Some solutions
to the 1st set of problems

- Question 1
- Question 2 (solved and discussed in class)
- Question 3 (solved and discussed in class)
- Question 4.1
- Question 4.2

Question 1

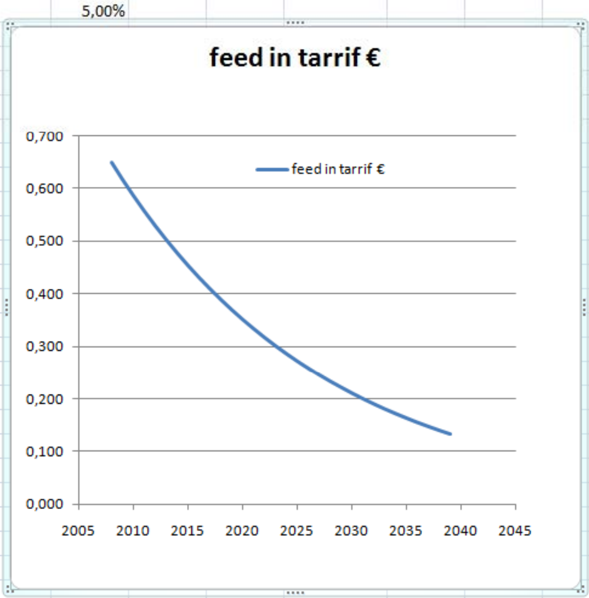
Microgeneration

Considering a yearly fulfilment of the 10MW cap of the Portuguese micro generation law:

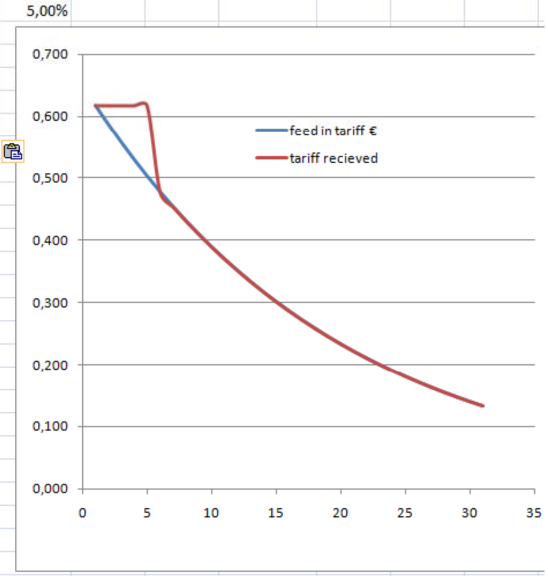
1. How much would a 3.68kW PV system produce in Portugal? [average insolation: 1.5kWh/Wp/year]
2. Determine the income from a PV system with maximum allowed power, installed in 2009 [lifetime: 30 years].
3. Compare with the evolution of the cost of electricity from the grid [12c€/kWh in 2009; 6% annual increment].
4. Assuming typical installation costs [6€/Wp], determine the payback time.

Chart 1

	A	B	C	D	E
1	year	date	feed in tarrif €		yearly decrease of tarrif
2		2008	0,650		5,00%
3	1	2009	0,618		
4	2	2010	0,587		
5	3	2011	0,557		
6	4	2012	0,529		
7	5	2013	0,503		
8	6	2014	0,478		
9	7	2015	0,454		
10	8	2016	0,431		
11	9	2017	0,410		
12	10	2018	0,389		
13	11	2019	0,370		
14	12	2020	0,351		
15	13	2021	0,334		
16	14	2022	0,317		
17	15	2023	0,301		
18	16	2024	0,286		
19	17	2025	0,272		
20	18	2026	0,258		
21	19	2027	0,245		
22	20	2028	0,233		
23	21	2029	0,221		
24	22	2030	0,210		
25	23	2031	0,200		
26	24	2032	0,190		



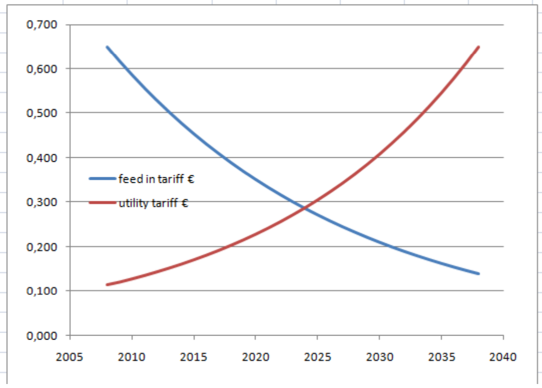
	A	B	C	D	E
1	year	date	feed in tariff €	tariff recieved	yearly decrease of tarrif
2		2008	0,650		5,00%
3	1	2009	0,618	0,618	
4	2	2010	0,587	0,618	
5	3	2011	0,557	0,618	
6	4	2012	0,529	0,618	
7	5	2013	0,503	0,618	
8	6	2014	0,478	0,478	
9	7	2015	0,454	0,454	
10	8	2016	0,431	0,431	
11	9	2017	0,410	0,410	
12	10	2018	0,389	0,389	
13	11	2019	0,370	0,370	
14	12	2020	0,351	0,351	
15	13	2021	0,334	0,334	
16	14	2022	0,317	0,317	
17	15	2023	0,301	0,301	
18	16	2024	0,286	0,286	
19	17	2025	0,272	0,272	
20	18	2026	0,258	0,258	
21	19	2027	0,245	0,245	
22	20	2028	0,233	0,233	
23	21	2029	0,221	0,221	
24	22	2030	0,210	0,210	
25	23	2031	0,200	0,200	
26	24	2032	0,190	0,190	



year	date	feed in tariff €	tariff recieved	utility tariff €
	2008	0,650		0,114
1	2009	0,618	0,618	0,12
2	2010	0,587	0,618	0,127
3	2011	0,557	0,618	0,135
4	2012	0,529	0,618	0,143
5	2013	0,503	0,618	0,151
6	2014	0,478	0,478	0,161
7	2015	0,454	0,454	0,170
8	2016	0,431	0,431	0,180
9	2017	0,410	0,410	0,191
10	2018	0,389	0,389	0,203
11	2019	0,370	0,370	0,215
12	2020	0,351	0,351	0,228
13	2021	0,334	0,334	0,241
14	2022	0,317	0,317	0,256
15	2023	0,301	0,301	0,271
16	2024	0,286	0,286	0,288
17	2025	0,272	0,272	0,305
18	2026	0,258	0,258	0,323
19	2027	0,245	0,245	0,343
20	2028	0,233	0,233	0,363
21	2029	0,221	0,221	0,385
22	2030	0,210	0,210	0,408

yearly decrease of feed in tariff 5,00%

yearly increase of utility tariff 6,00%

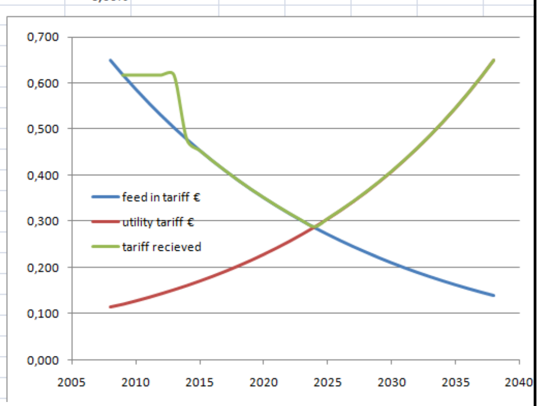


D9 =MAX(C9;E9)

year	date	feed in tariff €	tariff recieved	utility tariff €
	2008	0,650		0,114
1	2009	0,618	0,618	0,12
2	2010	0,587	0,618	0,127
3	2011	0,557	0,618	0,135
4	2012	0,529	0,618	0,143
5	2013	0,503	0,618	0,151
6	2014	0,478	0,478	0,161
7	2015	0,454	0,454	0,170
8	2016	0,431	0,431	0,180
9	2017	0,410	0,410	0,191
10	2018	0,389	0,389	0,203
11	2019	0,370	0,370	0,215
12	2020	0,351	0,351	0,228
13	2021	0,334	0,334	0,241
14	2022	0,317	0,317	0,256
15	2023	0,301	0,301	0,271
16	2024	0,286	0,288	0,288
17	2025	0,272	0,305	0,305
18	2026	0,258	0,323	0,323
19	2027	0,245	0,343	0,343
20	2028	0,233	0,363	0,363
21	2029	0,221	0,385	0,385
22	2030	0,210	0,408	0,408

yearly decrease of feed in tariff 5,00%

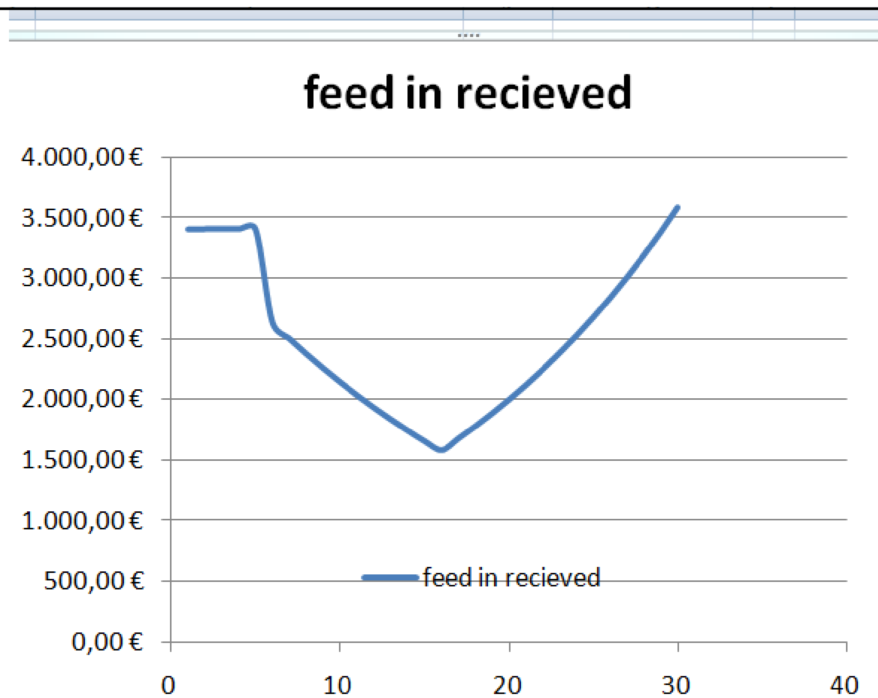
yearly increase of utility tariff 6,00%

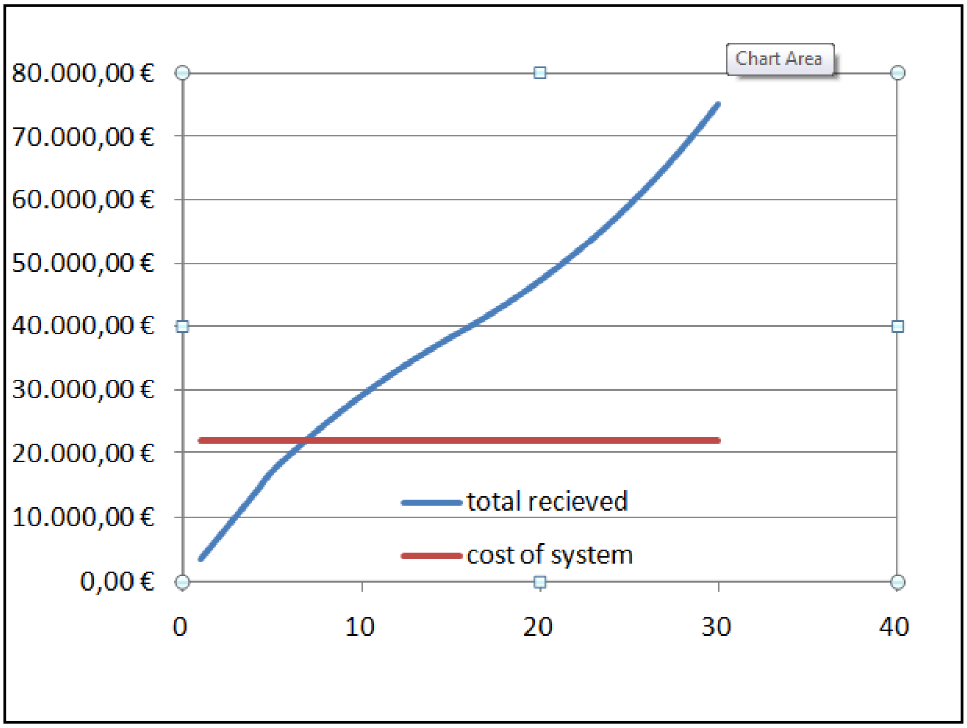


	A	B	C	D	E	F	G	H	I	J	K
1						recieved in lifetime 30 years					
2						75.170,88 €					
3	year	date	feed in tariff €	tariff recieved	utility tariff €	feed in recieved €		Installed Power	3,68	kWp	
4		2008	0,65 €		0,11 €				3680	Wp	
5	1	2009	0,62 €	0,62 €	0,12 €	3.408,60 €		insolation	1,5	kWh/Wp/year	
6	2	2010	0,59 €	0,62 €	0,13 €	3.411,36 €					
7	3	2011	0,56 €	0,62 €	0,13 €	3.411,36 €		Power Produced	5520	kWh/year	
8	4	2012	0,53 €	0,62 €	0,14 €	3.411,36 €					
9	5	2013	0,50 €	0,62 €	0,15 €	3.411,36 €					
10	6	2014	0,48 €	0,48 €	0,16 €	2.637,51 €		yearly decrease of feed in tariff	5,00%		
11	7	2015	0,45 €	0,45 €	0,17 €	2.505,63 €					
12	8	2016	0,43 €	0,43 €	0,18 €	2.380,35 €					
13	9	2017	0,41 €	0,41 €	0,19 €	2.261,33 €		yearly increase of utility tariff	6,00%		
14	10	2018	0,39 €	0,39 €	0,20 €	2.148,27 €					
15	11	2019	0,37 €	0,37 €	0,21 €	2.040,85 €					
16	12	2020	0,35 €	0,35 €	0,23 €	1.938,81 €		Installation Costs	6	€/Wp	
17	13	2021	0,33 €	0,33 €	0,24 €	1.841,87 €					
18	14	2022	0,32 €	0,32 €	0,26 €	1.749,78 €		total cost	22080	€	
19	15	2023	0,30 €	0,30 €	0,27 €	1.662,29 €					
20	16	2024	0,29 €	0,29 €	0,29 €	1.587,48 €					
21	17	2025	0,27 €	0,30 €	0,30 €	1.682,73 €					
22	18	2026	0,26 €	0,32 €	0,32 €	1.783,69 €					
23	19	2027	0,25 €	0,34 €	0,34 €	1.890,71 €					

Installed Power	3,68	kWp
	3680	Wp
insolation	1,5	kWh/Wp/year
Power Produced	5520	kWh/year
yearly decrease of feed in tariff	5,00%	
yearly increase of utility tariff	6,00%	
Installation Costs	6	€/Wp
total cost	22080	€

	A	B	C	D	E	F
1						recieved in lifetime 3
2						75.170,88 €
3	year	date	feed in tariff €	tariff recieved	utility tariff €	feed in recieved €
4		2008	0,65 €		0,11 €	
5	1	2009	0,62 €	0,62 €	0,12 €	3.408,60 €
6	2	2010	0,59 €	0,62 €	0,13 €	3.411,36 €
7	3	2011	0,56 €	0,62 €	0,13 €	3.411,36 €
8	4	2012	0,53 €	0,62 €	0,14 €	3.411,36 €
9	5	2013	0,50 €	0,62 €	0,15 €	3.411,36 €
10	6	2014	0,48 €	0,48 €	0,16 €	2.637,51 €
11	7	2015	0,45 €	0,45 €	0,17 €	2.505,63 €
12	8	2016	0,43 €	0,43 €	0,18 €	2.380,35 €
13	9	2017	0,41 €	0,41 €	0,19 €	2.261,33 €





recieved in lifetime 30 years				
75.170,88 €				
feed in recieved	total recieved	Installed Power	3,68	kWp
			3680	Wp
3.408,60 €	3.408,60 €	insolation	1,5	kWh/Wp/year
3.411,36 €	6.819,96 €			
3.411,36 €	10.231,32 €	Power Produced	5520	kWh/year
3.411,36 €	13.642,68 €			
3.411,36 €	17.054,04 €			
2.637,51 €	19.691,55 €	yearly decrease of feed in tariff	5,00%	
2.505,63 €	22.197,18 €			
2.380,35 €	24.577,54 €			
2.261,33 €	26.838,87 €	yearly increase of utility tariff	6,00%	
2.148,27 €	28.987,14 €			
2.040,85 €	31.027,99 €			
1.938,81 €	32.966,81 €	Installation Costs	6	€/Wp
1.841,87 €	34.808,68 €			
1.749,78 €	36.558,46 €	total cost	22080	€

Other ideas to pursue…

- Include capital cost analysis (initial investment costs money – the law accounts for this through bank loans)

- If the investment was to be made later, say, in 5 years time, would it be more or less profitable?

- The most unpredictable factor in this calculation is clearly the 'expected' rate of increase of electricity prices. Discuss possible growth models,

Question 4.1

Radiation

Determine the photon flux, power density and spectral irradiance for AM0, AM1.5D and AM1.5G. [use spreadsheet and excel data file]

E1

Wavelength (nm)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}
280,0	8,2000E-02	4,7309E-23	2,5361E-26
280,5	9,9000E-02	1,2307E-21	1,0917E-24
281,0	1,5000E-01	5,6895E-21	6,1253E-24
281,5	2,1200E-01	1,5662E-19	2,7479E-22
282,0	2,6700E-01	1,1946E-18	2,8346E-21
282,5	3,0300E-01	4,5436E-18	1,3271E-20
283,0	3,2500E-01	1,8452E-17	6,7646E-20
283,5	3,2300E-01	3,5360E-17	1,4614E-19
284,0	2,9900E-01	7,2670E-16	4,9838E-18
284,5	2,5024E-01	2,4856E-15	2,1624E-17
285,0	1,7589E-01	8,0142E-15	8,9998E-17
285,5	1,5500E-01	4,2613E-14	6,4424E-16
286,0	2,4200E-01	1,3684E-13	2,3503E-15
286,5	3,3300E-01	8,3823E-13	1,8458E-14
287,0	3,6200E-01	2,7367E-12	7,2547E-14
287,5	3,3900E-01	1,0903E-11	3,6618E-13
288,0	3,1100E-01	6,2337E-11	2,8061E-12
288,5	3,2500E-01	1,7162E-10	9,0651E-12
289,0	3,9200E-01	5,6265E-10	3,4978E-11
289,5	4,7900E-01	2,0749E-09	1,5368E-10
290,0	5,6300E-01	6,0168E-09	5,1454E-10
290,5	6,0600E-01	1,3783E-08	1,3303E-09

Note that the wavelength separation is 0.5nm
However this is not the case for the whole wavelength column.
There is an easy solution though...

E3 =(A4-A3)*B3

Wavelength (nm)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}	E
280,0	8,2000E-02	4,7309E-23	2,5361E-26	0,0
280,5	9,9000E-02	1,2307E-21	1,0917E-24	
281,0	1,5000E-01	5,6895E-21	6,1253E-24	
281,5	2,1200E-01	1,5662E-19	2,7479E-22	
282,0	2,6700E-01	1,1946E-18	2,8346E-21	
282,5	3,0300E-01	4,5436E-18	1,3271E-20	
283,0	3,2500E-01	1,8452E-17	6,7646E-20	
283,5	3,2300E-01	3,5360E-17	1,4614E-19	
284,0	2,9900E-01	7,2670E-16	4,9838E-18	
284,5	2,5024E-01	2,4856E-15	2,1624E-17	
285,0	1,7589E-01	8,0142E-15	8,9998E-17	

This is the power density within the range of wavelengths between 280,0 and 280,5nm

E4 | =E3+($A5-$A4)*B3

	A	B	C	D	E
1					
2	Wavelength (nm)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}	
3	280,0	8,2000E-02	4,7309E-23	2,5361E-26	0,0
4	280,5	9,9000E-02	1,2307E-21	1,0917E-24	0,1
5	281,0	1,5000E-01	5,6895E-21	6,1253E-24	0,1
6	281,5	2,1200E-01	1,5662E-19	2,7479E-22	0,2
7	282,0	2,6700E-01	1,1946E-18	2,8346E-21	0,3
8	282,5	3,0300E-01	4,5436E-18	1,3271E-20	0,4
9	283,0	3,2500E-01	1,8452E-17	6,7646E-20	0,6

The next line of the column is different, as we can now add the previous number is E3.

SUM | =E2003+($A2005-$A2004)*B2003

	A	B	C	D	E	F
1						
2	Wavelength (nm)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}		
1994	3950,0	9,1100E-03	7,6277E-03	7,6475E-03	1350,0	
1995	3955,0	9,0800E-03	7,7199E-03	7,7399E-03	1350,1	
1996	3960,0	9,0200E-03	7,7482E-03	7,7679E-03	1350,1	
1997	3965,0	9,0100E-03	7,8057E-03	7,8253E-03	1350,2	
1998	3970,0	8,9300E-03	7,6806E-03	7,6997E-03	1350,2	
1999	3975,0	8,9100E-03	7,5097E-03	7,5280E-03	1350,2	
2000	3980,0	8,8400E-03	7,3872E-03	7,4049E-03	1350,3	
2001	3985,0	8,8000E-03	7,4327E-03	7,4503E-03	1350,3	
2002	3990,0	8,7800E-03	7,3723E-03	7,3894E-03	1350,4	
2003	3995,0	8,7000E-03	7,2100E-03	7,2263E-03	1350,4	
2004	4000,0	8,6800E-03	7,1043E-03	7,1	=E2003+($A2005-$A2004)*B200	
2005						

One has to be carefull with the last number in the column as the next wavelength value is non-existante

7,4327E-03	7,4503E-03	1350,3
7,3723E-03	7,3894E-03	1350,4
7,2100E-03	7,2263E-03	1350,4
7,1043E-03	7,1	=E2003+($A2005-$A2004)*B2003

7,3894E-03	1350,4
7,2263E-03	1350,4
7,1	=E2003+($A2004-$A2003)*B2003

E1 | fx | =E2005

	A	B	C	D	E
1				Power Density W/m^{-2}	1350,5
2					
3	Wavelength (nm)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}	
4	280,0	8,2000E-02	4,7309E-23	2,5361E-26	0,0
5	280,5	9,9000E-02	1,2307E-21	1,0917E-24	0,1
6	281,0	1,5000E-01	5,6895E-21	6,1253E-24	0,1
7	281,5	2,1200E-01	1,5662E-19	2,7479E-22	0,2
8	282,0	2,6700E-01	1,1946E-18	2,8346E-21	0,3
9	282,5	3,0300E-01	4,5436E-18	1,3271E-20	0,4
10	283,0	3,2500E-01	1,8452E-17	6,7646E-20	0,6
11	283,5	3,2300E-01	3,5360E-17	1,4614E-19	0,8
12	284,0	2,9900E-01	7,2670E-16	4,9838E-18	0,9
13	284,5	2,5024E-01	2,4856E-15	2,1624E-17	1,1
14	285,0	1,7589E-01	8,0142E-15	8,9998E-17	1,2
15	285,5	1,5500E-01	4,2613E-14	6,4424E-16	1,3

The power density for whole spectrum is the sum of the individual power densities for each wavelength

	A	B	C	D	E	F	G
1				Power Density W/m^{-2}	1350,5	1002,4	901,9
2							
3	Wavelength (nm)	Extraterrestrial $W*m^{-2}*nm^{-1}$	Global tilt $W*m^{-2}*nm^{-1}$	Direct $W*m^{-2}*nm^{-1}$	Extraterrestrial $W*m^{-2}*nm^{-1}$	Global tilt $W*m^{-2}*nm^{-1}$	Direct $W*m^{-2}*nm^{-1}$
4	280,0	8,2000E-02	4,7309E-23	2,5361E-26	0,0	0,0	0,0
5	280,5	9,9000E-02	1,2307E-21	1,0917E-24	0,1	0,0	0,0
6	281,0	1,5000E-01	5,6895E-21	6,1253E-24	0,1	0,0	0,0
7	281,5	2,1200E-01	1,5662E-19	2,7479E-22	0,2	0,0	0,0
8	282,0	2,6700E-01	1,1946E-18	2,8346E-21	0,3	0,0	0,0
9	282,5	3,0300E-01	4,5436E-18	1,3271E-20	0,4	0,0	0,0
10	283,0	3,2500E-01	1,8452E-17	6,7646E-20	0,6	0,0	0,0
11	283,5	3,2300E-01	3,5360E-17	1,4614E-19	0,8	0,0	0,0
12	284,0	2,9900E-01	7,2670E-16	4,9838E-18	0,9	0,0	0,0
13	284,5	2,5024E-01	2,4856E-15	2,1624E-17	1,1	0,0	0,0
14	285,0	1,7589E-01	8,0142E-15	8,9998E-17	1,2	0,0	0,0
15	285,5	1,5500E-01	4,2613E-14	6,4424E-16	1,3	0,0	0,0

reference spectra

Photon Flux?

We have $Wm^{-2}nm^{-1}$

What is the energy of a photon?

$E_{photon}=h\nu$

$c=\nu\lambda$

So: $E_{photon}=hc/\lambda$

Or for handfull of photons n the total energy is $E_{n\ photons}=nhc/\lambda$

λ - photon wavelength
c – photon speed, speed of light
ν - photon frequency
h - plank's constant

B7 | fx | =$B$2*$B$1/(A7*0,000000001)

	A	B	C	D	E
1	c	3,00E+08	m s^{-1}		
2	h	6,63E-34	J s		
3					
4					
5					
6	**Wavelength (nm)**	**Photon Energy (J)**	**Extraterrestrial $W*m^{-2}*nm^{-1}$**	**Global tilt $W*m^{-2}*nm^{-1}$**	**Direct $W*m^{-2}*nm^{-1}$**
7	280,0	7,09E-19	8,20E-02	4,73E-23	2,54E-26
8	280,5		9,90E-02	1,23E-21	1,09E-24
9	281,0		1,50E-01	5,69E-21	6,13E-24
10	281,5		2,12E-01	1,57E-19	2,75E-22
11	282,0		2,67E-01	1,19E-18	2,83E-21
12	282,5		3,03E-01	4,54E-18	1,33E-20
13	283,0		3,25E-01	1,85E-17	6,76E-20
14	283,5		3,23E-01	3,54E-17	1,46E-19
15	284,0		2,99E-01	7,27E-16	4,98E-18
16	284,5		2,50E-01	2,49E-15	2,16E-17
17	285,0		1,76E-01	8,01E-15	9,00E-17
18	285,5		1,55E-01	4,26E-14	6,44E-16

A usual way of expressing photon energy is in electron volts eV, just devide the energy by the fundamental electric charge of an electron, 1.6e-19 C.

C7 | fx | =B7/1,6E-19

	A	B	C	D	E	F
2	h	6,63E-34	J s			
3						
4						
5						
6	**Wavelength (nm)**	**Photon Energy (J)**	**Photon Energy (eV)**	**Extraterrestrial $W*m^{-2}*nm^{-1}$**	**Global tilt $W*m^{-2}*nm^{-1}$**	**Direct $W*m^{-2}*nm^{-1}$**
7	280,0	7,09E-19	4,43E+00	8,20E-02	4,73E-23	2,54E-26
8	280,5			9,90E-02	1,23E-21	1,09E-24
9	281,0			1,50E-01	5,69E-21	6,13E-24
10	281,5			2,12E-01	1,57E-19	2,75E-22
11	282,0			2,67E-01	1,19E-18	2,83E-21
12	282,5			3,03E-01	4,54E-18	1,33E-20
13	283,0			3,25E-01	1,85E-17	6,76E-20
14	283,5			3,23E-01	3,54E-17	1,46E-19
15	284,0			2,99E-01	7,27E-16	4,98E-18
16	284,5			2,50E-01	2,49E-15	2,16E-17
17	285,0			1,76E-01	8,01E-15	9,00E-17
18	285,5			1,55E-01	4,26E-14	6,44E-16
19	286,0			2,42E-01	1,37E-13	2,35E-15

The electron volt (eV) is a convenient form of expressing photon energy, as this makes relating phton energy with electron energy more facile.
E.g. an important number in silicon PV is the bangap of silicon which is approx. 1.12eV. The importance of the number will become apparent in the later classes.

$E_{n\ photons}$=nhc/λ

We want n, photon flux $E_{n\ photons}$ λ /hc = n

G7 | =D7/B7

	A	B	C	D	E	F	G
3							
4							
5							
6	Wavelength (nm)	Photon Energy (J)	Photon Energy (eV)	Extraterrestrial $W*m^{-2}*nm^{-1}$	Global tilt $W*m^{-2}*nm^{-1}$	Direct $W*m^{-2}*nm^{-1}$	Photon Flux Extra. $m^{-2}*nm^{-1}$
7	280,0	7,09E-19	4,43	8,20E-02	4,73E-23	2,54E-26	1,16E+17
8	280,5	7,08E-19	4,42	9,90E-02	1,23E-21	1,09E-24	

We need to be more carefull with the addition of the photon fluxes for each data point. The data is "per nanometer" but the data points are not separated by 1 nanometer at a time, so we have to do the same as before. Note column title is not strictly correct!

G7 | =D7/$B7*($A8-$A7)

	A	B	C	D	E	F	G	H
3								
4								
5								
6	Wavelength (nm)	Photon Energy (J)	Photon Energy (eV)	Extraterrestrial $W*m^{-2}*nm^{-1}$	Global tilt $W*m^{-2}*nm^{-1}$	Direct $W*m^{-2}*nm^{-1}$	Photon Flux Extra. $m^{-2}*nm^{-1}$	
7	280,0	7,09E-19	4,43	8,20E-02	4,73E-23	2,54E-26	5,78E+16	
8	280,5	7,08E-19	4,42	9,90E-02	1,23E-21	1,09E-24		

SUM | =D2008/$B2008*($A2008-$A2007)

	A	B	C	D	E	F	G	H
3								
4								
5								
6	Wavelength (nm)	Photon Energy (J)	Photon Energy (eV)	Extraterrestrial $W*m^{-2}*nm^{-1}$	Global tilt $W*m^{-2}*nm^{-1}$	Direct $W*m^{-2}*nm^{-1}$	Photon Flux Extra. $m^{-2}*nm^{-1}$	
1994	3930,0	5,05E-20	0,32	9,32E-03	7,05E-03	7,07E-03	9,22E+17	
1995	3935,0	5,05E-20	0,32	9,30E-03	7,35E-03	7,37E-03	9,21E+17	
1996	3940,0	5,04E-20	0,32	9,23E-03	7,40E-03	7,42E-03	9,16E+17	
1997	3945,0	5,03E-20	0,31	9,20E-03	7,54E-03	7,56E-03	9,14E+17	
1998	3950,0	5,03E-20	0,31	9,11E-03	7,63E-03	7,65E-03	9,06E+17	
1999	3955,0	5,02E-20	0,31	9,08E-03	7,72E-03	7,74E-03	9,04E+17	
2000	3960,0	5,01E-20	0,31	9,02E-03	7,75E-03	7,77E-03	8,99E+17	
2001	3965,0	5,01E-20	0,31	9,01E-03	7,81E-03	7,83E-03	8,99E+17	
2002	3970,0	5,00E-20	0,31	8,93E-03	7,68E-03	7,70E-03	8,93E+17	
2003	3975,0	5,00E-20	0,31	8,91E-03	7,51E-03	7,53E-03	8,92E+17	
2004	3980,0	4,99E-20	0,31	8,84E-03	7,39E-03	7,40E-03	8,86E+17	
2005	3985,0	4,98E-20	0,31	8,80E-03	7,43E-03	7,45E-03	8,83E+17	
2006	3990,0	4,98E-20	0,31	8,78E-03	7,37E-03	7,39E-03	8,82E+17	
2007	3995,0	4,97E-20	0,31	8,70E-03	7,21E-03	7,23E-03	8,75E+17	
2008	4000,0	4,96E-20	0,31	8,68E-03	7,10E-03	7,12E-03	=D2008/$B2008*($A2008-$A2007)	
2009								

Check the last number of the column is correct...

	A	B	C	D	E	F	G	H	I
1	c	3,00E+08	m s^{-1}						
2	h	6,63E-34	J s						
3						Photon Flux m^{-2}	6,15E+21	4,31E+21	3,99E+21
4									
5									
6	Wavelength (nm)	Photon Energy (J)	Photon Energy (eV)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}	Photon Flux Extra. m^{-2}*nm^{-1}	Photon Flux Extra. m^{-2}*nm^{-1}	Photon Flux Direct m^{-2}*nm^{-1}
1994	3930,0	5,05E-20	0,32	9,32E-03	7,05E-03	7,07E-03	9,22E+17	6,98E+17	7,00E+17
1995	3935,0	5,05E-20	0,32	9,30E-03	7,35E-03	7,37E-03	9,21E+17	7,29E+17	7,31E+17
1996	3940,0	5,04E-20	0,32	9,23E-03	7,40E-03	7,42E-03	9,16E+17	7,34E+17	7,36E+17
1997	3945,0	5,03E-20	0,31	9,20E-03	7,54E-03	7,56E-03	9,14E+17	7,49E+17	7,51E+17
1998	3950,0	5,03E-20	0,31	9,11E-03	7,63E-03	7,65E-03	9,06E+17	7,59E+17	7,61E+17
1999	3955,0	5,02E-20	0,31	9,08E-03	7,72E-03	7,74E-03	9,04E+17	7,69E+17	7,71E+17
2000	3960,0	5,01E-20	0,31	9,02E-03	7,75E-03	7,77E-03	8,99E+17	7,73E+17	7,75E+17
2001	3965,0	5,01E-20	0,31	9,01E-03	7,81E-03	7,83E-03	8,99E+17	7,79E+17	7,81E+17
2002	3970,0	5,00E-20	0,31	8,93E-03	7,68E-03	7,70E-03	8,93E+17	7,68E+17	7,70E+17
2003	3975,0	5,00E-20	0,31	8,91E-03	7,51E-03	7,53E-03	8,92E+17	7,52E+17	7,53E+17
2004	3980,0	4,99E-20	0,31	8,84E-03	7,39E-03	7,40E-03	8,86E+17	7,40E+17	7,42E+17
2005	3985,0	4,98E-20	0,31	8,80E-03	7,43E-03	7,45E-03	8,83E+17	7,46E+17	7,48E+17
2006	3990,0	4,98E-20	0,31	8,78E-03	7,37E-03	7,39E-03	8,82E+17	7,41E+17	7,42E+17
2007	3995,0	4,97E-20	0,31	8,70E-03	7,21E-03	7,23E-03	8,75E+17	7,25E+17	7,27E+17
2008	4000,0	4,96E-20	0,31	8,68E-03	7,10E-03	7,12E-03	8,74E+17	7,16E+17	7,17E+17
2009									

reference spectra / power density / photon flux

Select destination and press ENTER or choose Paste

Do the same for the other two columns to obtain the total photon flux for the differing spectra

SUM =SUM(G7:G3000)

	A	B	C	D	E	F	G
1	c	3,00E+08	m s^{-1}			Photon Flux m^{-2}	=SUM(G7:G3000)
2	h	6,63E-34	J s				
3							
4							
5							
6	Wavelength (nm)	Photon Energy (J)	Photon Energy (eV)	Extraterrestrial W*m^{-2}*nm^{-1}	Global tilt W*m^{-2}*nm^{-1}	Direct W*m^{-2}*nm^{-1}	Photon Flux Extra. m^{-2}*nm^{-1}
1994	3930,0	5,05E-20	0,32	9,32E-03	7,05E-03	7,07E-03	9,22E+17
1995	3935,0	5,05E-20	0,32	9,30E-03	7,35E-03	7,37E-03	9,21E+17
1996	3940,0	5,04E-20	0,32	9,23E-03	7,40E-03	7,42E-03	9,16E+17

We've done things a little differently than from the last time, but the result is the same.
Use the SUM command to add up all the values in the column to have the photon flux for a meter square

Question 4.2

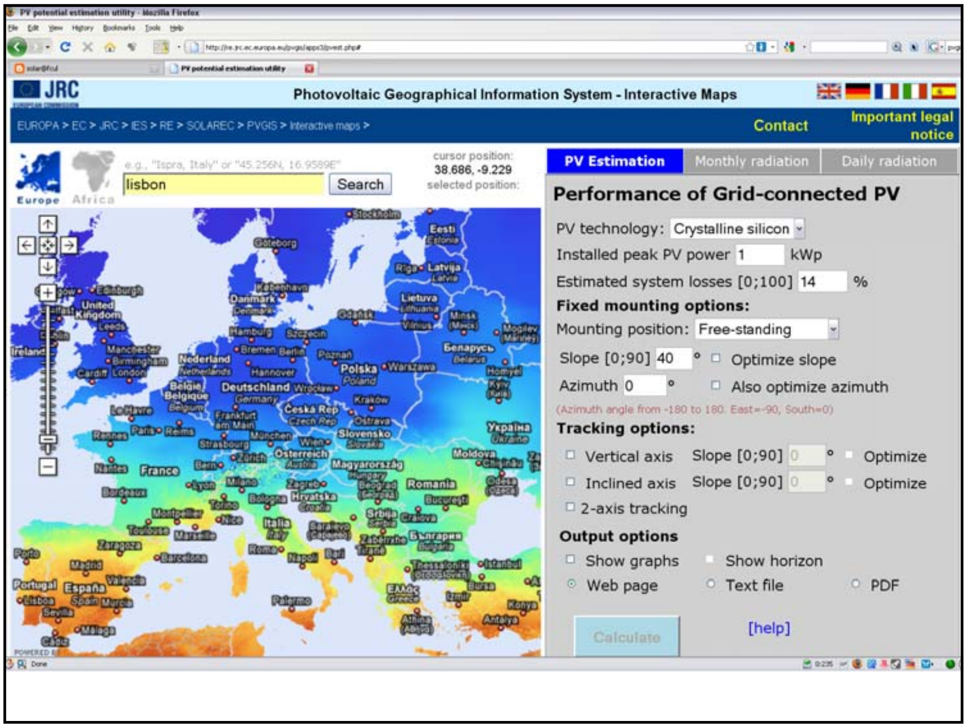
Radiation

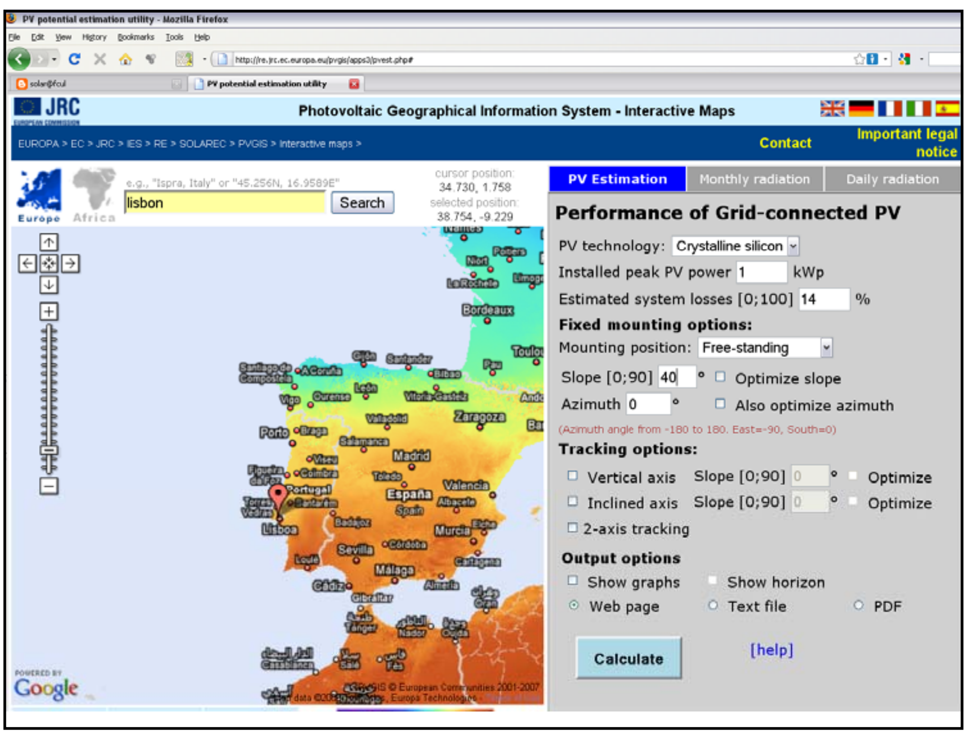
Use the PVGIS tool to determine the increase in yield using monthly inclination adjustment [reference: fixed system with optimum inclination for location; use insolation data for your hometown]

Open PVGIS interactive maps
http://re.jrc.ec.europa.eu/pvgis/imaps/index.htm

Open the Interactive access to solar resource and PV potential
http://re.jrc.ec.europa.eu/pvgis/apps3/pvest.php#

Select location, PV system orientation, inclination, etc and Calculate!


PV potential estimation utility - Mozilla Firefox
JRC
Photovoltaic Geographical Information System - Interactive Maps
EUROPA > EC > JRC > IES > RE > SOLAREC > PVGIS > Interactive maps >
Contact
Important legal notice
Europe
Africa
lisbon
Search
cursor position:
38.686, -9.229
selected position:
PV Estimation
Monthly radiation
Daily radiation
Performance of Grid-connected PV
PV technology: Crystalline silicon
Installed peak PV power 1 kWp
Estimated system losses [0;100] 14 %
Fixed mounting options:
Mounting position: Free-standing
Slope [0;90] 40 ° Optimize slope
Azimuth 0 ° Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)
Tracking options:
Vertical axis Slope [0;90] 0 ° Optimize
Inclined axis Slope [0;90] 0 ° Optimize
2-axis tracking
Output options
Show graphs Show horizon
Web page Text file PDF
Calculate
[help]


PV potential estimation utility - Mozilla Firefox
JRC
Photovoltaic Geographical Information System - Interactive Maps
EUROPA > EC > JRC > IES > RE > SOLAREC > PVGIS > Interactive maps >
Contact
Important legal notice
Europe
Africa
lisbon
Search
cursor position:
34.730, 1.758
selected position:
38.754, -9.229
PV Estimation
Monthly radiation
Daily radiation
Performance of Grid-connected PV
PV technology: Crystalline silicon
Installed peak PV power 1 kWp
Estimated system losses [0;100] 14 %
Fixed mounting options:
Mounting position: Free-standing
Slope [0;90] 40 ° Optimize slope
Azimuth 0 ° Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)
Tracking options:
Vertical axis Slope [0;90] 0 ° Optimize
Inclined axis Slope [0;90] 0 ° Optimize
2-axis tracking
Output options
Show graphs Show horizon
Web page Text file PDF
Calculate
[help]
Google

PV power estimate information - Mozilla Firefox

http://re.jrc.ec.europa.eu/pvgis/apps3/PVcalc.php

Performance of Grid-connected PV

NOTE: before using these calculations for anything serious, you should read [this]

PVGIS estimates of solar electricity generation

Location: 38°45'14" North, 9°13'42" West, Elevation: 136 m a.s.l.,
Nearest city: Queluz, Portugal (2 km away)

Nominal power of the PV system: 1.0 kW (crystalline silicon)
Estimated losses due to temperature: 10.6% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.6%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 25.1%

Fixed system: inclination=40°, orientation=0°

Month	E_d	E_m	H_d	H_m
Jan	2.88	89.4	3.65	113
Feb	3.02	84.6	3.89	109
Mar	4.18	130	5.49	170
Apr	3.98	119	5.30	159
May	4.27	133	5.75	178
Jun	4.41	132	6.06	182
Jul	4.58	142	6.35	197
Aug	4.69	145	6.50	202
Sep	4.39	132	6.01	180
Oct	3.77	117	5.04	156
Nov	2.77	83.2	3.64	109
Dec	2.60	80.7	3.34	104
Yearly average	**3.80**	**116**	**5.09**	**155**
Total for year		**1390**		**1860**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

some solutions - Microsoft Excel

E_m: Average monthly electricity production from the given system (kWh)

Location: 38°41'7" North, 9°18'59" West, Elevation: 28 m a.s.l., Nearest city: Parede, Portugal (3 km away)

Inclination	0	10	20	30	34	40	50	60	70	80	90	Mensal	2-axis tracking
Jan	50.6	63.4	74.2	82.9	85.8	89.4	93.5	95.2	94.4	91.2	85.6	95.2	110
Feb	59	68.3	75.9	81.5	83.3	85.2	86.9	86.4	83.8	79.1	72.3	86.9	104
Mar	105	116	124	129	130	131	130	126	118	108	93.5	131	170
Apr	118	123	125	125	125	122	117	108	97.2	83.5	67.2	125	166
May	146	148	146	142	140	135	125	112	95.8	77.1	56.5	148	196
Jun	155	155	151	145	141	135	123	107	89.1	68.8	47.3	155	212
Jul	164	164	161	155	152	146	133	117	98	76.4	52.9	164	228
Aug	150	155	157	155	153	149	140	128	112	92.5	70.1	157	218
Sep	115	124	131	135	135	135	132	126	116	103	87.1	135	182
Oct	84.5	97.1	107	115	117	119	121	119	115	107	96.6	121	150
Nov	52	63	72.2	79.5	81.9	84.8	87.8	88.8	87.6	84.1	78.6	88.8	105
Dec	44.5	56.5	67	75.5	78.3	81.9	86.1	88.1	87.9	85.5	80.9	88.1	102
Total year	1243.6	1333.3	1391.3	1420.4	1422.3	1413.3	1375.3	1301.5	1194.8	1056.2	888.6	1495	1943

Table shows variation of monthly electricity production for different inclinations.
Monthly optimization corresponds to maximum (shown in yellow).
Over one year, it's about 5% better than constant optimum (34º for Lisbon),
probably not worth it, unless you don't have anything else to do…