FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF ELECTRONICS AND INFORMATION SYSTEMS
LIQUID CRYSTALS AND PHOTONICS GROUP

PREDICTING ENERGY YIELD OF OUTDOOR SI-BASED PV INSTALLATIONS FOR BELGIUM AND VIETNAM REGIONS AT ARBITRARY TILT AND ORIENTATION

Nguyen Dang Phuc Nguyen, Johan Lauwaert

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Outline

1. Introduction
2. Proposed methodology
3. Results
4. Conclusion

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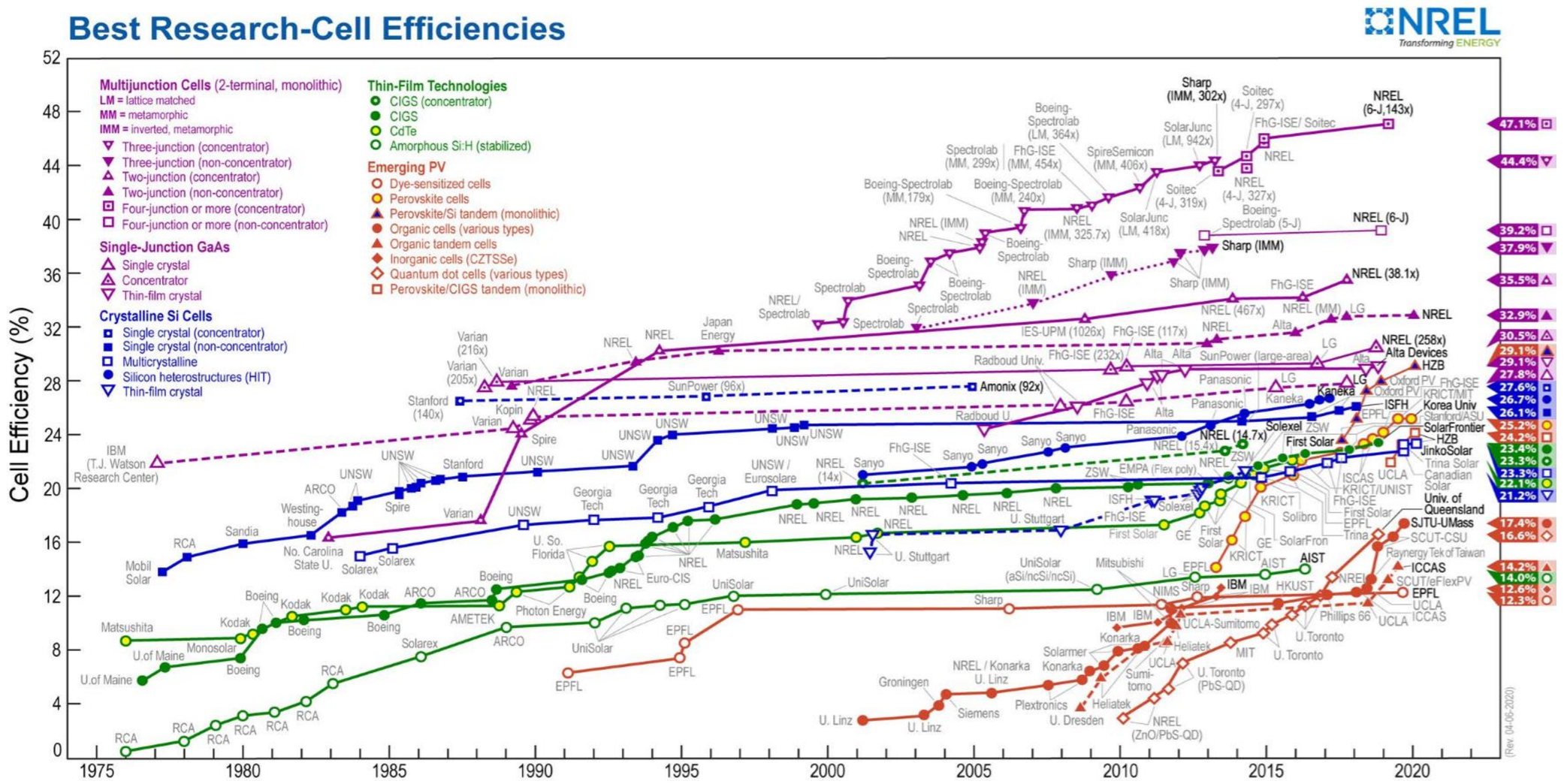
PV efficiency and technology



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Model’s Objectives

- Calculating energy yield of outdoor PV systems based on local weather conditions.
- Easy to transfer to other locations.
- Available for Si-based PV technologies.
- Flexibility in applying.

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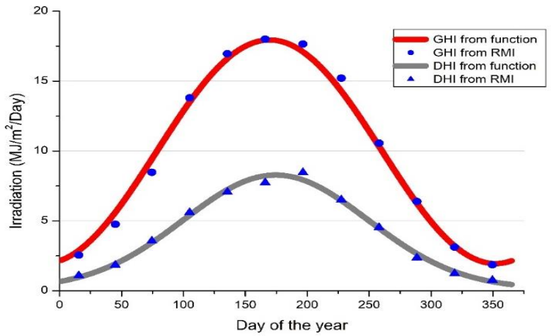
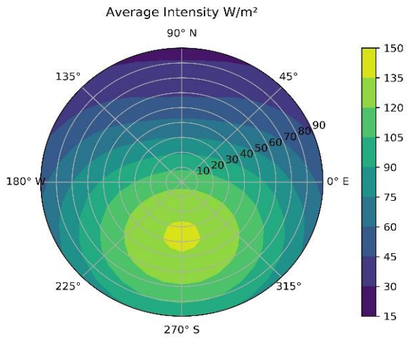
Methodology

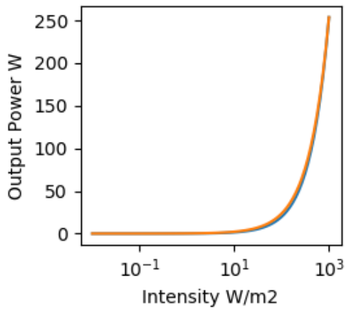
Commercial PV panel



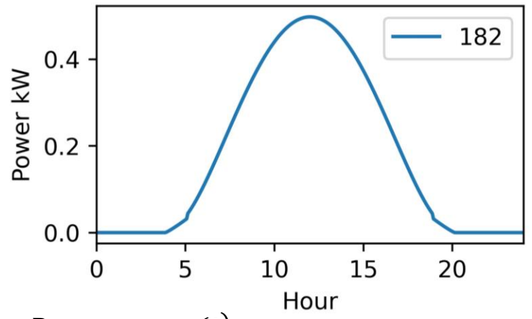
Horizontal Irradiation



Irradiation on panel surface

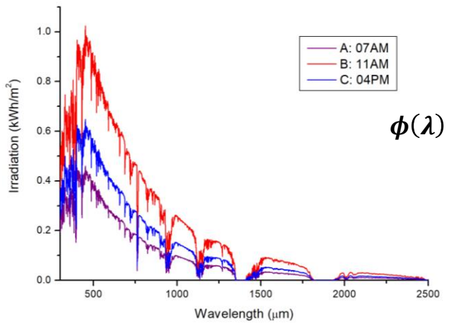


Energy yield

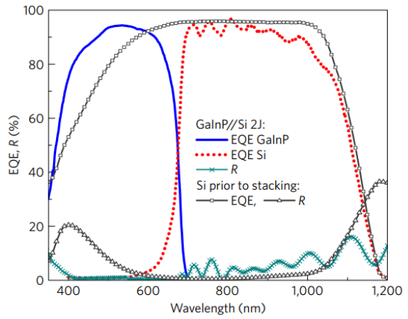


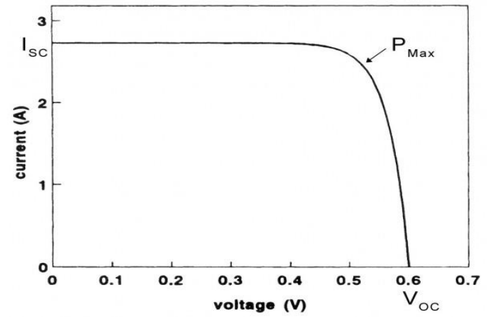
$$P_{INV_{DC}}(t) = Intensity(t).\frac{P_{panel\_Intensity}(t)}{P_{panel\_STC}} \quad (2)$$

$$I(V) = I_0\left[exp\left(\frac{qV}{nkT} - 1\right)\right] - I_{sc} \quad (1)$$



$$\phi(\lambda) = \frac{E'_\beta(\lambda)}{hc/\lambda} \quad (3)$$





$$I_{sc} = q\int_{300\ nm}^{4000\ nm} \phi(\lambda).EQE(\lambda)d\lambda \quad (4)$$

$$I_0 = q\rho\frac{2\pi}{c^2h^3}\int_{E_g}^{\infty}\frac{E(\lambda)^2}{\exp(E(\lambda)/kT) - 1}dE(\lambda) \quad (5)$$

Weather database

- Latitude
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Nann, S.; Riordan, C. Solar spectral irradiance under clear and cloudy skies: Measurements and a semiempirical model. *J. Appl. Meteorol.* 1991, 30, 447–462

S. Essig *et al.*, *Nat. Energy*, vol. 2, no. 9, 2017.

Tandem solar cell

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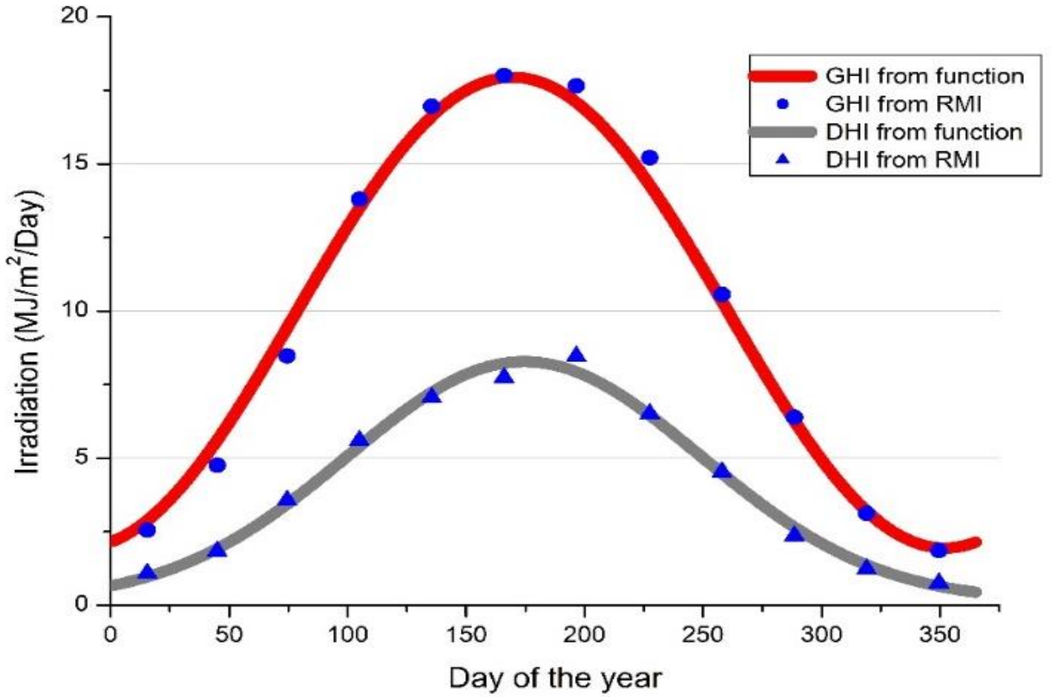
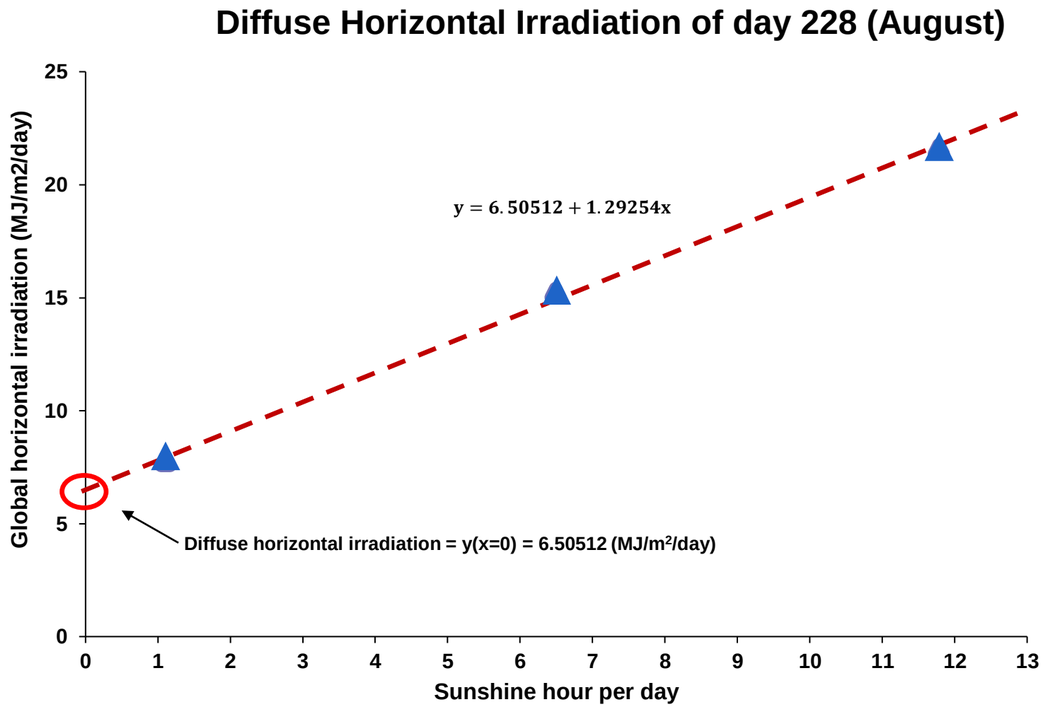
Solar Irradiation on horizontal surface





GHI = DNI + DHI

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Methodology

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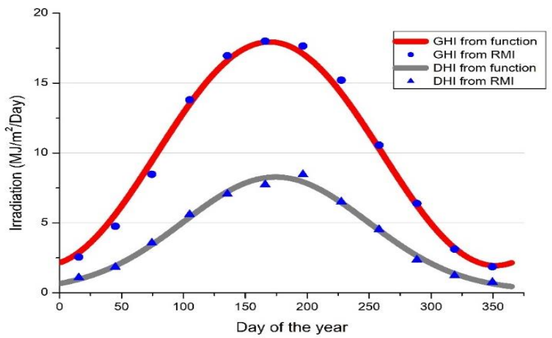
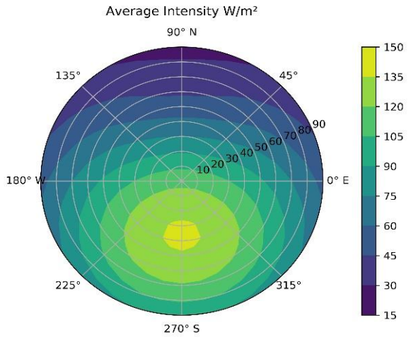
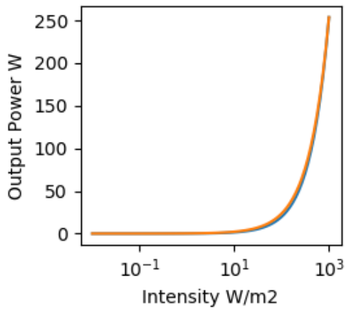


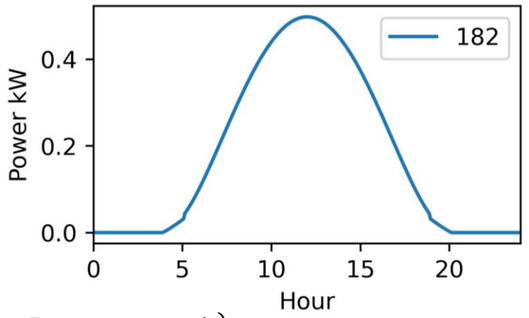
Horizontal Irradiation



Irradiation on panel surface



Energy yield



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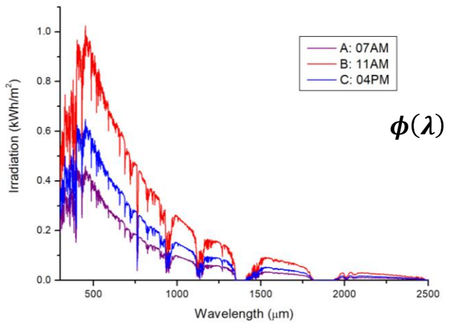

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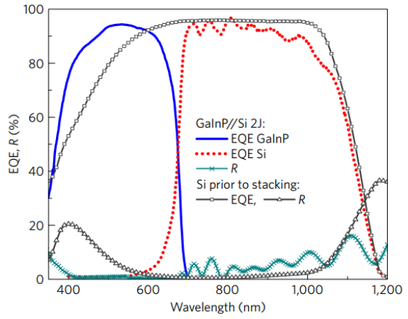

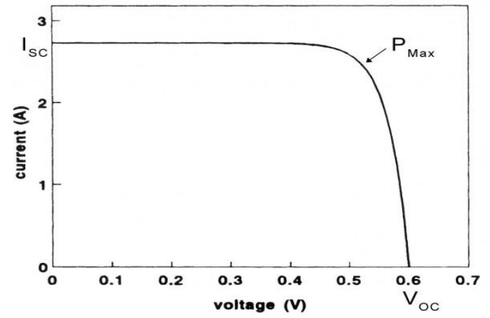

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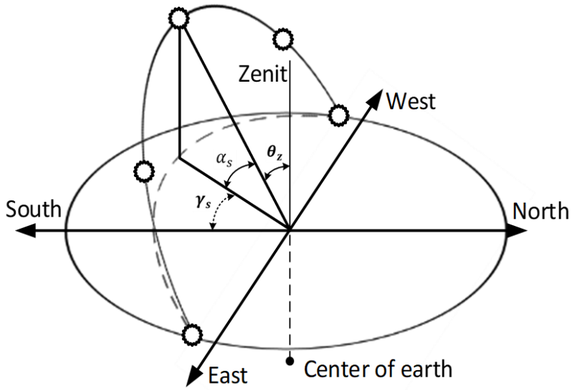
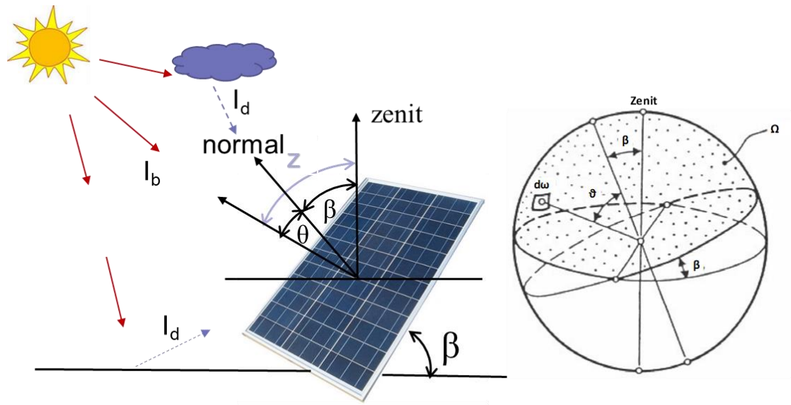
Modelling solar spectrum



Soteris A. Kalogirou Solar energy engineering: processes and systems; *Elsevier Inc.*, 2009; ISBN 9780123745019



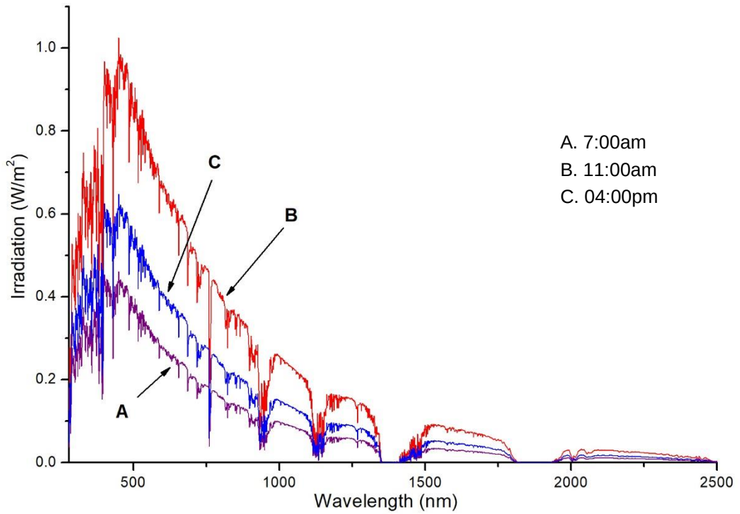
$$\cos(\theta) = \sin(\alpha_s)\cos(\beta) + \cos(\alpha_s)\sin(\beta)\cos(\gamma_s - \gamma)$$

$$I_b = I_{DNI}\cos(\theta)$$

$$I_d = I_{DHI}\frac{\iint_{\Omega}\cos(\vartheta)d\omega}{\iint_{2\pi}\cos(\vartheta)\,d\omega}$$

$$I_{total} = I_b + I_d$$

Snapshots of solar spectra
Day 182, Flanders, Belgium



$$E'_{\beta}(\lambda) = \frac{I_{b\beta}.E_b(\lambda)}{\int_{300nm}^{4000nm}E_b(\lambda)\,d\lambda} + \frac{I_{d\beta}.E_d(\lambda)}{\int_{300nm}^{4000nm}E_d(\lambda)\,d\lambda}$$

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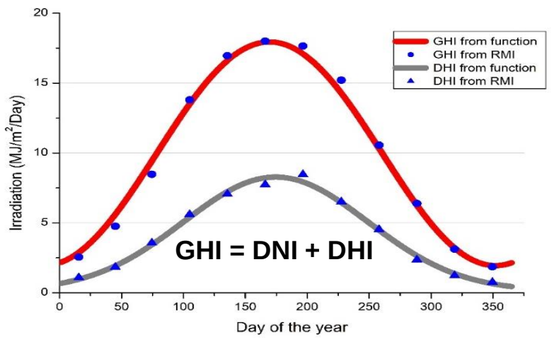
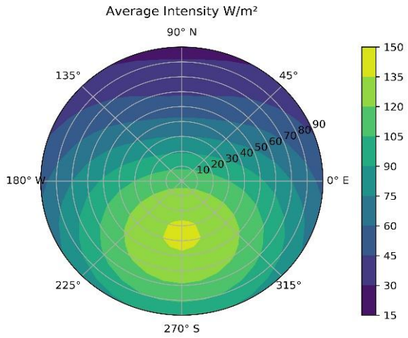
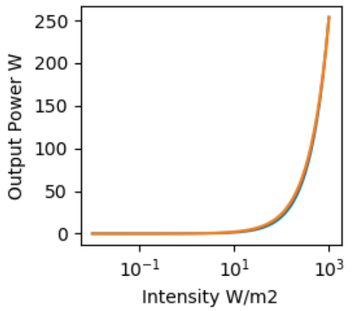


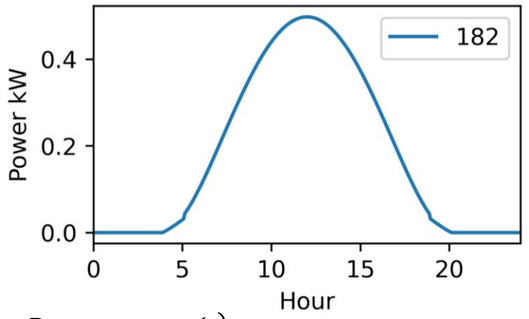
Horizontal Irradiation



Irradiation on panel surface



Energy yield



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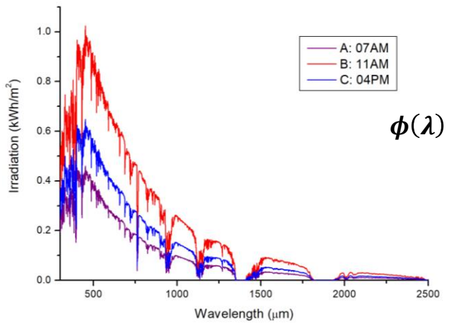

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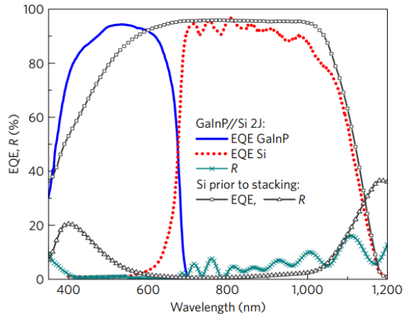

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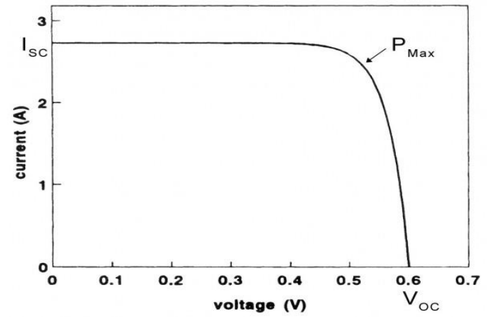

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Calculating for Flanders, Belgium

System	Frank Deboosere		T_36_Brugge	
Power	4.35 kWp		5.28 kWp	
Orientation	Tilt = 45^0, Azimuth = 22.5^0 (SSE)		Tilt = 45^0, Azimuth = 22.5^0 (SW)	
	Average Annual Yield (kWh/year)	Deviation (%)	Average Annual Yield (kWh/year)	Deviation (%)
Actual yield	4123		4869	
This work	3972	3.67	5042	3.55
PVGIS-CMSAF***	4323	4.85	5846	20.07
PVGIS-SARAH***	4415	7.08	5858	20.31
PVGIS-ERA5***	4678	13.46	6587	35.28
PVGIS-COSMO***	4512	9.43	5619	15.40

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*: https://www.frankdeboosere.be
**: https://pvoutput.org/
***: https://re.jrc.ec.europa.eu

Calculating for Vietnam regions

Unit: kWh/kWp

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Tri An Latitude = 11	This work	149	154	174	162	156	141	138	135	132	141	139	140	1760
	PVGIS-SARAH*	140	145	160	149	146	134	138	144	126	133	131	134	1680
	PVWATTS**	147	143	165	166	128	115	113	118	114	134	139	141	1622
Da Nang Latitude = 16	This work	88	97	132	152	173	172	169	150	120	100	81	79	1513
	PVGIS-SARAH	83	108	134	148	162	151	148	145	126	107	86	67	1466
	PVWATTS	86	82	102	120	135	125	133	129	117	107	94	80	1308
Ha Noi Latitude = 21	This work	70	70	93	109	131	138	146	138	118	103	81	72	1269
	PVGIS-SARAH	75	82	111	125	153	152	157	152	135	120	98	85	1445
	PVWATTS	62	52	72	104	142	139	143	132	135	118	102	88	1288

*: https://re.jrc.ec.europa.eu
**: https://pvwatts.nrel.gov/index.php

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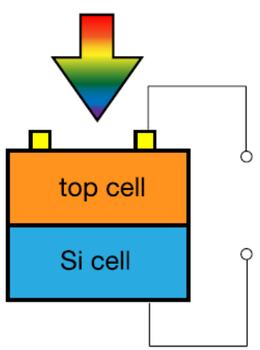
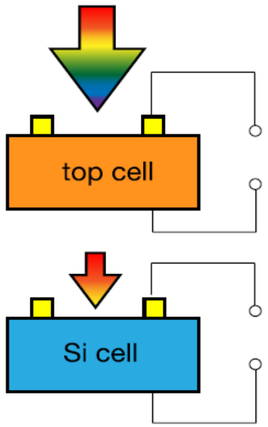
Calculating for tandem solar cells



2-T structure



4-T structure

Unit: kWh/m^2

	Tri An	Da Nang	Ha Noi	Flanders
Si	304.3	260.3	260.1	219.6
2-T-GaInP/Si	506.7	430.1	429.9	346.2
4-T-GaInP/Si	551.7	476.8	476.1	372.2
2-T-GaAs/Si	187.6	155.4	115.3	155.7
4-T-GaAs/Si	507.3	435.1	358.9	355.7

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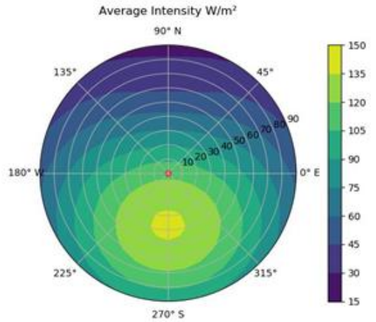
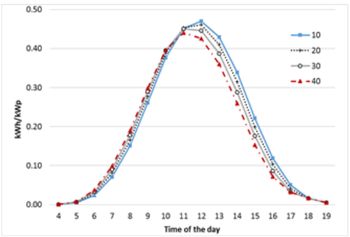
Conclusion





- Average daily, monthly and annual energy yield can be calculated accurately.
- Be able to transfer to other locations.
- Evaluating potential benefit of outdoor PV systems.
- Operating temperture and other PV technologies need to be taken into account.

Nguyen, D.P.N.; Lauwaert, J. Calculating the Energy Yield of Si-Based Solar Cells for Belgium and Vietnam Regions at Arbitrary Tilt and Orientation under Actual Weather Conditions. *Energies* **2020**, *13*, 3180.

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Thank you for your attention!

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