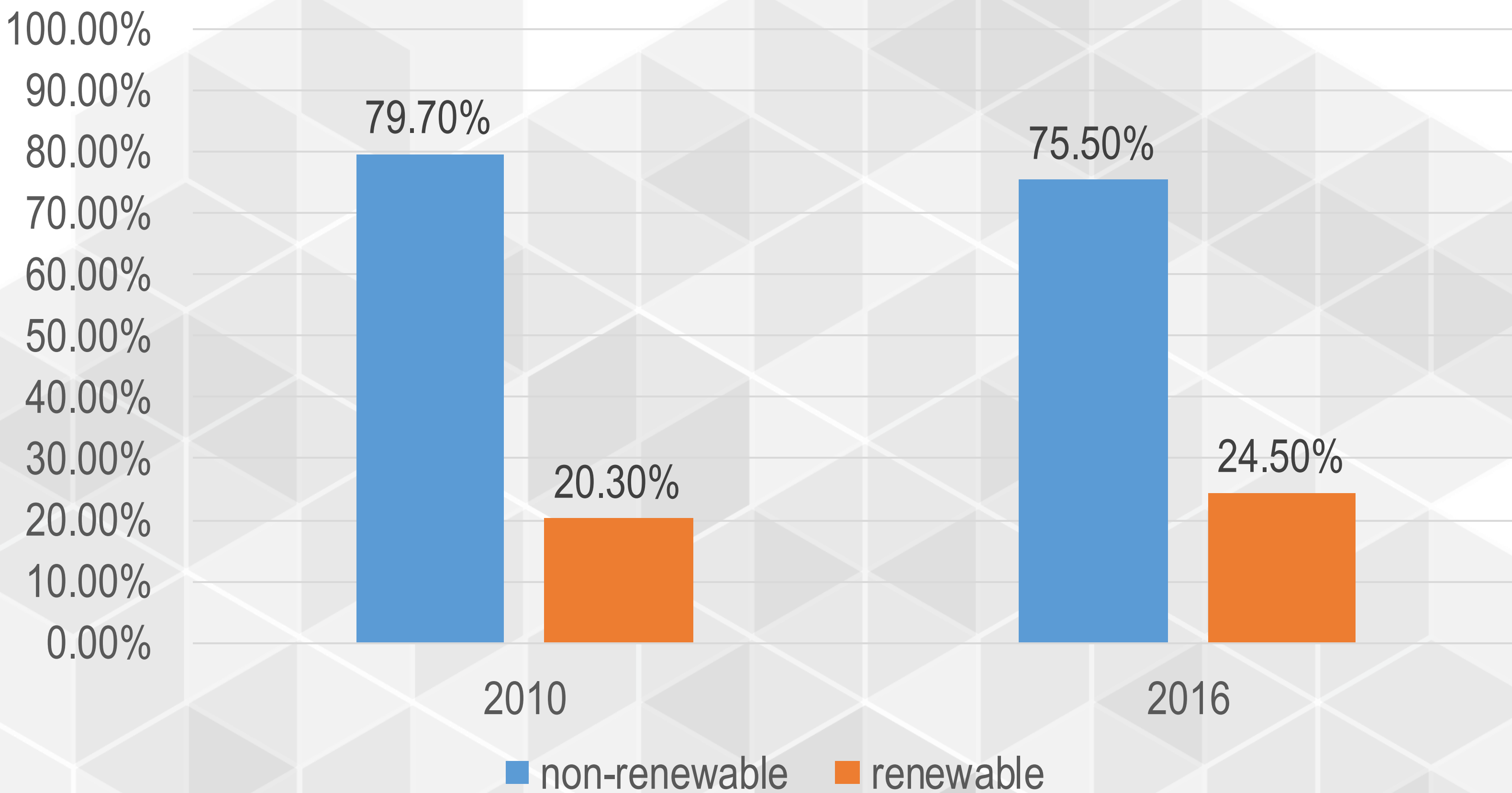


PV systems

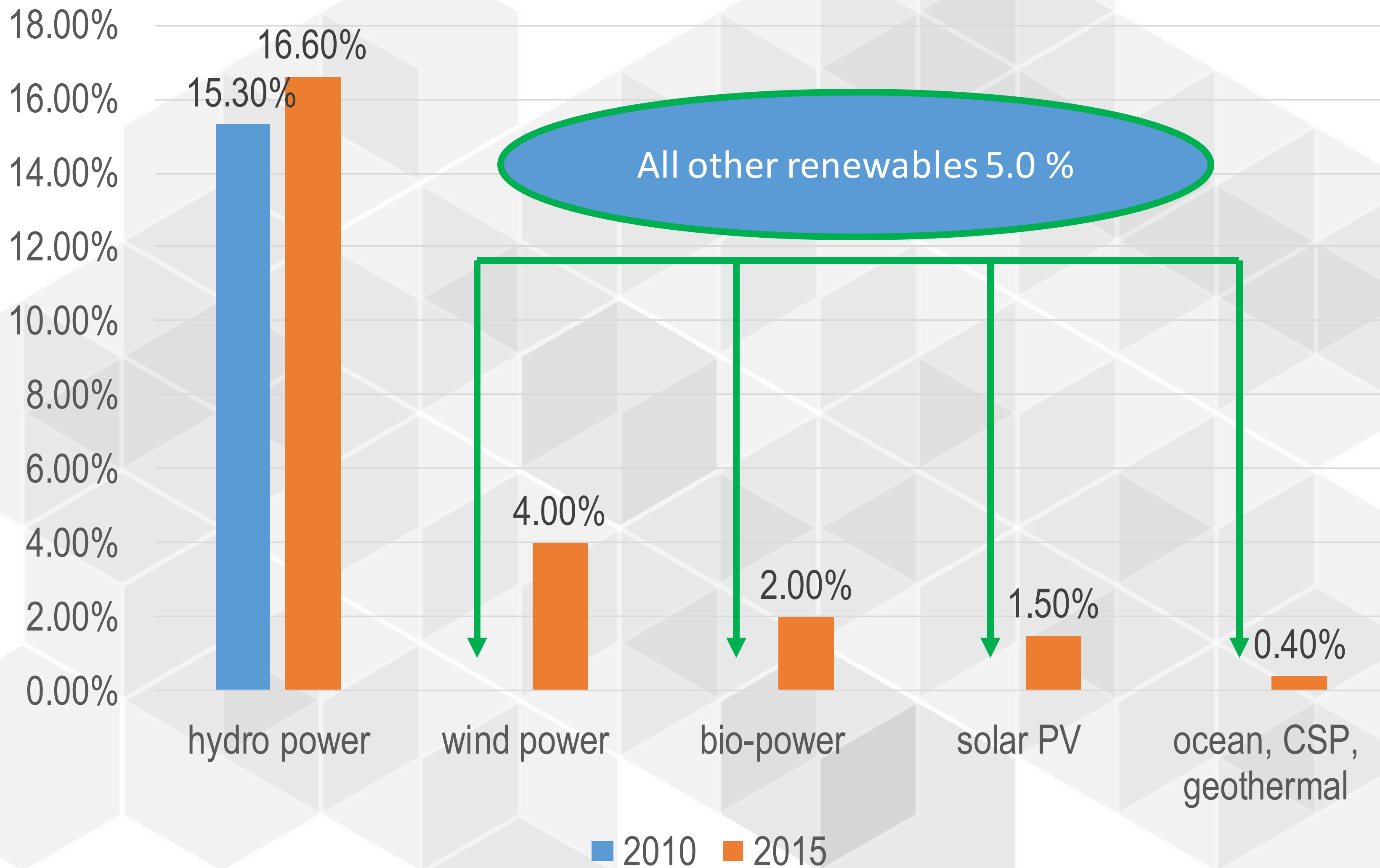
Market and trends

Estimated Renewable Energy Share of Global Electricity Production (2010/2016)



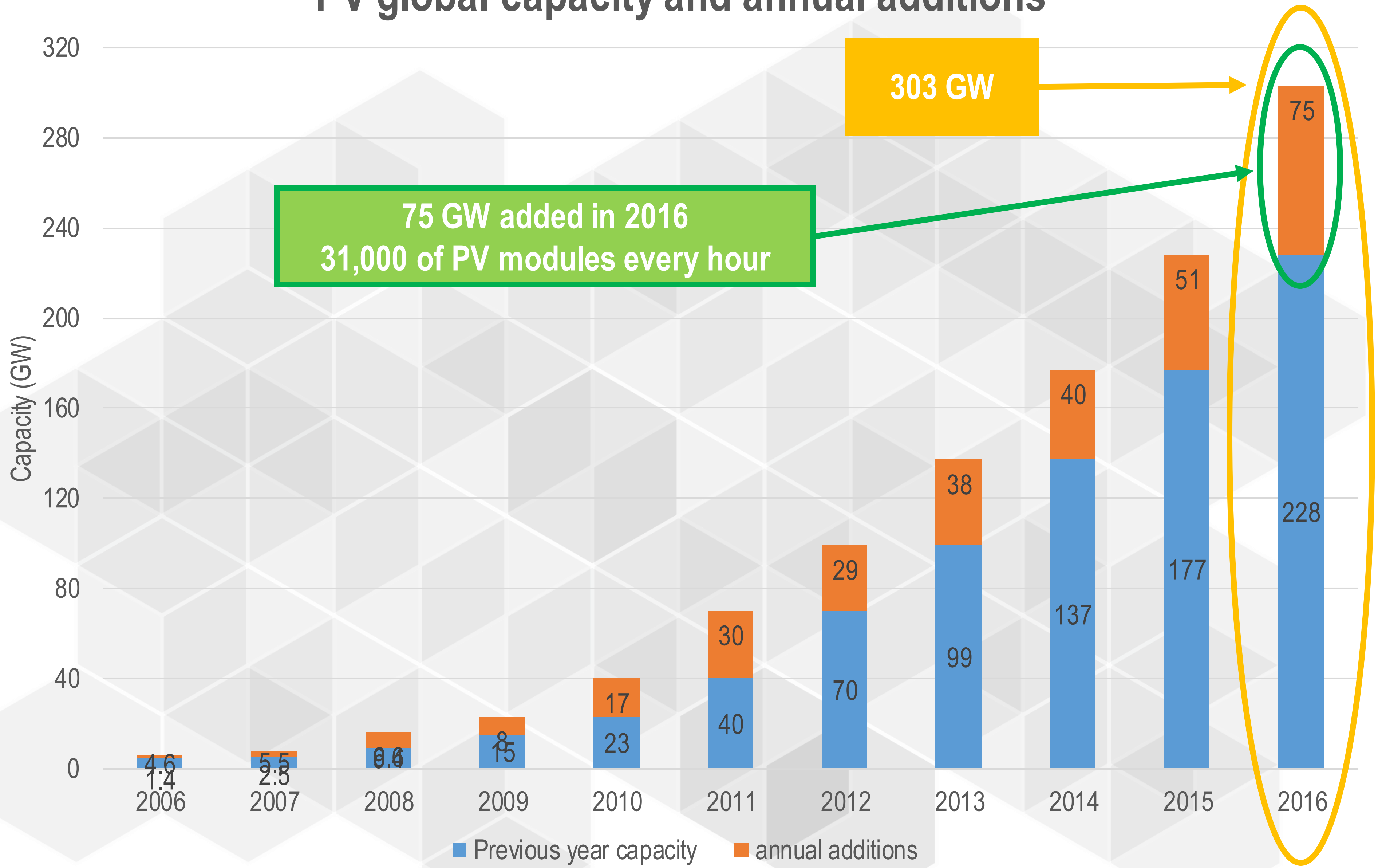
Source: REN21 Global Status Report 2014, 2017

Estimated Renewable Energy Share of Global Electricity Production (2010/2016)



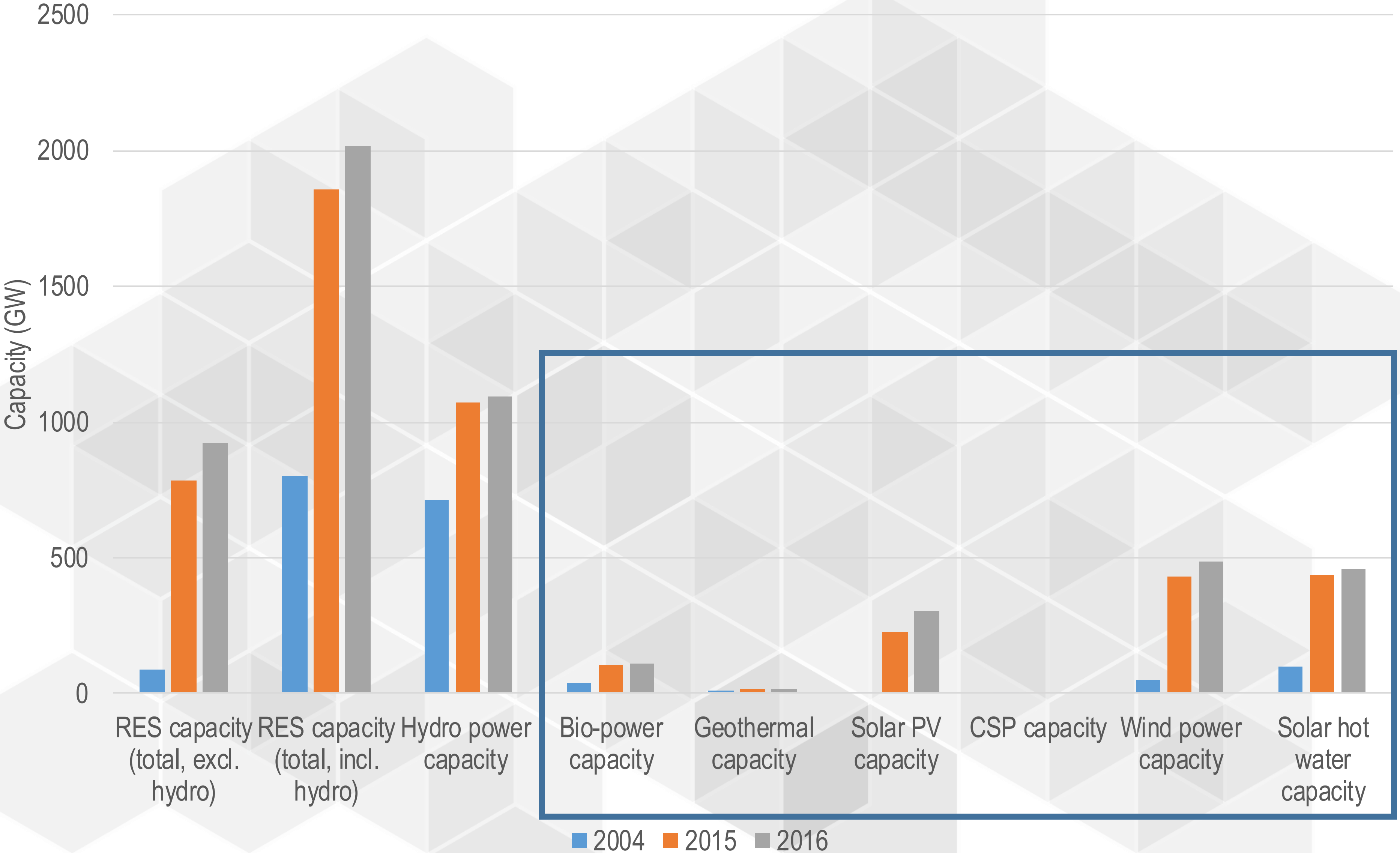
Source: REN21 Global Status Report 2014, 2017

PV global capacity and annual additions



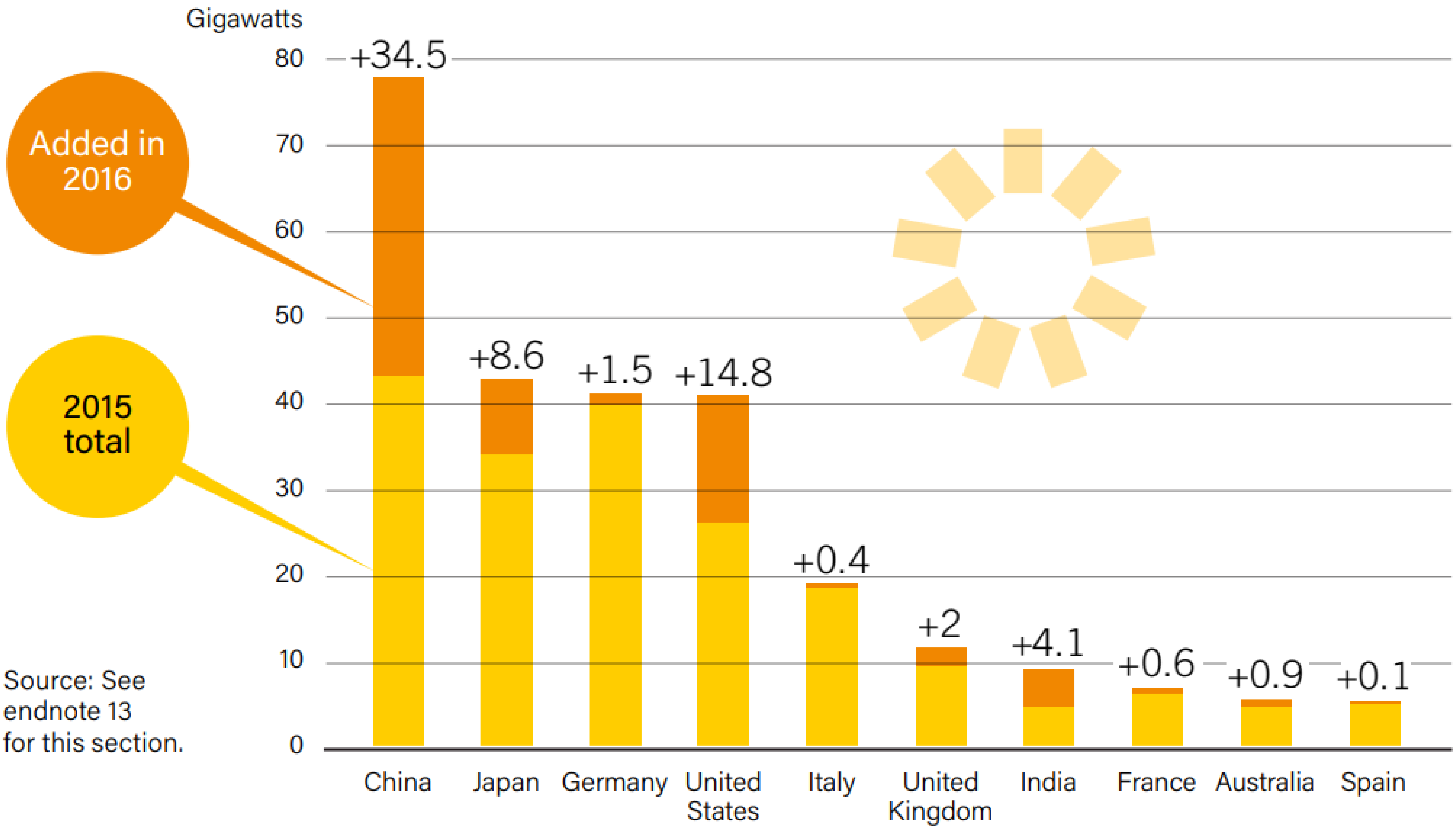
Source: REN21 Global Status Report 2014, 2017

Power capacity od different RES



Source: REN21 Global Status Report 2014, 2017

Solar PV Capacity and Additions, Top 10 Countries, 2016



Source: See endnote 13 for this section.

Source: REN21 Global Status Report 2014, 2017

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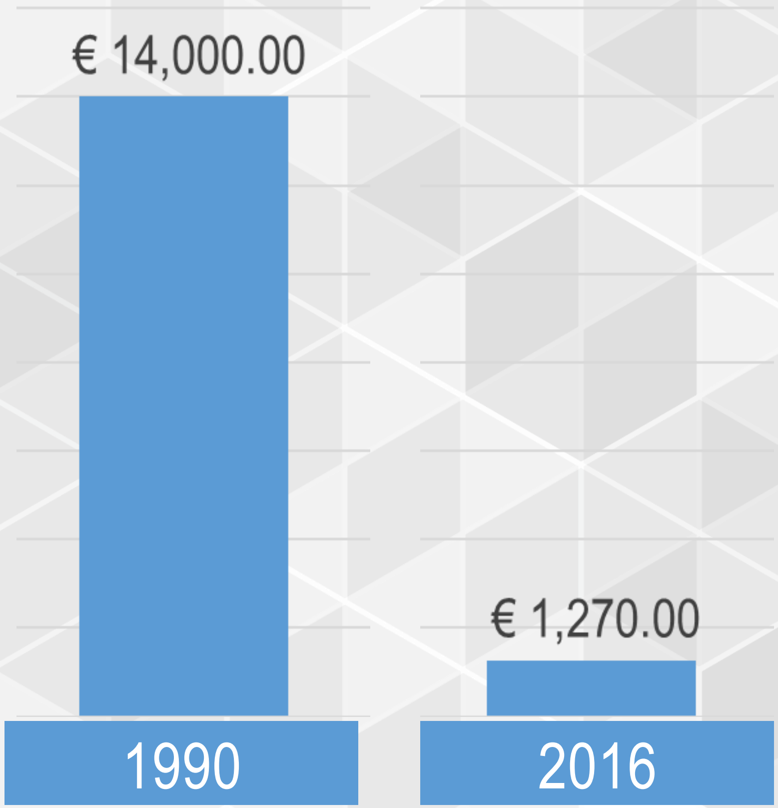
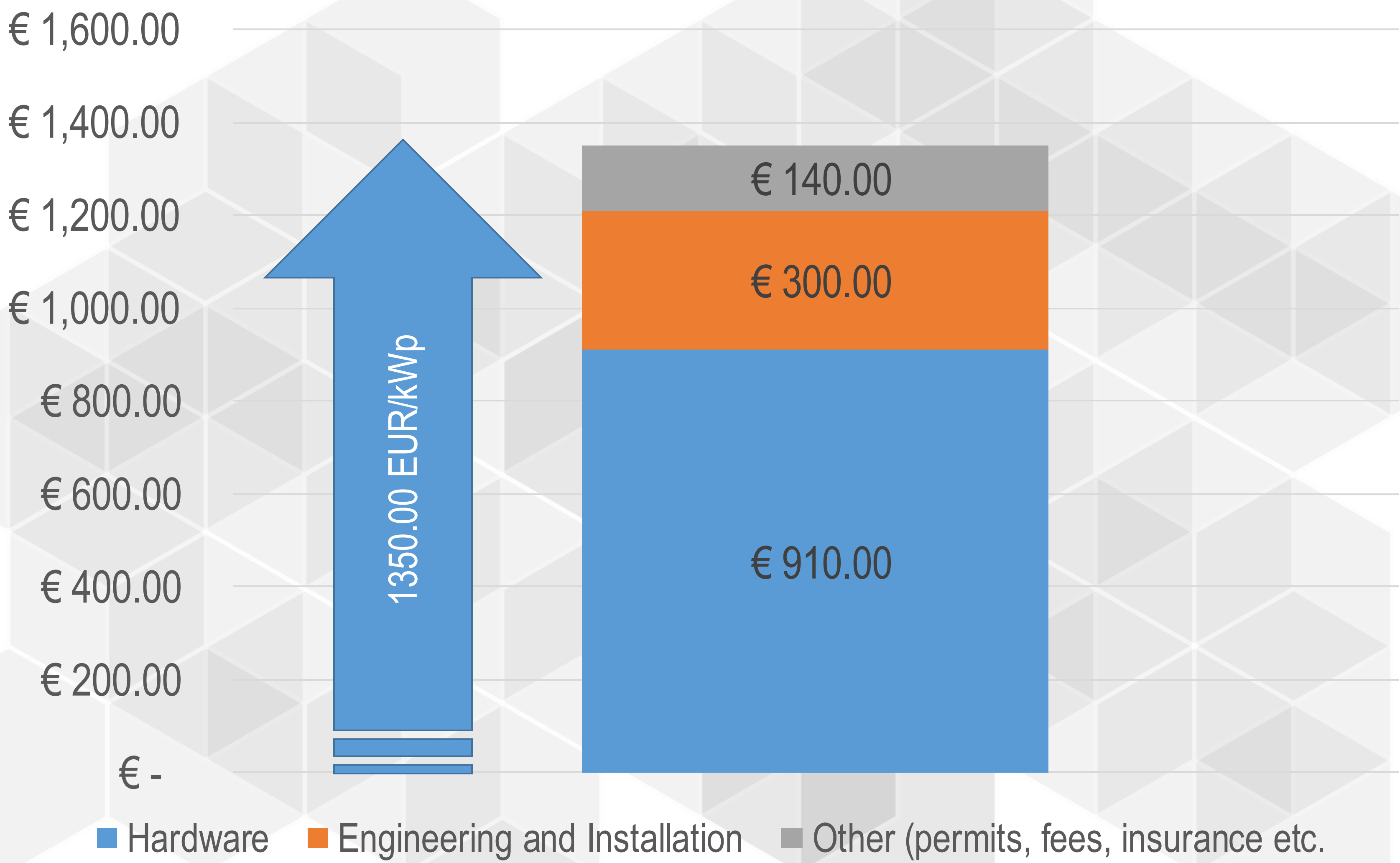
Price development



This is a net-price regression of about 90% over a period of 25 years and is equivalent to an annual compound average price reduction rate of 9% .

Source: Photovoltaci Reportss, Fraunhofer Institue for Solar energy Systems https://www.ise.fraunhofer.de/

Installation costs of residential PV systems



Source: PV Status Report 2017

Levelized cost of electricity (LCOE) (EURct/kWh)			
WACC	3.00%	5.00%	10.00%
1000 kWh/kWp	11.51	13.02	17.12
1300 kWh/kWp	8.85	10.01	13.17

Wien
1080 kWh/kWp

Venice
1290 kWh/kWp

WACC - weighted cost of capital

Average electricity price in EU-28 (EURct/kWh)			
	2013	2014	2015
Households	20.2	20.6	21.1
Industry	11.8	12	11.9

Source:
PV Status Report 2017
http://ec.europa.eu/eurostat

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PV cells efficiency

- Mono-crystalline cell: 26.7%
- Poly-crystalline cell: 21.9%

→ Silicon wafer-based technology

- CIGS cell: 21.7%
- CdTe cell: 21.0%

→ Thin film technology

Source: Photovoltaci Reportss, Fraunhofer Institue for Solar energy Systems
https://www.ise.fraunhofer.de/

PV modules efficiency

12% → Efficiency of silicon wafer-based PV modules → 17% (21%)

9% → Efficiency of CdTe PV modules → 16%

In last 10 years

Source: Photovoltaci Reportss, Fraunhofer Institue for Solar energy Systems
https://www.ise.fraunhofer.de/

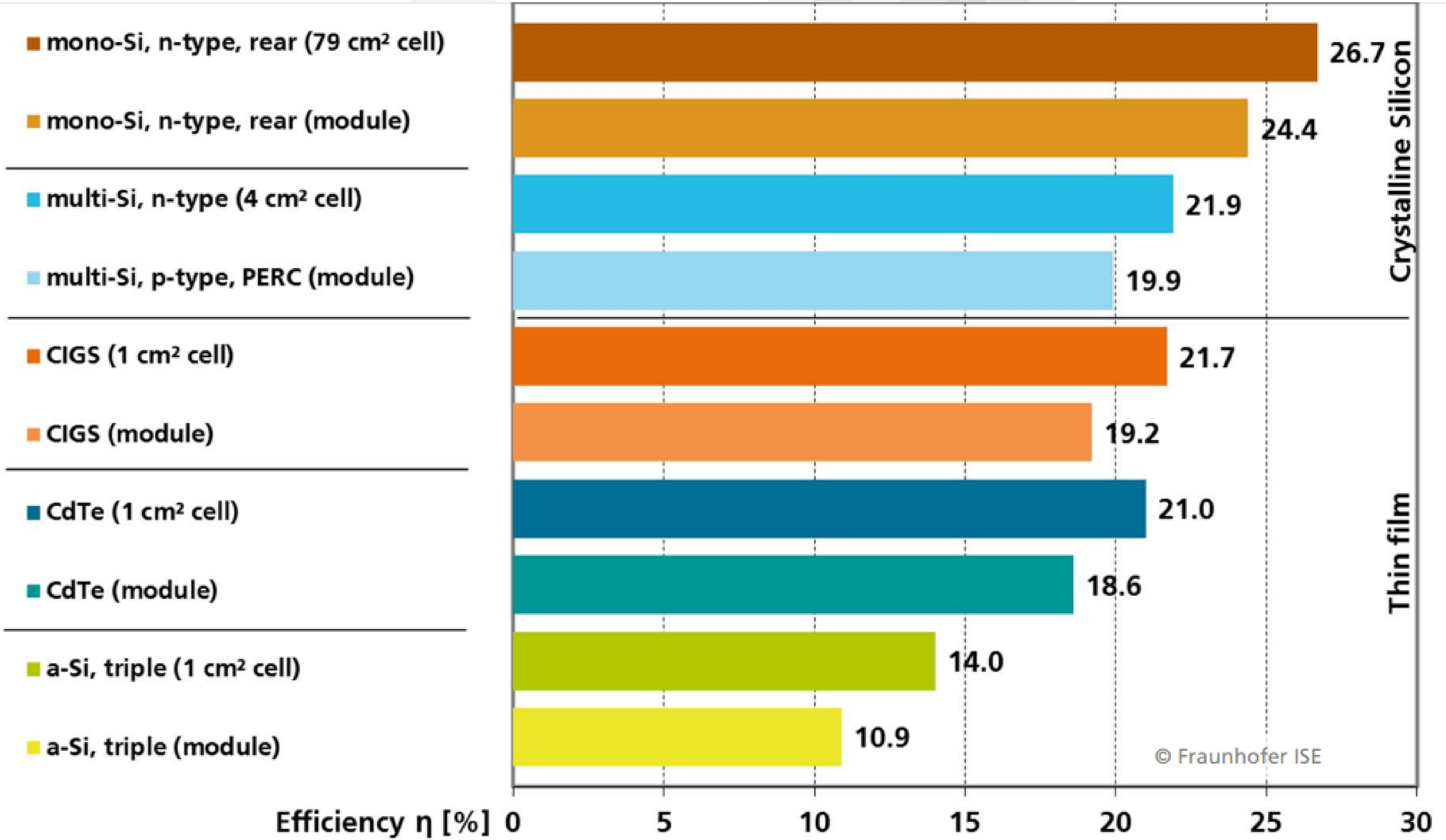
Energy Payback Time

Material usage for silicon cells has been reduced significantly

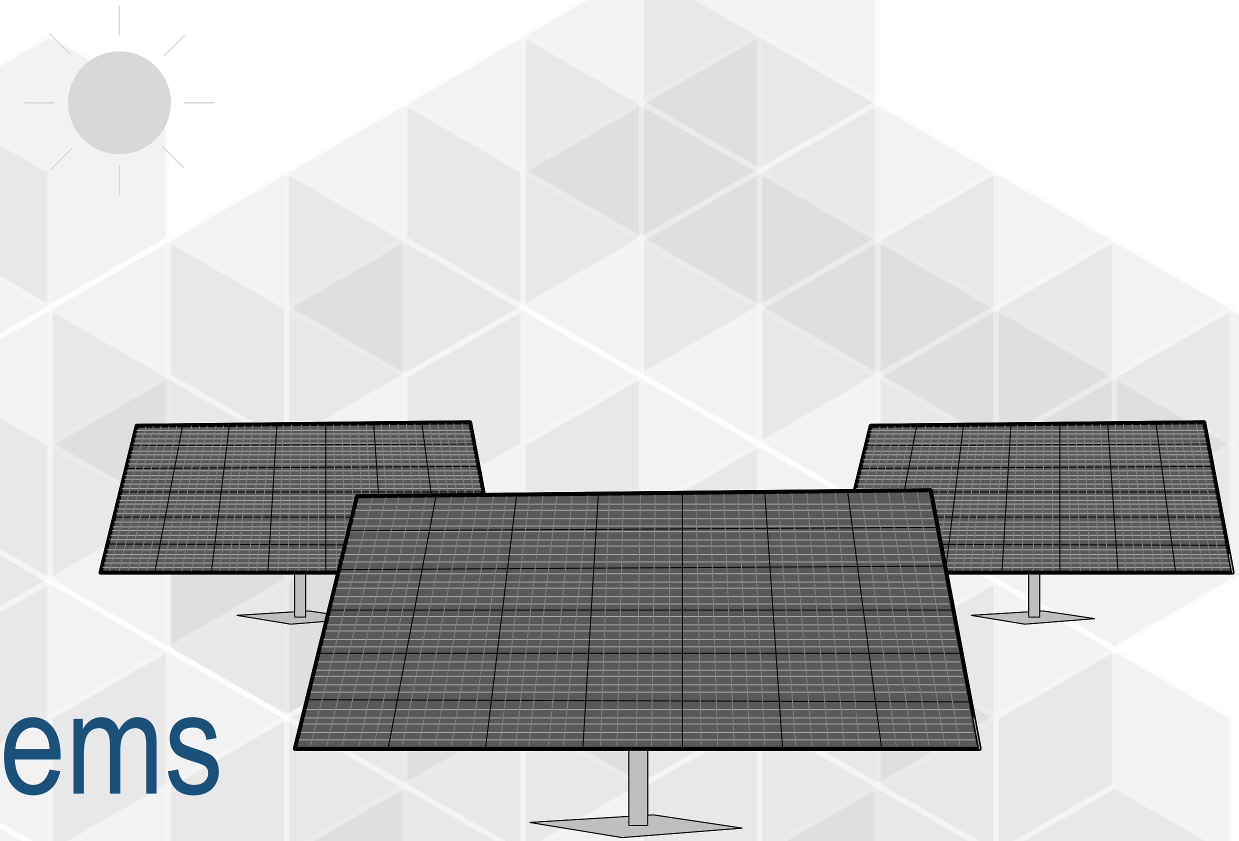
16g/Wp → In last 12 years → 6g/Wp

Source: Photovoltaci Reportss, Fraunhofer Institue for Solar energy Systems
https://www.ise.fraunhofer.de/

Efficiency Comparison of Technologies: Best Lab Cells vs. Best Lab Modules



Source: Photovoltaci Reportss, Fraunhofer Institue for Solar energy Systems
https://www.ise.fraunhofer.de/



PV systems

External factors influencing perfomance of PV systems

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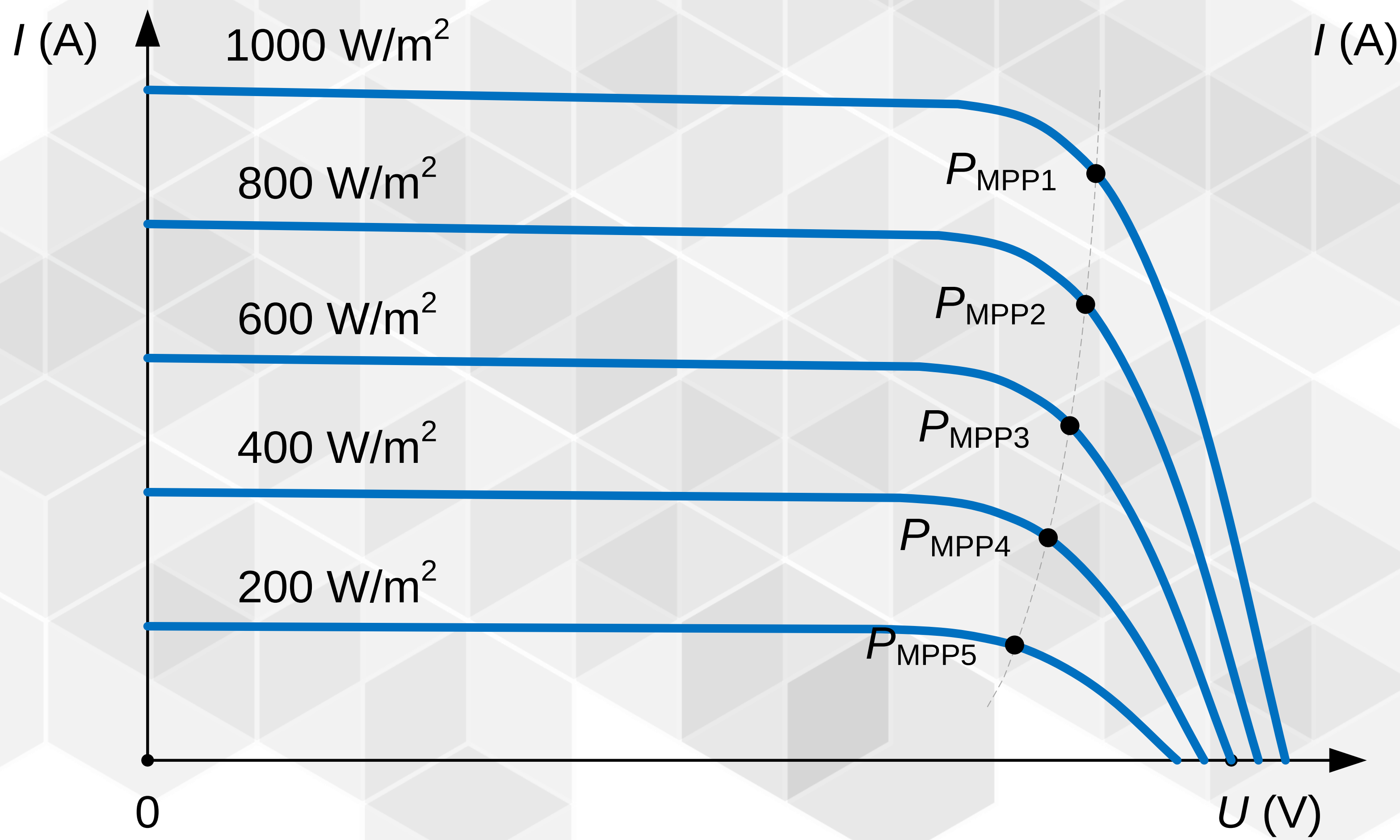
External factors influencing performance of PV systems

- Influence of irradiance on PV modules
- Influence of dust deposition on PV modules
- Influence of shading effect on PV modules
- Influence of temperature, humidity and wind velocity on PV modules

Influence of irradiance on PV modules

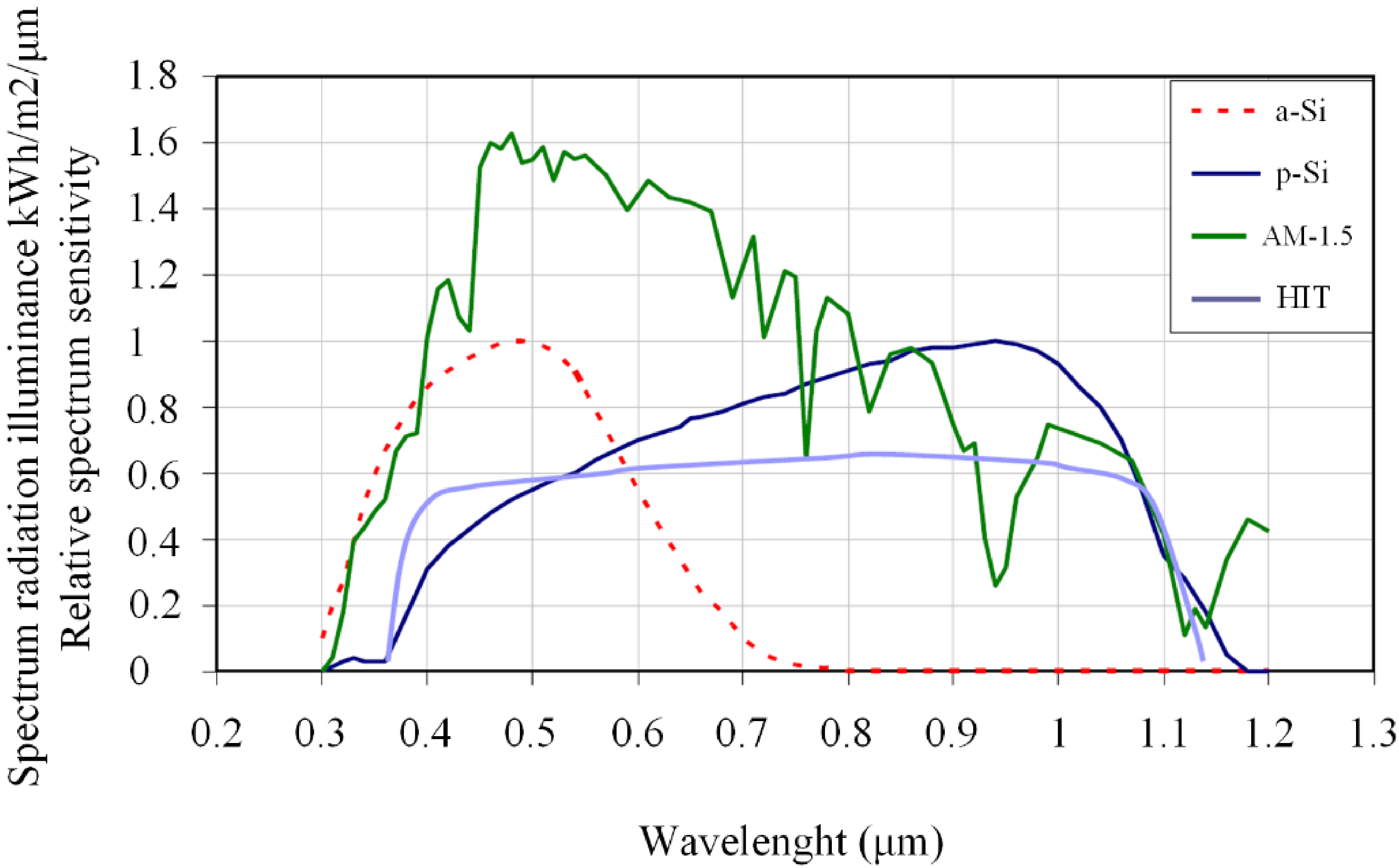


Influence of irradiance on PV modules

- ► Research showed that efficiency of wafer-based Si technologies is not as much affected by fast irradiance changes as Si-based thin-film technologies.
- ► a-Si technologies show higher efficiencies at low irradiances, while µ-Si modules react like m-Si at high irradiances.
- ► Furthermore, each PV technology owns a different spectral response.
- ► Spectral response is defined as a probability that the absorbed photon will generate a carrier to the photocurrent of the PV cell.

Source: Ye JY, Ding K, Reindl T, Aberle AG. Outdoor PV module performance under fluctuating irradiance conditions in tropical climates. Energy Procedia 2013;33:238–47.

Spectrum response of different PV technologies



Source: Sirisamphanwong C, Sirisamphanwong C. The effect of photon flux density and module temperature on power output of photovoltaic array. Energy Procedia 2013;34:430–8..

Influence of dust deposition on PV modules

- Influence of dust deposition depends on different factors such as:
  - geographical location,
  - climate (tropical, desert),
  - micro climate,
  - site,
  - dust type
  - tilt angle of the module
  - etc.

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Influence of dust deposition on PV modules

- There are many papers that investigate influence of dust deposition on PV modules (systems) from different aspects.
- Tanesab et. al. In investigated contribution of dust deposition long term degradation of performance of different types of PV modules. Modules were in operation during eighteen years without any cleaning.

Source: Tanesab J, Parlevliet D, Whale J, Urmee T, Pryor T. The contribution of dust to performance degradation of PV modules in a temperate climate zone. Sol Energy 2015;120:147–57.

Influence of dust deposition on PV modules

- Main results of this research show **that degradation of power during 18 years** was around **19 to 33 %**. (Perth, Australia) – temperate climate region.
- Main influences on degradation of tested modules (seven different modules: two m-Si, two p-Si and three a-Si, north oriented with tilt angle of 32^0) were non-dust influences.

Source: Tanesab J, Parlevliet D, Whale J, Urmee T, Pryor T. The contribution of dust to performance degradation of PV modules in a temperate climate zone. Sol Energy 2015;120:147–57.

Influence of dust deposition on PV modules

- Influence of corrosion, delamination and discoloration on power output losses were around 71–84 % .
- **Power output losses caused by dust** were around **16–29%** which is still significant.
- That means that **dust deposition was responsible** for **3.04% - 9.57%** power degradation.
- This paper also shows that dust has **fairly uniform influence** on performance degradation **for all three technologies**.

Source: Tanesab J, Parlevliet D, Whale J, Urmee T, Pryor T. The contribution of dust to performance degradation of PV modules in a temperate climate zone. Sol Energy 2015;120:147–57.

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Influence of dust deposition on PV modules

- Lopez- Garcia et. al. in investigated long term influence of soiling (dust deposition) on PV modules in moderate subtropical climate (Ispra, Italy).
- This paper investigates **influence of soiling on silicon PV modules** performance that were **exposed to outdoor conditions for more than 30 years**.
- They investigated how much will output power increase after cleaning of PV module. Two methods of cleaning modules are investigated.
- Research results showed that **overall power increase** after **cleaning was between 3.5 % and 19.4 %**. Average value of **power increase** after cleaning of modules **was 9.8 %**.

Source: Lopez-Garcia J, Pozza A, Sample T. Long-term soiling of silicon PV modules in a moderate subtropical climate. Sol Energy 2016;130:174–83.

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Influence of dust deposition on PV modules

Decrease in short circuit current, maximum current and efficiency of the modules						
Time of measurement	Decrease in I_{sc} (%)	Decrease in I_m (%)	η_{mod} (%)	Decrease in efficiency (%)		
				Experimental data	Dust deposition density "ΔM" (g/m²)	Calculation results
Daily	3.6	6.93	10.22	5.87	0.21	4.81
Weekly	9.09	12.87	10.22	10.57	0.4	9.23
Monthly	14	16.41	10.39	15.78	0.64	14.26

- Saidan et. al. in made **experimental study** on the effect of dust deposition on PV modules in **desert environment** (Bagdad, Iraq).
- Research presents influence of dust deposition on PV modules performance on **daily, weekly and monthly basis**.

Source: Saidan M, Albaali AG, Alasis E, Kaldellis JK. Experimental study on the effect of dust deposition on solar photovoltaic panels in desert environment. Renew Energy 2016;92:499–505

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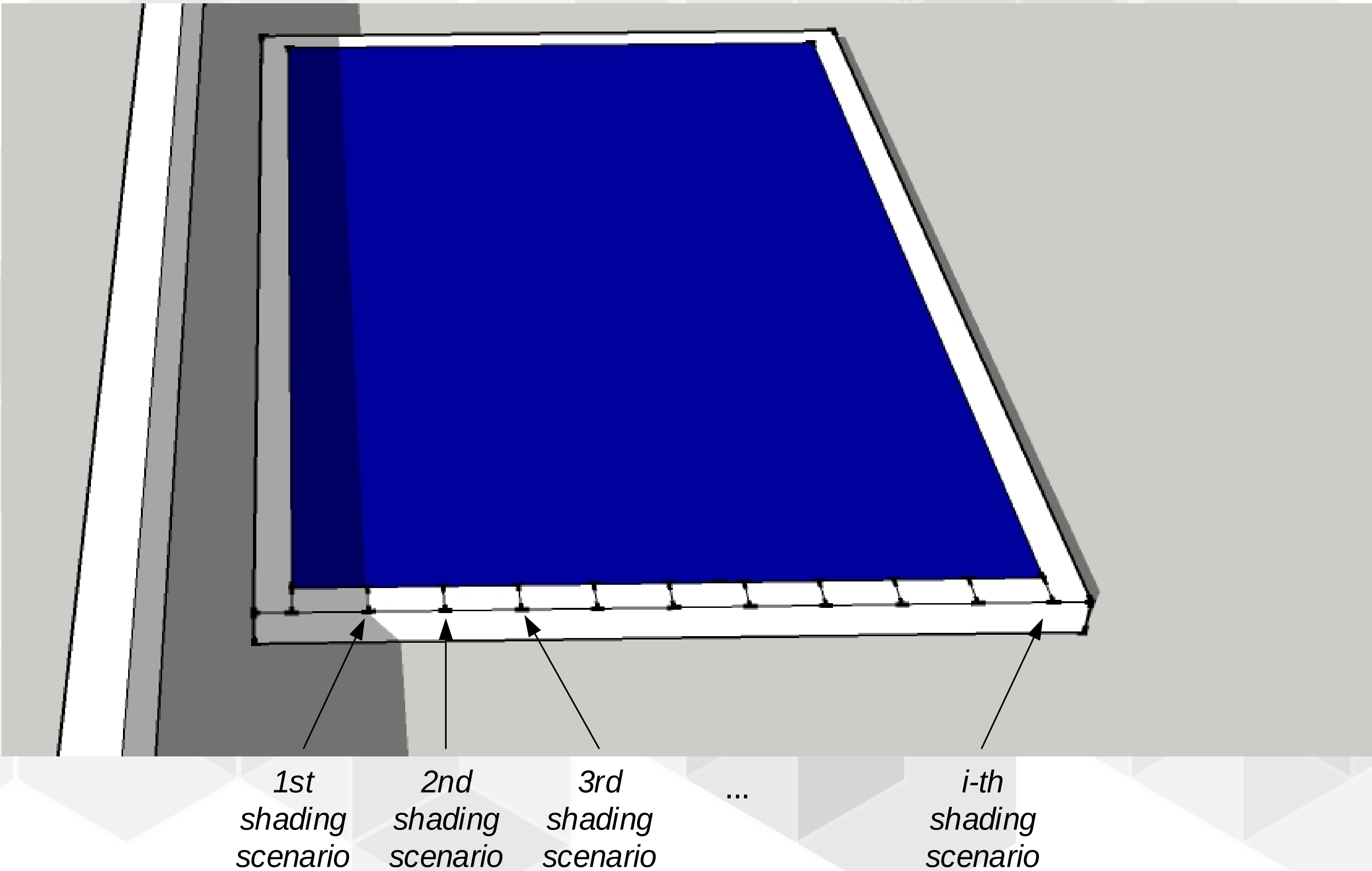
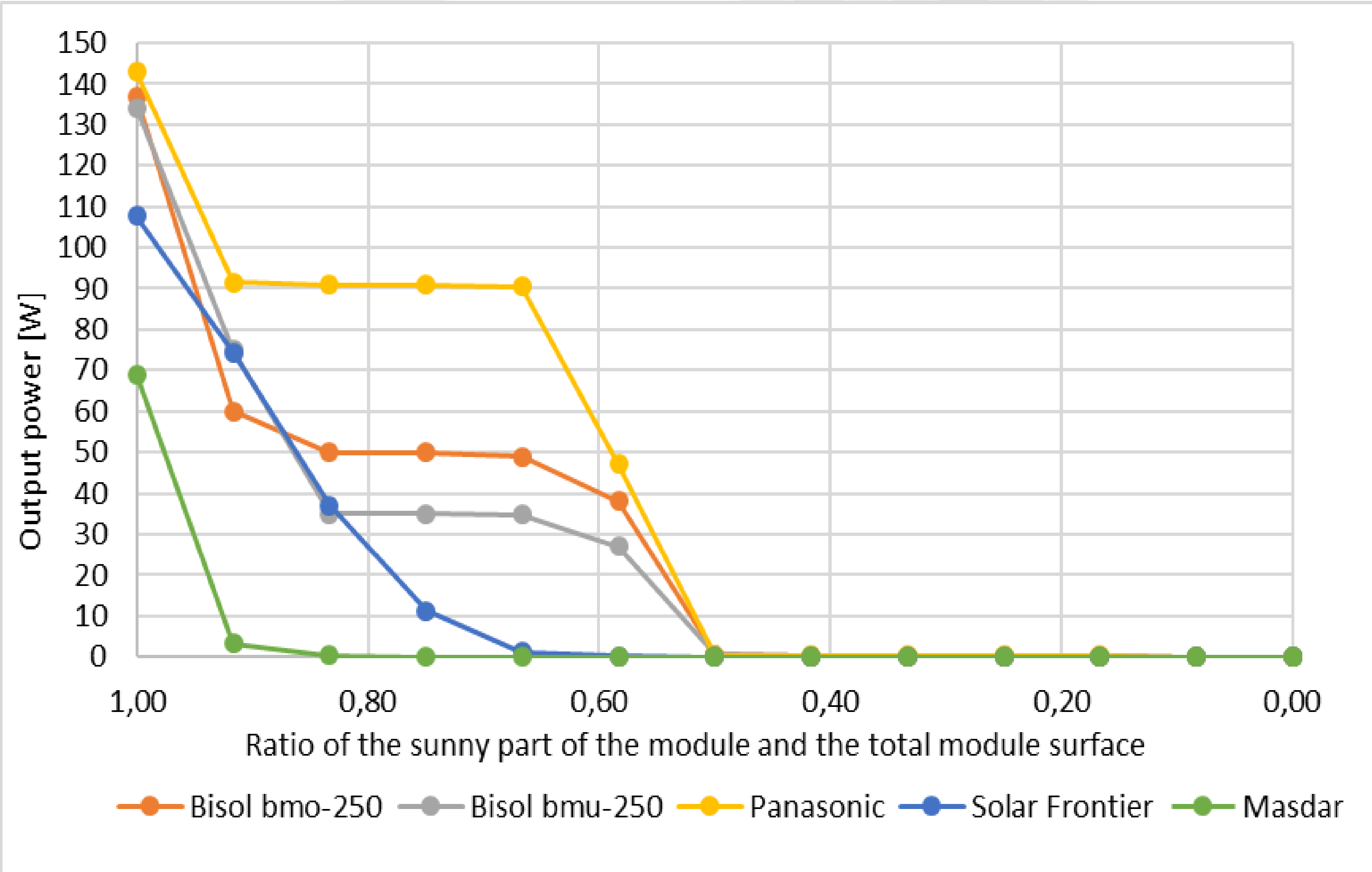
Influence of shading effect on PV modules

- ► **Shading has significant influence** on power decrease of PV module.
- ► Influence of shading is different for different technologies of PV modules.
- ► For some types of PV modules **shading of even a small area** of module (e.g. 10%) **can lead to decrease** of output power **close to zero**.
- ► During the designing process of PV systems, shading should be considered to **avoid shading influence as much as possible**.

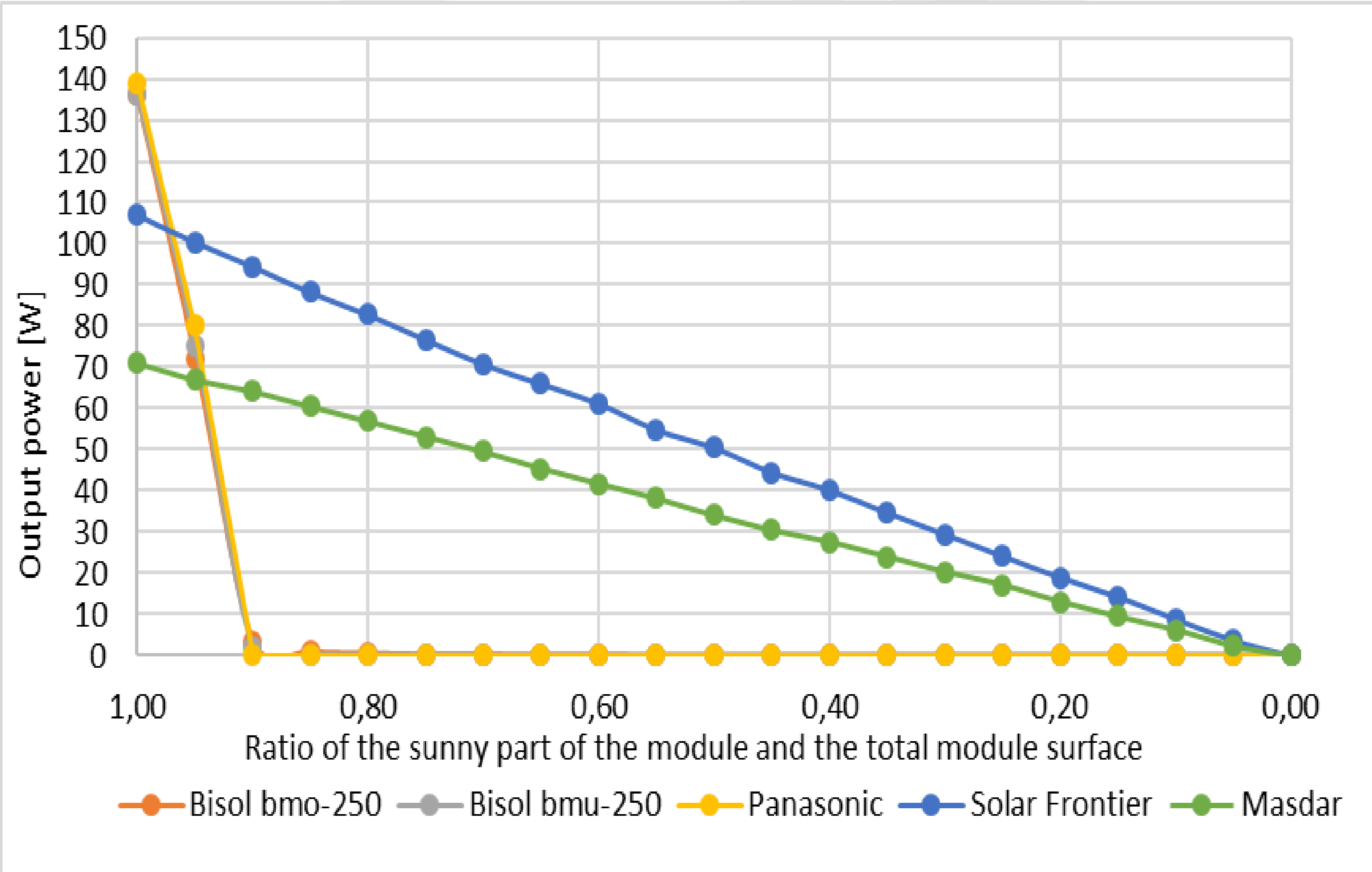
Influence of shading effect on PV modules



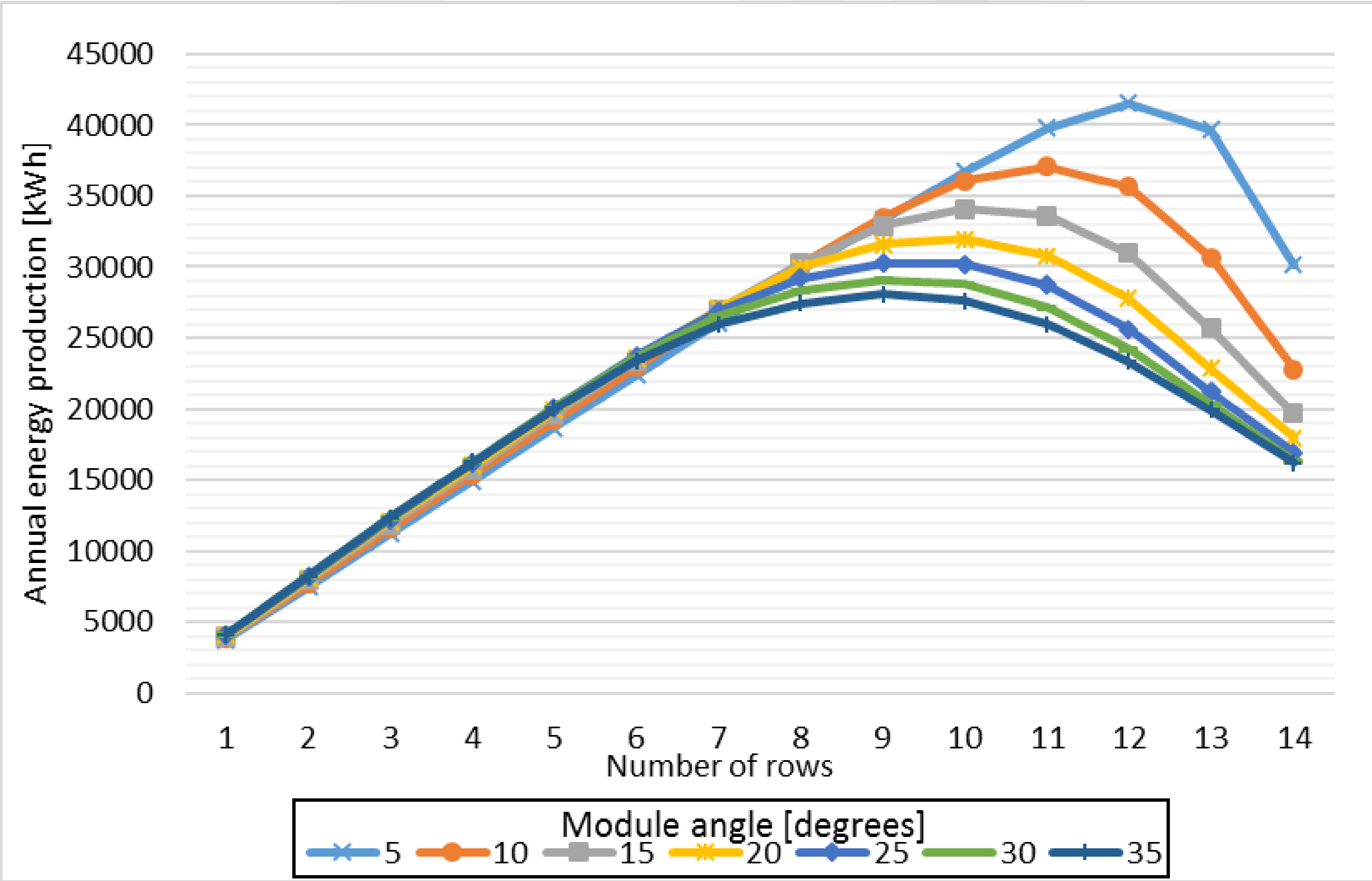
Measurement Results of the Output Power of the Landscape Oriented PV Modules in Respect to *As/A*



Measurement Results of the Output Power of the Portrait Oriented PV Modules in Respect to As/A



Annual energy production of BMU 250 PV module (landscape orientation) in respect to the number of rows



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Influence of temperature, humidity and wind velocity on PV modules

- Besides influence of dust deposition, irradiance and shading effect on electricity production from PV systems there are also other parameters such as humidity, wind velocity, ambient temperature and most important operating temperature that can affect their power output and efficiency.
- Influence of these parameters on PV electricity production is previously researched which is indicated by a large number of papers.

Ref.	PV module technology	Test duration	Location	Performance ratio	Temperature losses	Wind speed
[1]	m-Si	8 months	Salento, Italy	Max (Mar): 86.5 % Min (Jun): 79 %	Max: 8 % Min: 3.5 %	Monthly average: 3.5 - 4.9 m/s
[2]	m-Si	1 year	Colombia (Arauica, Choco-Bahia Solano, Barranquilla, Bogota, Bucaramanga, Guajira, Leticia, Tunja)	Max annual: 82.5 %	Max: 14.83 % Min: 6.38 %	Average: 1.4 - 6.2 m/s
	p-Si			Max annual: 80.5 %	Max: 15.54 % Min: 6.73 %	
	CdTe			Max annual: 86.5 %	Max: 8.08 % Min: 3.71 %	
	a-Si			Max annual: 84.5 %	Max: 9.1 % Min: 4.34 %	
	CIS			Max annual: 85.8 %	Max: 10.37 % Min: 4.6 %	
[3]	a-Si/μc-Si	16 months	Antofagasta, Chile	Max. (summer): 82 % Min. (spring): 79 %	PR slope max: -0.178 %/day PR slope min: -0.091 %/day	N/A
	m-Si			Max. (summer): 80 % Min. (spring): 70 %	PR slope max: -0.172 %/day PR slope min: -0.042 %/day	N/A
[4]	a-Si/μc-Si	2 years	Chania, Greece	Max. (summer): 93.1 % Min. (winter): 80 %	Power loss slope: -6.2713 W/°C Efficiency loss slope: -0.0289 %/°C	Max: 4.3 m/s Min: 2.5 m/s

Ref.	PV module technology	Test duration	Location	Performance ratio	Temperature losses	Wind speed
[5]	a-Si/µc-Si	21 months	Atacama Desert, Chile	Max. (February): 77 % (clean) Min. (May): 52 % (dirty)	Increasing temp: -4.8 to -4.4 %/month PR drop Decreasing tem: -4.2 to -3.7 %/month PR drop	N/A
	p-Si			Max. (August): 72 % (clean) Min. (May): 48 % (dirty)	Increasing temp: -6.2 to -3.7 %/month PR drop Decreasing tem: -2.4 to -1.8 %/month PR drop	N/A
[6]	p-Si	3 years	Chang Wat Pathum Thani, Thailand	N/A	Max: 12 % Min: 8.5 %	N/A
	hj-Si			N/A	Max: 8 % Min: 5.8 %	N/A
	tf-Si			N/A	Max: 6.1 % Min: 4.5 %	N/A
	CIGS			N/A	Max: 8.2 % Min: 6 %	N/A

Ref.	PV module technology	Test duration	Location	Performance ratio	Temperature losses	Wind speed
[7]	m-Si	1 year	Ouagadougou, Burkina Faso; Dakar, Senegal	Annual: 84%	Calculated γ = -0.06 %/°C	N/A
	p-Si			Annual: 84%	Calculated γ = -0.19 %/°C	N/A
	p-Si			Annual: 80%	Calculated γ = -0.37 %/°C	N/A
	a-Si/μc-Si			Annual: 92%	Calculated γ = -0.09 %/°C	N/A
[8]	m-Si	1 year	Düzce Province, Turkey	Annual: 73%	Efficiency decrease: -0.084 %/°C	Average: 1.1 m/s
	p-Si			Annual: 81%	Efficiency decrease: -0.033 %/°C	
	a-Si			Annual: 91%	Efficiency decrease: -0.029 %/°C	

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Conclusion

- Fast irradiance changes differently affect wafer-based Si technologies and thin-film technologies. Thin film a-Si modules show higher efficiency at low irradiance, while µ-Si modules react like m-Si at high irradiances.
- Influence of dust deposition on electricity production of PV modules of different technologies depends on several factors such as: geographical location, climate (tropical, desert), dust type, micro climate, site, tilt angle of the module etc. Cleaning of the modules has a significant influence on performance of PV modules.

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Conclusion

- ► Shading has strongest influence on power decrease of PV module and during the design phase of PV systems it should be taken into account to avoid shading as much as possible. Influence of shading is different for different technologies of PV modules. Shading influence is different for different PV module orientation (portrait/landscape).
- ► Besides influence of dust deposition, irradiance and shading effect on electricity production of PV systems there are also other parameters such as humidity, wind velocity, ambient temperature and most important operating cell temperature that can affect their power output and efficiency.

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