Optoelectronică

Curs 13
2023/2024

Disciplina 2023/2024

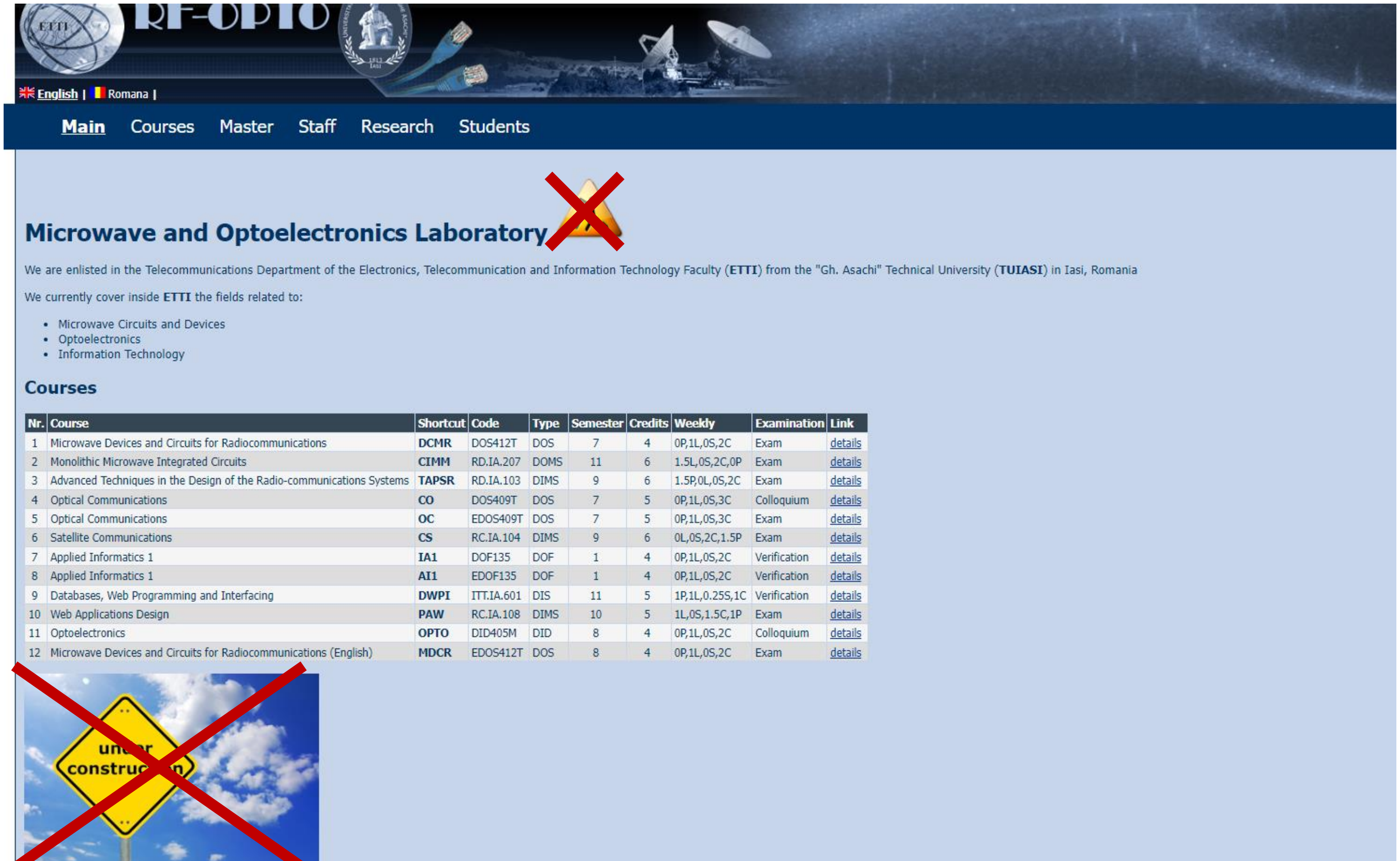
- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Marti 14(:10)–16:00, P8
  - E – 70% din nota (50%+20%)
    - **20% test (VP) la curs**, saptamana 4-6?
  - probleme + (2p prez. curs)
  - toate materialele permise
- Laborator – drd. Stefan Stoica
  - an IV μE
    - Marti 16-20 par
    - Max. 7 prezente
  - L – 30% din nota (+Caiet de laborator)

Cuprins

- **Lumina ca undă electromagnetică*** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie*** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

*** – VP**

Documentatie



RF-OPTO

English | Romana |

Main Courses Master Staff Research Students

Microwave and Optoelectronics Laboratory

We are enlisted in the Telecommunications Department of the Electronics, Telecommunication and Information Technology Faculty (**ETTI**) from the "Gh. Asachi" Technical University (**TUIASI**) in Iasi, Romania

We currently cover inside **ETTI** the fields related to:

- Microwave Circuits and Devices
- Optoelectronics
- Information Technology

Courses

Nr.	Course	Shortcut	Code	Type	Semester	Credits	Weekly	Examination	Link
1	Microwave Devices and Circuits for Radiocommunications	**DCMR**	DOS412T	DOS	7	4	0P,1L,0S,2C	Exam	details
2	Monolithic Microwave Integrated Circuits	**CIMM**	RD.IA.207	DOMS	11	6	1.5L,0S,2C,0P	Exam	details
3	Advanced Techniques in the Design of the Radio-communications Systems	**TAPSR**	RD.IA.103	DIMS	9	6	1.5P,0L,0S,2C	Exam	details
4	Optical Communications	**CO**	DOS409T	DOS	7	5	0P,1L,0S,3C	Colloquium	details
5	Optical Communications	**OC**	EDOS409T	DOS	7	5	0P,1L,0S,3C	Exam	details
6	Satellite Communications	**CS**	RC.IA.104	DIMS	9	6	0L,0S,2C,1.5P	Exam	details
7	Applied Informatics 1	**IA1**	DOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
8	Applied Informatics 1	**AI1**	EDOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
9	Databases, Web Programming and Interfacing	**DWPI**	ITT.IA.601	DIS	11	5	1P,1L,0.25S,1C	Verification	details
10	Web Applications Design	**PAW**	RC.IA.108	DIMS	10	5	1L,0S,1.5C,1P	Exam	details
11	Optoelectronics	**OPTO**	DID405M	DID	8	4	0P,1L,0S,2C	Colloquium	details
12	Microwave Devices and Circuits for Radiocommunications (English)	**MDCR**	EDOS412T	DOS	8	4	0P,1L,0S,2C	Exam	details

Documentatie

- RF-OPTO
  - http://rf-opto.etti.tuiasi.ro
- Fotografie
  - “examen” online
  - necesara la laborator/curs

Utilizare celule solare

Capitolul 10

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
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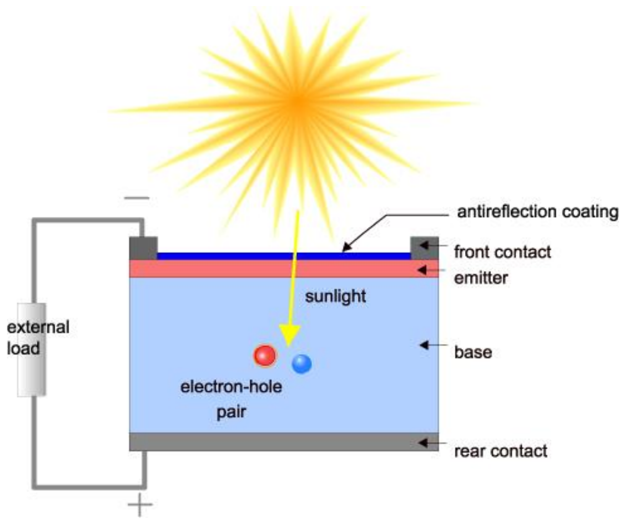
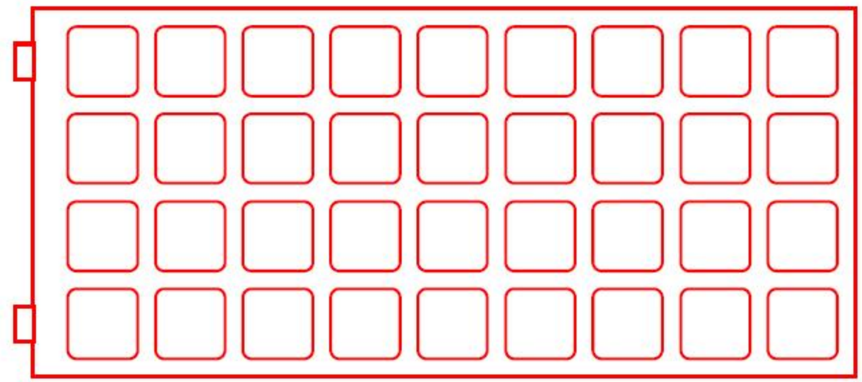
Celula solara (fotovoltaica)

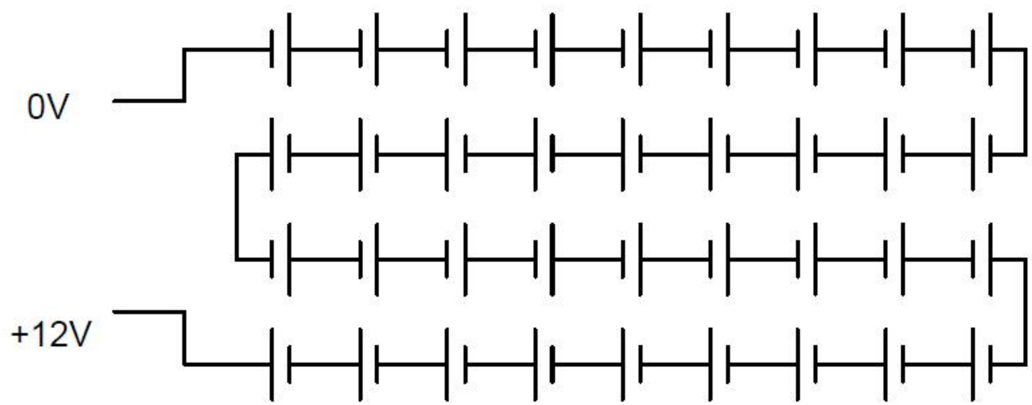
- in principiu o dioda
  - cu arie mare (~100cm^2)
  - cu suprafata tratata antireflectorizant
  - genereaza o tensiune electromotoare de 0.5÷1V
  - genereaza curenti de scurtcircuit de x0 mA/cm^2



Celula solara (fotovoltaica)

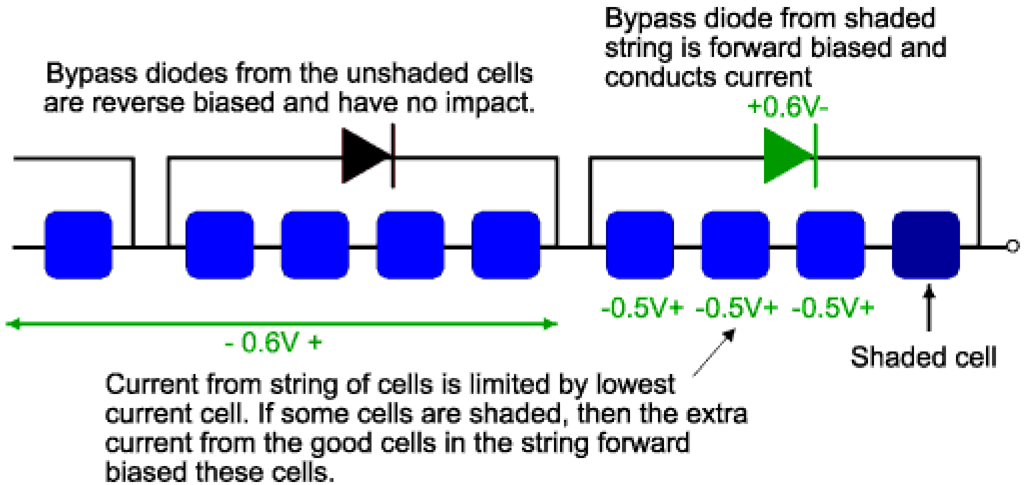
- pentru utilizare in practica
  - module de 28 – 36 de celule conectate in serie
  - creste tensiunea la 12V (tipic)

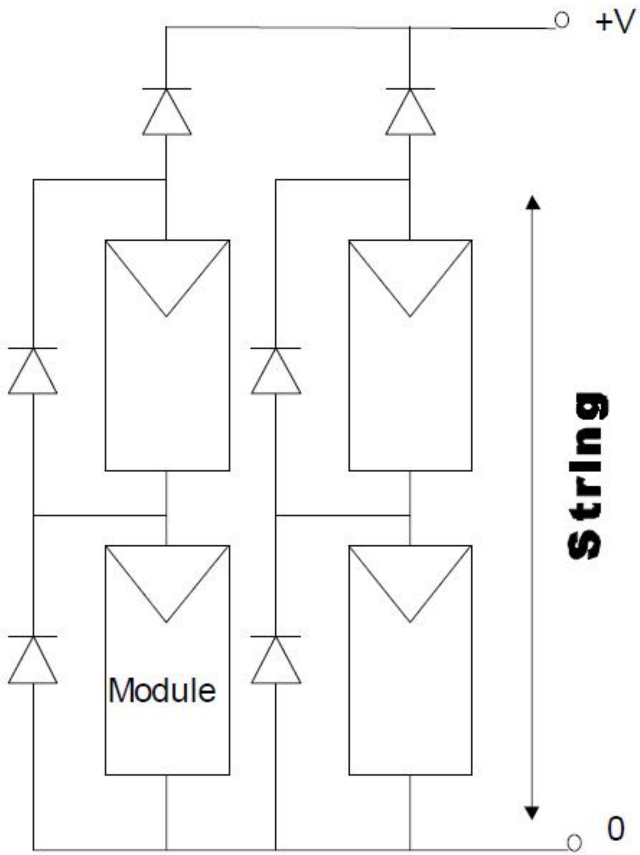




Celula solara (fotovoltaica)

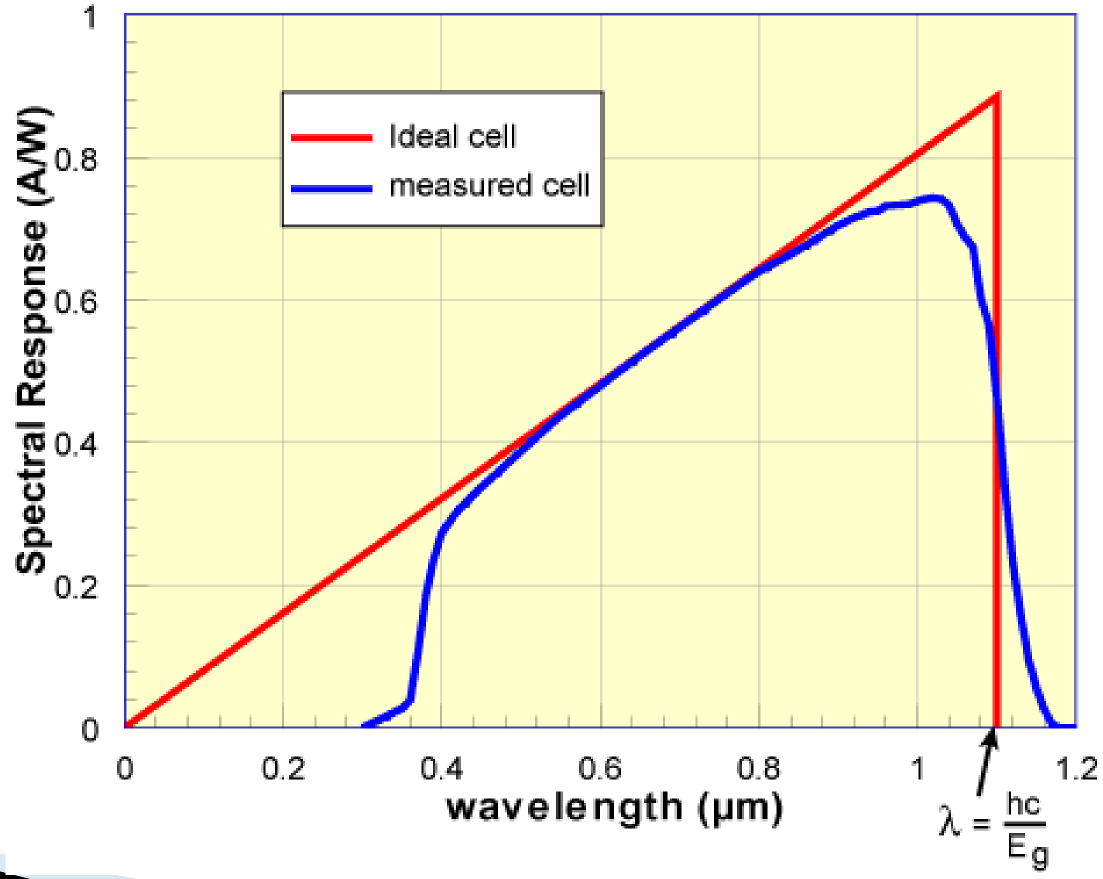
- pentru utilizare in practica
  - diode pentru flexibilitate





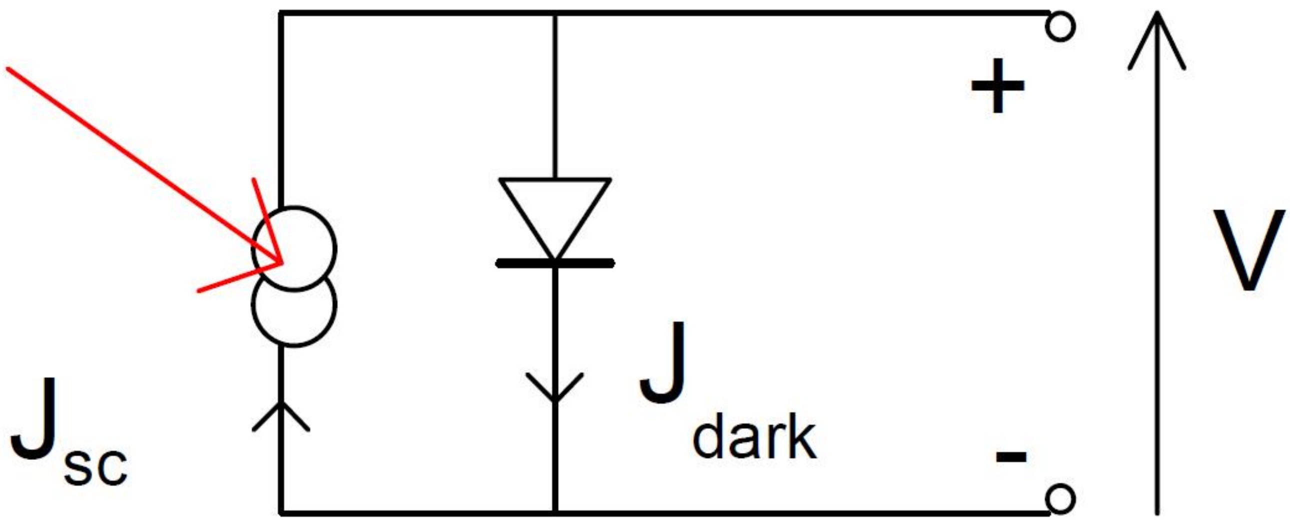
Celula solara

- raspuns spectral

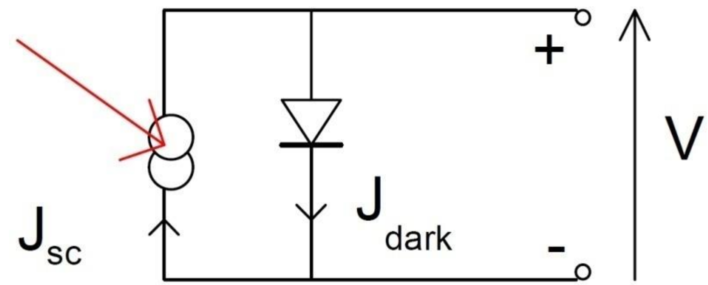


Celula solara

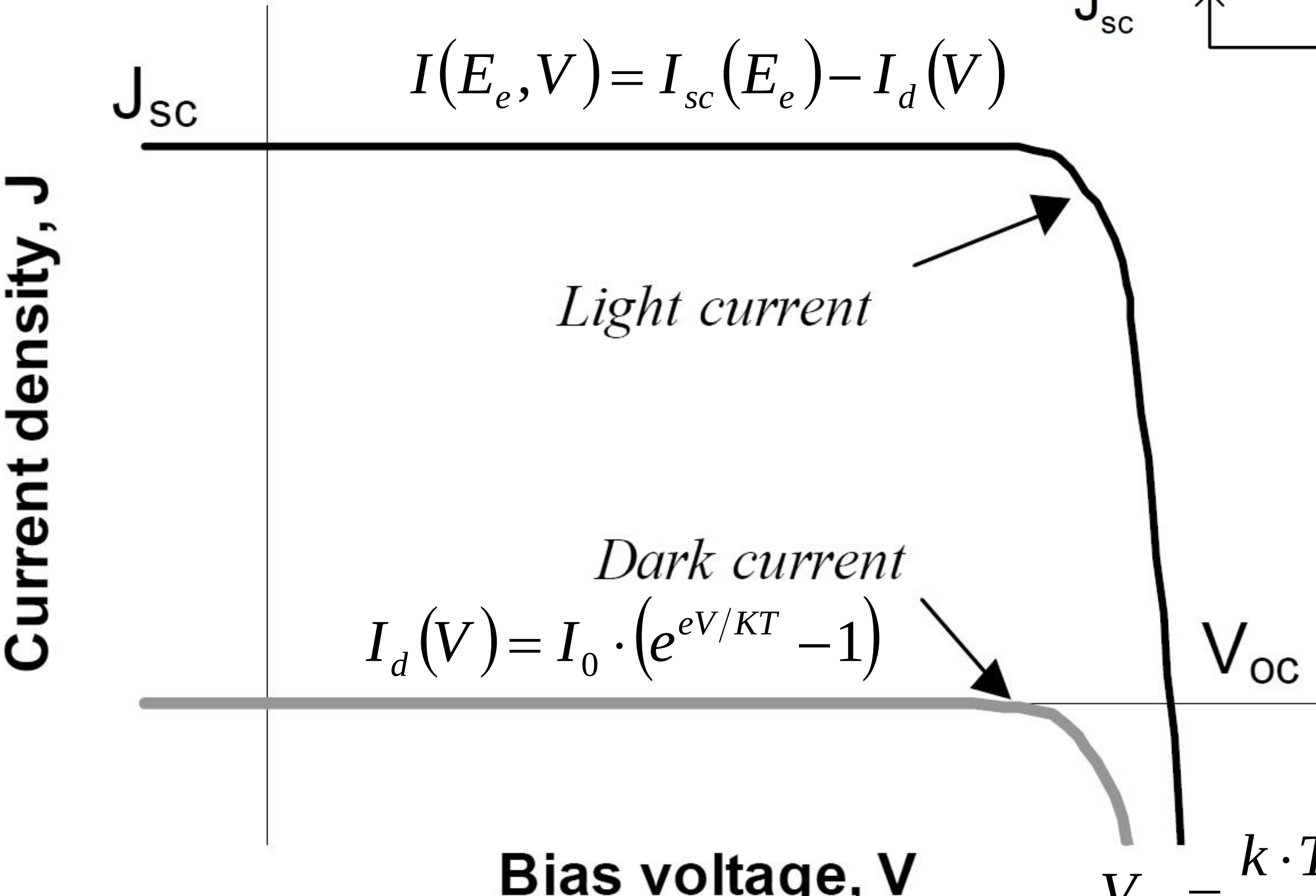
- Schema echivalenta
  - dioda
  - sursa de curent generat de fluxul de fotoni incident



Celula solara



$$I(E_e,V)=I_{sc}(E_e)-I_d(V)$$



$$I_d(V)=I_0\cdot\left(e^{eV/KT}-1\right)$$

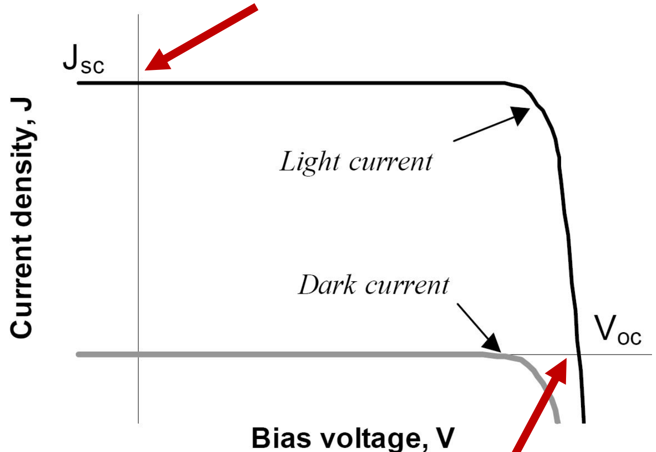
$$V_{oc}=\frac{k\cdot T}{e}\cdot\ln\left(\frac{I_{sc}(E_e)}{I_0}-1\right)$$

Putere generata

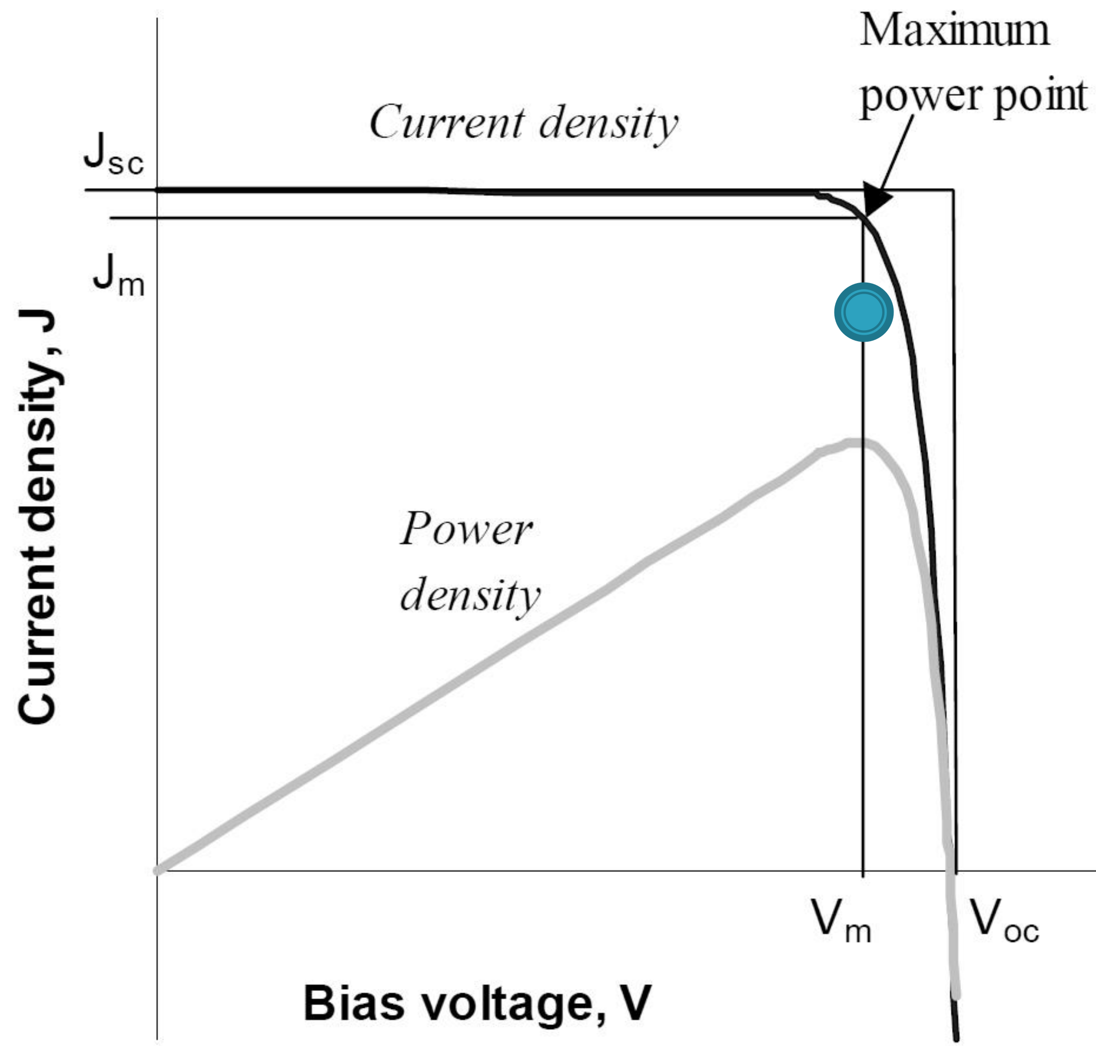
- Putere generata

$$P = V \cdot I$$

$$P_{sc} = 0 \cdot I_{sc} = 0$$

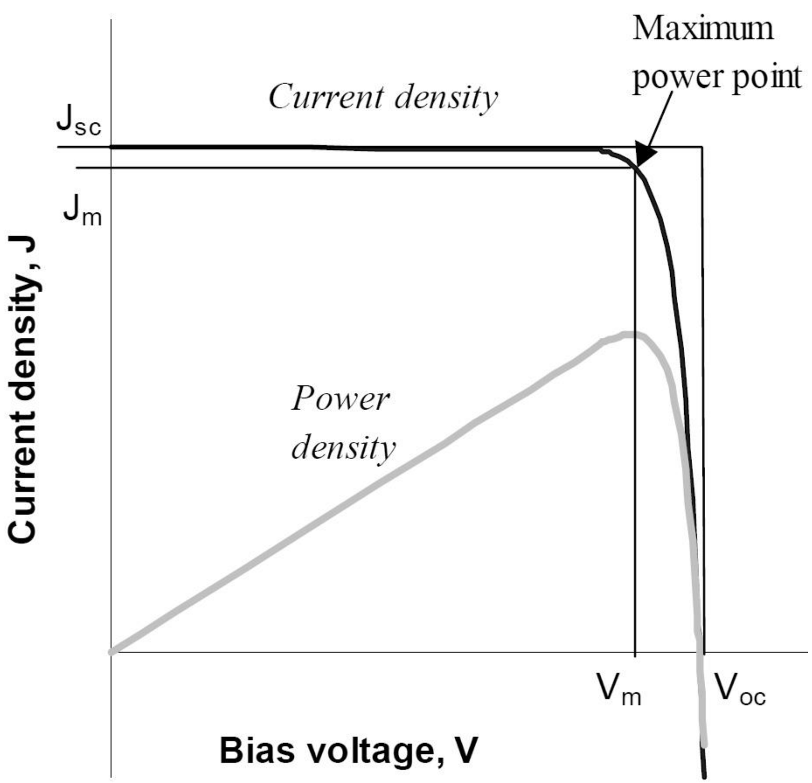


$$P_{oc} = V_{oc} \cdot 0 = 0$$



Putere generata

- Putere generata

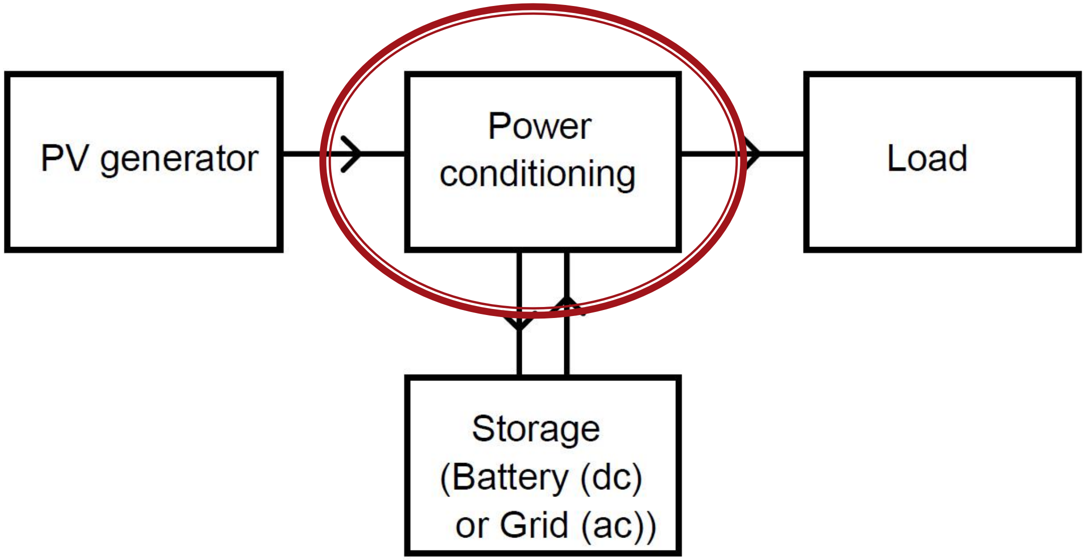


$$P_m = V_{pm} \cdot I_{pm}$$

- Valorile de curent si tensiune pentru putere maxima sunt date de catalog, circuitul de conditionare care urmeaza dupa celule poate fi **optimizat** sa functioneze la aceste valori

Putere generata

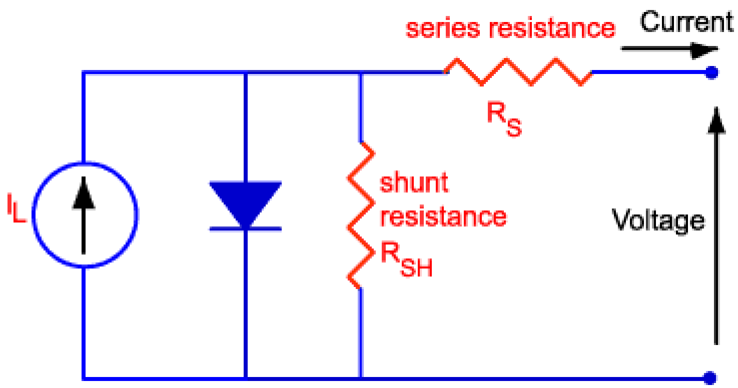
- Controlerul de incarcare este responsabil pentru detectarea si urmarirea punctului de putere maxima
  - MPPT – Maximum power point tracking

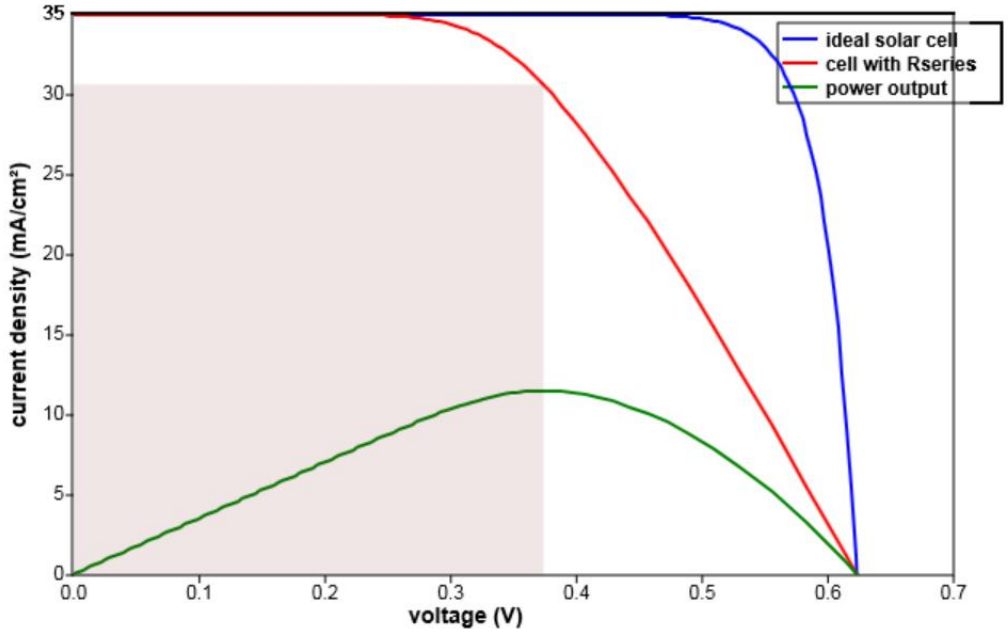


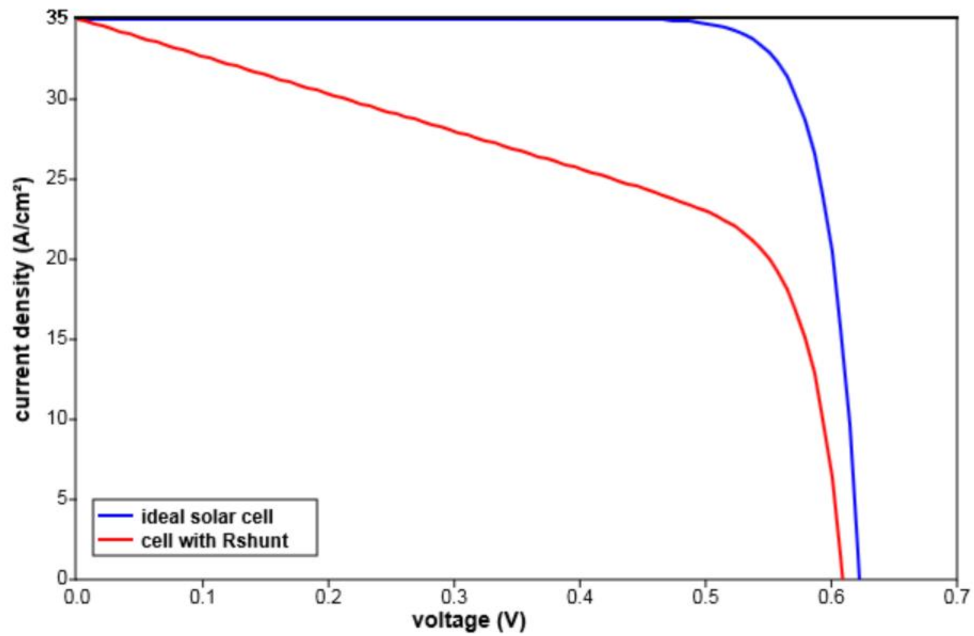
Efect pierderi

- Rezistenta serie
  - rezistenta echivalenta a semiconductorului utilizat
  - rezistenta jonctiunilor metal/semiconductor
  - rezistenta contactului metalic al anodului si colectorului
- Rezistenta paralel
  - generata de defecte de fabricatie

Efect pierderi

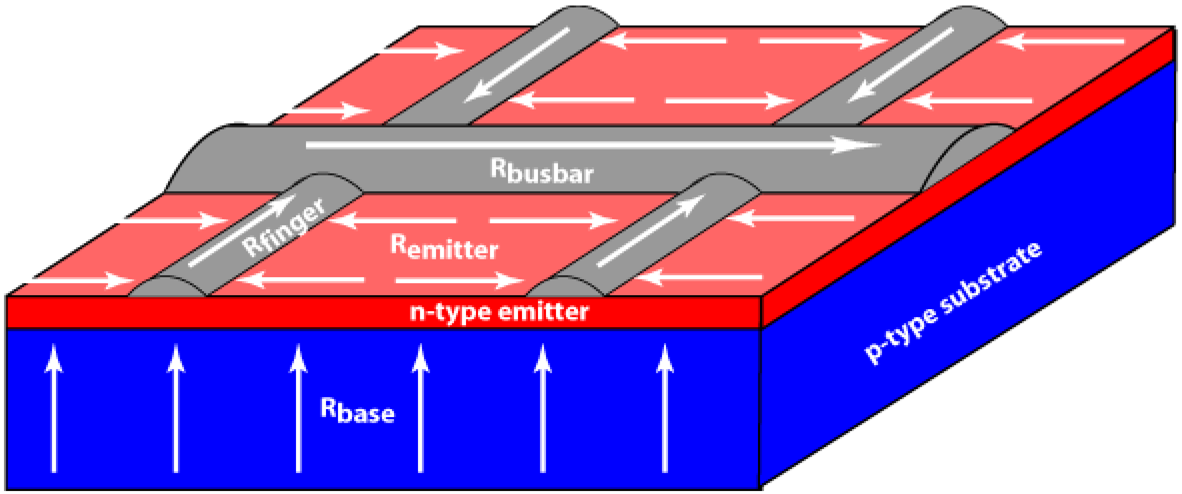


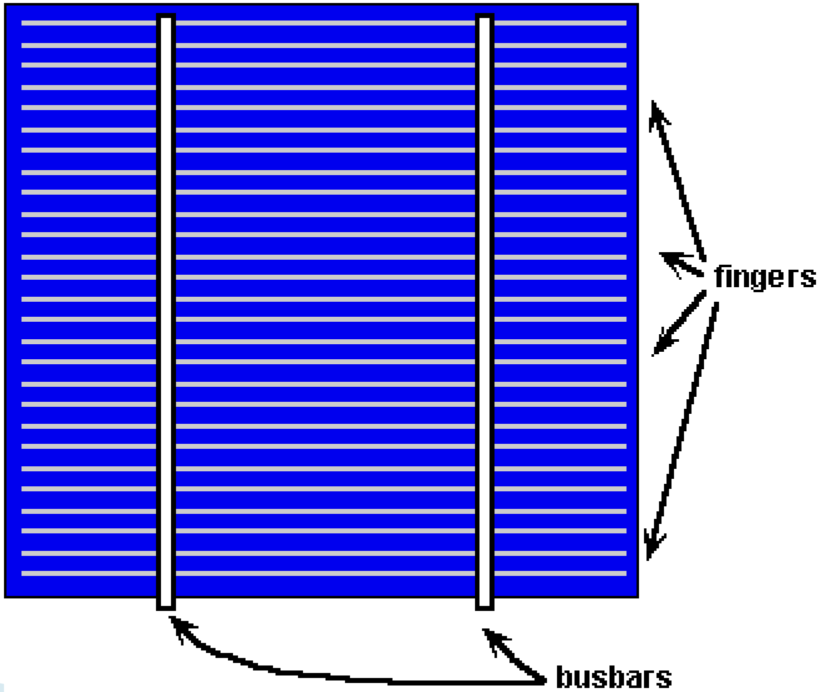




Rezistenta serie

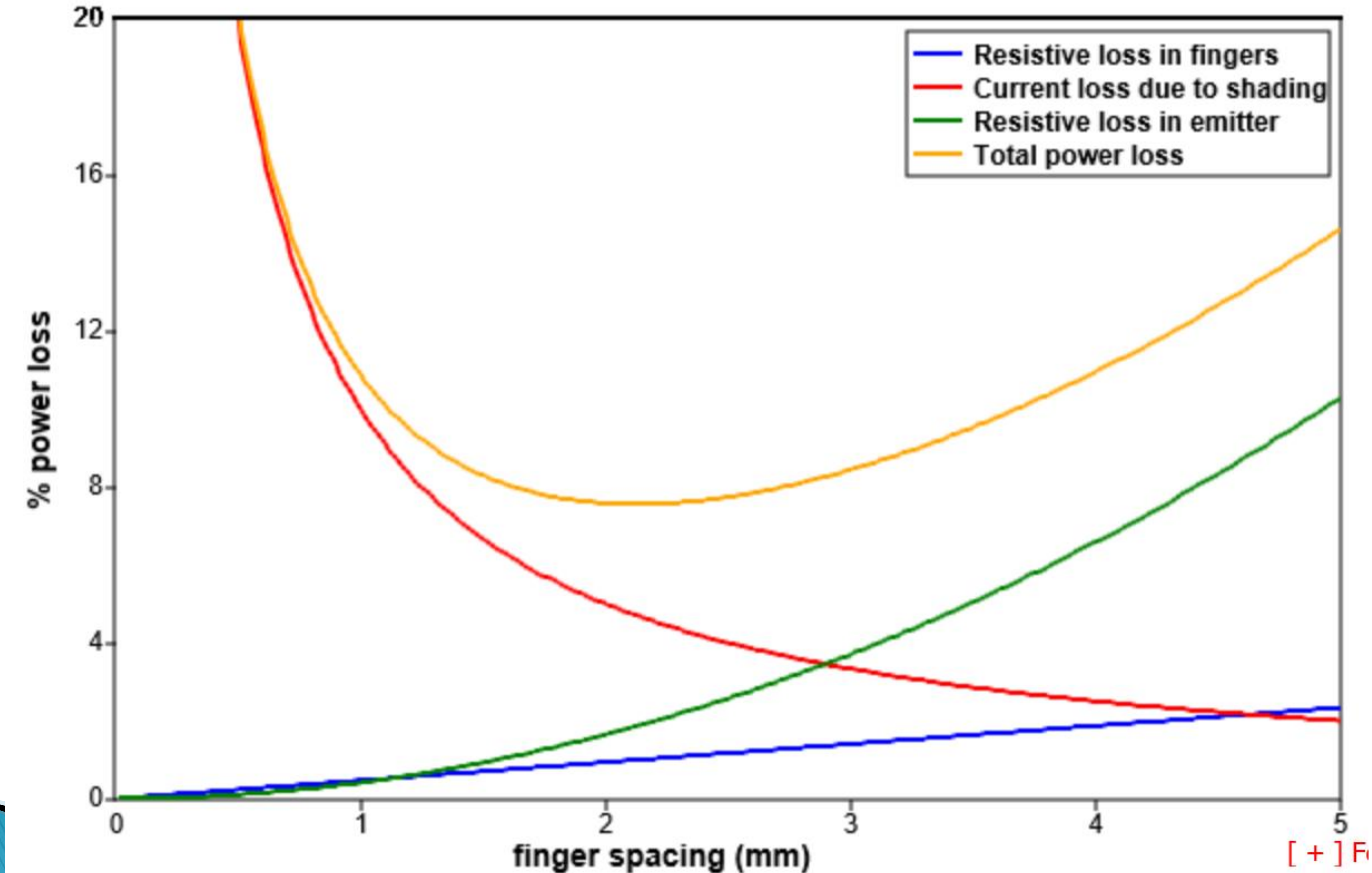
- Minimizare Rs
  - bare colectoare
  - “degete”
- Compromis
  - rezistenta
  - suprafata metalica reflectorizanta





Rezistenta serie

- Comprimis rezistenta/suprafata metalica

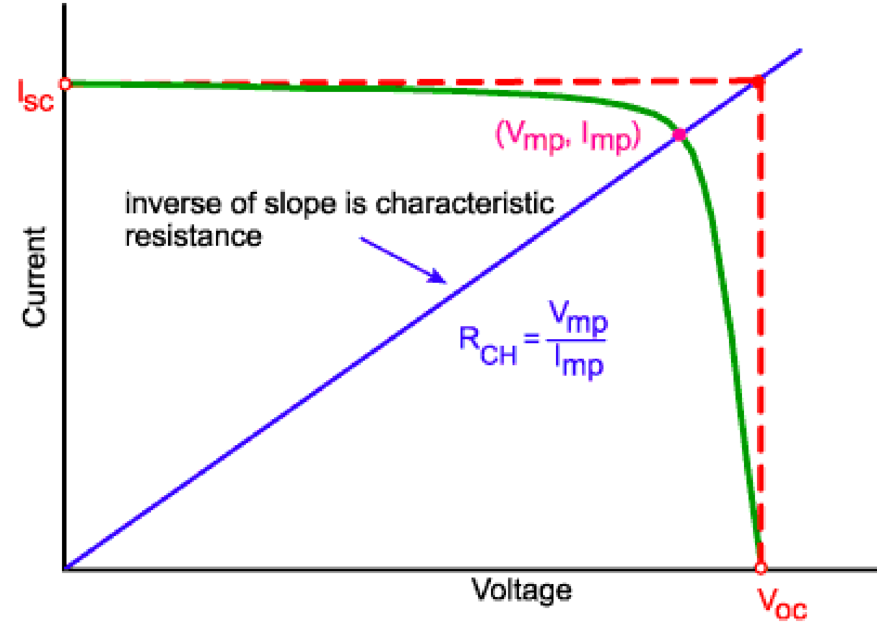


Rezistenta caracteristica

- Raportul intre V si I cand celula lucreaza la eficienta maxima

$$R_C = \frac{V_{pm}}{I_{pm}} \approx \frac{V_{OC}}{I_{SC}}$$

- Daca sarcina este egala cu R_C, celula lucreaza la eficienta maxima
  - Tipic, celulele comerciale opereaza la tensiune mica si curent mare
    - conexiunile la celule trebuie sa aiba rezistente de ordinul mΩ



$$R_C = \frac{0.6V}{9A} \approx 0.067\Omega$$

Eficienta celulei solare

- raportul dintre puterea electrica generata si puterea optica incidenta

$$\eta = \frac{P_m}{P_o} = \frac{V_{pm} \cdot I_{pm}}{P_o}$$

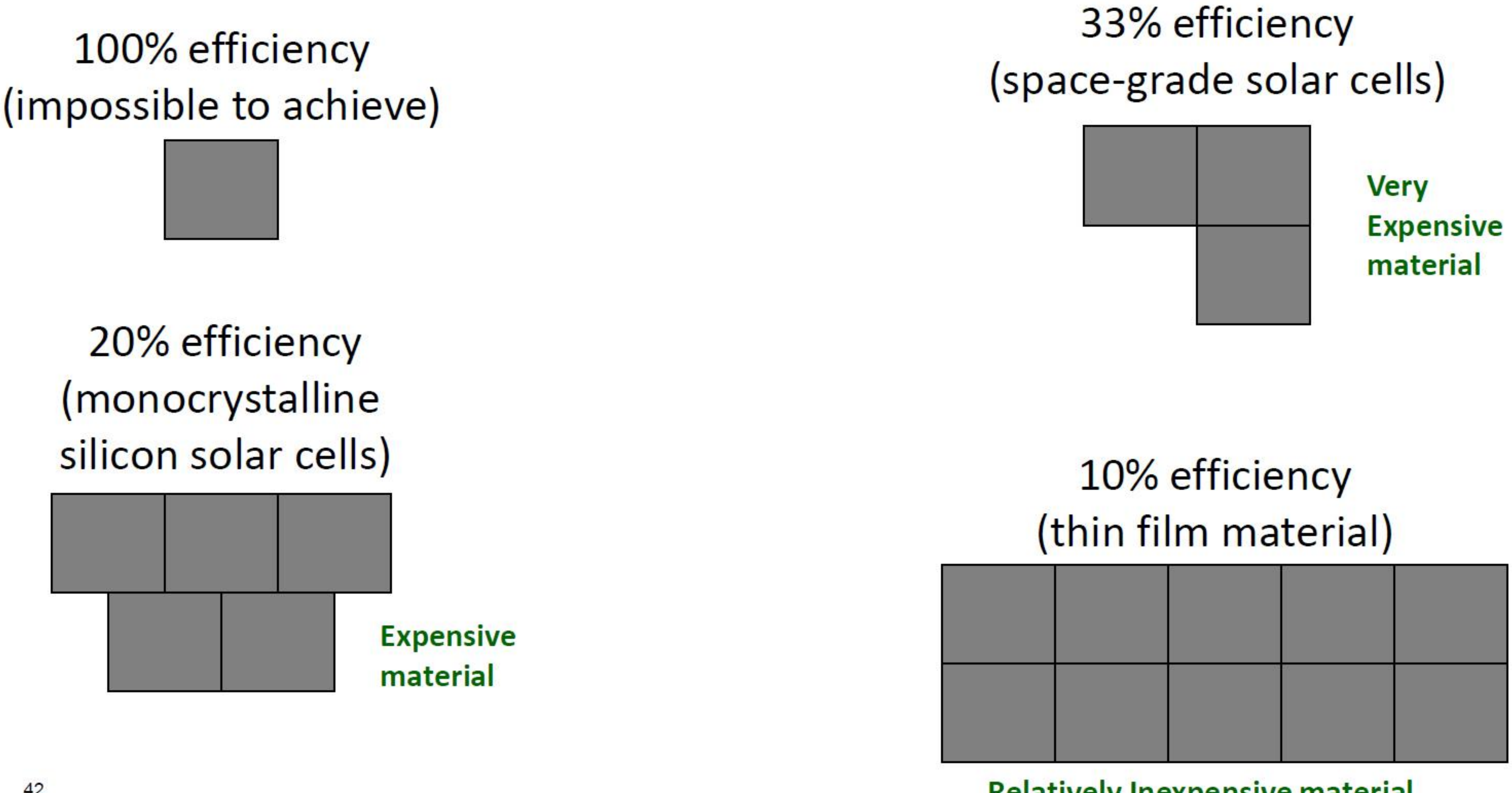
$$\eta = \frac{P_m}{P_o} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_o}$$

- Puterea optica depinde de fluxul energetic al luminii incidente si suprafata celulei

$$P_o = S \cdot \int_0^{\infty} \Phi_e(\lambda) d\lambda$$

Eficienta celulei solare

- determina suprafata necesara pentru obtinerea unei puteri dorite



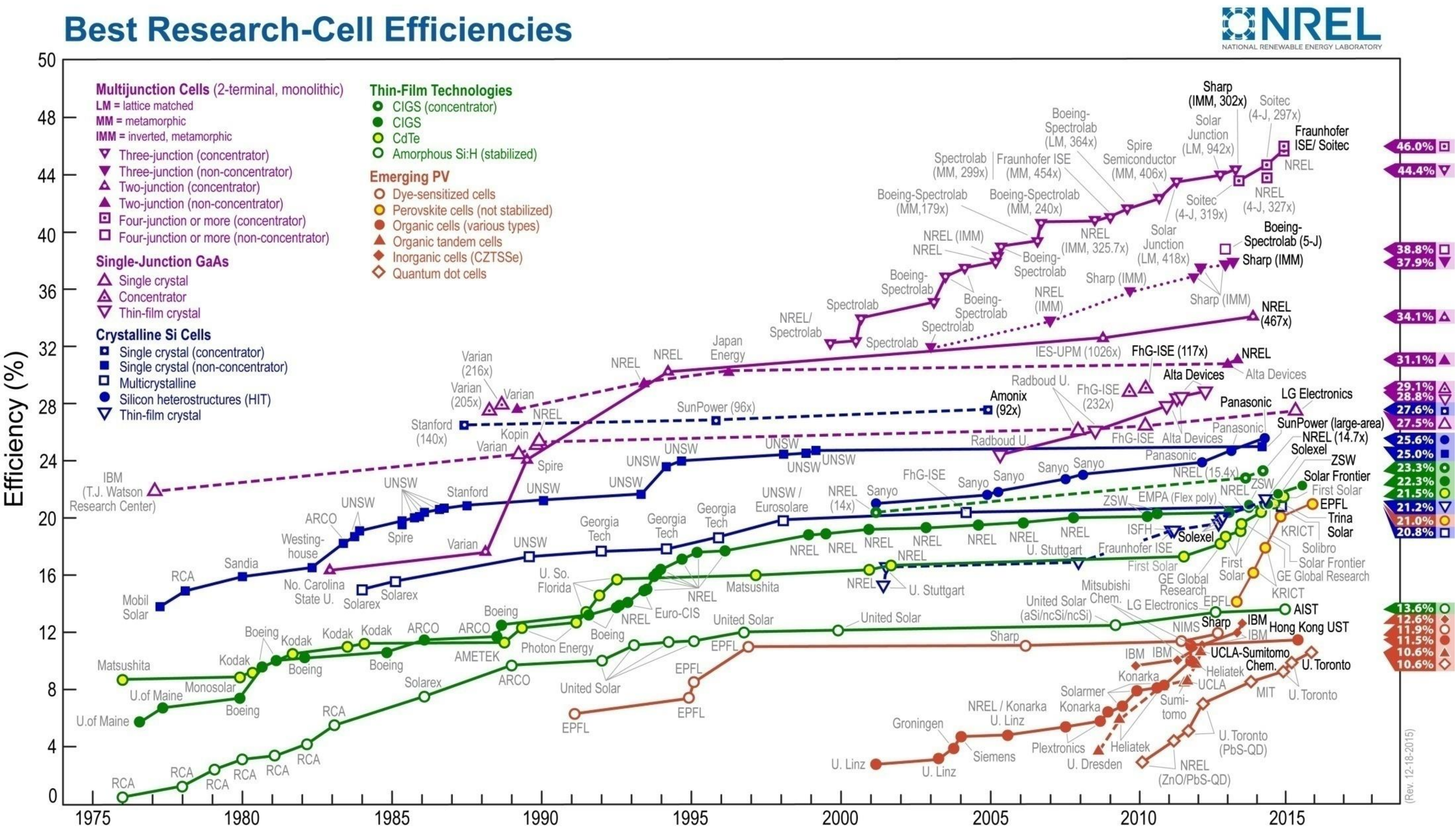
Eficienta celulei solare

- Exista o limita maxima teoretica pentru fiecare material semiconductor
  - fiecare material are o banda spectrala proprie, **mai mica** decat banda spectrala a soarelui
- valorile nu sunt foarte mari
  - din motive economice, recordurile nu sunt repetate in practica

Table 1.1. Performance of some types of PV cell [Green *et al.*, 2001].

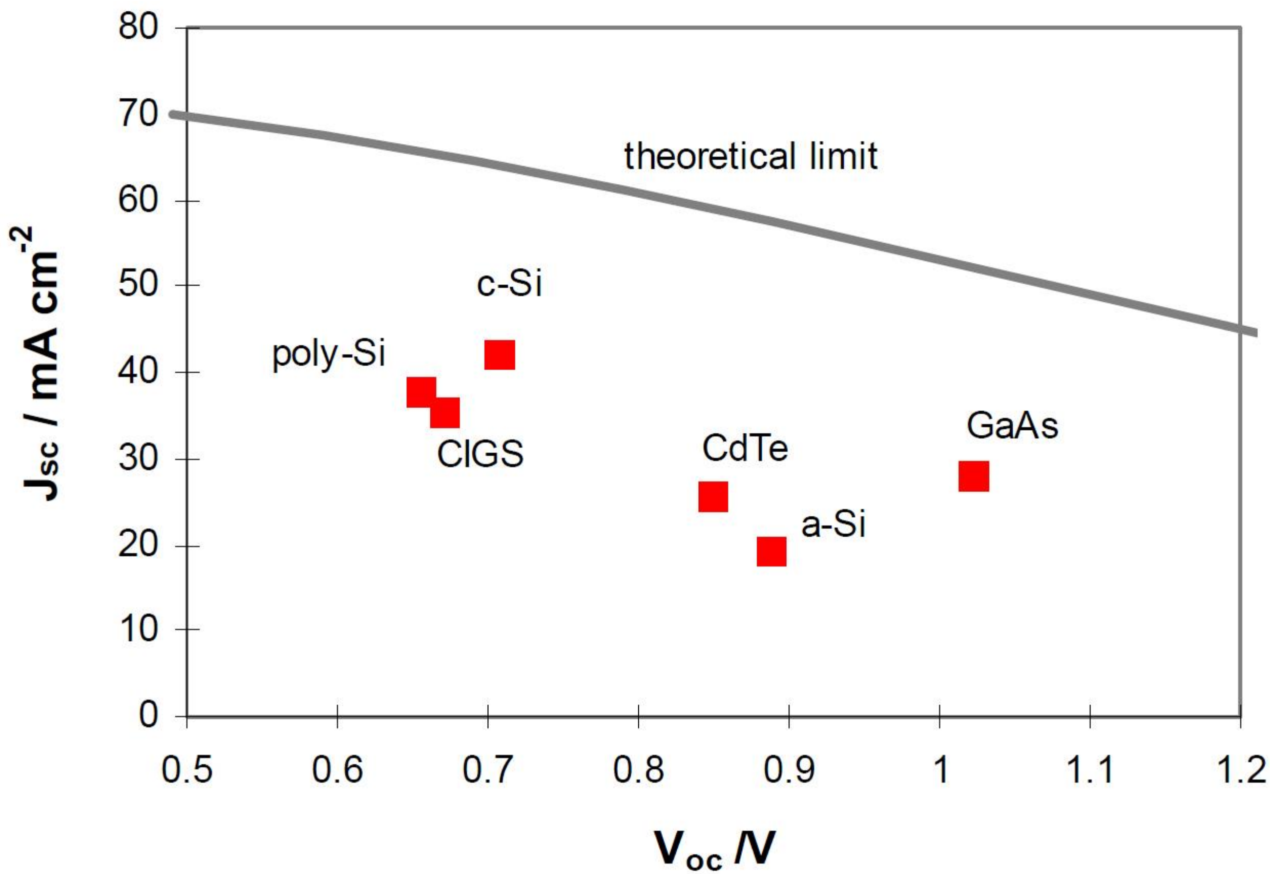
Cell Type	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	Efficiency (%)
crystalline Si	4.0	0.706	42.2	82.8	24.7
crystalline GaAs	3.9	1.022	28.2	87.1	25.1
poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

Eficienta maxima a celulei solare



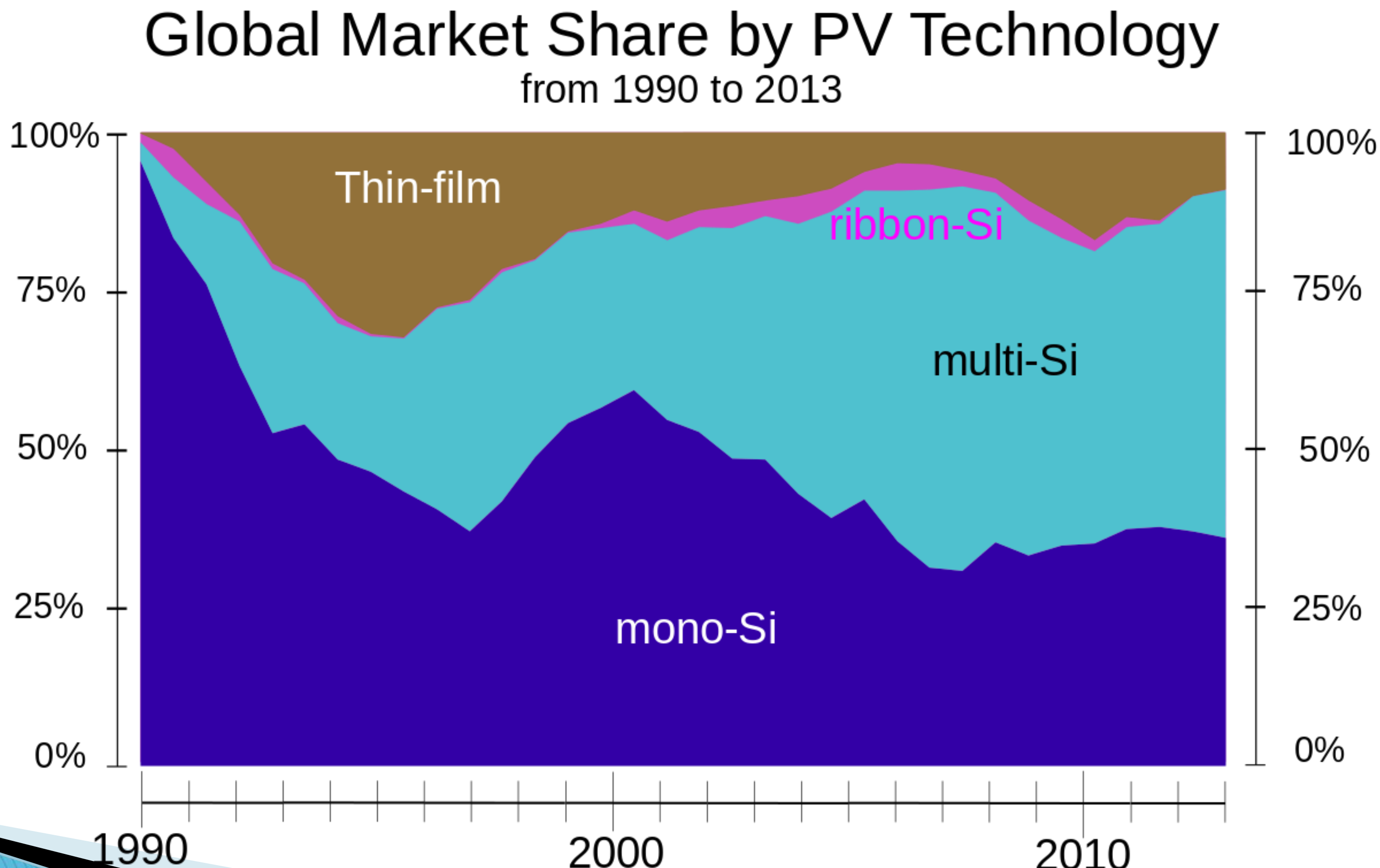
Dependenta de material

- materialele care ofera tensiuni mari au de obicei curenti mai mici
  - dependent de latimea benzii interzise



Realizari practice

- materialul preferat este Si



Tipic

80 WATT

POWERFUL PERFORMANCE. SHARP RELIABILITY.

POLY-CRYSTALLINE SILICON PHOTOVOLTAIC MODULE WITH 80W MAXIMUM POWER

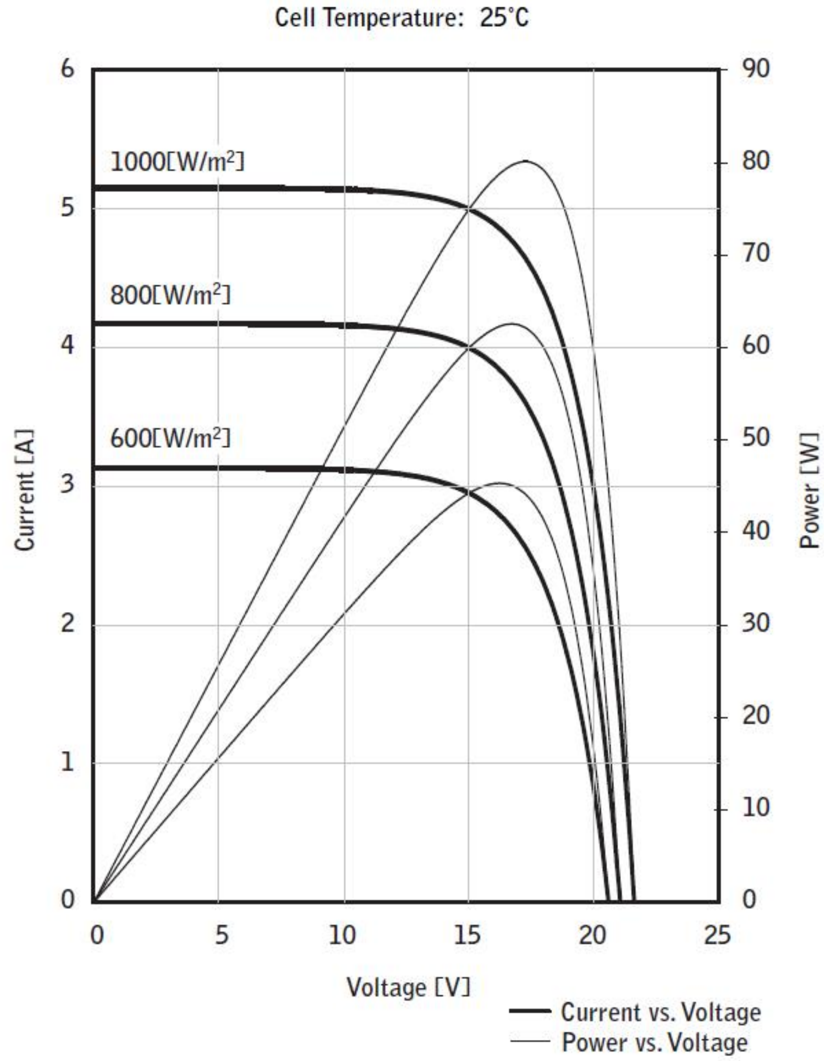
Sharp's NE-80EJEA photovoltaic modules offer industry-leading performance, durability, and reliability for a variety of electrical power requirements. Using breakthrough technology perfected by Sharp's 45 years of research and development, these modules incorporate an advanced surface texturing process to increase light absorption and improve efficiency. Common applications include cabins, solar power stations, pumps, beacons,

Tipic

ELECTRICAL CHARACTERISTICS

Cell	Poly-crystalline silicon
No. of Cells and Connections	36 in series
Open Circuit Voltage (Voc)	21.6V
Maximum Power Voltage (Vpm)	17.3V
Short Circuit Current (Isc)	5.16A
Maximum Power Current (Ipm)	4.63A
Maximum Power (Pmax)*	80W (+10% / -5%)
Module Efficiency (ηm)	12.40%
Maximum System Voltage	600VDC
Series Fuse Rating	10A
Type of Output Terminal	Junction Box

IV CURVES



Current, Power vs. Voltage Characteristics

Conectori

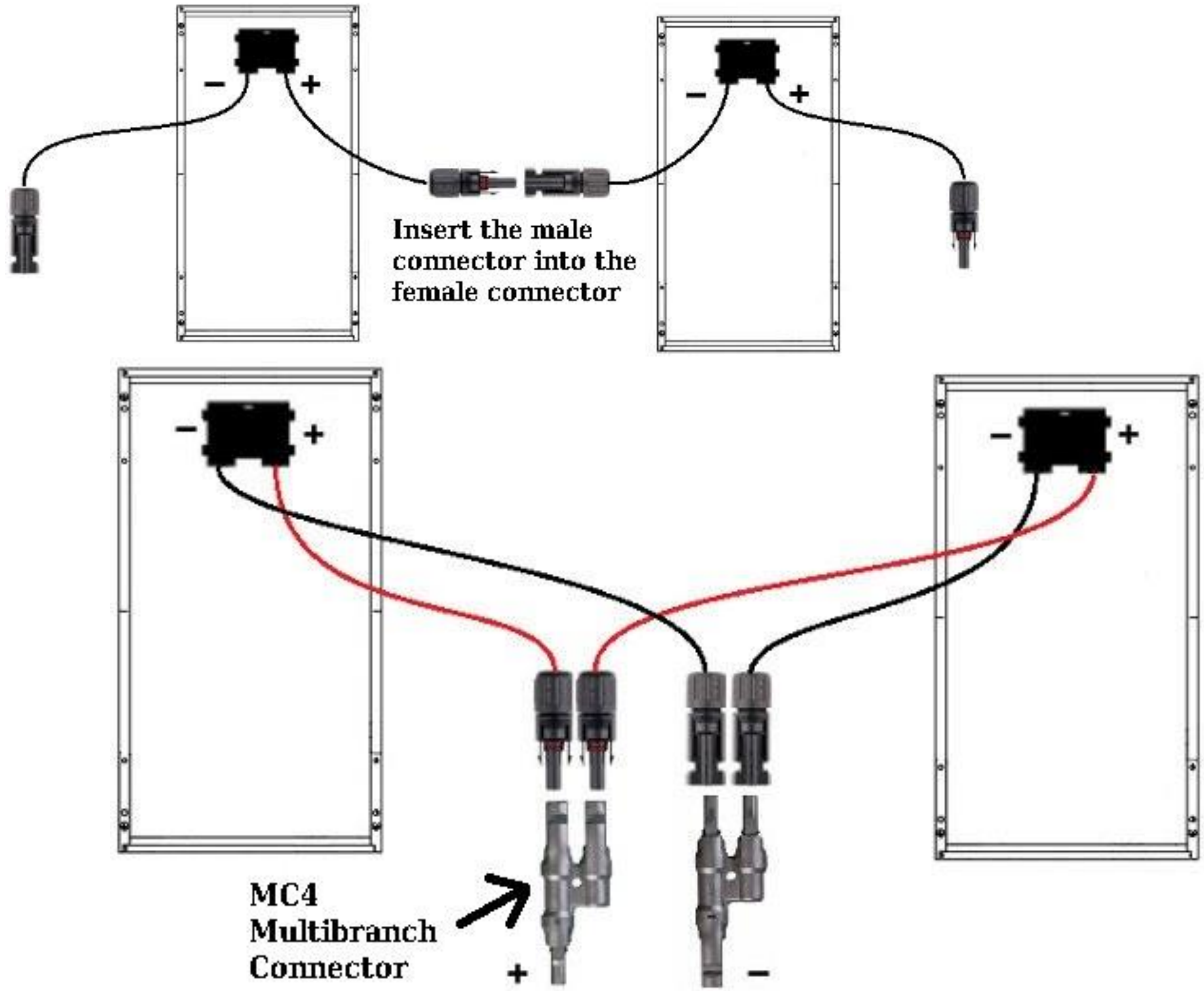
- MC4

Conectori

- MC4

Conectori

- MC4
  - serie
  - paralel



Conexiuni

- serie
  - acelasi curent
    - senzitivitate la umbra partiala
  - tensiunile se aduna (cresc)
- paralel
  - aceeasi tensiune
  - curentii se aduna (cresc)
    - restrictii asupra cablurilor utilizate

Cabluri

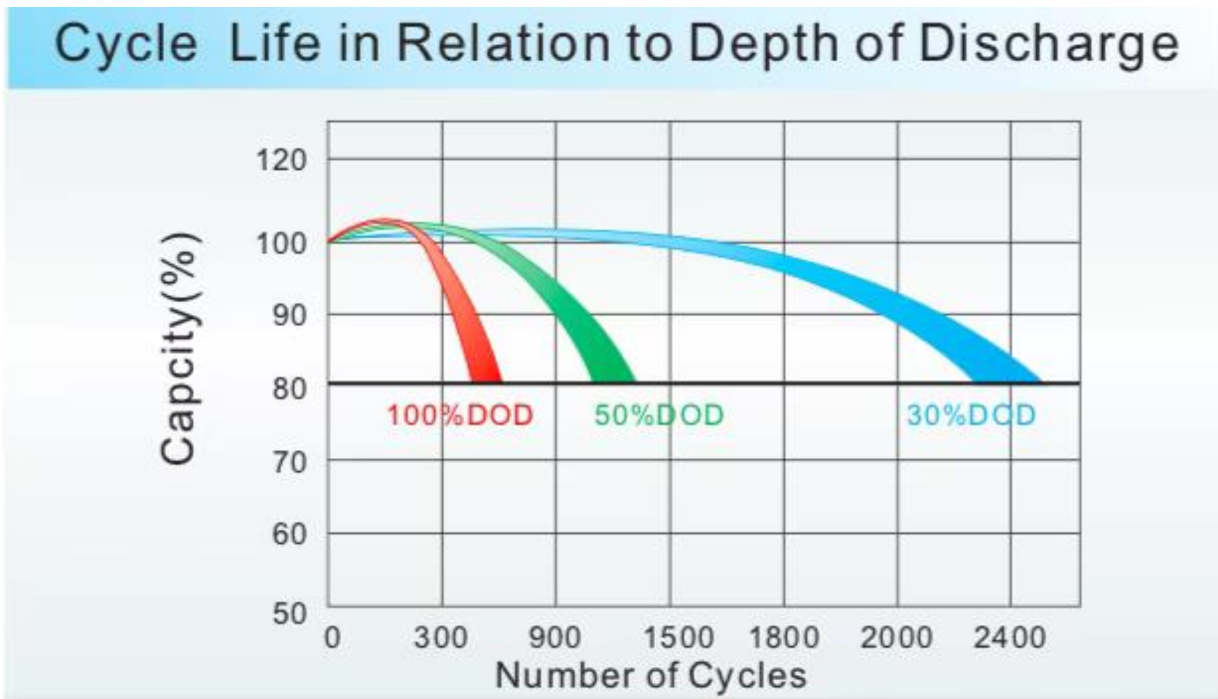
- operare in curent continuu
  - tensiuni in general scazute
  - puteri mari
  - rezulta curenti ridicati
- apare necesitatea utilizarii cablurilor de sectiune mare
  - pret ridicat
  - uneori peste limita de curent a cablului datorita rezistentei intrinseci
- conditii de mediu extreme (deseori expuse razelor solare, temperaturi ridicate)

Cabluri

- Exemplu
- Sistem 12V, 10A, 20m
  - curent 10A, necesar 1.5mm^2
  - $R = \frac{\rho \times l}{S}$
    - sectiune mica rezulta in rezistenta mare
  - 1.5mm^2 -> 12.7Ω/km
  - 1.5mm^2, 20m dus-intors (total 40m), 10A : cadere de tensiune pe cablu: **5.08V** (**42.3%**)
  - 6mm^2 (supradimensionat pentru 10A): 3.14Ω/km
    - cadere de tensiune pe cablu: 1.26V (10.5%)
  - 10mm^2 : 1.82Ω/km
    - cadere de tensiune pe cablu: 0.73V (6.07%)

Baterii

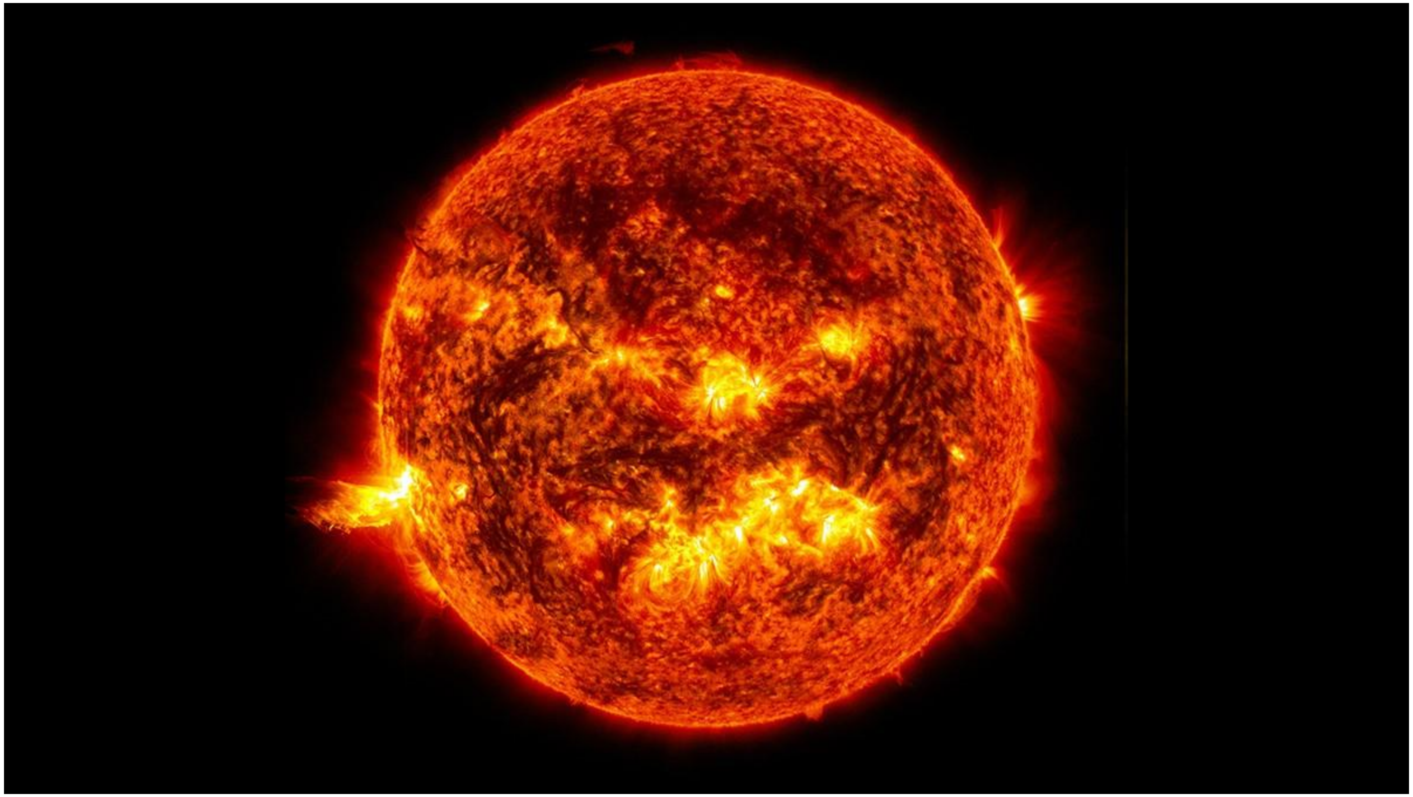
- Cycle Life vs. Depth of Discharge



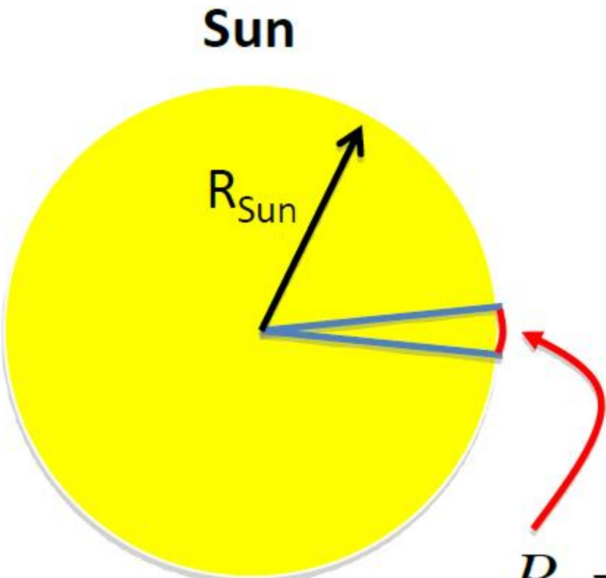
Baterii

- In sistemele solare deseori toata energia acumulata in timpul zilei se consuma in timpul noptii (DOD -> 100%)
- Baterii concepute pentru descarcare partiala (ex: auto) isi reduc numarul de cicluri de incarcare descarcare semnificativ
- Baterie auto tipica (Pb-acid, Gel)
  - DOD 80%, Numar de cicluri: 200-300, durata de viata < 1 an
- Li Ion, DOD 80%, Numar de cicluri: 500-1000, 3 ani
- $LiFePO_4$, DOD 80%, Numar de cicluri: 2000-3000, 8-10 ani, mai stabil termic

Energia solara disponibila



Energia solara disponibila



$$P_o = \sigma \cdot T^4$$

Total Radiative Power of Sun (from Stefan-Boltzman law, T =5762±50K)

Power radiated per unit area $6.250x10^7$ W/m^2

Assumes Sun is a "black body."

Energia solara disponibila

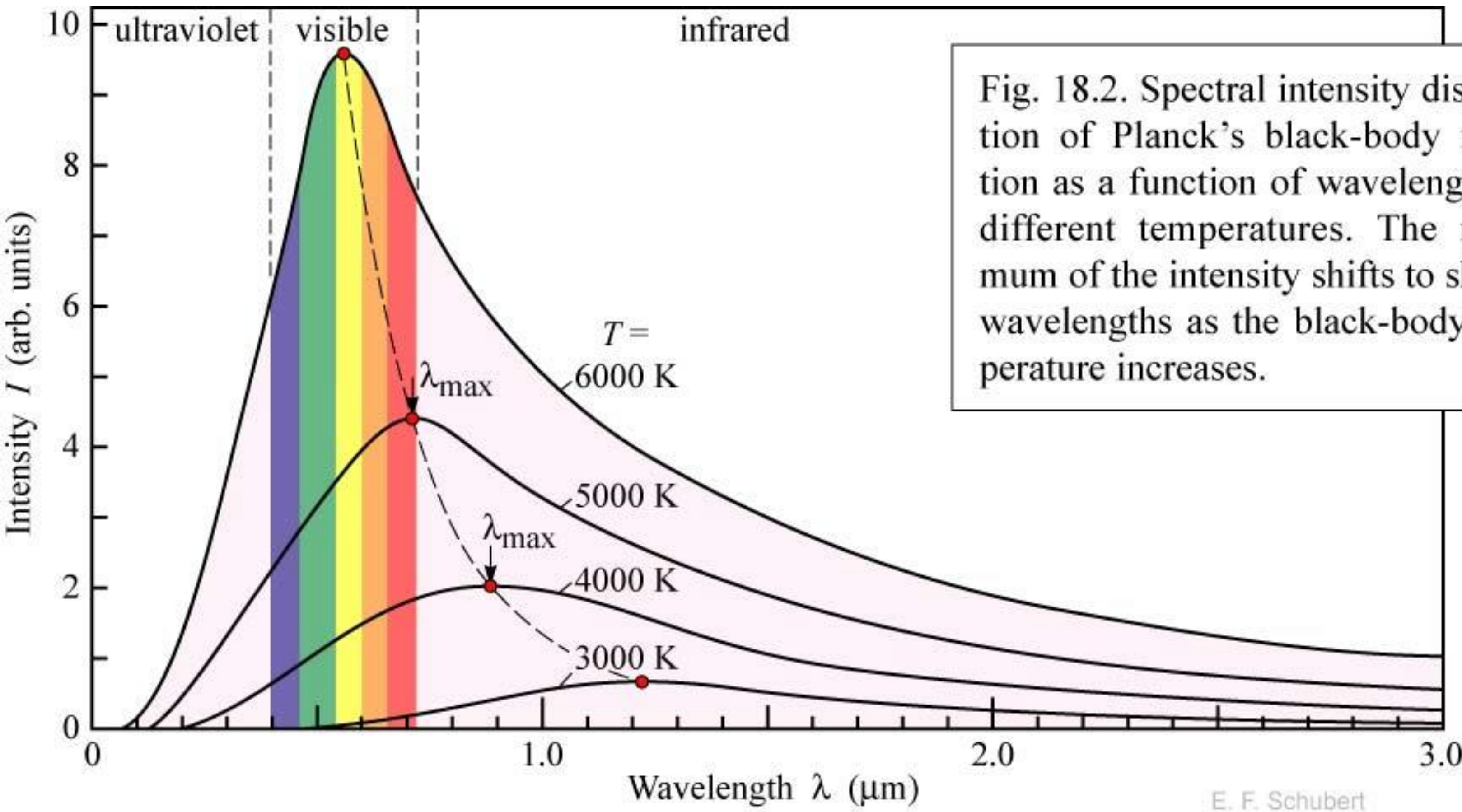
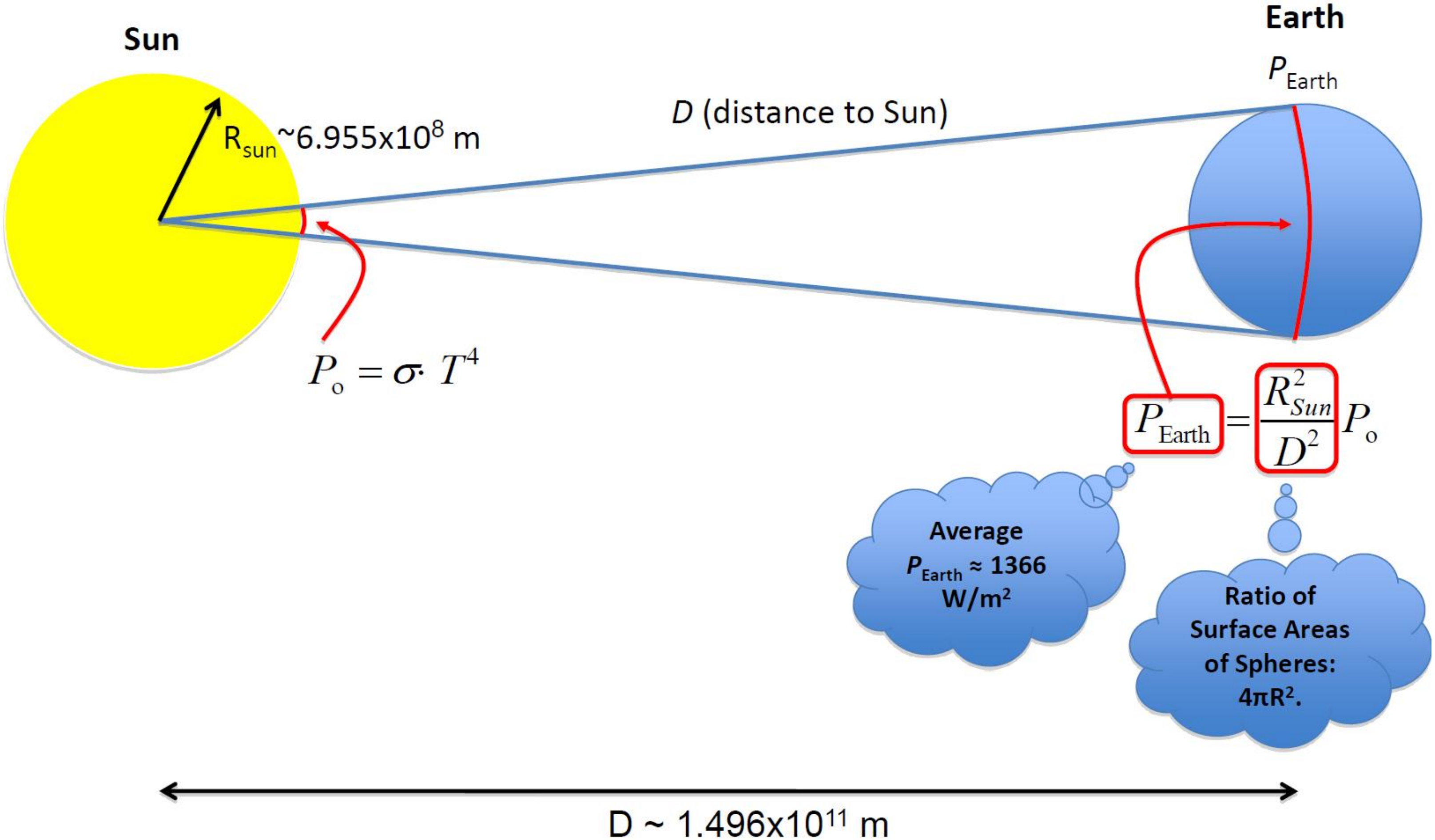


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

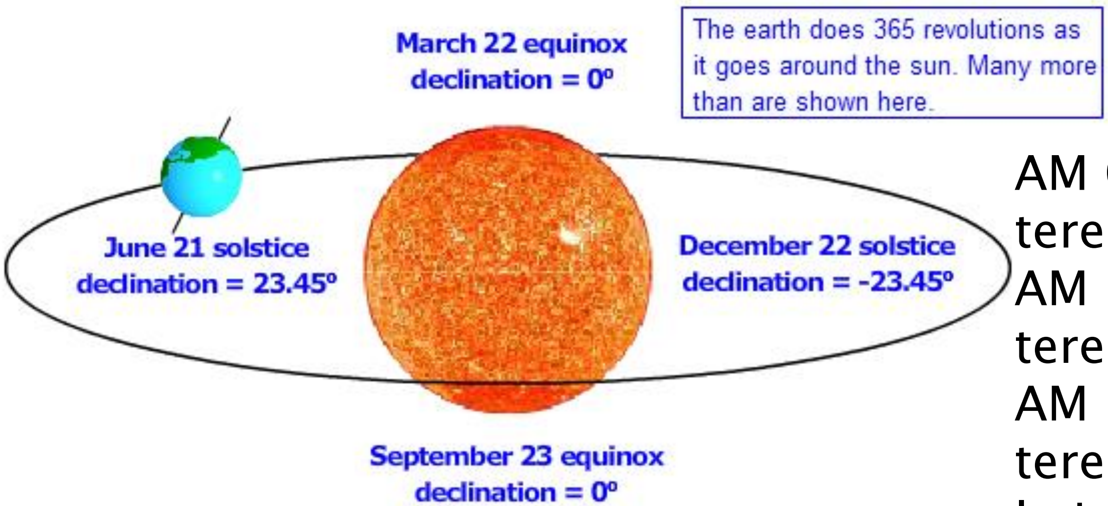
E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Energia solara disponibila

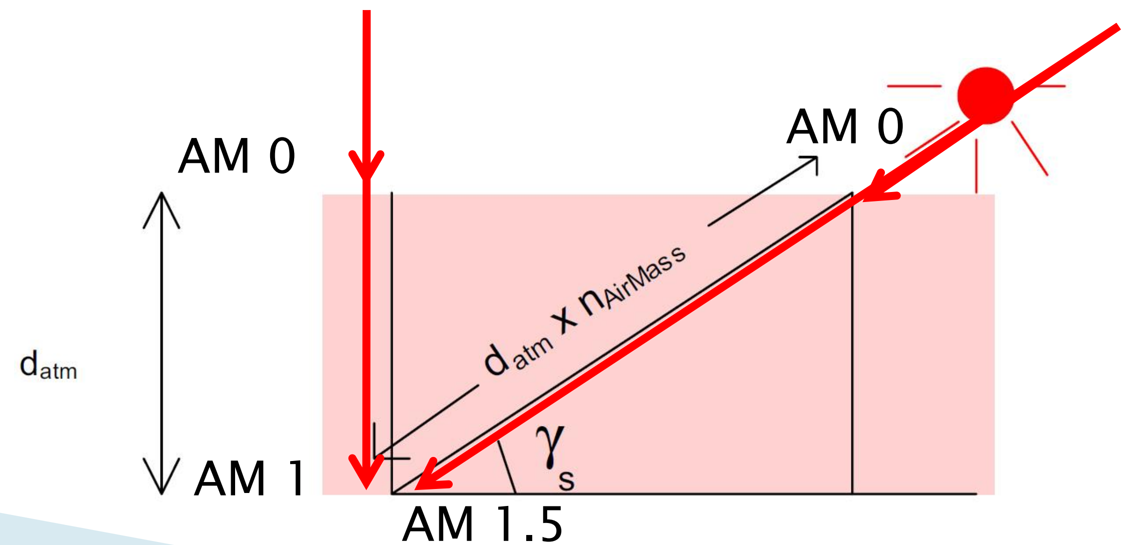


Energia receptionata pe toata suprafata Pamantului intr-**o ora** mai mare decat toata energia consumata de intreaga populatie intr-**un an**

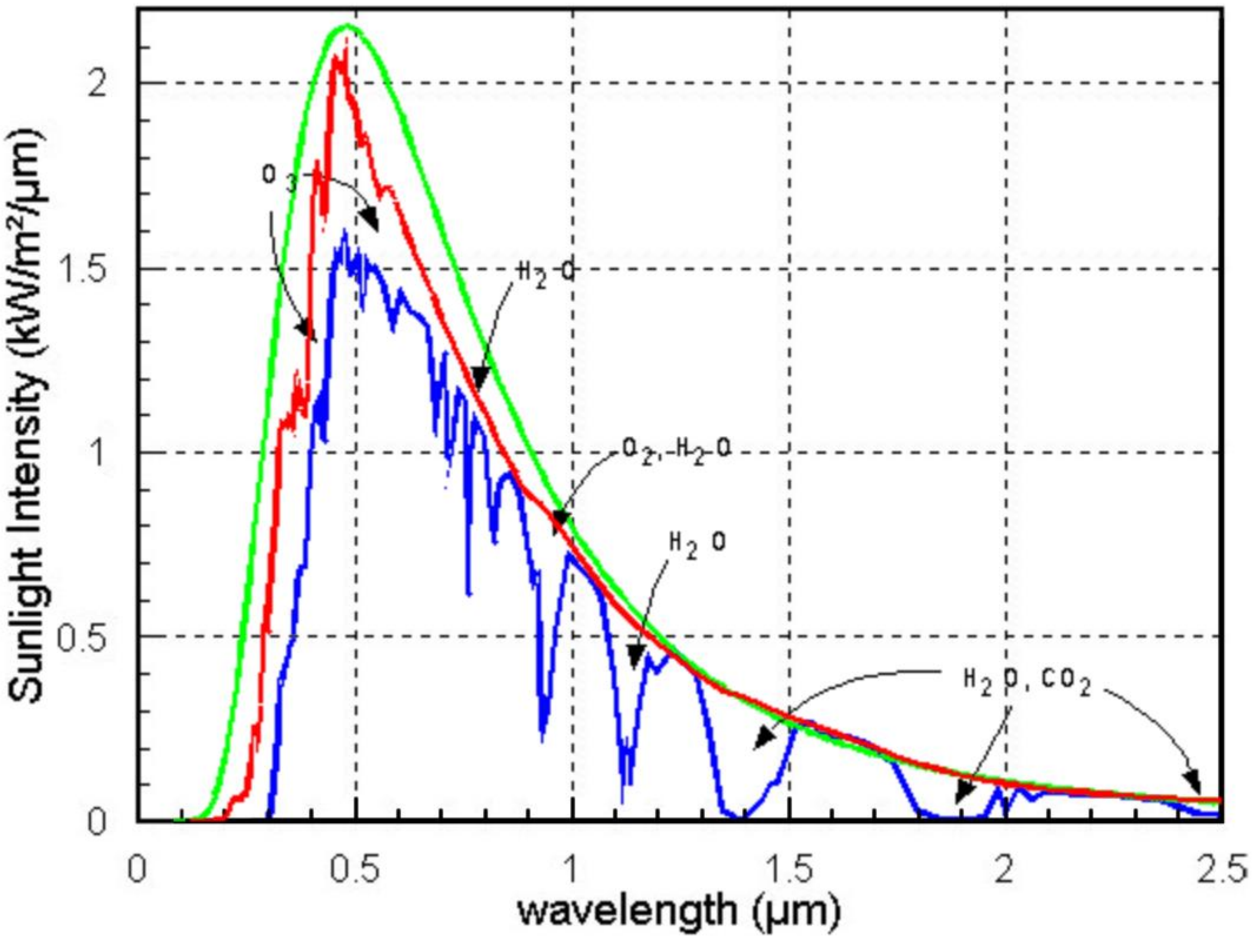
Energia solara disponibila



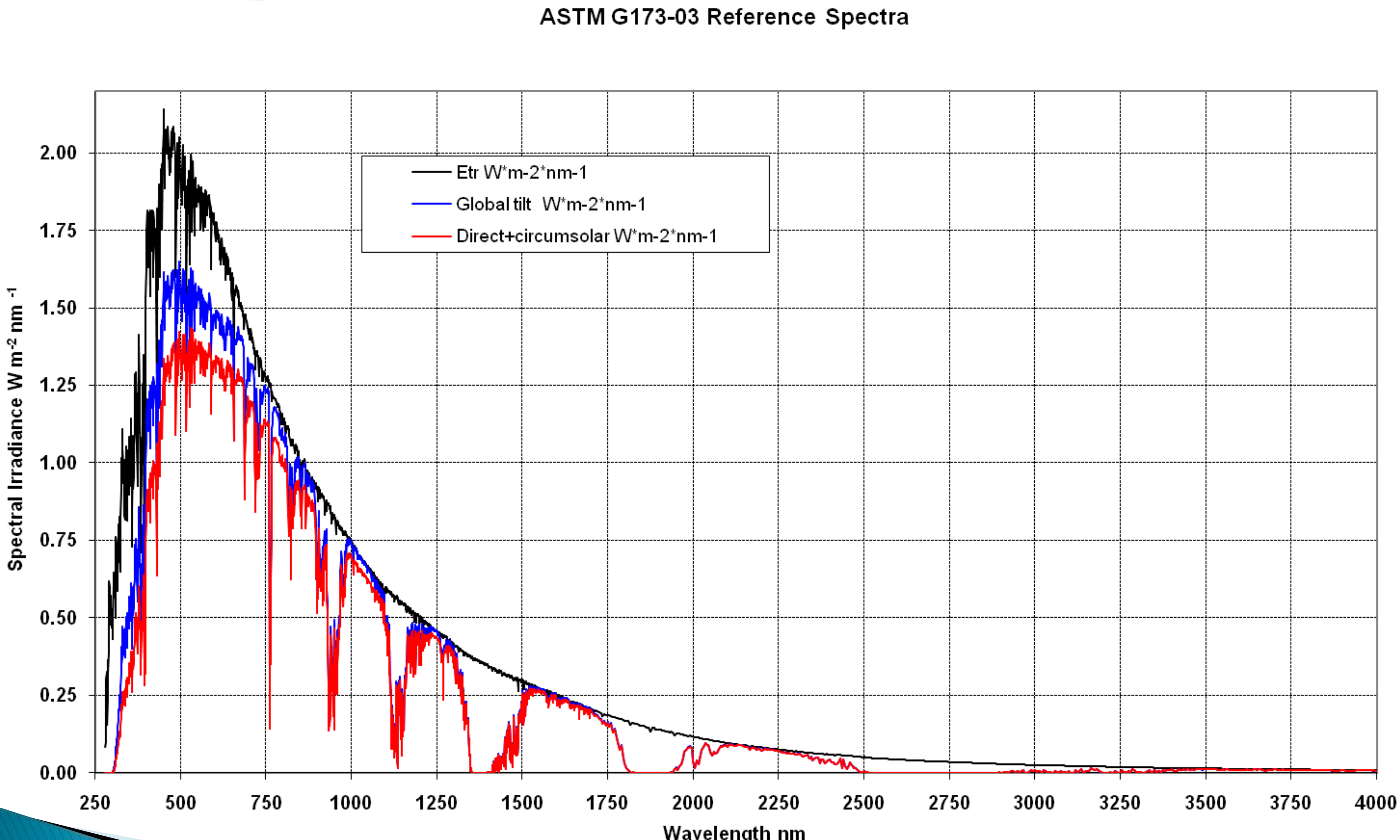
AM 0 = radiatia in afara atmosferei terestre
AM 1 = radiatia la suprafata terestra, incidenta normala
AM 1.5 = radiatia la suprafata terestra, incidenta corespunzatoare latitudinii de 48° (**standard**)



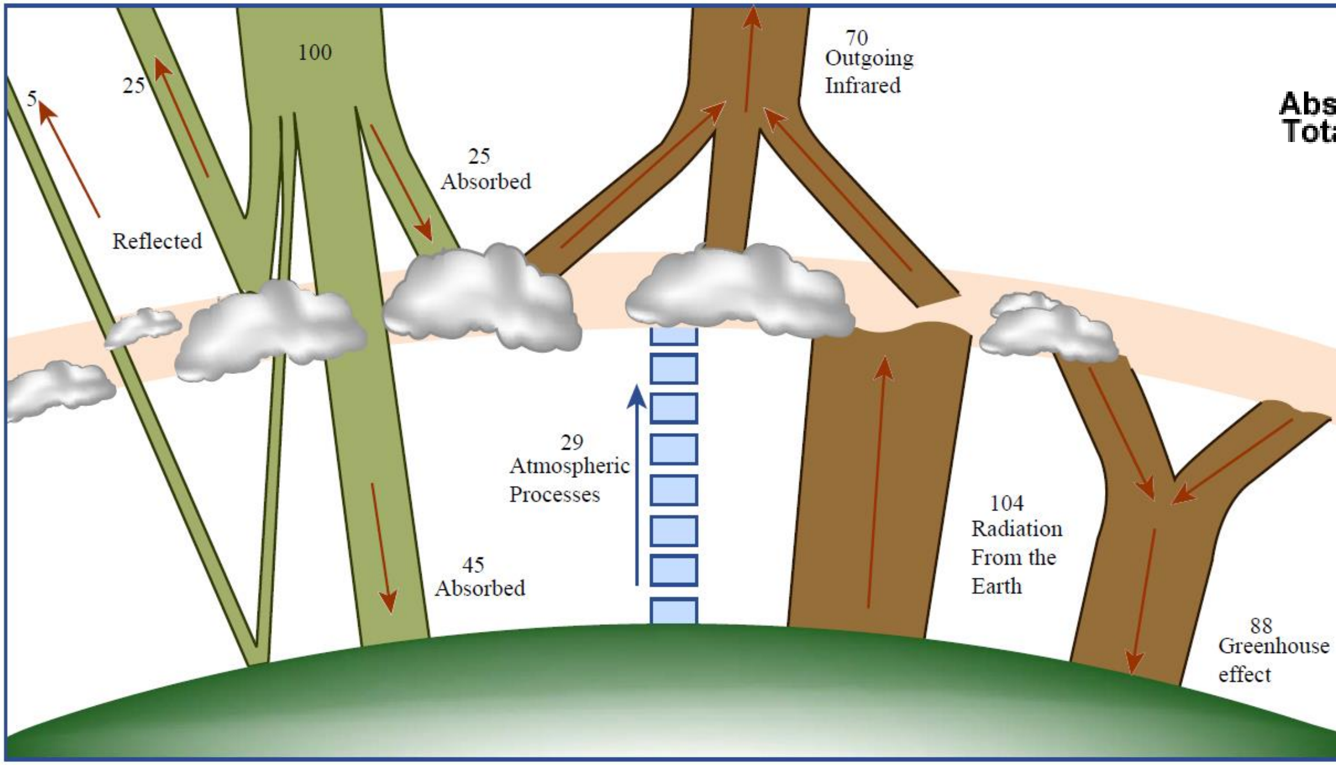
Energia solara disponibila



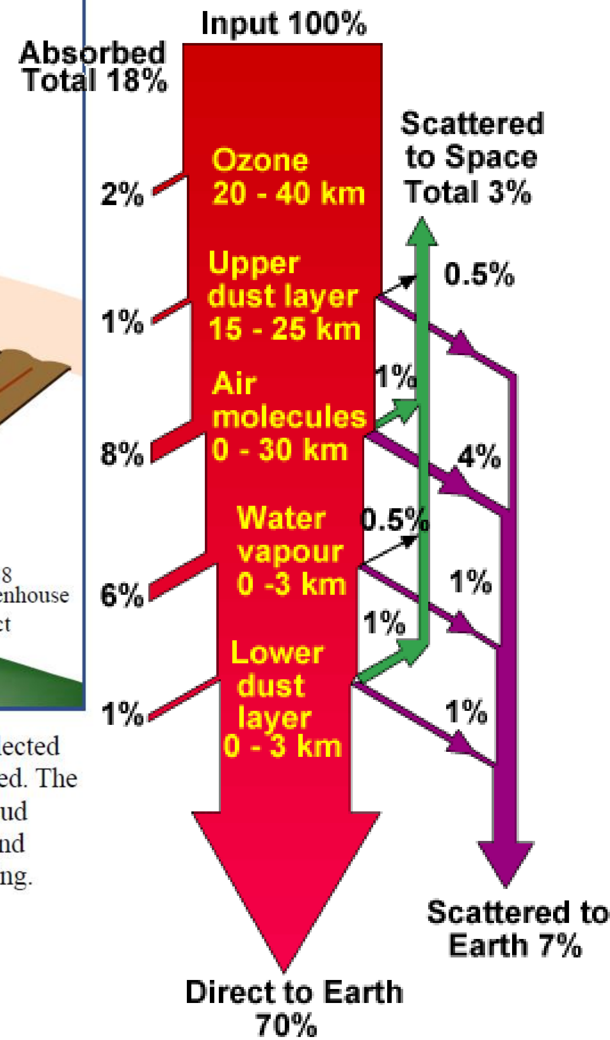
Energia solara disponibila



Energia solara disponibila



Heat trapping in the atmosphere dominates the earth's energy balance. Some 30% of incoming solar energy is reflected (left), either from clouds and particles in the atmosphere or from the earth's surface; the remaining 70% is absorbed. The absorbed energy is reemitted at infrared wavelengths by the atmosphere (which is also heated by updrafts and cloud formation) and by the surface. Because most of the surface radiation is trapped by clouds and greenhouse gases and returned to the earth, the surface is currently about 33 degrees Celsius warmer than it would be without the trapping.



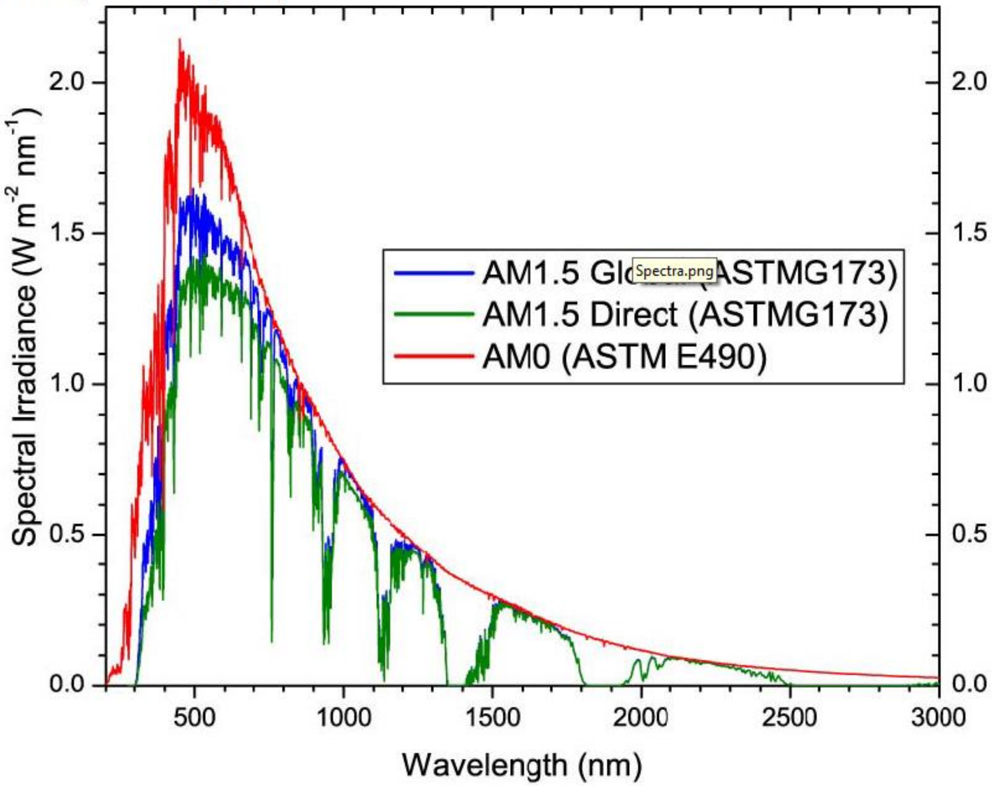
Energia solara disponibila

SOLAR SPECTRUM

AM1.5 Global: Used for testing of Flat Panels (Integrated power intensity: 1000 W/m^2)

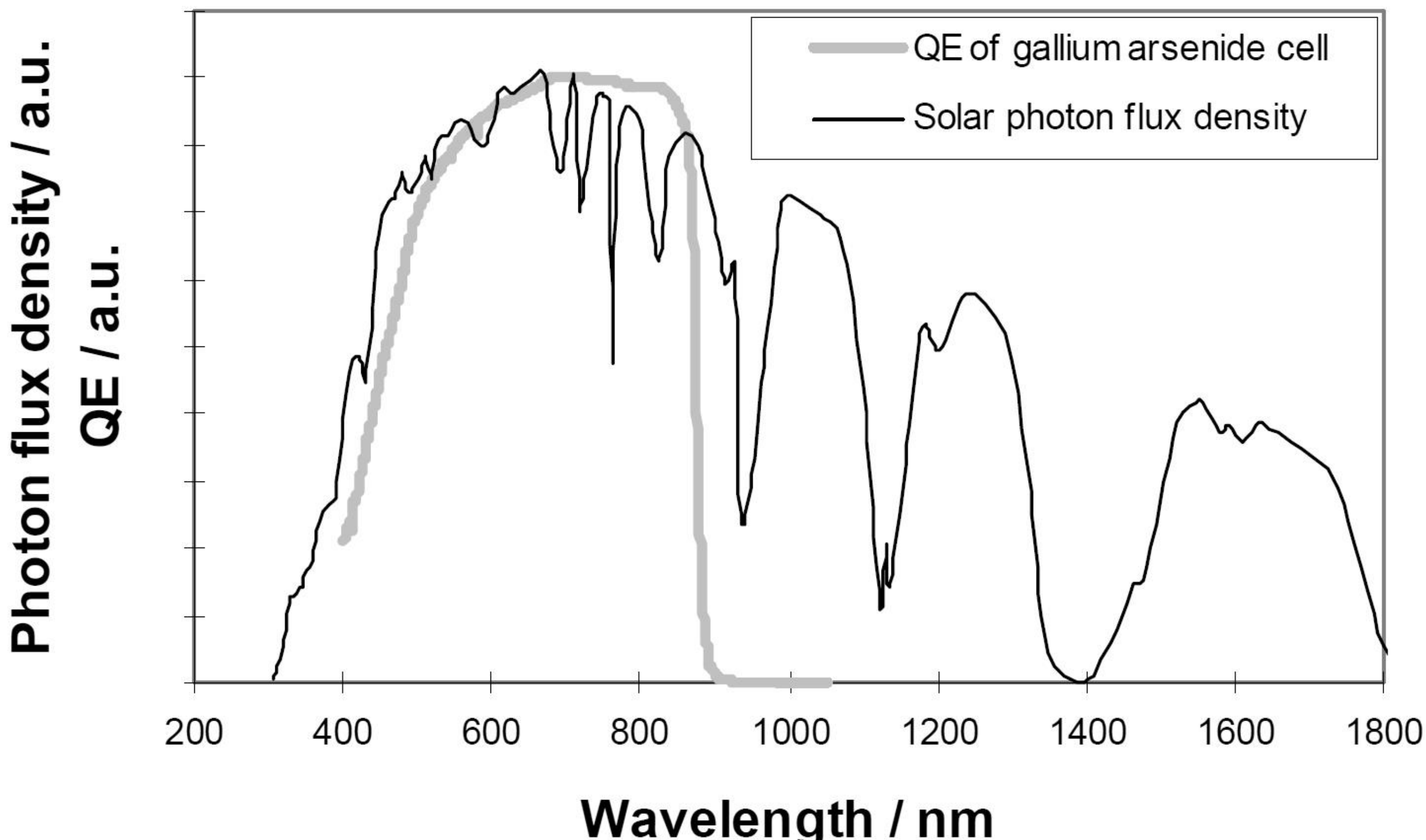
AM1.5 Direct: Used for testing of concentrators (900 W/m^2)

AM0: Outer space (1366 W/m^2)

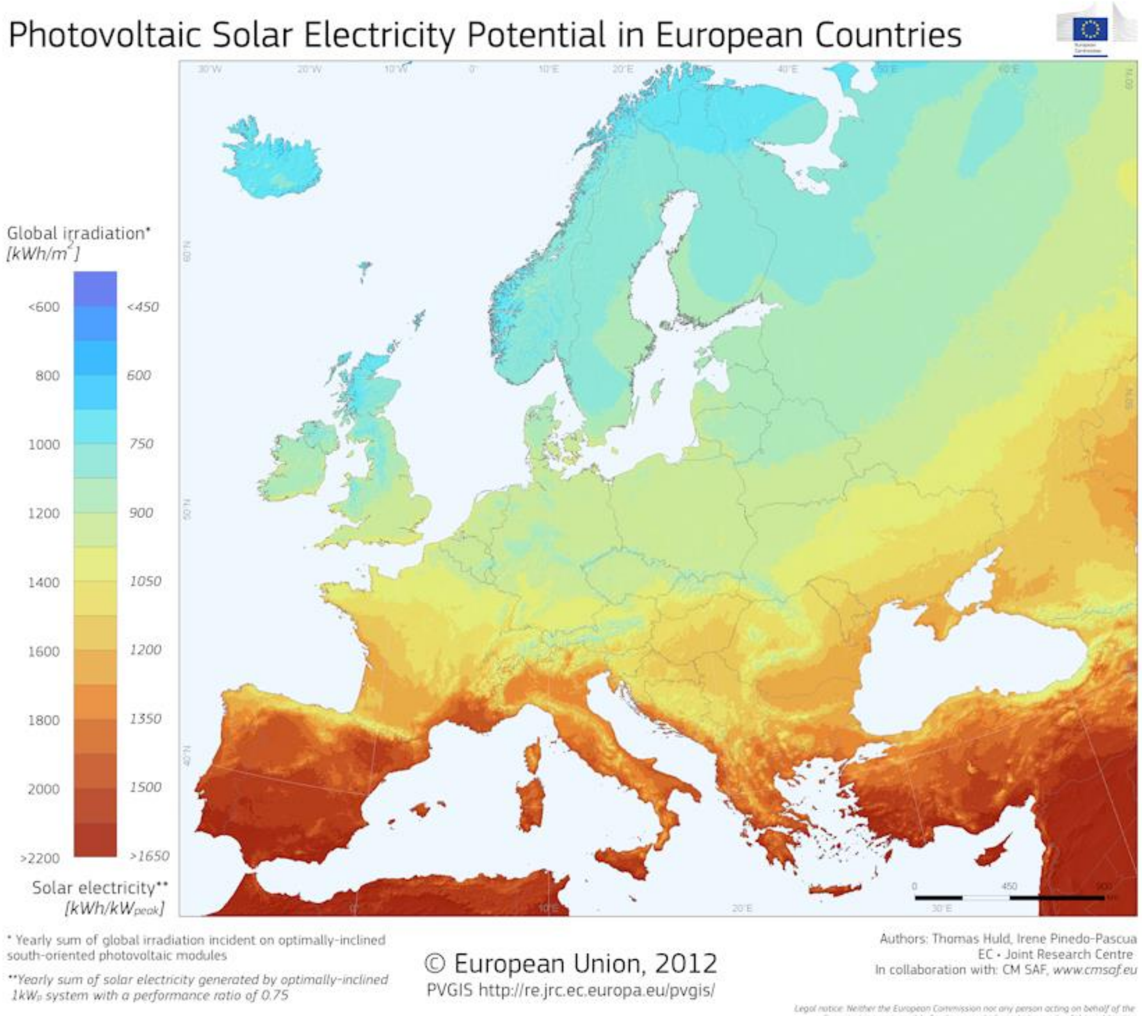


Motivatie eficienta limitata

- Toate materialele utilizate au o banda care acopera **doar** partial spectrul solar (ex. GaAs)



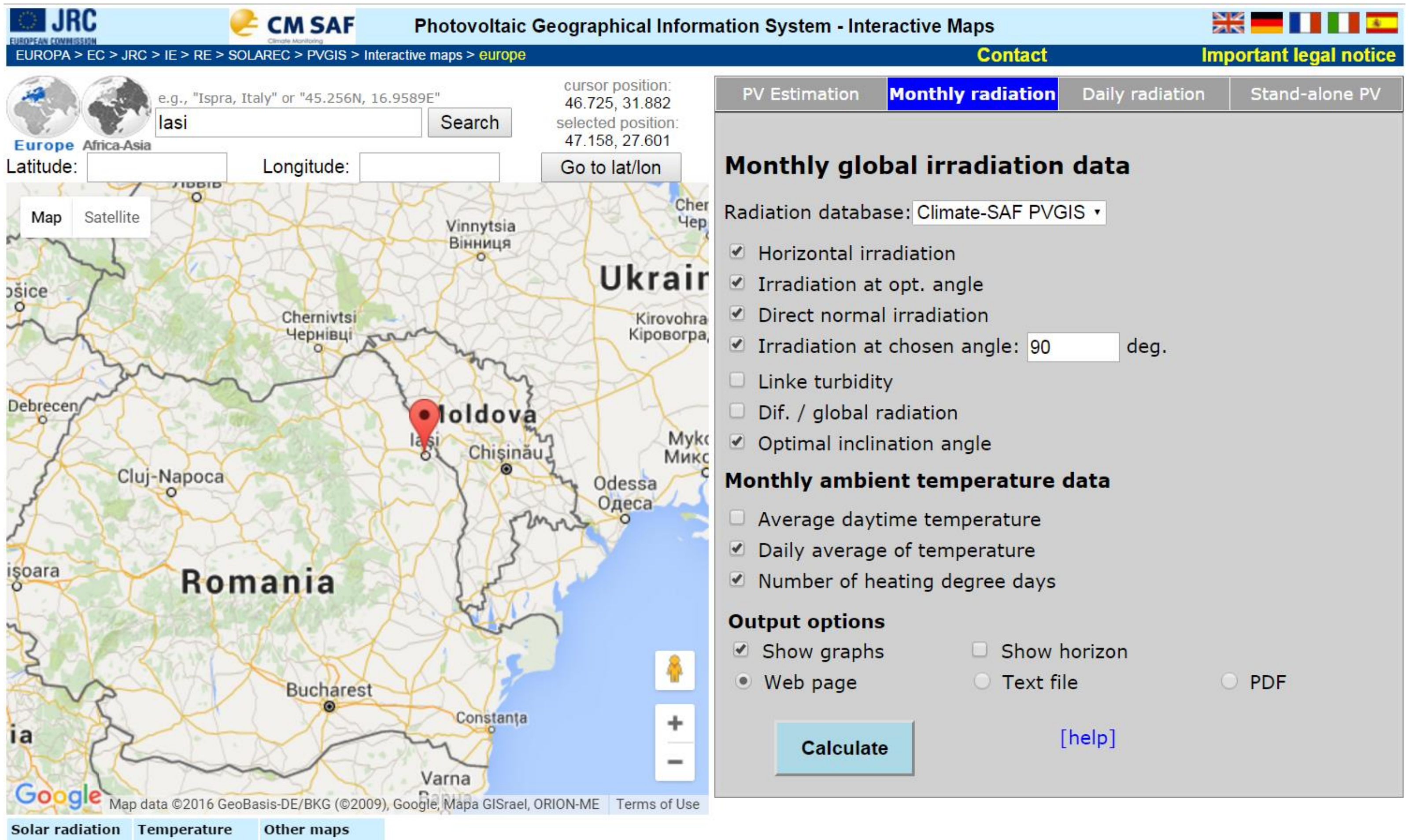
Energia solara disponibila



http://re.jrc.ec.europa.eu/pvgis/

Energia solara disponibila

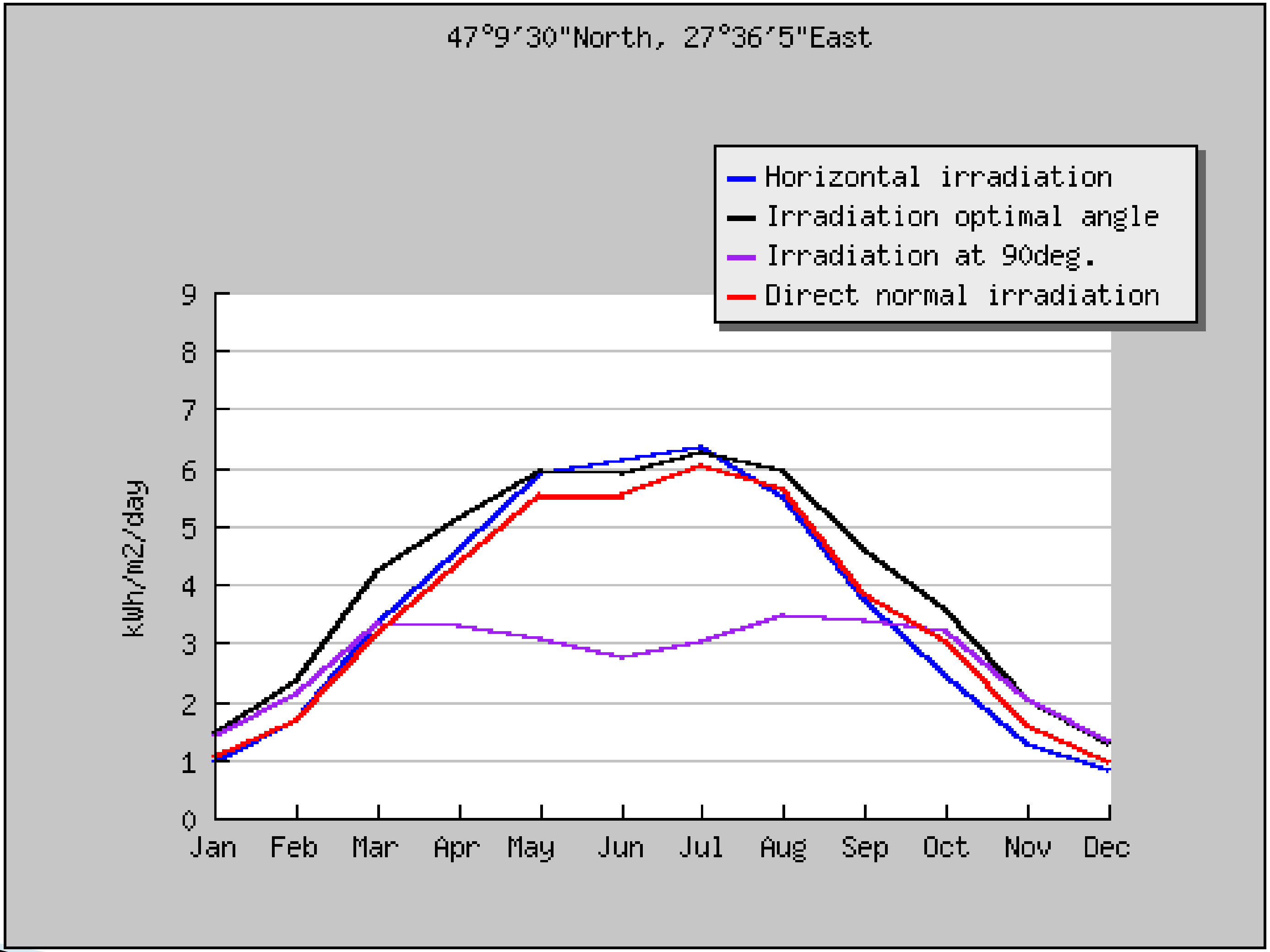
Energia solara disponibila



Photovoltaic Geographical Information System (PVGIS)

http://re.jrc.ec.europa.eu/pvgis/

Energia solara disponibila – Iasi



Unghi optim de inclinare

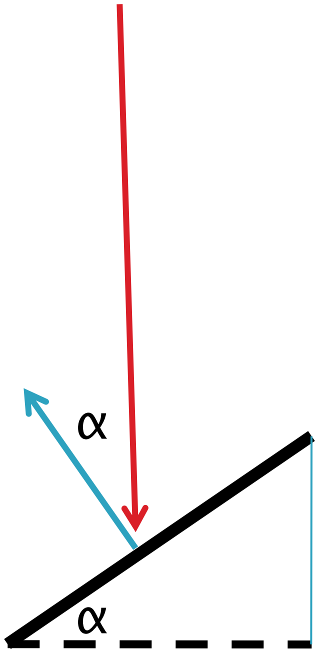
- Puterea optica depinde de fluxul energetic al luminii incidente si suprafata celulei
  - la **incidenta normala**

$$P_o = S \cdot \int_0^\infty \Phi_e(\lambda) d\lambda$$

  - la **incidenta oarecare**

$$\Phi_e(\lambda) = \int_\Sigma \vec{S} \cdot \vec{n} dA = |S| \cdot A \cdot \cos\alpha$$

$$\vec{S} = \vec{E} \times \vec{H}$$

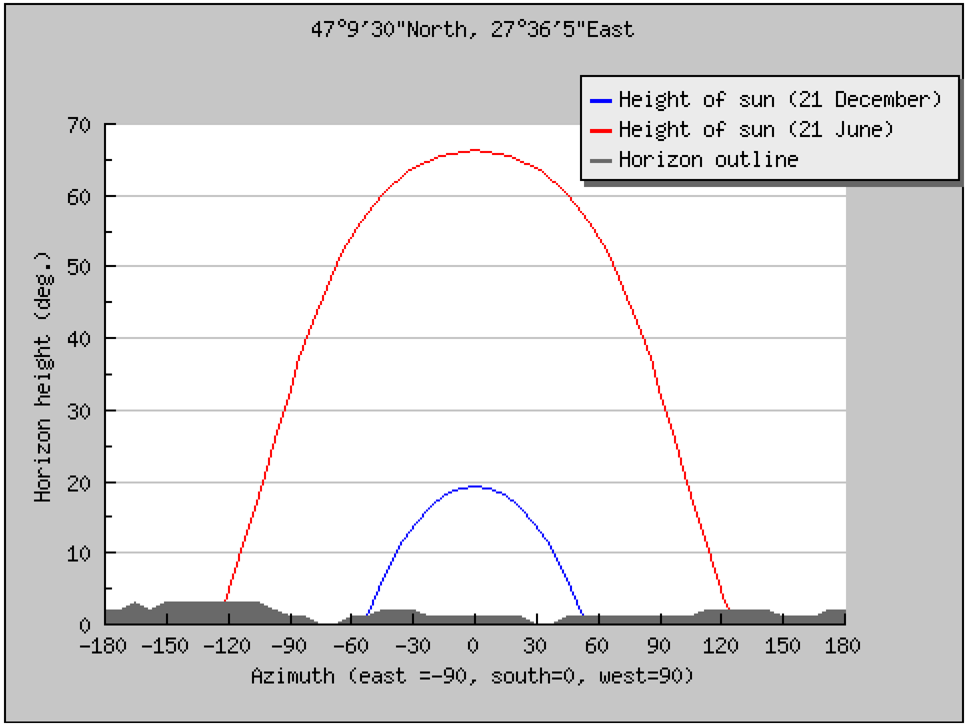


Unghi optim de inclinare

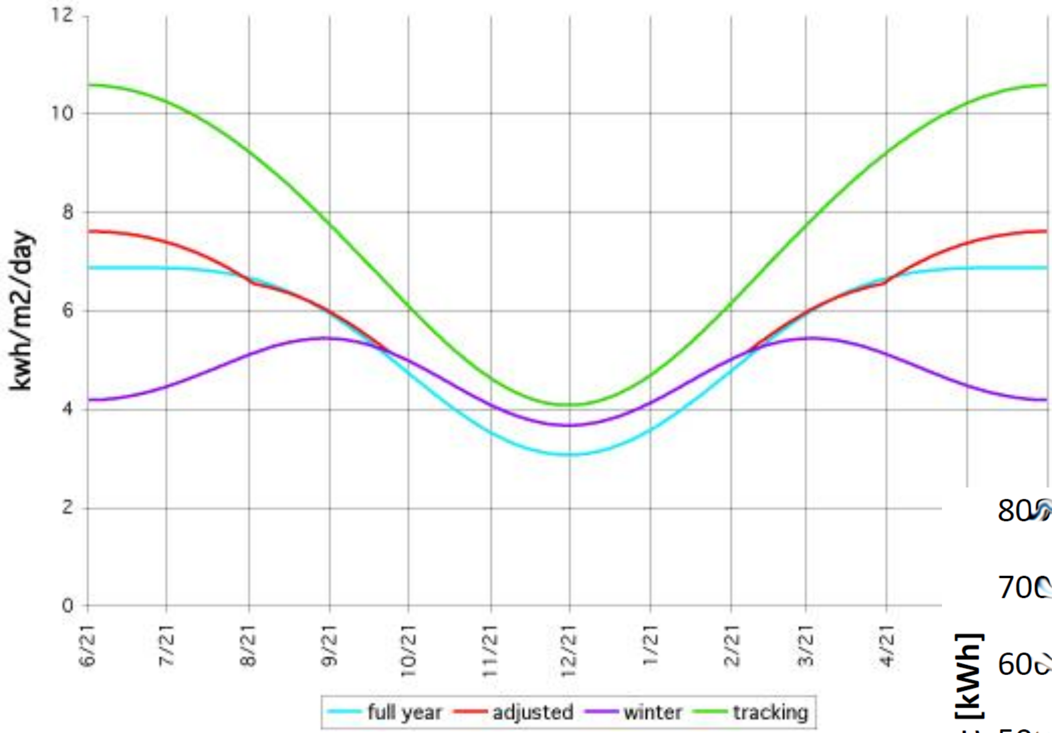
- Pozitia soarelui este diferita
  - in functie de ora
  - in functie de anotimp

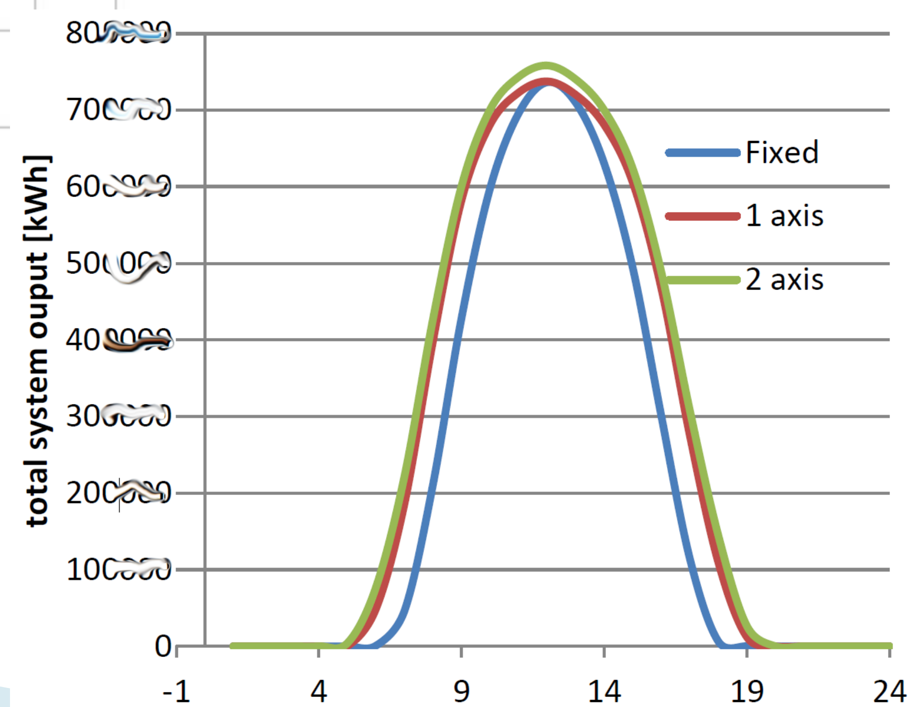
Sisteme de urmarire

- Sisteme motorizate de urmarire a soarelui
  - o axa
  - doua axe
- Reglaj
  - fix (optim an)
  - doua pozitii (anotimp)



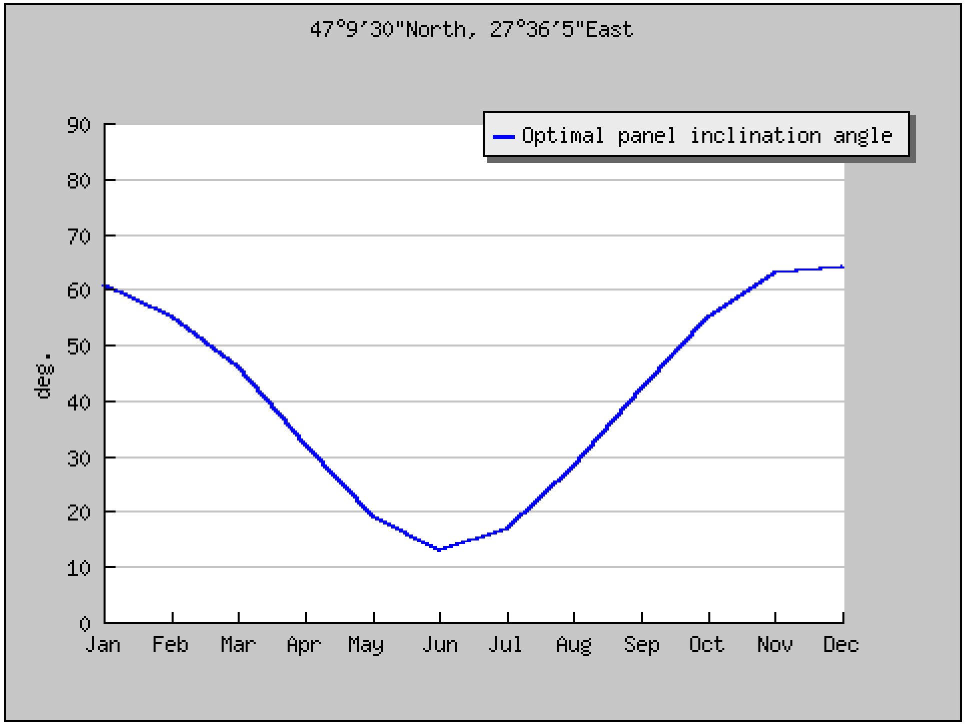
Sisteme de urmarire



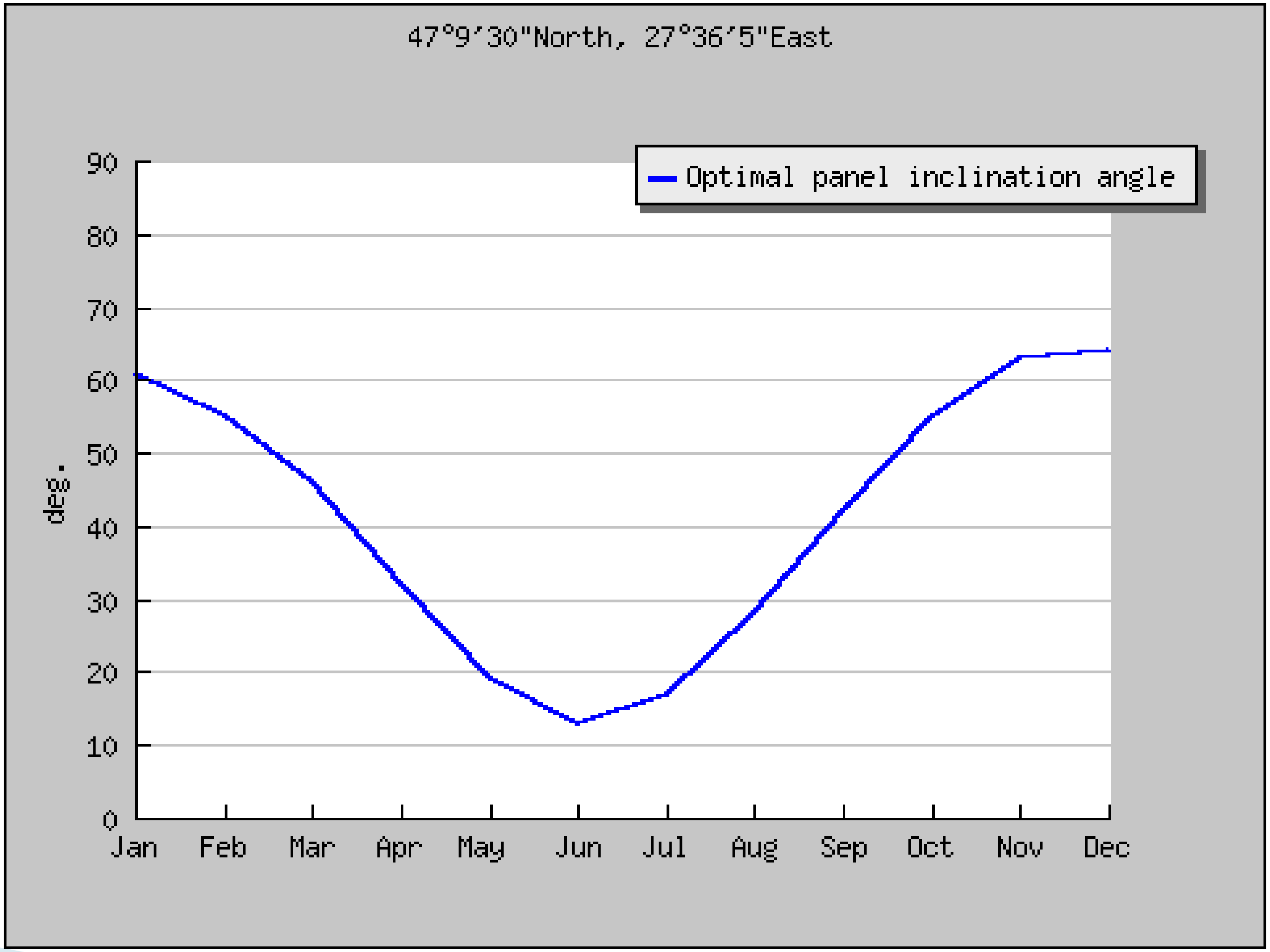


Unghi optim de inclinare

- Panourile se orienteaza spre sud (**geografic**)
- Inclinarea pe verticala se poate calcula din considerente
  - geometrice
  - astronomice



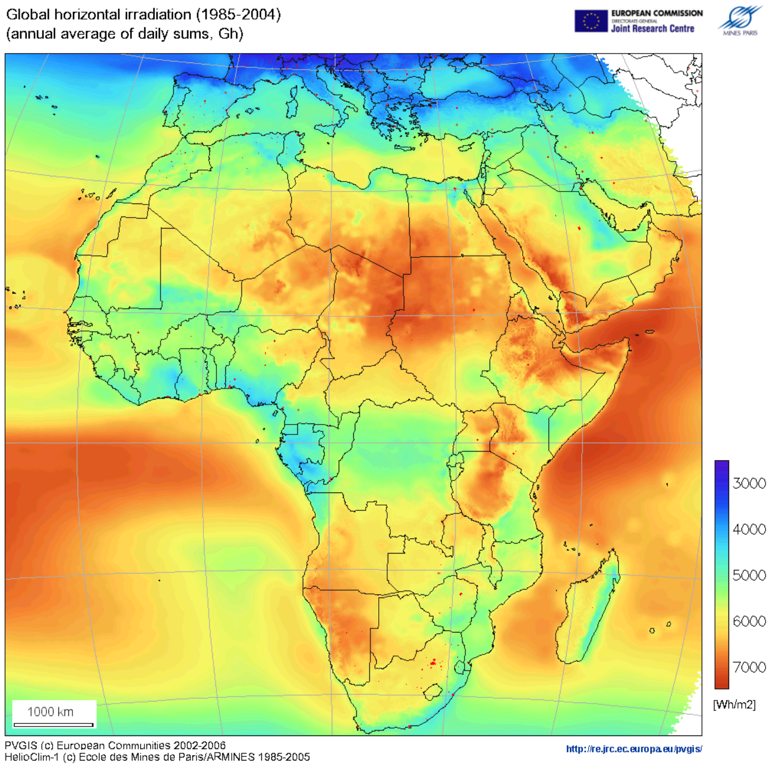
Iasi

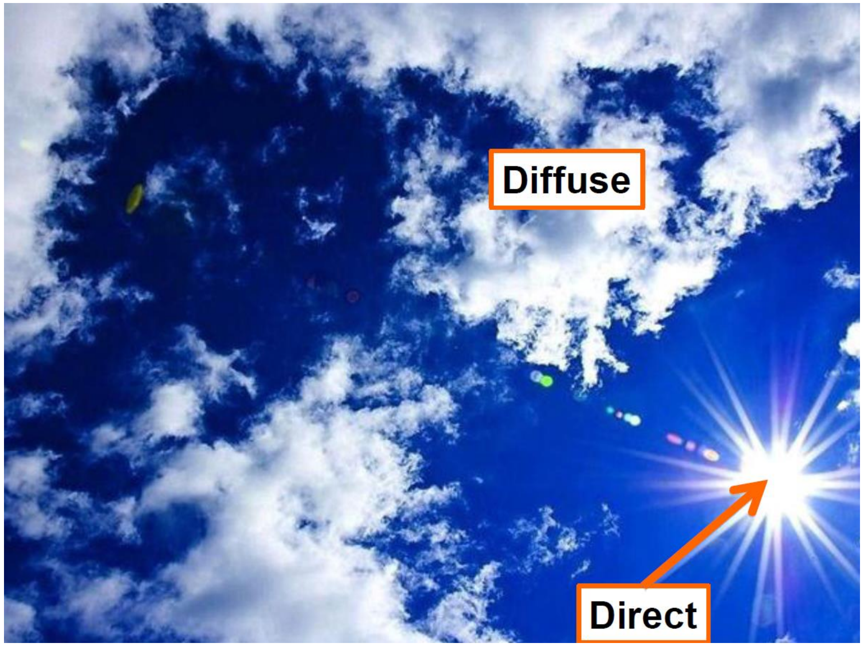


47°9′30"North, 27°36′5"East
Optimal panel inclination angle
deg.
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

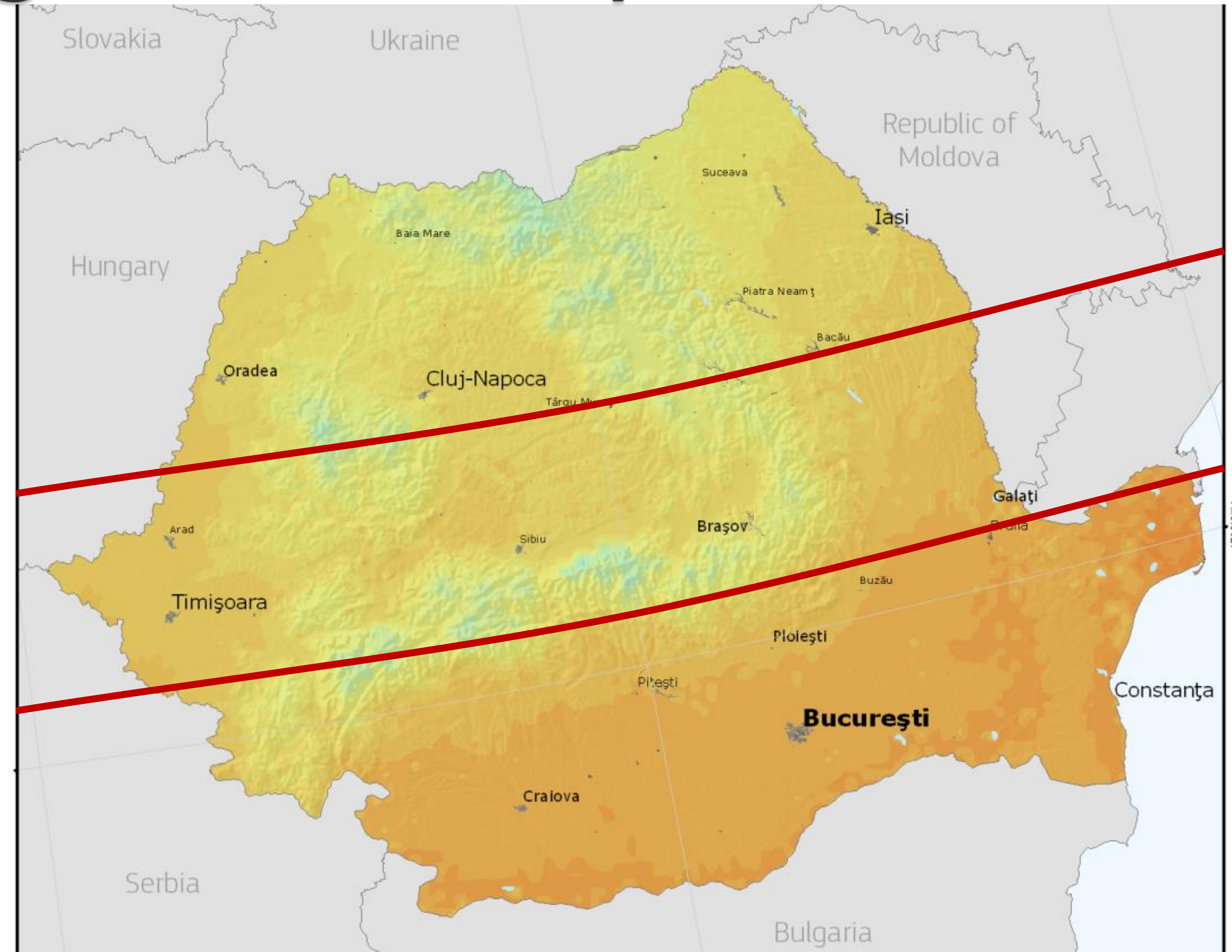
Tip de sistem de urmarire

- depinde de tipul de sistem solar
  - cu concentrare
  - fara concentrare
- depinde de conditii meteorologice





Energia solara disponibila



Iasi

Month	H_h	H_{opt}	H(90)	DNI	I_{opt}	T_{24h}
Jan	956	1440	1410	1020	61	-2.5
Feb	1680	2350	2130	1670	55	-1.4
Mar	3310	4210	3330	3150	46	4.0
Apr	4580	5150	3280	4380	32	10.6
May	5900	5960	3070	5530	19	16.7
Jun	6140	5900	2760	5530	13	20.0
Jul	6320	6240	3010	6010	17	22.3
Aug	5470	5960	3460	5630	28	21.4
Sep	3720	4600	3390	3820	42	16.1
Oct	2450	3570	3210	3000	55	10.2
Nov	1260	2000	2010	1600	63	5.5
Dec	802	1280	1310	959	64	-0.8
Year	3560	4070	2700	3540	35	10.2

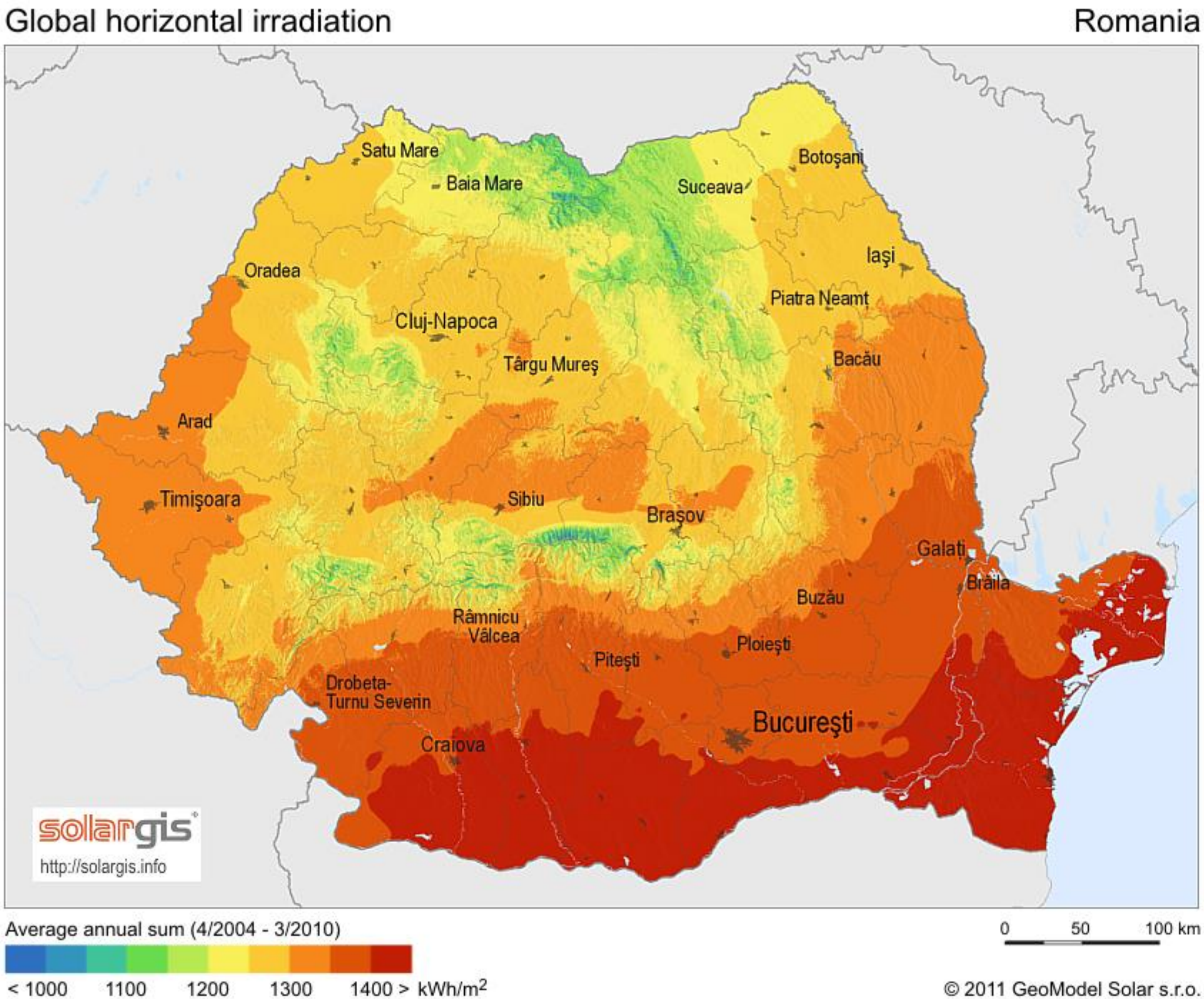
Iasi

http://re.jrc.ec.europa.eu/pvgis/

Month	H_h	H_{opt}	H(90)	DNI	I_{opt}	T_{24h}
Jan	956	1440	1410	1020	61	-2.5
Feb	1680	2350	2130	1670	55	-1.4
Mar	3310	4210	3330	3150	46	4.0
Apr	4580	5150	3280	4380	32	10.6
May	5900	5960	3070	5530	19	16.7
Jun	6140	5900	2760	5530	13	20.0
Jul	6320	6240	3010	6010	17	22.3
Aug	5470	5960	3460	5630	28	21.4
Sep	3720	4600	3390	3820	42	16.1
Oct	2450	3570	3210	3000	55	10.2
Nov	1260	2000	2010	1600	63	5.5
Dec	802	1280	1310	959	64	-0.8
Year	3560	4070	2700	3540	35	10.2

H_h: Irradiation on horizontal plane (Wh/m^2/day)
H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)
H(90): Irradiation on plane at angle: 90deg. (Wh/m^2/day)
DNI: Direct normal irradiation (Wh/m^2/day)
I_{opt}: Optimal inclination (deg.)
T_{24h}: 24 hour average of temperature (°C)

Romania



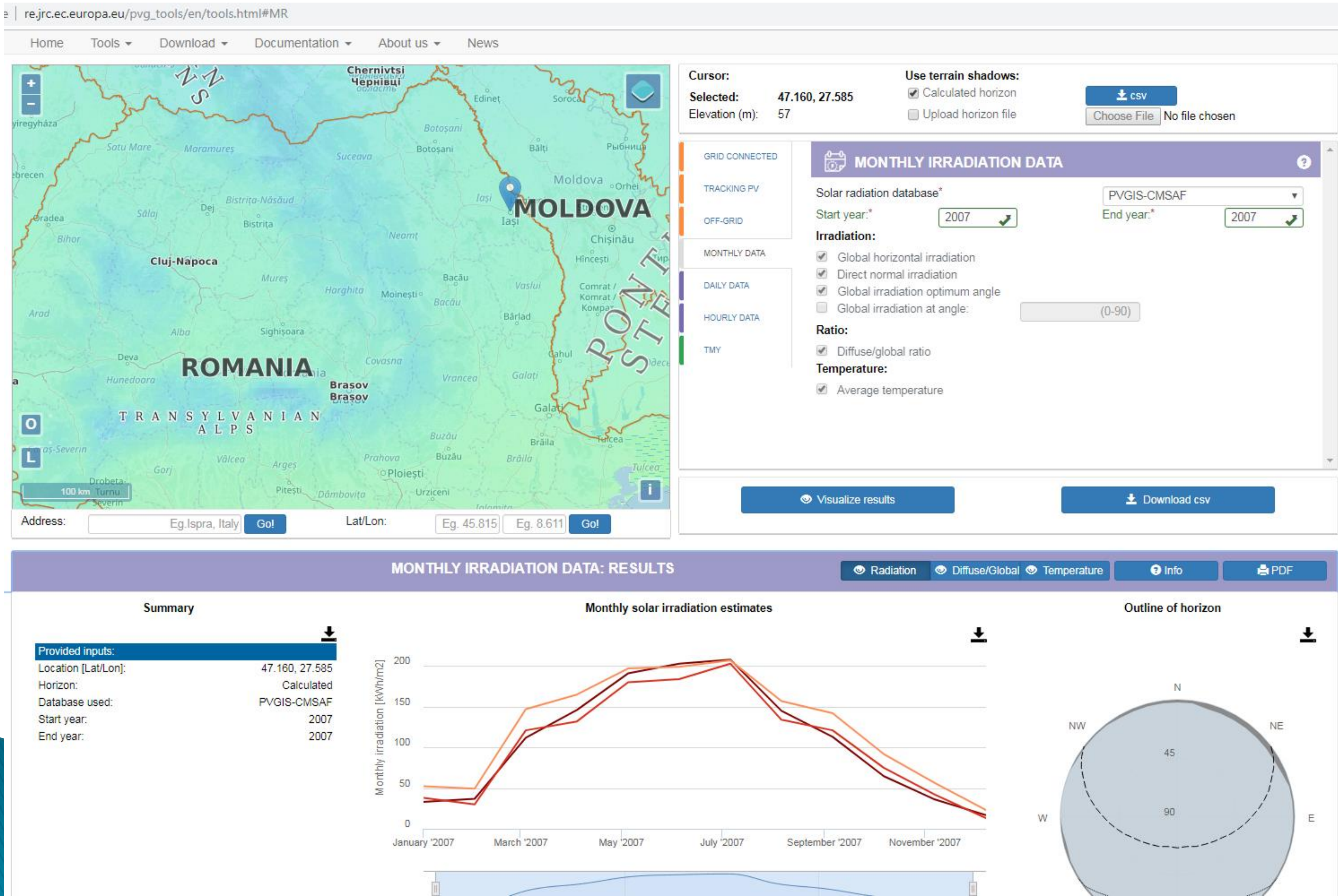
Global horizontal irradiation
Romania
Satu Mare
Baia Mare
Suceava
Botoşani
Iaşi
Oradea
Piatra Neamt
Cluj-Napoca
Târgu Mureş
Bacău
Arad
Timişoara
Sibiu
Braşov
Galati
Brăila
Buzău
Râmnicu Vâlcea
Piteşti
Ploieşti
Drobeta-Turnu Severin
Craiova
Bucureşti
solargis
http://solargis.info
Average annual sum (4/2004 - 3/2010)
< 1000
1100
1200
1300
1400 > kWh/m2
0
50
100 km
© 2011 GeoModel Solar s.r.o.

2019

- Schimbare de:
  - adresa
  - aplicatie
- Alte modalitati de prezentare a rezultatelor
  - acces la date individuale 2005 – 2020
  - unitati de masura diferite (kWh/m^2/**luna**)
  - lipsesc unele date (unghi optim lunar, H90)

https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

2019


re.jrc.ec.europa.eu/pvg_tools/en/tools.html#MR
Home
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MOLDOVA
ROMANIA
TRANSYLVANIAN ALPS
Cluj-Napoca
Chișinău
Iași
Brasov
Ploiești
Address:
Eg.Ispra, Italy
Go!
Lat/Lon:
Eg. 45.815
Eg. 8.611
Go!
Cursor:
Selected: 47.160, 27.585
Elevation (m): 57
Use terrain shadows:
Calculated horizon
Upload horizon file
csv
Choose File No file chosen
GRID CONNECTED
TRACKING PV
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY
MONTHLY IRRADIATION DATA
Solar radiation database*
PVGIS-CMSAF
Start year:* 2007
End year:* 2007
Irradiation:
Global horizontal irradiation
Direct normal irradiation
Global irradiation optimum angle
Global irradiation at angle:
(0-90)
Ratio:
Diffuse/global ratio
Temperature:
Average temperature
Visualize results
Download csv
MONTHLY IRRADIATION DATA: RESULTS
Radiation
Diffuse/Global
Temperature
Info
PDF
Summary
Provided inputs:
Location [Lat/Lon]: 47.160, 27.585
Horizon: Calculated
Database used: PVGIS-CMSAF
Start year: 2007
End year: 2007
Monthly solar irradiation estimates
Monthly irradiation [kWh/m2]
200
150
100
50
0
January '2007
March '2007
May '2007
July '2007
September '2007
November '2007
Outline of horizon
N
NE
E
W
NW
45
90

Iasi, date 2016

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	34.8	55.5	39	0.67	-2.3
Feb	50.5	72.2	50	0.63	4.1
Mar	100	128	94	0.51	5.2
Apr	147	167	141	0.43	12.4
May	168	169	141	0.46	14.2
Jun	184	180	162	0.4	20.2
Jul	215	215	216	0.33	21.7
Aug	174	191	185	0.35	20.4
Sep	130	164	149	0.38	17
Oct	55.2	73.7	54	0.59	6.6
Nov	36.3	58.5	44	0.62	2.8
Dec	29.6	49.2	35	0.68	-1

Iasi, date 2015

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	29.5	45.6	31	0.71	-0.9
Feb	50.6	73.5	53	0.61	-0.2
Mar	95.4	123	94	0.51	4.1
Apr	142	160	134	0.44	9.1
May	190	193	177	0.39	16.6
Jun	209	205	200	0.35	19.7
Jul	199	200	187	0.36	22.8
Aug	173	189	180	0.35	22.6
Sep	113	140	118	0.42	17.6
Oct	73.7	107	85	0.51	8
Nov	38.3	61.6	48	0.59	6.1
Dec	34.7	64	52	0.6	1.1

Iasi, date 2016

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	34.8	55.5	39	0.67	-2.3
Feb	50.5	72.2	50	0.63	4.1
Mar	100	128	94	0.51	5.2
Apr	147	167	141	0.43	12.4
May	168	169	141	0.46	14.2
Jun	184	180	162	0.4	20.2
Jul	215	215	216	0.33	21.7
Aug	174	191	185	0.35	20.4
Sep	130	164	149	0.38	17
Oct	55.2	73.7	54	0.59	6.6
Nov	36.3	58.5	44	0.62	2.8
Dec	29.6	49.2	35	0.68	-1

Hh: Irradiation on horizontal plane (kWh/m2/month)

Hopt: Irradiation on optimally inclined plane (kWh/m2/month)

DNI: Direct normal irradiation (kWh/m2/month)

D/G: Ratio of diffuse to global irradiation (-)

T24h: 24 hour average of temperature (−C)

Iasi, date 2020

Month	H(h)_m	H(i_opt)_m	Hb(n)_m	Kd	T2m
Jan	42.42	84.29	77.65	0.48	0.2
Feb	61.58	97.82	82.35	0.48	3.4
Mar	112.28	150.87	130.45	0.41	6.6
Apr	175.65	205.88	199.18	0.33	11.3
May	145.46	144.31	112.26	0.5	14.2
Jun	181.37	173.26	148.87	0.44	21.4
Jul	196.06	192.45	171.95	0.4	22.7
Aug	186.03	202.9	189.24	0.36	23.6
Sep	137.27	177.73	161.36	0.35	19.2
Oct	69.29	97.6	70.7	0.55	13.6
Nov	36.67	59.98	44.53	0.6	4.6
Dec	20.75	31.54	20.21	0.74	2.4

Iasi, date 2020

Month	H(h)_m	H(i_opt)_m	Hb(n)_m	Kd	T2m
Jan	42.42	84.29	77.65	0.48	0.2
Feb	61.58	97.82	82.35	0.48	3.4
Mar	112.28	150.87	130.45	0.41	6.6
Apr	175.65	205.88	199.18	0.33	11.3
May	145.46	144.31	112.26	0.5	14.2
Jun	181.37	173.26	148.87	0.44	21.4
Jul	196.06	192.45	171.95	0.4	22.7
Aug	186.03	202.9	189.24	0.36	23.6
Sep	137.27	177.73	161.36	0.35	19.2
Oct	69.29	97.6	70.7	0.55	13.6
Nov	36.67	59.98	44.53	0.6	4.6
Dec	20.75	31.54	20.21	0.74	2.4

H(h)_m: Irradiation on horizontal plane (kWh/m2/mo)

H(i_opt)_m: Irradiation on optimally inclined plane (kWh/m2/mo)

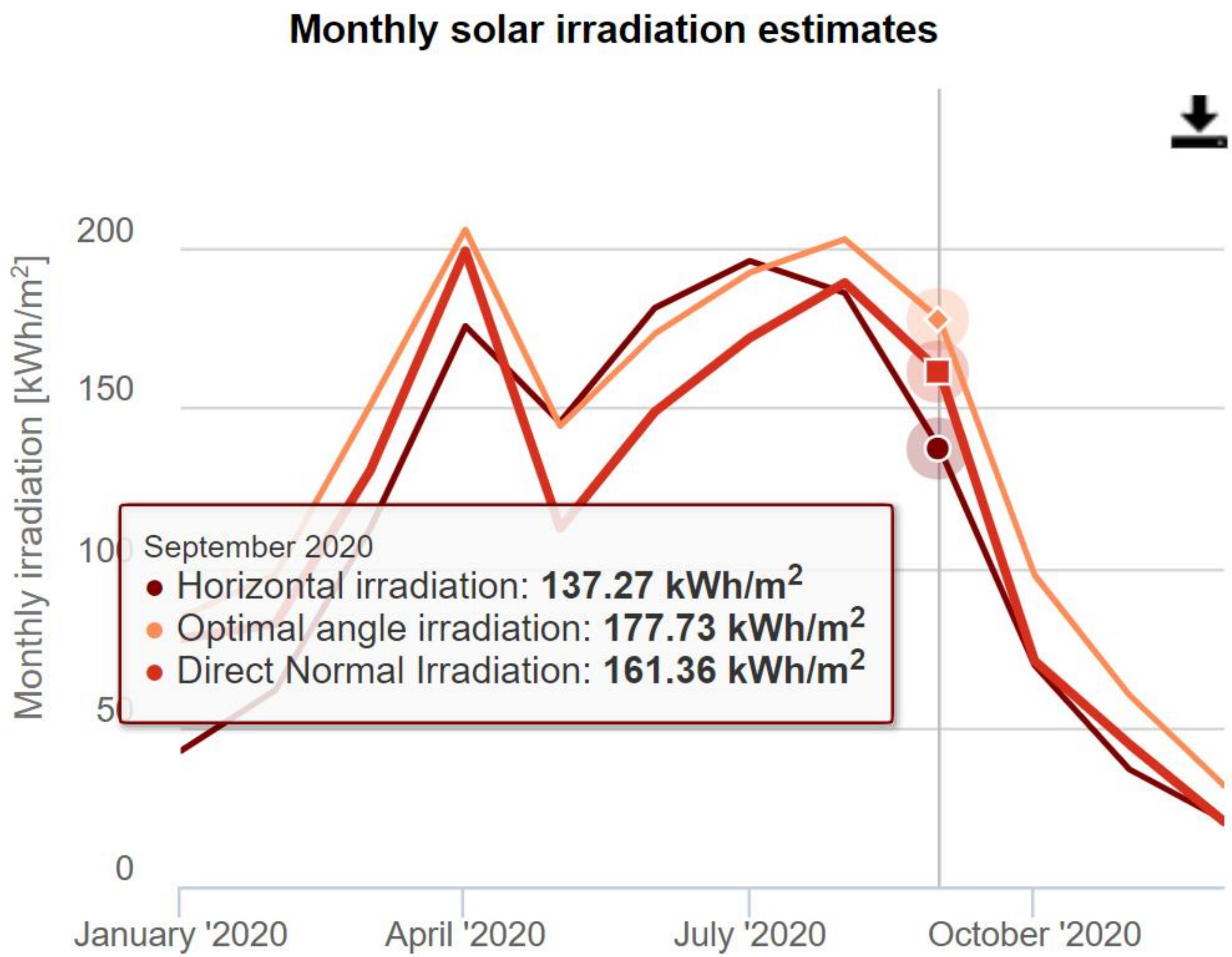
Hb(n)_m: Monthly beam (direct) irradiation on a plane always normal to sun rays (kWh/m2/mo)

Kd: Ratio of diffuse to global irradiation (-)

T2m: 24 hour average of temperature (degree Celsius)

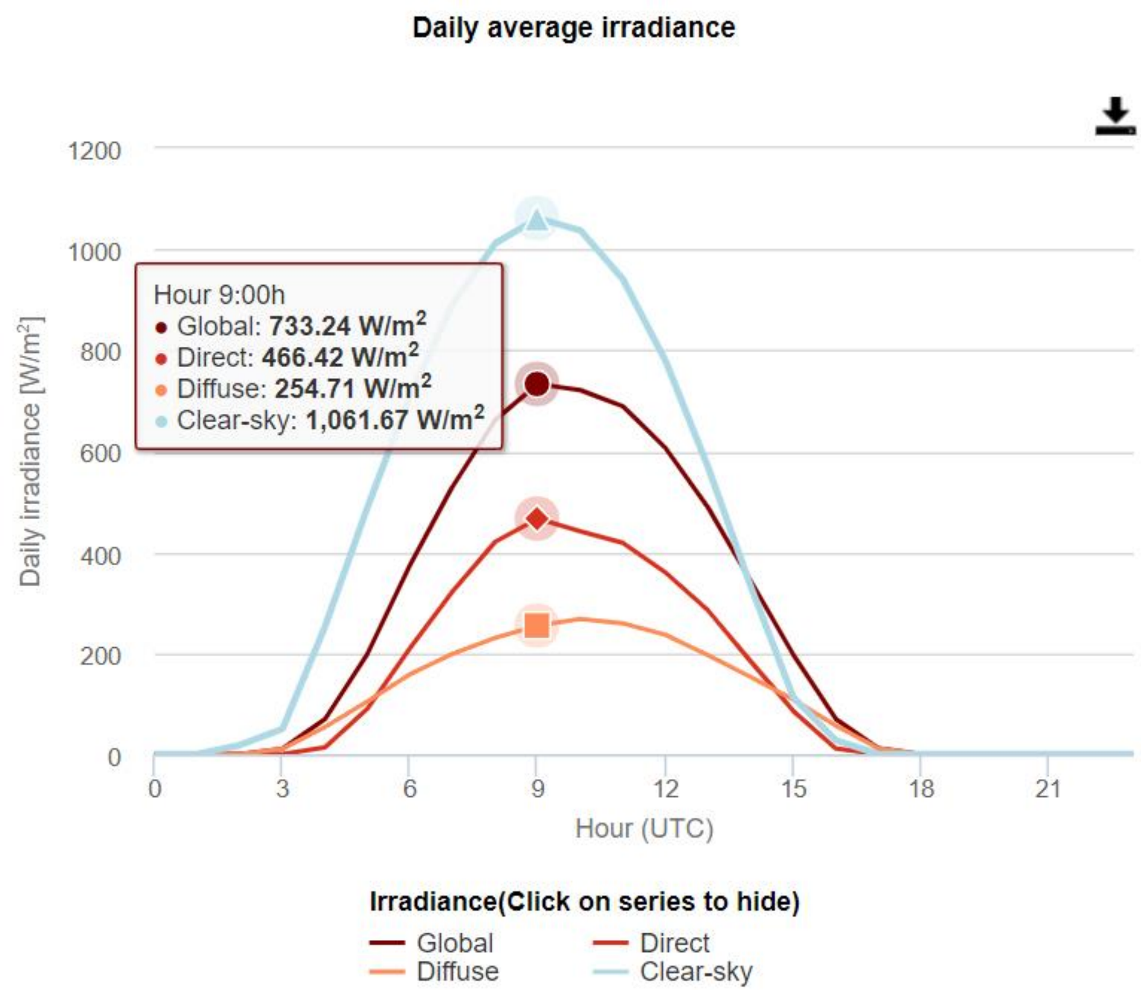
Iasi, date 2020

- Lunar
  - kWh/m²/luna
  - Unghi optim (an) in csv



Iasi, date 2020

- Zi (mai)
  - W/m^2
  - Ore in UTC!! (-3h)
  - Clear sky – conditii ideale



Contact

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- https://ocw.mit.edu/
- **MIT Course Number** 2.627
- Fundamentals of Photovoltaics

- https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
- https://www.pveducation.org/