IEA INTERNATIONAL ENERGY AGENCY

Compared assessment of selected environemental indicators of photovoltaic electricity in OECD cities

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS-T10-01:2006

INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

COMPARED ASSESSMENT OF SELECTED ENVIRONMENTAL INDICATORS OF PHOTOVOLTAIC ELECTRICITY IN OECD CITIES

IEA PVPS Task 10, Activity 4.4

Report IEA-PVPS T10-01:2006

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Contents

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its member countries. The European Commission also participates in the work of the IEA.
The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative R & D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity.

The mission of the Photovoltaic Power Systems Programme is “to enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option”. The underlying assumption is that the market for PV systems is gradually expanding from the present niche markets of remote applications and consumer products, to the rapidly growing markets for building-integrated and other diffused and centralised PV generation systems.

The overall programme is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By the end of 2005, ten Tasks were established within the PVPS programme.

The objective of Task 10 is to enhance the opportunities for wide-scale, solution-oriented application of photovoltaics (PV) in the urban environment as part of an integrated approach that maximizes building energy efficiency and solar thermal and Photovoltaics usage. The Task’s long term goal is for urban-scale PV to be a desirable and commonplace feature of the urban environment in IEA PVPS member countries.

This technical report has been prepared by Bruno Gaiddon and Marc Jedliczka, Hespul, Villeurbanne, France under the supervision of PVPS Task 10 and in co-operation with the experts of the following countries: Christy Herig, Operating Agent, Segue Energy Consulting, Redington Shores, United States of America, Maria Joâo Rodrigues, Centre for Innovation Technology and Policy Research, Lisbon, Portugal and Kenn H.B. Frederiksen, EnergiMidt A/S, Braedstrup, Denmark and with the help of Erik A. Alsema, Copernicus Institute of Sustainable Development and Innovation, Utrecht , The Netherlands.

The report expresses, as nearly as possible, the international consensus of opinion of the Task 10 experts on the subjects dealt with.

Further information on the activities and results of the Task can be found at:
http://www.iea-pvps-task10.org and http://www.iea-pvps.org.

Introduction

Photovoltaic (PV) based electricity production is pollution-free at the local as well as the global level, it does not emit greenhouse gases, it does not dip into finite fossil fuel resources and it can be easily integrated into the urban environment, close to major consumption needs.

Photovoltaic systems are therefore among the most efficient means to reduce the use of "conventional electricity" - i.e. made from hydrocarbon - and their negative impacts on the environment.

However, prior to producing electricity, manufacturing and installing PV systems and later on dismantling and recycling them require spending a certain amount of energy, which must be "reimbursed" before PV can be considered as renewable and clean.

Although the qualification of photovoltaics as a renewable energy has long been considered as definitively unquestionable among the "PV community" worldwide, there are still rumours circulating here and there about the actual capability of PV to reimburse its "embedded energy" content.

Based on the latest available scientific publications at the time of writing, the main objective of the present study is to provide clear and well-documented answers to politicians, decision-makers and the general public about what PV can and cannot achieve.

Through this publication, the authors hope to contribute to a better understanding of PV potential by closing the debate on an unjustified controversy and by providing clear and useful information to all interested people, most importantly to national and local decision-makers in OECD countries, who will inevitably have to deal with PV in the coming years considering its huge potential for deployment at large scale on the short to medium term.

Executive Summary

Photovoltaic (PV) based electricity production is pollution-free at the local as well as the global level, it does not emit greenhouse gases, it does not dip into finite fossil fuel resources and it can be easily integrated into the urban environment, close to major consumption needs. However, prior to producing electricity, manufacturing and installing PV systems and later on dismantling and recycling them require spending a certain amount of energy, which must be “reimbursed” before PV can be considered as renewable and clean. The purpose of this report is to provide clear and well-documented answers to politicians, decision-makers and the general public about what PV can and cannot achieve in terms of renewable, clean energy production and environmental protection.

The conclusion of this study is that, depending on the location, rooftop-mounted PV systems produce the amount of energy so as to recover their energy content from manufacturing and recycling in the range of 1.6 to 3.3 years and produce during their energy production period or service life between 17.9 and 8 times their initial energy content. Once they have reimbursed their initial energy input, rooftop-mounted PV systems can avoid, during their lifetime, the emission of up to 40 tons of CO_2 depending on their location and on the local electricity mix available.

Results for PV facades are logically slightly worse than for roof-top PV systems since they produce less energy for the same installed power. They produce the amount of energy to recover their energy content from manufacturing and recycling in the range of 2,7 to 4,7 years and produce during their service life between 10,1 and 5,4 times their initial energy content. Their contribution to CO_2 emissions mitigation can be up to 23 tons of CO_2 per kWp installed.

The first part of this report describes the methodology used for the calculation of two energy indicators, the “Energy Payback Time” (EPBT) and the “Energy Return Factor (ERF) and one environmental indicator, the potential for CO_2 emissions mitigation. All factors are dependant on the PV installation location. EPBT and ERF are calculated with the yearly energy production which depends on the amount of sun at a location and the environmental indicator depends on the local electricity mix. The performance of PV systems is therefore assessed on a country-by-country basis and even a city-by-city approach in larger countries where the potential for urban-scale integrated PV is highest, with a view to both better reflect the varying reality and to facilitate the use of the results at national and local levels. The global range for 41 main cities in 26 OECD countries are presented in the second section of the study and detailed results on a country-by-country - and city-by-city when relevant - basis are given in the third part. Finally, some indications of comparison and ranking between countries are given in annexes for the purpose of comparison of an individual country’s performance amongst the others.

These figures clearly demonstrate how beneficial urban-scale PV systems are for reducing the use of highly polluting conventional energy sources and for contributing to improving the general efficiency of large cities wherever they are located worldwide. Country results can be used to raise the awareness of politicians and decision-makers at national level in order to accelerate the development and the deployment of PV technologies in a given country.

1 Definitions, methodology and assumptions

1.1 Definition of Urban Scale Photovoltaic Systems

For the purpose of this study, only grid-connected PV-systems that are made of mainstream components available on the market (standard multi-crystalline silicon modules and standard grid-tied inverters) and architecturally integrated in buildings are considered.

Since the tilt angle of the modules when installed has a significant impact on the annual energy output of the PV systems, and therefore on their environmental benefits, the two most common types of PV systems are considered:

- Rooftop-mounted systems with a tilt angle of 30° (see figure 1)
- PV façades with a tilt angle of 90° (see figure 2)

It is furthermore assumed that all PV systems are installed in the most favourable conditions, i.e. facing South and without any shade at any hour of the day in all seasons. Thus, results found for rooftop-mounted PV systems can be considered as optimistic values and results for PV façades as pessimistic values so that the environmental benefits of a broad range of PV systems, for instance not ideally oriented, can also be evaluated

Figure 1 - 131 kWp Solar PV Community in The Netherlands (source: Bear Architecten)

Figure 2 - 92 kWp Solar PV Community in France (source: ADEME)

1.2 Definition of indicators used

Consistent with the position of PV as an energy technology and with the fact that energy consumption is the major contributor to the environmental impacts of crystalline silicon PV [1], the study focuses on two energy indicators, the “Energy Pay Back Time” (EPBT) and the “Energy Return Factor” (ERF), and one environmental indicator considered as the most relevant indicator at global level (potential for CO_2 emissions), given the fact that it is assessed that the electricity produced by PV systems will substitute to the local energy mix composed mainly of conventional energy sources.

Energy indicators used are:

- the “Energy Pay Back Time” (EPBT), defined as the ratio of the total energy input during the system life cycle and the yearly energy generation during system operation, both should be of course expressed in the same unit, either in primary energy or in final electrical energy [1]. The EPBT is expressed in years,

- the “Energy Return Factor” (ERF) defined as the ratio of the total energy generation during the system operation lifetime and the total energy input during the system life cycle. An ERF equal to ten means that a PV system produces ten times more energy than it consumes throughout its life cycle. The ERF is expressed as a single figure with no unit.

The environmental indicator used is:

- the “Potential for CO_2 Mitigation” defined as the quantity of greenhouse gas emissions that will be avoided by a given PV system. It is calculated by multiplying the energy output of a PV system during its lifetime by the average CO_2 content of the local electricity mix (taken at national level). It is expressed in tons of CO_2 per kWp installed.

This last indicator of course makes sense only after PV systems have paid back their energy input.

Another approach adopted by some scientific studies is to consider the greenhouse gas content of PV systems themselves rather than their substitution potential as production facilities.

It has been decided not to assess this value in the framework of the present study because this is a task that must be performed separately for each manufacturer and even for each single factory, which is hardly compatible with the usual confidentiality of sensitive production data.

In addition this value does not depend only on the PV technology used, but also on the electricity mix of the different locations where the different components are manufactured, and this mix can change at any time when switching from one electricity supplier to another.

Finally this approach does not make much sense when considered at global level, simply leading to the irrelevant conclusion that PV components manufacturing should be concentrated where the electricity mix is carbon-free.

1.3 Detailed methodology

The main innovation of the present study lies in the assessment of the environmental benefits of PV systems for a broad range of specific locations where PV systems can be installed and produce electricity. The methodology used is divided into 7 steps:

1- Selection of a sample of cities representative of the area covered by IEA on a country-by-country basis, completed by a city-by-city approach in the largest countries with contrasted climates, provided that the potential for urban-scale integration of PV is significant enough. This resulted in a set of 41 main cities spread over 26 OECD countries

2- Calculation of the average annual energy production for each type of system (roof-top PV systems with a tilt angle of 30° and PV façades) in each city following the same protocol (same source of data and same software)

3- Comprehensive survey of the latest available scientific publications concerning the energy input of PV component manufacturing, focused on silicon technologies

4- Calculation of the EPBT for each system in each location

5- Calculation of the ERF for each system in each location

6- Evaluation of the average CO_2 content of the local electricity mix with the same source of data and the same protocol

7- Calculation of the Potential for CO_2 mitigation for each system in each location

1.4 Assumptions and source of data

1.4.1 Annual energy output

The annual energy output for each system at each location is estimated with the simplified conventional method:

$$E_{out}=H_i.P_o.PR \quad [2]$$

With:
E_{out}: annual energy output in kWh/year
H_i: global in-plane irradiation in kWh/m²/year
P_o: nominal power of the photovoltaic system in kWp
PR: Performance Ratio

The global in-plane irradiation is calculated with the global horizontal irradiation database Meteonorm 4.10 [3] and a conversion factor generated for each location with PVsyst 3.3 software [4] used to convert horizontal irradiation into in-plane irradiation (transposition factor). Although the Performance Ratio may vary from one location to the other, it is set at 75% for each system at each location, which is the average PR value observed by Task 2 - Performance, Reliability and Analysis of Photovoltaic Systems of the IEA PVPS program [5]. The annual energy output for each system in each location is given in annex A.

1.4.2 Energy input

Many scientific studies have been undertaken so far in view to assess the energy input necessary to manufacture a PV system. Most of them are now out-of-date and the conclusions are not relevant to modern photovoltaics. The Energy Input data used for this study comes from an up-to-date set of life-cycle inventories based on real, measured data from production lines of nine PV companies in Europe and the USA [6]. The Preliminary results of these up-dated data that have been published recently [7] for PV systems composed of multi-crystalline silicon modules are summarised in table 1.

Table 1 – Energy input of current technology grid connected PV system expressed in primary energy

	Primary energy [MJ/kWp]
Laminate	25 606
Frame	1 061
Balance of system	2 660
Total system	***29 327***

Energy input are expressed either in primary energy or in final electrical energy (see table 2), with the help of an average grid efficiency value, making it compatible with the annual electrical energy generated by the same PV system in operation for calculating EPBT and ERF.

Table 2 – Energy input of current technology grid connected PV system expressed in final electrical energy

	Electrical energy [kWh/kWp]
Laminate	2 205
Frame	91
Balance of system	229
Total system	***2 525***

The source of data [7] uses a grid efficiency value of 31%, which is the commonly agreed value for Western Europe Mainland medium voltage grid (the so-called “UCTE Region”). It includes:

- Energy consumption for building infrastructures, i.e. centralised power stations and transmission networks,
- Energy consumption during transport and distribution of fuels,
- Electric losses in transmission from power stations to medium-voltage consumers.

This value concretely results in the need to use an average 3.23 kWh of primary energy to supply 1 kWh of electricity through the grid to a medium-voltage consumer [8].

Although PV systems considered in this rapport are composed of multi-crystalline modules, it is possible to assess the value of indicators for PV systems composed of PV modules with other technologies as the published scientific up-to-date set of life-cycle inventories [7] gives for PV systems composed of mono-crystalline modules an energy input which is 31% higher than the total value given in table 1 and 2 and for PV systems composed of ribbon silicon modules an energy input which is 21% lower.

1.4.3 PV systems lifetime

An average lifetime of PV-systems as power production facilities must be determined prior to being able to evaluate any specific indicators.

This study uses the maximum lifetime of PV modules, estimated to be 30 years [7] consistent with most published studies on this topic. The actual PV modules power production capability guaranteed by major module suppliers worldwide is generally over 25 years [9].

The weakest part of a grid-connected PV system however is the inverter, for which the Mean Time Between Failures (MTBF) is claimed by inverter manufacturers to be between 80 000 and 100 000 hours, i.e approximately 10 years [10]. This means that although inverters are reliable devices, two repairs are necessary on average during the system’s lifetime: this value has also been taken into account for calculating ERF, but has very little impact on the final results.

1.4.4 CO_2 content of electricity mix

Since the CO_2 content of the electricity mix is not directly available in international publications for each OECD country, it has been calculated for the purpose of the present study using two different sources of data:

- the "Electricity Information 2005" published by the IEA [11] provides the gross electricity production of each OECD country, given by type of fuel and for conventional or Combined Heat & Power (CHP) plants
- freely available on the Internet "Retscreen" software [12] provides the Greenhouse Gas (GHG) content per MWh for all electricity production primary sources, the specific GHG emission factors (see table 3 below).

Table 3 – Greenhouse Gas emission factor for electricity production by fuel type [12]

	[tCO_2/MWh]
Nuclear	0
Hydro power	0
Coal	0,999
Oil	0,942
Gas	0,439
Geothermal, Solar, Tide, Wave, Ocean, Wind, Waste and other	0

In case of CHP, the GHG factor specifically designated to the electricity production has been assumed to be equal on average to 40% of the total GHG emissions as given in table 3, in order to take into account the fact that not only electricity is produced, but also heat, and that therefore GHG emissions must be shared with regards to the ratio of heat and electricity produced.

It is possible to derive from these data and assumptions an average CO_2 content of the specific energy mix for each OECD country (see annex B).

1.5 Selected cities

Depending on the size of each country and the climatic variation observed between major cities in each country, from 1 to 3 cities of each OECD member country have been selected (see table 4).

Table 4 – list of selected OECD cities

Australia	Sydney, Perth, Brisbane
Austria	Vienna
Belgium	Brussels
Canada	Ottawa, Vancouver
Czech Republic	Prague
Denmark	Copenhagen
Finland	Helsinki
France	Paris, Lyon, Marseille
Germany	Berlin, Cologne, Munich
Greece	Athens
Hungary	Budapest
Ireland	Dublin
Italy	Rome, Milan
Japan	Tokyo, Hiroshima, Sapporo
Republic of Korea	Seoul
Luxembourg	Luxembourg
The Netherlands	Amsterdam
New Zealand	Wellington
Norway	Oslo
Portugal	Lisbon
Spain	Barcelona, Madrid, Sevilla
Sweden	Stockholm
Switzerland	Bern
Turkey	Ankara
United Kingdom	London, Edinburgh
United States	Washington, Los Angeles, Houston

2 Overall results

The Environmental Benefits of Photovoltaic Systems in selected OECD cities listed in §1.5 was evaluated using the methodology developed in §1.3. This methodology was based on the assumptions explained in §1.4. The results are presented for different PV systems (see §1.1) using four specific indicators as detailed in §1.2. Detailed results for each country and each city are presented in §3 and the annex of this report

2.1 Energy Pay-Back Time (EPBT)

For rooftop-mounted PV systems, the range of EPBT is between 1.6 and 3.3 years, with the best case in Perth, Australia and the worst case in Edinburgh, UK.

The EPBT for PV façades is logically slightly longer, since their production rate per installed kWp is significantly lower, all other parameters being equal, with a range from 2.7 to 4.7 years, with the best case in Perth, Australia and the worst case in Brussels, Belgium (see Table 5 and Figure 3).

Table 5 – Energy Payback Time of Urban Scale PV systems

	Minimum value [Years]	Maximum value [Years]
Roof-top mounted PV system	1,6	3,3
PV facade	2,7	4,7

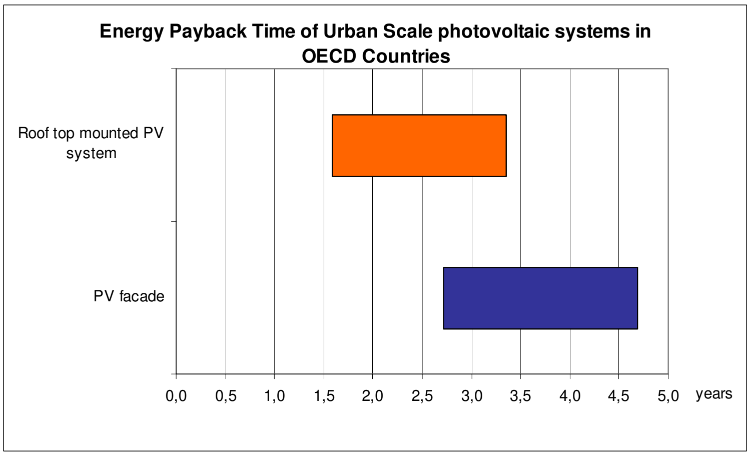


Figure 3 : EPBT of Urban Scale PV systems

The Energy Payback Time of each system in each location is given in annex C.

2.2 Energy Return Factor (ERF)

Rooftop-mounted PV systems are expected to produce during their whole lifetime between 8 and 17.9 times the amount of energy that was needed for their manufacture, installation and dismantling, with the best case in Perth, Australia and the worst case in Edinburgh, UK

PV façades are expected to produce during their whole lifetime between 5.4 and 10.1 times the amount of energy that was needed for their manufacture, installation and dismantling, with the best case in Perth, Australia and the worst case in Brussels, Belgium (see Table 6 and Figure 4).

Table 6 – Energy Return Factor of Urban Scale PV systems

	Minimum value [-]	Maximum value [-]
Roof-top mounted PV system	8,0	17,9
PV facade	5,4	10,0

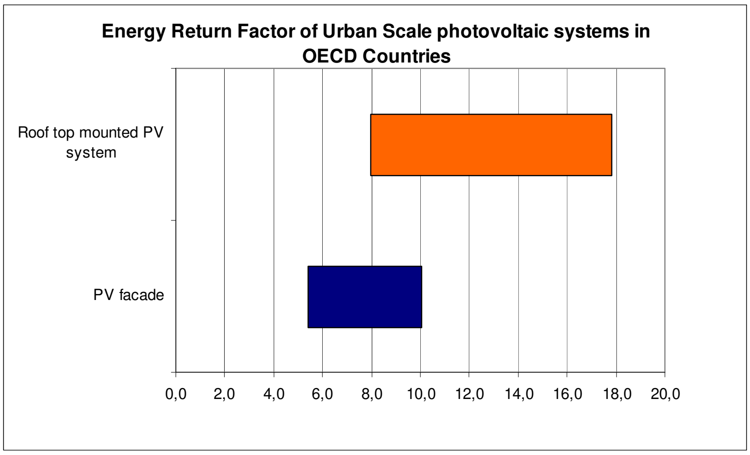


Figure 4 : ERF of Urban Scale PV systems

The Energy Return Factor of each system in each location is given in annex D.

2.3 Potential for Greenhouse Gases Emissions Mitigation

Once they have paid back their energy input, rooftop-mounted PV-systems can avoid during their lifetime the emission of up to 40 tons of CO_2 for each kWp installed, with the highest value in Perth, Australia due to a combination of high solar irradiation and a high CO_2 content of the power mix, and the lowest in Oslo, Norway, with a combination of an almost carbon-free power mix and a low solar irradiation.

The corresponding figure for PV façades is limited to 23,5 tons of CO_2 per kWp installed, with the same best and worst cases (see Table 7 and Figure 5).

Table 7 – Potential for CO_2 Mitigation of Urban Scale PV systems

	Minimum value [tCO_2/kWp]	Maximum value [tCO_2/kWp]
Roof-top mounted PV system	0,1	40,0
PV facade	0,0	23,5

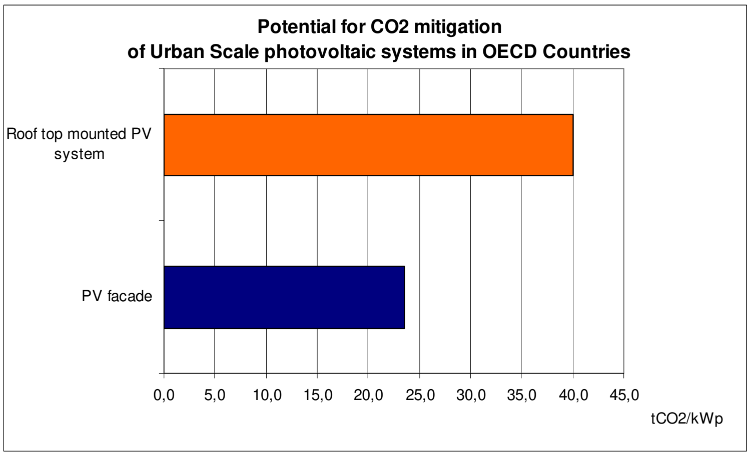


Figure 5 : potential for CO_2 mitigation of Urban Scale PV systems

The potential for CO_2 mitigation of each system in each location is given in annex E.

3 Results by country

3.1 Results template

In this section, results are summarised on a country-by-country basis with the same template for all OECD countries. The results template is composed of one table per city that summarises results and a minimum of 3 figures as presented below :

Figure 6 : location of studied cities

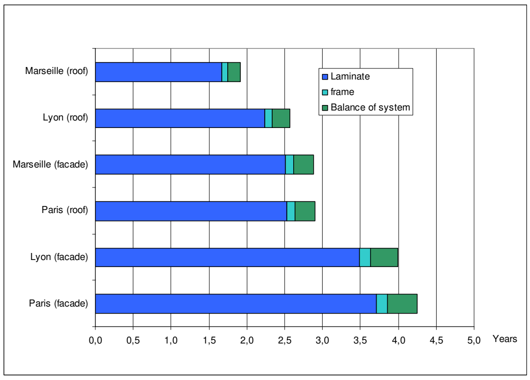


Figure 7 : Energy Payback time

For each country, a map shows the location of cities that were selected for the calculation of indicators defined in §1.2 in order to assess the environmental benefits of PV systems (see figure 6).

A figure gives, for each PV systems and for each city, the EPBT ranked from the shortest to the longest (see figure 7). It also shows the contribution of the laminate, the frame and the balance of system.

Table 8 : results for the considered city

Lyon	Global horizontal irradiation 1204 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	984	632
Energy Pay-Back Time [years]	2,6	4,0
Energy Return Factor [number of times]	10,7	6,5
Potential for CO_2 mitigation [tCO_2/kWp]	2,4	1,5

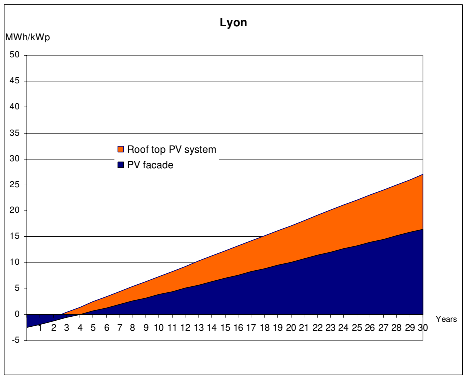


Figure 8 : Energy Payback time

Tables such as table 8 summarise for each city the value of each indicator calculated within this study and also gives specific data such as the global horizontal irradiation of the city and the estimated annual energy output of PV systems in kWh/kWp in this city.

For each city, a graph shows the net energy production over the system lifetime (see figure 8). The negative value at year 0 corresponds to the energy required for manufacturing the PV system expressed in electrical energy (2 525 kWh/kWp). The year at which the curve crosses the x-axis is the EPBT and the value at year 30 is the net energy production over the system lifetime.

3.2 Results for Australia

Figure 9 : location of studied cities

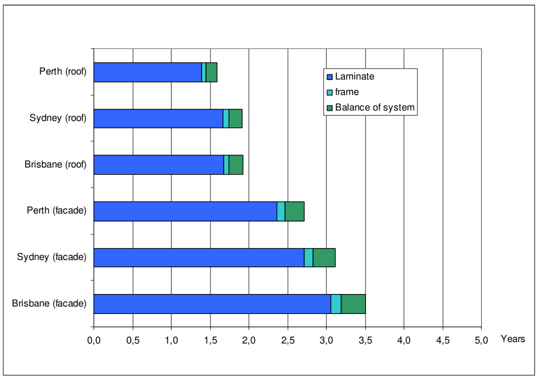


Figure 10 : Energy Payback time

Table 9 : results for Sydney

Sydney	Global horizontal irradiation 1614 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 319	811
Energy Pay-Back Time [years]	1,9	3,1
Energy Return Factor [number of times]	14,7	8,6
Potential for CO_2 mitigation [tCO_2/kWp]	33,3	20,5

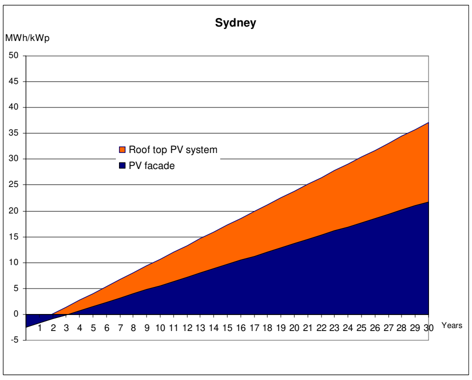


Figure 11 : Cumulative net energy production over system lifetime for Sydney

Table 10 : results for Perth

Perth	Global horizontal irradiation 1941 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 587	932
Energy Pay-Back Time [years]	1,6	2,7
Energy Return Factor [number of times]	17,9	10,1
Potential for CO_2 mitigation [tCO_2/kWp]	40,0	23,5

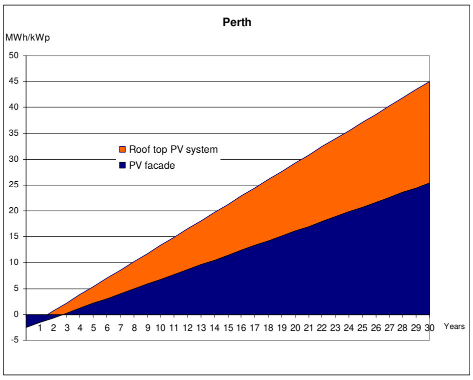


Figure 12 : Cumulative net energy production over system lifetime for Perth

Table 11 : results for Brisbane

Brisbane	Global horizontal irradiation 1686 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 315	721
Energy Pay-Back Time [years]	1,9	3,5
Energy Return Factor [number of times]	14,6	7,6
Potential for CO_2 mitigation [tCO_2/kWp]	33,2	18,2

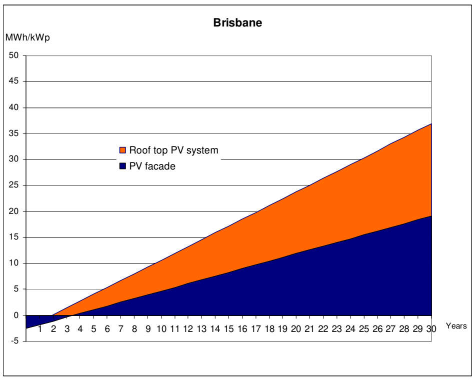


Figure 13 : Cumulative net energy production over system lifetime for Brisbane

3.3 Results for Austria

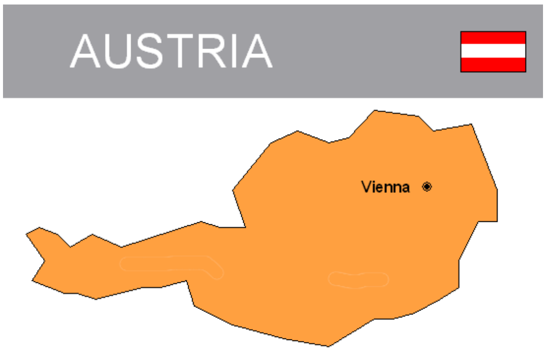


Figure 14 : location of studied cities

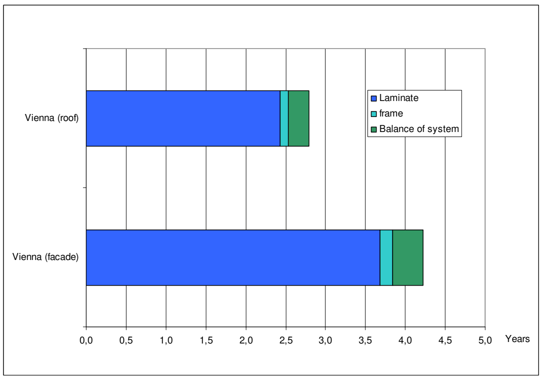


Figure 15 : Energy Payback time

Table 12 : results for Vienna

Vienna	Global horizontal irradiation 1108 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	906	598
Energy Pay-Back Time [years]	2,8	4,2
Energy Return Factor [number of times]	9,8	6,1
Potential for CO_2 mitigation [tCO_2/kWp]	5,7	3,8

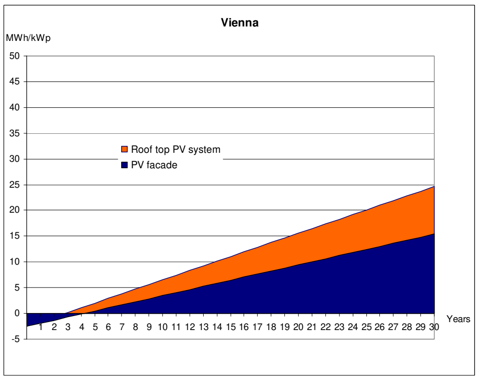


Figure 16 : Cumulative net energy production over system lifetime for Vienna

3.4 Results for Belgium

Figure 17 : location of studied cities

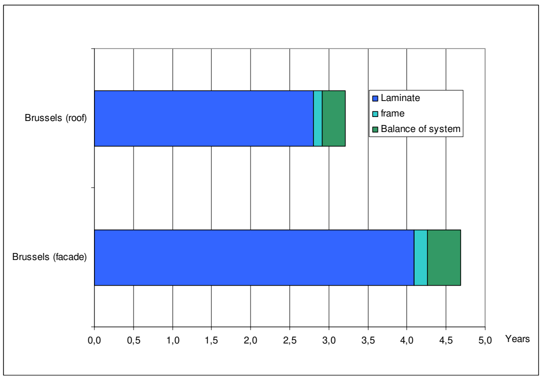


Figure 18 : Energy Payback time

Table 13 : results for Brussels

Brussels	Global horizontal irradiation 946 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	788	539
Energy Pay-Back Time [years]	3,2	4,7
Energy Return Factor [number of times]	8,4	5,4
Potential for CO_2 mitigation [tCO_2/kWp]	5,9	4,0

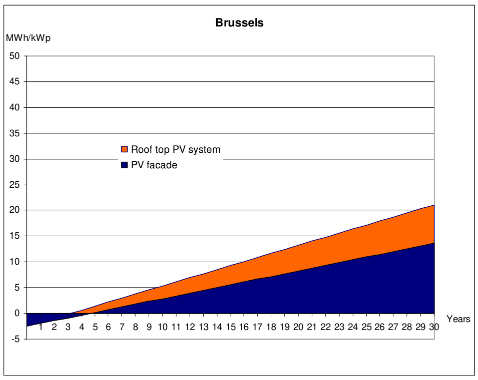


Figure 19 : Cumulative net energy production over system lifetime for Brussels

3.5 Results for Canada

Figure 20 : location of studied cities

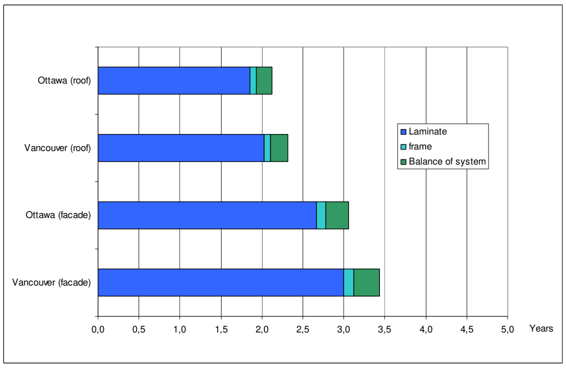


Figure 21 : Energy Payback time

Table 14 : results for Ottawa

Ottawa	Global horizontal irradiation 1377 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 188	826
Energy Pay-Back Time [years]	2,1	3,1
Energy Return Factor [number of times]	13,1	8,8
Potential for CO_2 mitigation [tCO_2/kWp]	8,7	6,0

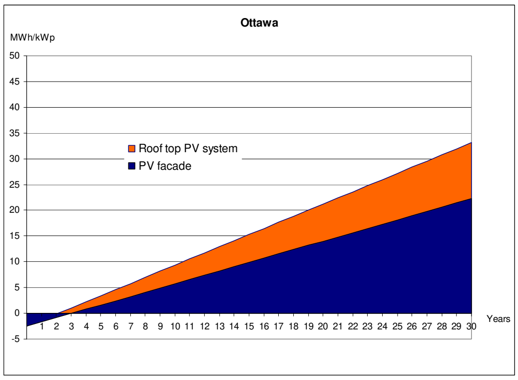


Figure 22 : Cumulative net energy production over system lifetime for Ottawa

Table 15 : results for Vancouver

Vancouver	Global horizontal irradiation 1273 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 088	735
Energy Pay-Back Time [years]	2,3	3,4
Energy Return Factor [number of times]	11,9	7,7
Potential for CO_2 mitigation [tCO_2/kWp]	7,9	5,4

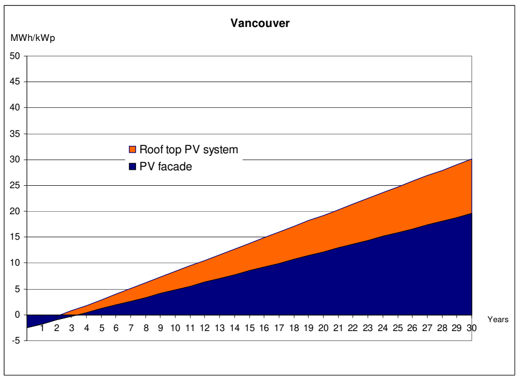


Figure 23 : Cumulative net energy production over system lifetime for Vancouver

3.6 Results for the Czech Republic

Figure 24 : location of studied city

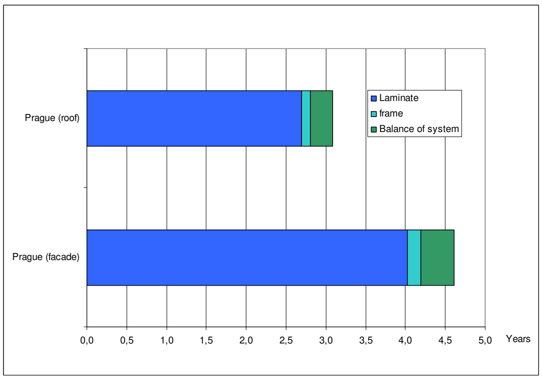


Figure 25 : Energy Payback time

Table 16 : results for Prague

Prague	Global horizontal irradiation 1000 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	818	548
Energy Pay-Back Time [years]	3,1	4,6
Energy Return Factor [number of times]	8,7	5,5
Potential for CO_2 mitigation [tCO_2/kWp]	12,7	8,5

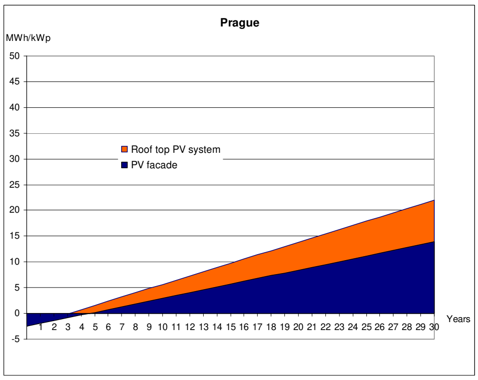


Figure 26 : Cumulative net energy production over system lifetime for Prague

3.7 Results for Denmark

Figure 27 : location of studied city

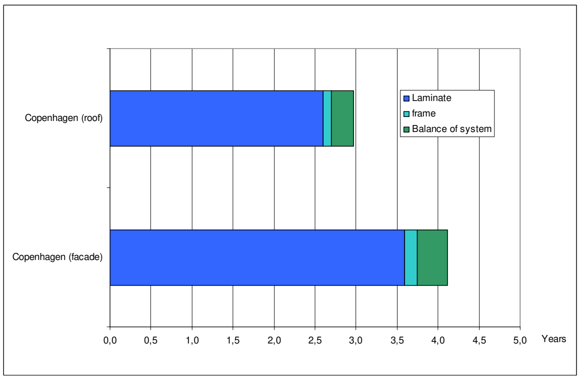


Figure 28 : Energy Payback time

Table 17 : results for Copenhagen

Copenhagen	Global horizontal irradiation 985 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	850	613
Energy Pay-Back Time [years]	3,0	4,1
Energy Return Factor [number of times]	9,1	6,3
Potential for CO_2 mitigation [tCO_2/kWp]	13,7	9,9

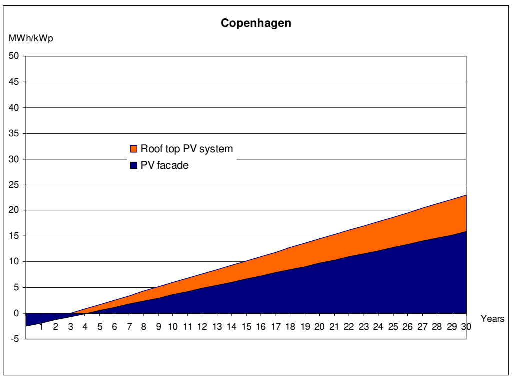


Figure 29 : Cumulative net energy production over system lifetime for Copenhagen

3.8 Results for Finland

Figure 30 : location of studied city

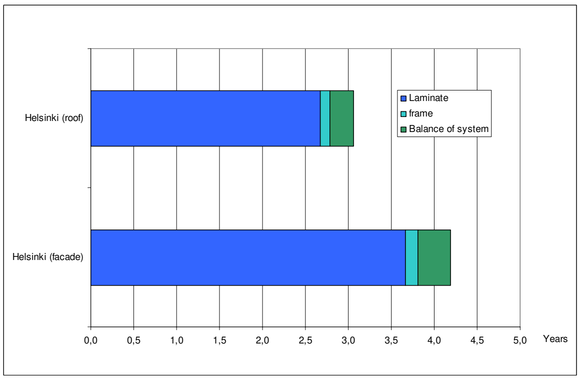


Figure 31 : Energy Payback time

Table 18 : results for Helsinki

Helsinki	Global horizontal irradiation 956 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	825	602
Energy Pay-Back Time [years]	3,1	4,2
Energy Return Factor [number of times]	8,8	6,2
Potential for CO_2 mitigation [tCO_2/kWp]	7,8	5,7

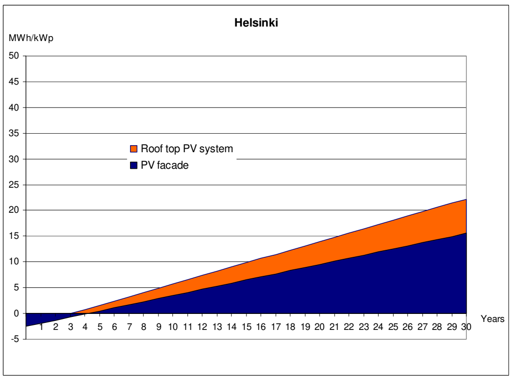


Figure 32 : Cumulative net energy production over system lifetime for Helsinki

3.9 Results for France

Figure 33 : location of studied cities

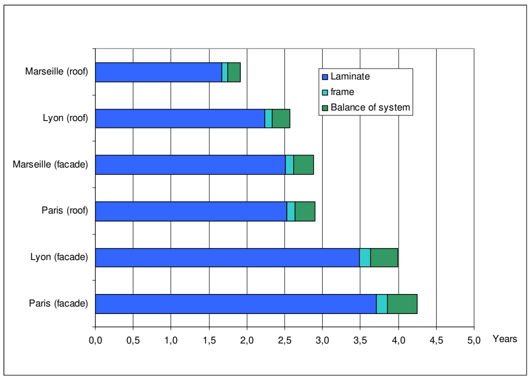


Figure 34 : Energy Payback time

Table 19 : results for Paris

Paris	Global horizontal irradiation 1057 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	872	595
Energy Pay-Back Time [years]	2,9	4,2
Energy Return Factor [number of times]	9,4	6,1
Potential for CO_2 mitigation [tCO_2/kWp]	2,1	1,4

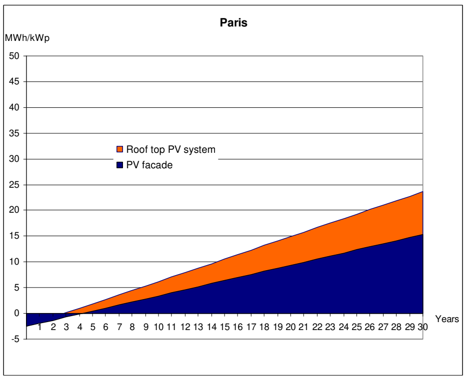


Figure 35 : Cumulative net energy production over system lifetime for Paris

Table 20 : results for Lyon

Lyon	Global horizontal irradiation 1204 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	984	632
Energy Pay-Back Time [years]	2,6	4,0
Energy Return Factor [number of times]	10,7	6,5
Potential for CO_2 mitigation [tCO_2/kWp]	2,4	1,5

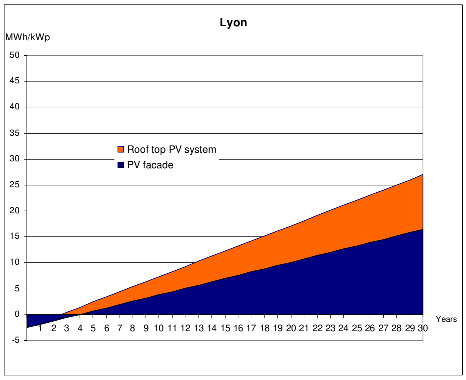


Figure 36 : Cumulative net energy production over system lifetime for Lyon

Table 21 : results for Marseille

Marseille	Global horizontal irradiation 1540 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 317	878
Energy Pay-Back Time [years]	1,9	2,9
Energy Return Factor [number of times]	14,6	9,4
Potential for CO_2 mitigation [tCO_2/kWp]	3,2	2,1

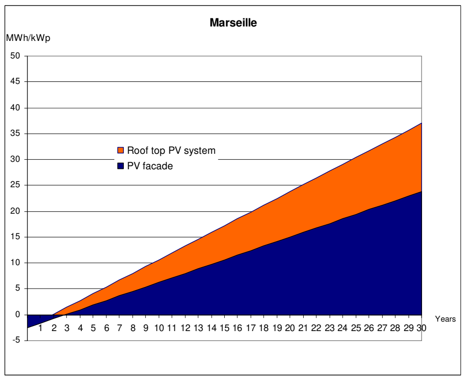


Figure 37 : Cumulative net energy production over system lifetime for Marseille

3.10 Results for Germany

Figure 38 : location of studied cities

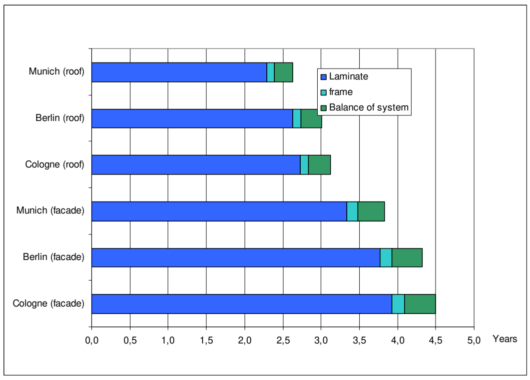


Figure 39 : Energy Payback time

Table 22 : results for Berlin

Berlin	Global horizontal irradiation 999 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	839	584
Energy Pay-Back Time [years]	3,0	4,3
Energy Return Factor [number of times]	9,0	5,9
Potential for CO_2 mitigation [tCO_2/kWp]	14,4	10,1

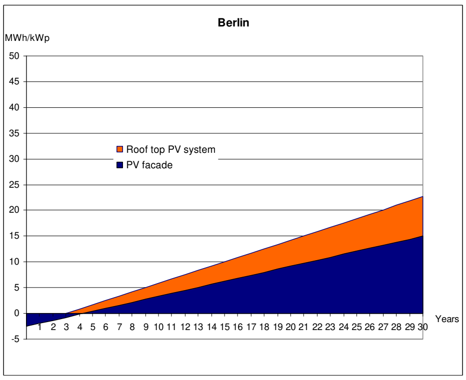


Figure 40 : Cumulative net energy production over system lifetime for Berlin

Table 23 : results for Cologne

Cologne	Global horizontal irradiation 972 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	809	561
Energy Pay-Back Time [years]	3,1	4,5
Energy Return Factor [number of times]	8,6	5,7
Potential for CO_2 mitigation [tCO_2/kWp]	13,9	9,7

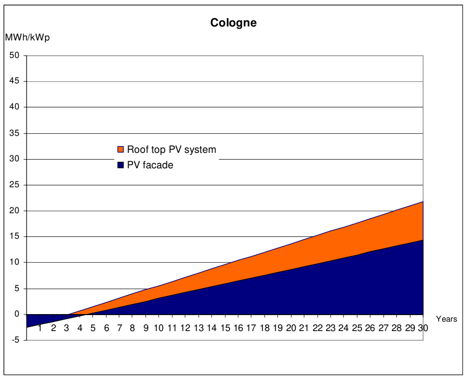


Figure 41 : Cumulative net energy production over system lifetime for Cologne

Table 24 : results for Munich

Munich	Global horizontal irradiation 1143 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	960	660
Energy Pay-Back Time [years]	2,6	3,8
Energy Return Factor [number of times]	10,4	6,8
Potential for CO_2 mitigation [tCO_2/kWp]	16,5	11,4

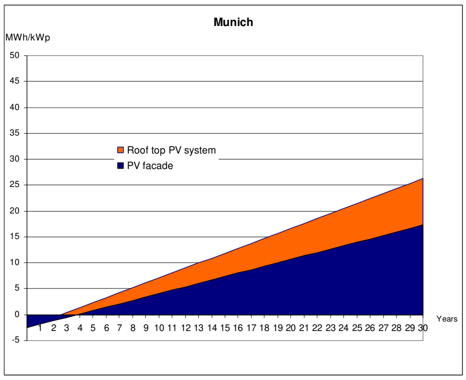


Figure 42 : Cumulative net energy production over system lifetime for Munich

3.11 Results for Greece

Figure 43 : location of studied city

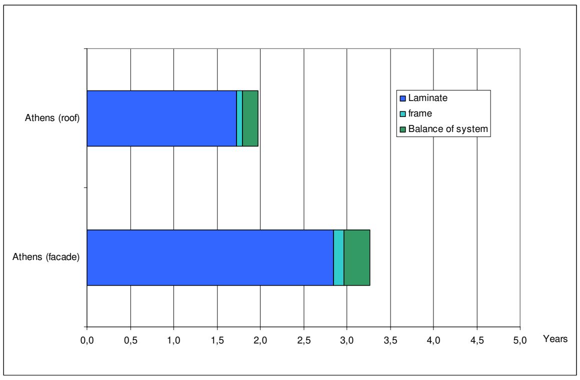


Figure 44 : Energy Payback time

Table 25 : results for Athens

Athens	Global horizontal irradiation 1563 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 278	774
Energy Pay-Back Time [years]	2,0	3,3
Energy Return Factor [number of times]	14,2	8,2
Potential for CO_2 mitigation [tCO_2/kWp]	30,7	18,6

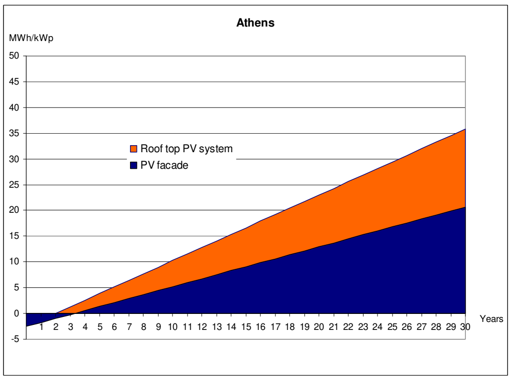


Figure 45 : Cumulative net energy production over system lifetime for Athens

3.12 Results for Hungary

Figure 46 : location of studied city

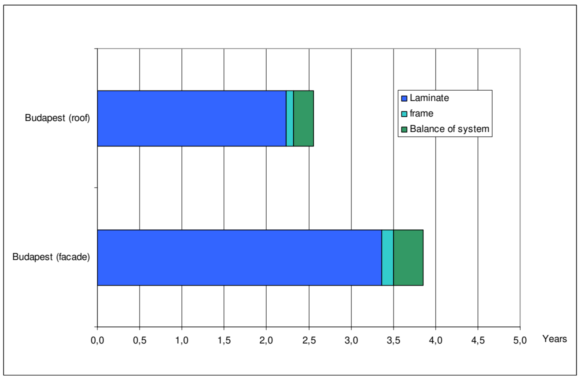


Figure 47 : Energy Payback time

Table 26 : results for Budapest

Budapest	Global horizontal irradiation 1198 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	988	656
Energy Pay-Back Time [years]	2,6	3,9
Energy Return Factor [number of times]	10,7	6,8
Potential for CO_2 mitigation [tCO_2/kWp]	12,1	8,0

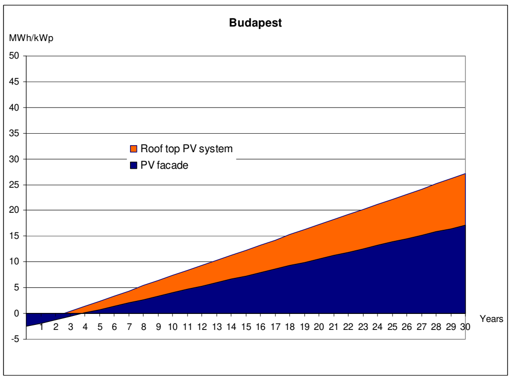


Figure 48 : Cumulative net energy production over system lifetime for Budapest

3.13 Results for Ireland

Figure 49 : location of studied city

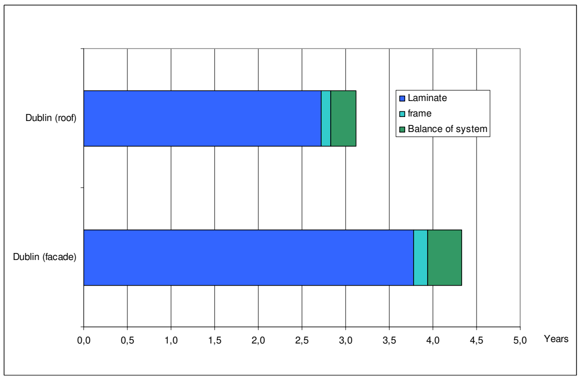


Figure 50 : Energy Payback time

Table 27 : results for Dublin

Dublin	Global horizontal irradiation 948 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	811	583
Energy Pay-Back Time [years]	3,1	4,3
Energy Return Factor [number of times]	8,6	5,9
Potential for CO_2 mitigation [tCO_2/kWp]	15,6	11,2

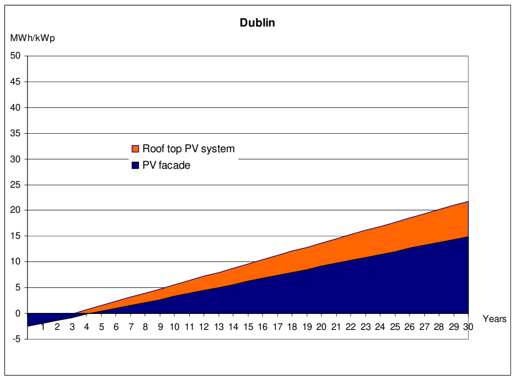


Figure 51 : Cumulative net energy production over system lifetime for Dublin

3.14 Results for Italy

Figure 52: location of studied cities

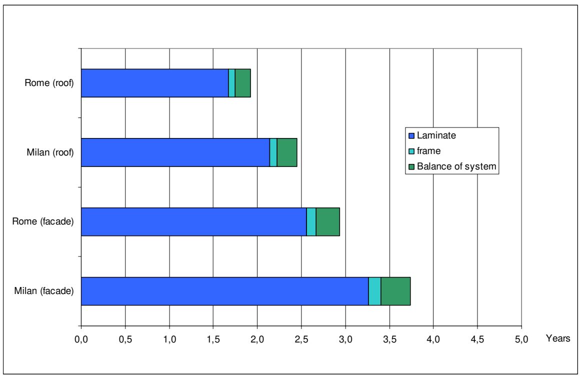


Figure 53: Energy Payback time

Table 28 : results for Rome

Rome	Global horizontal irradiation 1552 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 315	861
Energy Pay-Back Time [years]	1,9	2,9
Energy Return Factor [number of times]	14,6	9,2
Potential for CO_2 mitigation [tCO_2/kWp]	22,4	14,7

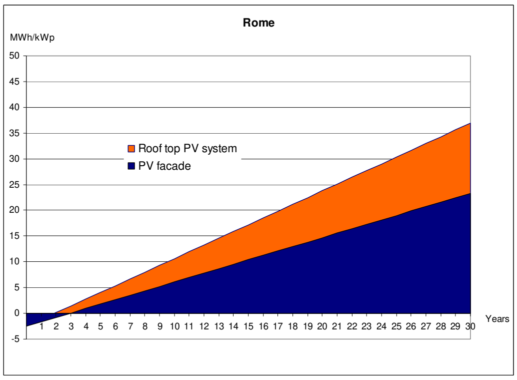


Figure 54 Cumulative net energy production over system lifetime for Rome

Table 29 : results for Milan

Milan	Global horizontal irradiation 1251 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 032	676
Energy Pay-Back Time [years]	2,4	3,7
Energy Return Factor [number of times]	11,3	7,0
Potential for CO_2 mitigation [tCO_2/kWp]	17,6	11,5

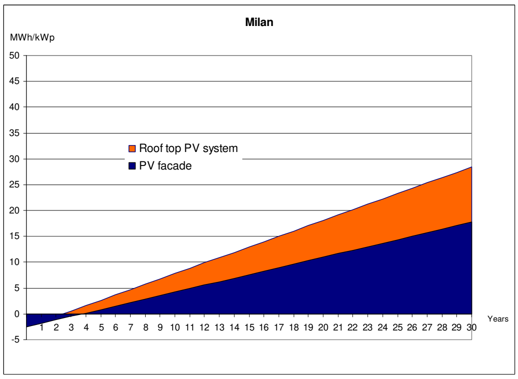


Figure 55 : Cumulative net energy production over system lifetime for Milan

3.15 Results for Japan

Figure 56 : location of studied cities

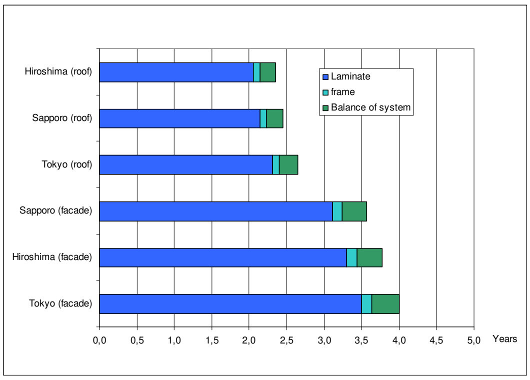


Figure 57 : Energy Payback time

Table 30 : results for Tokyo

Tokyo	Global horizontal irradiation 1168 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	955	631
Energy Pay-Back Time [years]	2,6	4,0
Energy Return Factor [number of times]	10,3	6,5
Potential for CO_2 mitigation [tCO_2/kWp]	14,5	9,6

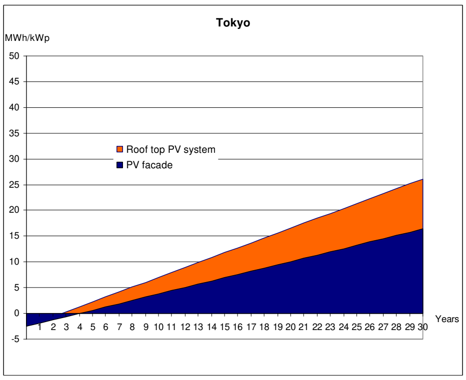


Figure 58 : Cumulative net energy production over system lifetime for Tokyo

Table 31 : results for Hiroshima

Hiroshima	Global horizontal irradiation 1350 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 073	668
Energy Pay-Back Time [years]	2,4	3,8
Energy Return Factor [number of times]	11,7	6,9
Potential for CO_2 mitigation [tCO_2/kWp]	16,3	10,2

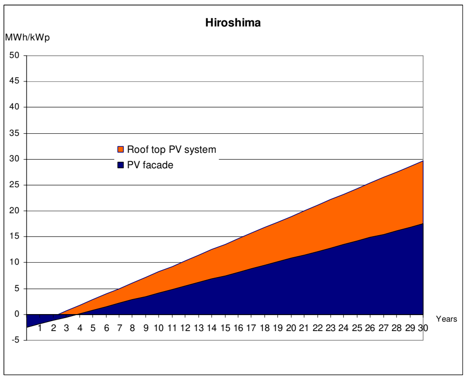


Figure 59 : Cumulative net energy production over system lifetime for Hiroshima

Table 32 : results for Sapporo

Sapporo	Global horizontal irradiation 1225 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 029	707
Energy Pay-Back Time [years]	2,5	3,6
Energy Return Factor [number of times]	11,2	7,4
Potential for CO_2 mitigation [tCO_2/kWp]	15,7	10,8

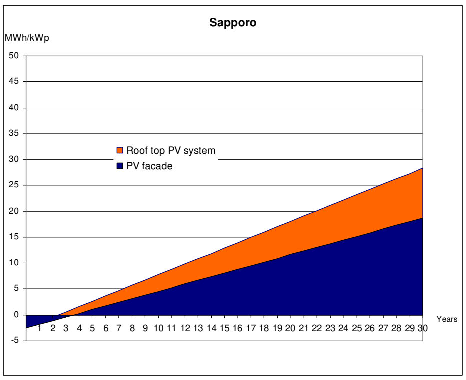


Figure 60 : Cumulative net energy production over system lifetime for Sapporo

3.16 Results for the Republic of Korea

Figure 61 : location of studied city

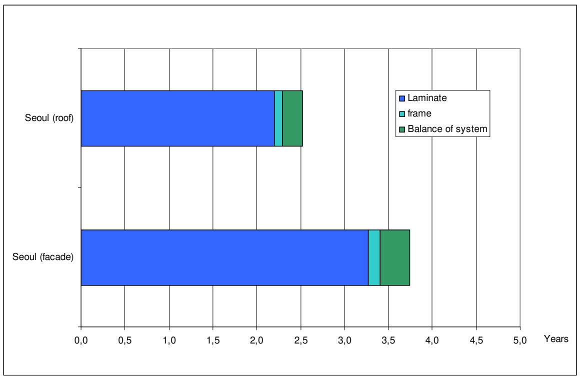


Figure 62 : Energy Payback time

Table 33 : results for Seoul

Seoul	Global horizontal irradiation 1215 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 002	674
Energy Pay-Back Time [years]	2,5	3,7
Energy Return Factor [number of times]	10,9	7,0
Potential for CO_2 mitigation [tCO_2/kWp]	15,0	10,1

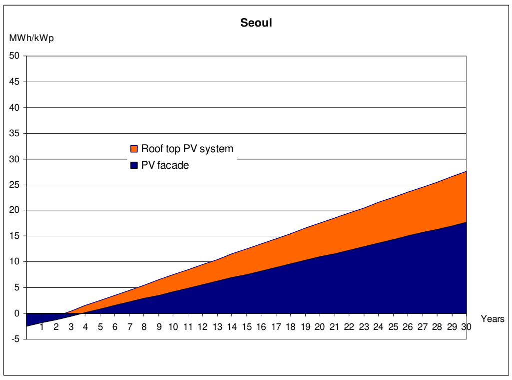


Figure 63 : Cumulative net energy production over system lifetime for Seoul

3.17 Results for Luxembourg

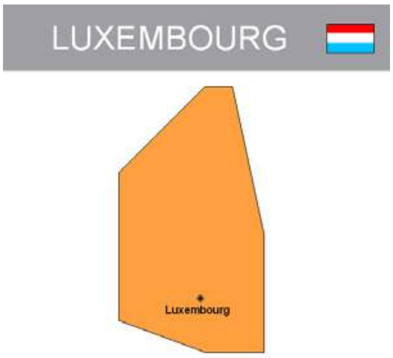


Figure 64 : location of studied city

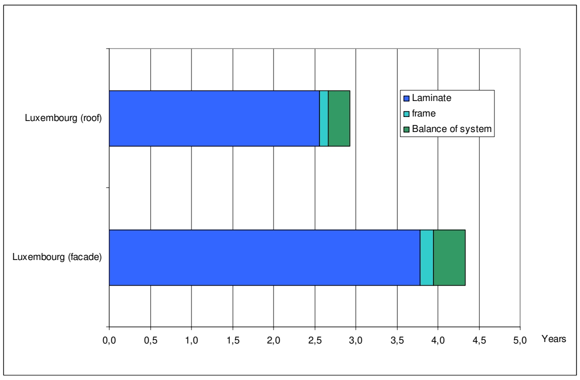


Figure 65 : Energy Payback time

Table 34 : results for Luxembourg

Luxembourg	Global horizontal irradiation 1035 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	862	582
Energy Pay-Back Time [years]	2,9	4,3
Energy Return Factor [number of times]	9,2	5,9
Potential for CO_2 mitigation [tCO_2/kWp]	7,6	5,2

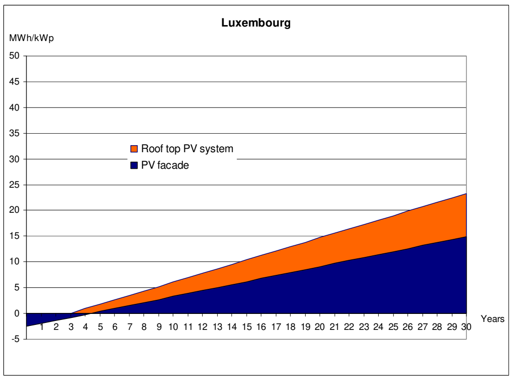


Figure 66 : Cumulative net energy production over system lifetime for Luxembourg

3.18 Results for the Netherlands

Figure 67 : location of studied city

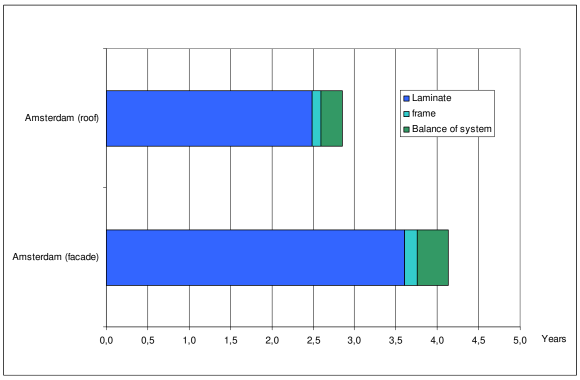


Figure 68 : Energy Payback time

Table 35 : results for Amsterdam

Amsterdam	Global horizontal irradiation 1045 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	886	611
Energy Pay-Back Time [years]	2,9	4,1
Energy Return Factor [number of times]	9,5	6,3
Potential for CO_2 mitigation [tCO_2/kWp]	13,6	9,4

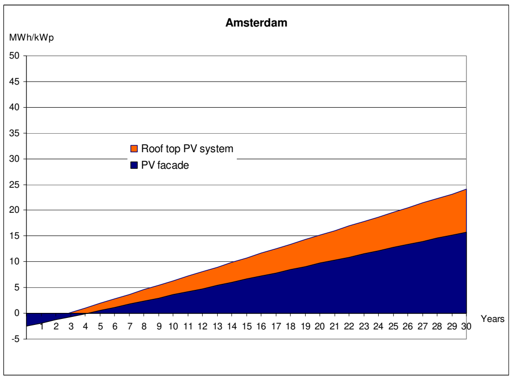


Figure 69 : Cumulative net energy production over system lifetime for Amsterdam

3.19 Results for New Zealand

Figure 70 : location of studied city

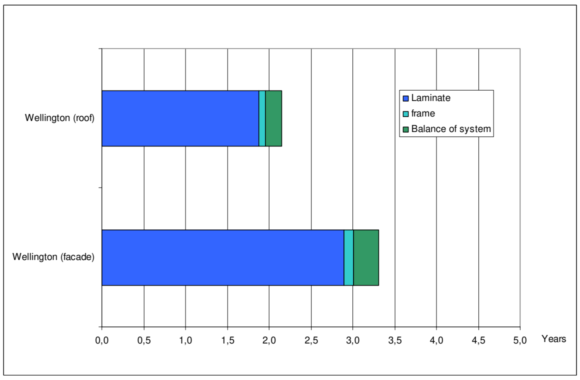


Figure 71 : Energy Payback time

Table 36 : results for Wellington

Wellington	Global horizontal irradiation 1412 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 175	762
Energy Pay-Back Time [years]	2,1	3,3
Energy Return Factor [number of times]	13,0	8,1
Potential for CO_2 mitigation [tCO_2/kWp]	6,6	4,3

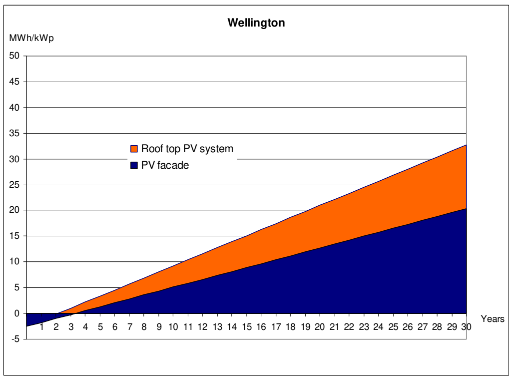


Figure 72 : Cumulative net energy production over system lifetime for Wellington

3.20 Results for Norway

Figure 73 : location of studied city

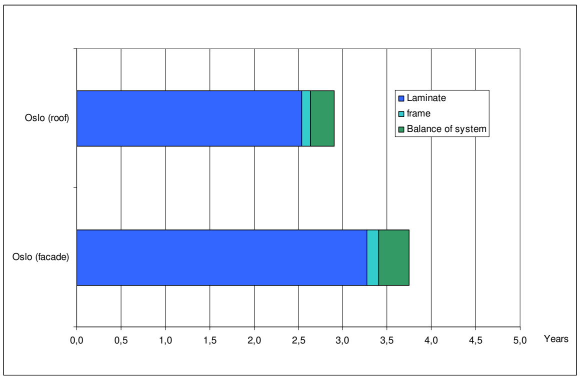


Figure 74 : Energy Payback time

Table 37 : results for Oslo

Oslo	Global horizontal irradiation 967 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	870	674
Energy Pay-Back Time [years]	2,9	3,7
Energy Return Factor [number of times]	9,3	7,0
Potential for CO_2 mitigation [tCO_2/kWp]	0,1	0,0

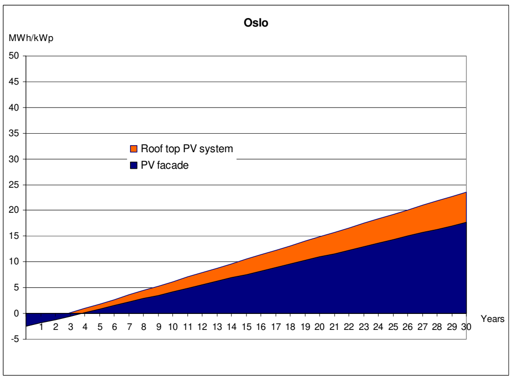


Figure 75 : Cumulative net energy production over system lifetime for Oslo

3.21 Results for Portugal

Figure 76 : location of studied city

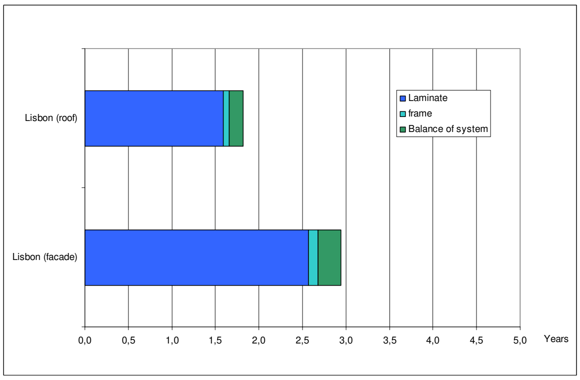


Figure 77 : Energy Payback time

Table 38 : results for Lisbon

Lisbon	Global horizontal irradiation 1682 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 388	858
Energy Pay-Back Time [years]	1,8	2,9
Energy Return Factor [number of times]	15,5	9,2
Potential for CO_2 mitigation [tCO_2/kWp]	20,5	12,6

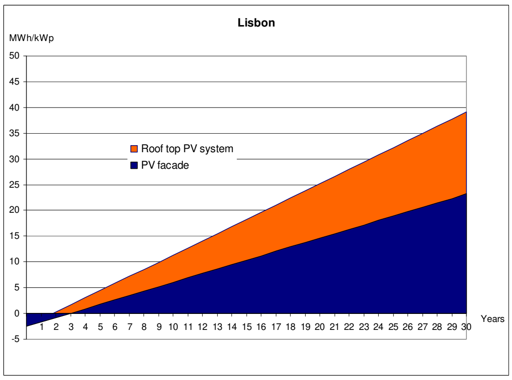


Figure 78 : Cumulative net energy production over system lifetime for Lisbon

3.22 Results for Spain

Figure 79 : location of studied cities

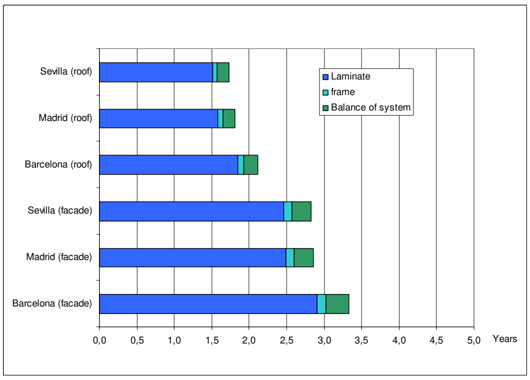


Figure 80 : Energy Payback time

Table 39 : results for Barcelona

Barcelona	Global horizontal irradiation 1446 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 193	759
Energy Pay-Back Time [years]	2,1	3,3
Energy Return Factor [number of times]	13,2	8,0
Potential for CO_2 mitigation [tCO_2/kWp]	15,9	10,1

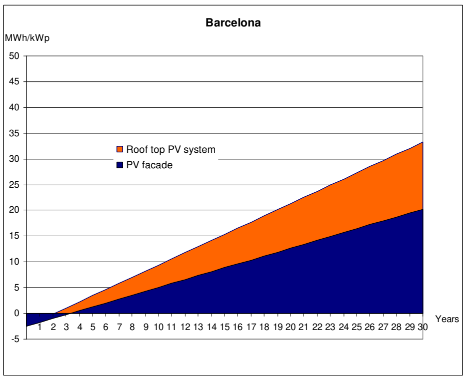


Figure 81 : Cumulative net energy production over system lifetime for Barcelona

Table 40 : results for Madrid

Madrid	Global horizontal irradiation 1660 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 394	884
Energy Pay-Back Time [years]	1,8	2,9
Energy Return Factor [number of times]	15,6	9,5
Potential for CO_2 mitigation [tCO_2/kWp]	18,6	11,8

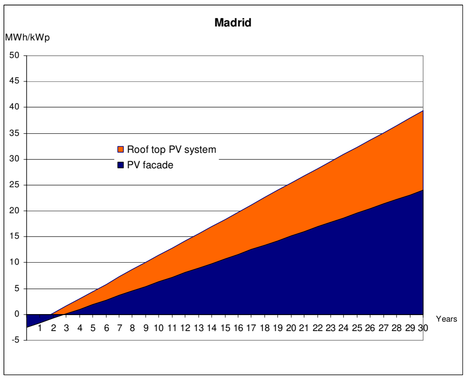


Figure 82 : Cumulative net energy production over system lifetime for Madrid

Table 41 : results for Sevilla

Sevilla	Global horizontal irradiation 1754 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 460	895
Energy Pay-Back Time [years]	1,7	2,8
Energy Return Factor [number of times]	16,3	9,6
Potential for CO_2 mitigation [tCO_2/kWp]	19,5	11,9

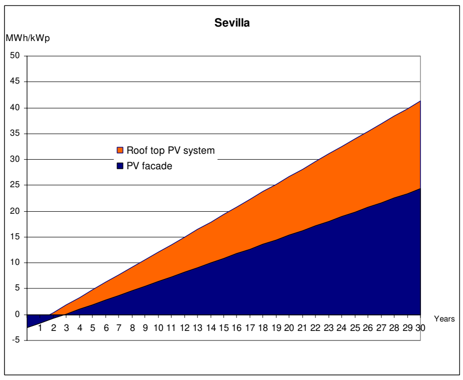


Figure 83 : Cumulative net energy production over system lifetime for Sevilla

3.23 Results for Sweden

Figure 84 : location of studied city

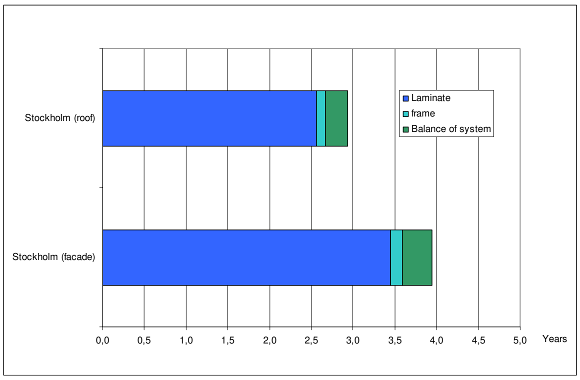


Figure 85 : Energy Payback time

Table 42 : results for Stockholm

Stockholm	Global horizontal irradiation 980 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	860	639
Energy Pay-Back Time [years]	2,9	3,9
Energy Return Factor [number of times]	9,2	6,6
Potential for CO_2 mitigation [tCO_2/kWp]	1,1	0,8

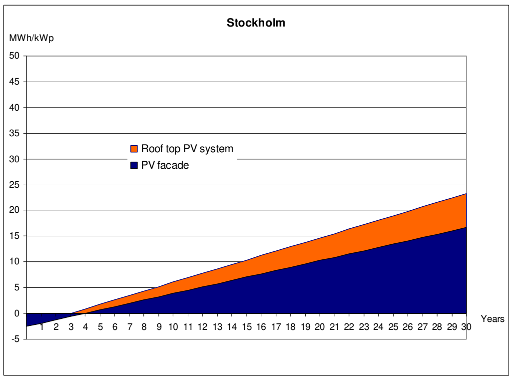


Figure 86 : Cumulative net energy production over system lifetime for Stockholm

3.24 Results for Switzerland

Figure 87 : location of studied city

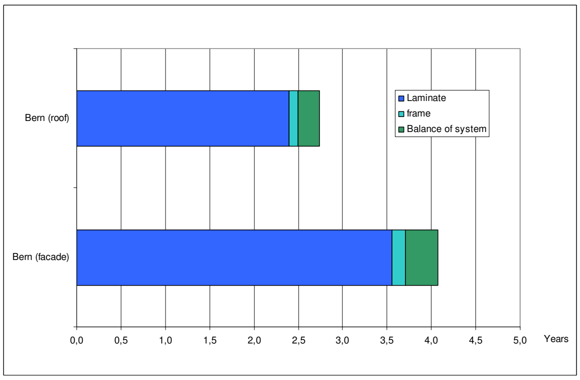


Figure 88 : Energy Payback time

Table 43 : results for Bern

Bern	Global horizontal irradiation 1117 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	922	620
Energy Pay-Back Time [years]	2,7	4,1
Energy Return Factor [number of times]	9,9	6,4
Potential for CO_2 mitigation [tCO_2/kWp]	0,2	0,1

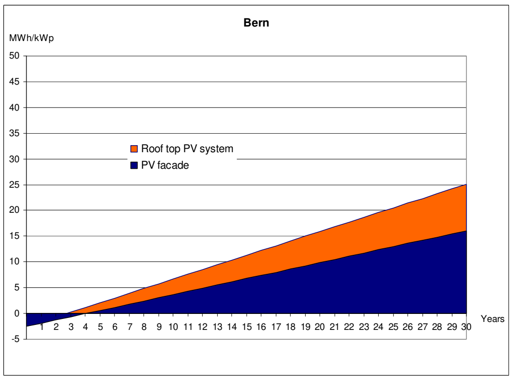


Figure 89 : Cumulative net energy production over system lifetime for Bern

3.25 Results for Turkey

Figure 90 : location of studied city

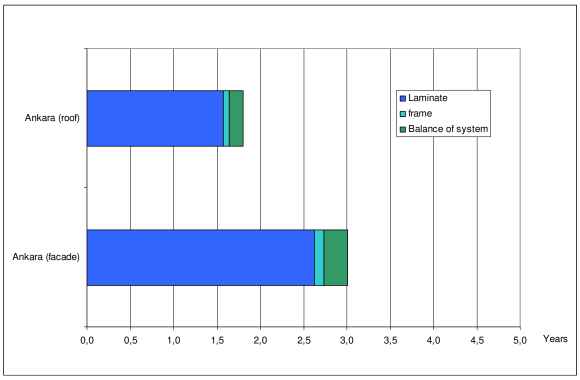


Figure 91 : Energy Payback time

Table 44 : results for Ankara

Ankara	Global horizontal irradiation 1697 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 400	840
Energy Pay-Back Time [years]	1,8	3,0
Energy Return Factor [number of times]	15,6	9,0
Potential for CO_2 mitigation [tCO_2/kWp]	20,6	12,3

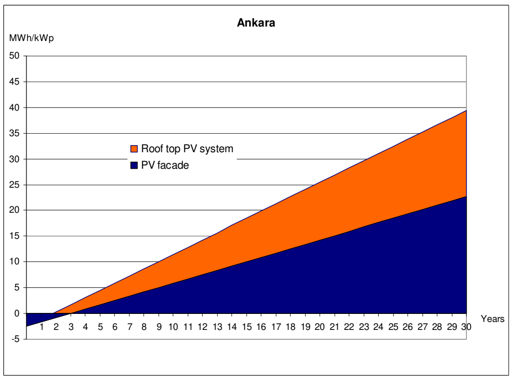


Figure 92 : Cumulative net energy production over system lifetime for Ankara

3.26 Results for The United Kingdom

Figure 93 : location of studied cities

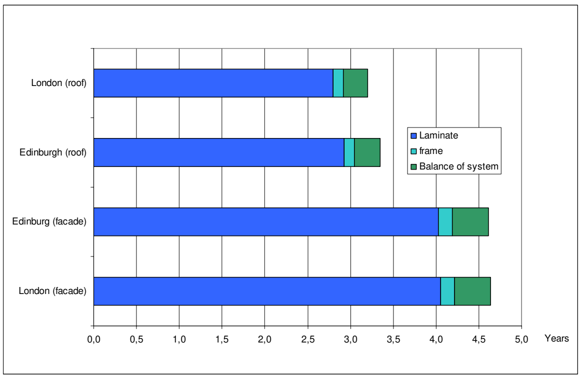


Figure 94 : Energy Payback time

Table 45 : results for London

London	Global horizontal irradiation 955 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	788	544
Energy Pay-Back Time [years]	3,2	4,6
Energy Return Factor [number of times]	8,4	5,5
Potential for CO_2 mitigation [tCO_2/kWp]	12,6	8,7

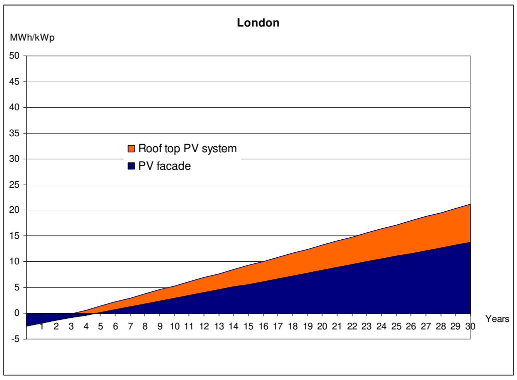


Figure 95 : Cumulative net energy production over system lifetime for London

Table 46 : results for Edinburgh

Edinburgh	Global horizontal irradiation 890 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	754	547
Energy Pay-Back Time [years]	3,3	4,6
Energy Return Factor [number of times]	8,0	5,5
Potential for CO_2 mitigation [tCO_2/kWp]	12,0	8,7

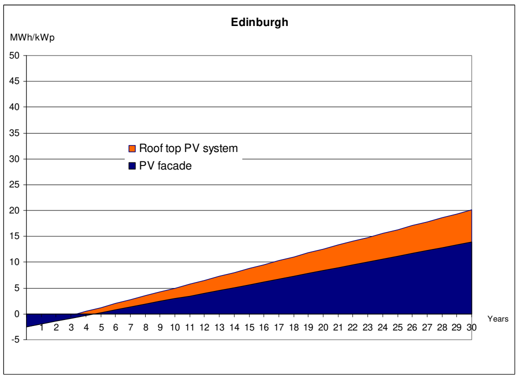


Figure 96 : Cumulative net energy production over system lifetime for Edinburgh

3.27 Results for the United States

Figure 97 : location of studied cities

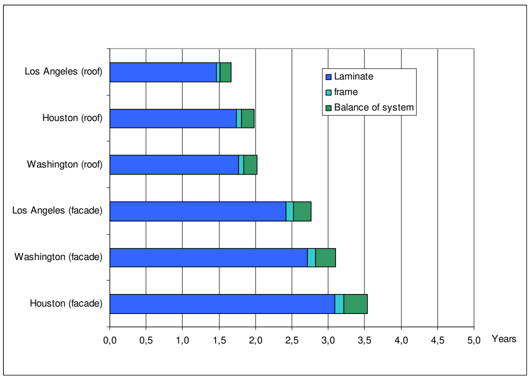


Figure 98 : Energy Payback time

Table 47 : results for Washington

Washington	Global horizontal irradiation 1487 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 249	814
Energy Pay-Back Time [years]	2,0	3,1
Energy Return Factor [number of times]	13,8	8,7
Potential for CO_2 mitigation [tCO_2/kWp]	22,8	14,9

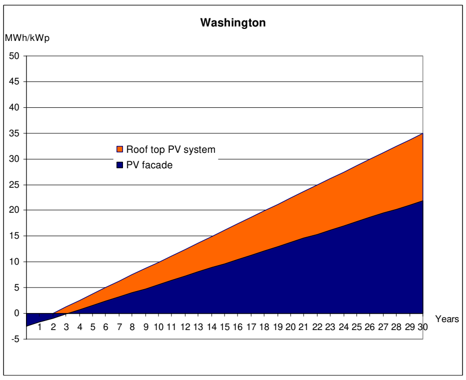


Figure 99 : Cumulative net energy production over system lifetime for Washington

Table 48 : results for Los Angeles

Los Angeles	Global horizontal irradiation 1816 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 512	913
Energy Pay-Back Time [years]	1,7	2,8
Energy Return Factor [number of times]	17,0	9,8
Potential for CO_2 mitigation [tCO_2/kWp]	27,6	16,7

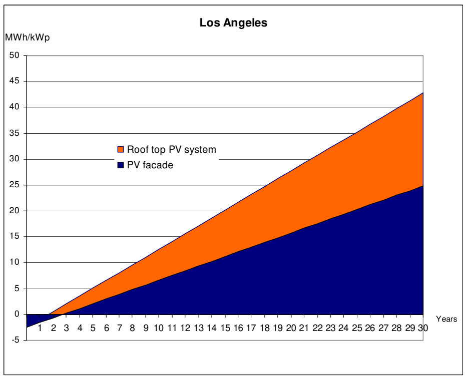


Figure 100 : Cumulative net energy production over system lifetime for Los Angeles

Table 49 : results for Houston

Houston	Global horizontal irradiation 1615 kWh/m2	
	Roof-top	***Façade***
Annual output [kWh/kWp]	1 272	715
Energy Pay-Back Time [years]	2,0	3,5
Energy Return Factor [number of times]	14,1	7,5
Potential for CO_2 mitigation [tCO_2/kWp]	23,2	13,1

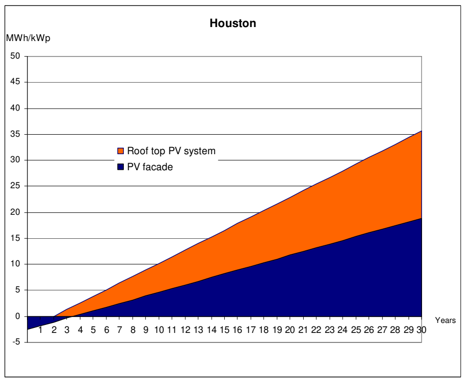


Figure 101 : Cumulative net energy production over system lifetime for Huston

4 References

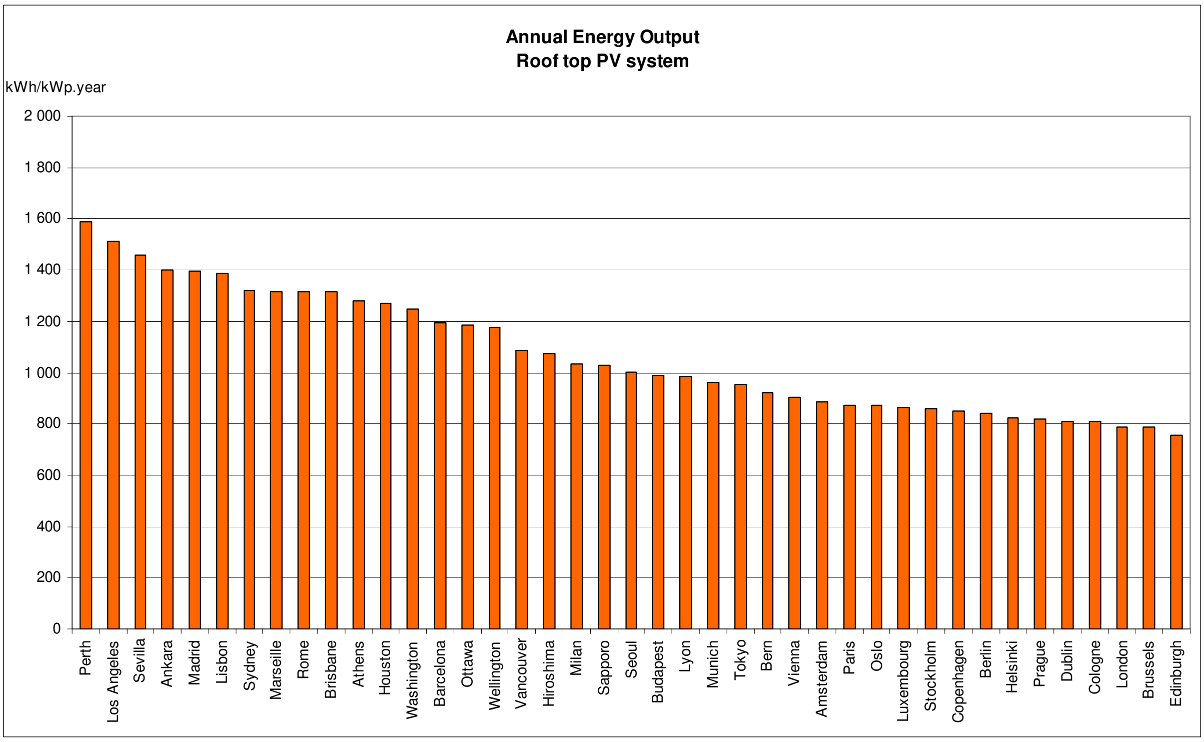
[1] Alsema, E.A., Nieuwlaar, E., Energy Viability of Photovoltaic Systems, Energy Policy 28 (2000) 999-1010, 2000
[2] based on CEI-IEC 61724 photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis
[3] Meteornorm 4.10 is a Meteotest software available at www.meteotest.ch
[4] Pvsyst 3.3 is a PV simulation tool developed by the University of Geneva and is available at www.pvsyst.com
[5] Clavadetscher, L., Country Reports on PV system performance, Report IEA-PVPS T2-05:2005 available at www.iea-pvps.org
[6] European Integrated Research project, Crystalclear : www.ipcrystalclear.info
[7] Alsema, E.A., de Wild-Scholten, M.J., The real environmental impacts of crystalline silicon PV modules : an analysis based on up-to-date manufacturers data, in : 20th European PV Solar Conference, Barcelona, 2005
[8] The grid efficiency value of 31% is derived from the Swiss Ecoinvent database : www.ecoinvent.ch
[9] for instance, see Sharp's module datasheets, www.sharpusa.com/solar
[10] for instance, see SMA's inverter datasheets www.sma.de
[11] Electricity Information 2005, IEA Statistics, www.iea.org
[12] RETSCreen 3 is a Clean Energy Decision Support software managed by the CANMET Energy Technologie Centre – Varennes (CETC – Varennes) www.retscreen.net

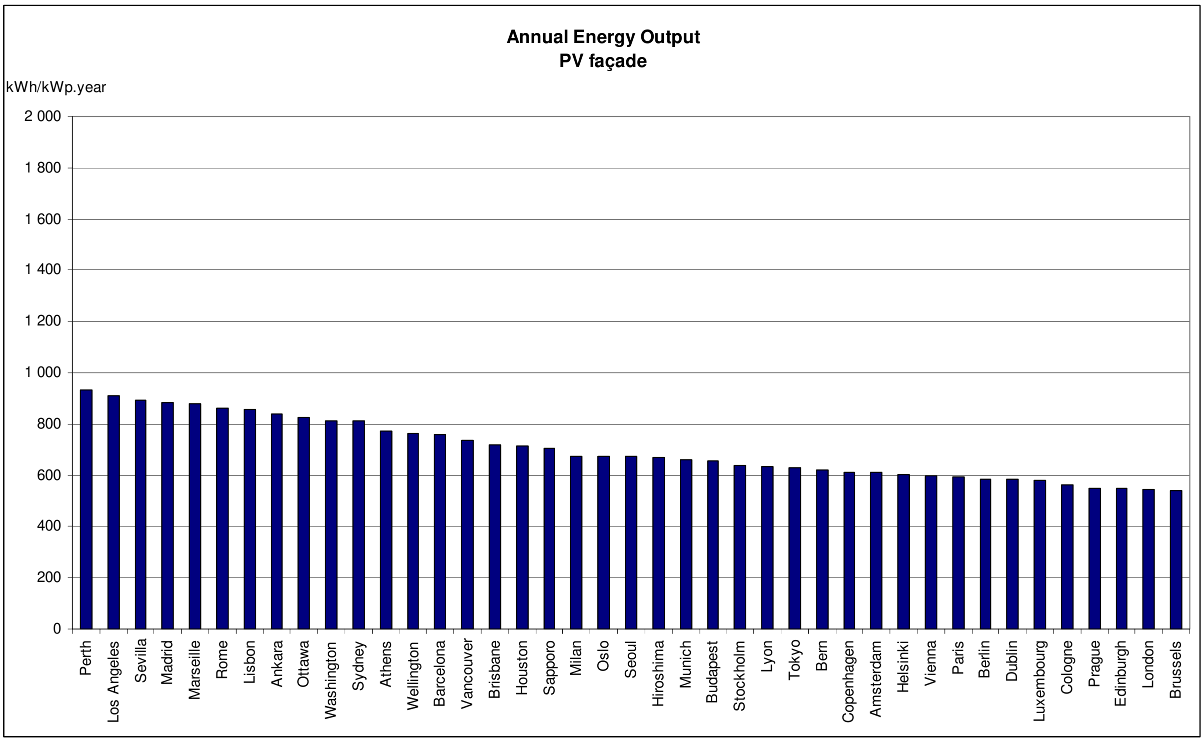
5 Annexes

Annex A : Annual energy output

See part 1.4.1 for assumptions, methodology and source of data

Country	City	Roof top PV system [kWh/kWp.year]	PV façade [kWh/kWp.year]
Australia	Sydney	1 319	811
	Perth	1 587	932
	Brisbane	1 315	721
Austria	Vienna	906	598
Belgium	Brussels	788	539
Canada	Ottawa	1 188	826
	Vancouver	1 088	735
Czech Republic	Prague	818	548
Denmark	Copenhagen	850	613
Finland	Helsinki	825	602
France	Paris	872	595
	Lyon	984	632
	Marseille	1 317	878
Germany	Berlin	839	584
	Cologne	809	561
	Munich	960	660
Greece	Athens	1 278	774
Hungary	Budapest	988	656
Ireland	Dublin	811	583
Italy	Rome	1 315	861
	Milan	1 032	676
Japan	Tokyo	955	631
	Hiroshima	1 073	668
	Sapporo	1 029	707
Republic of Korea	Seoul	1 002	674
Luxembourg	Luxembourg	862	582
The Netherlands	Amsterdam	886	611
New Zealand	Wellington	1 175	762
Norway	Oslo	870	674
Portugal	Lisbon	1 388	858
Spain	Barcelona	1 193	759
	Madrid	1 394	884
	Sevilla	1 460	895
Sweden	Stockholm	860	639
Switzerland	Bern	922	620
Turkey	Ankara	1 400	840
United Kingdom	London	788	544
	Edinburgh	754	547
United States	Washington	1 249	814
	Los Angeles	1 512	913
	Houston	1 272	715

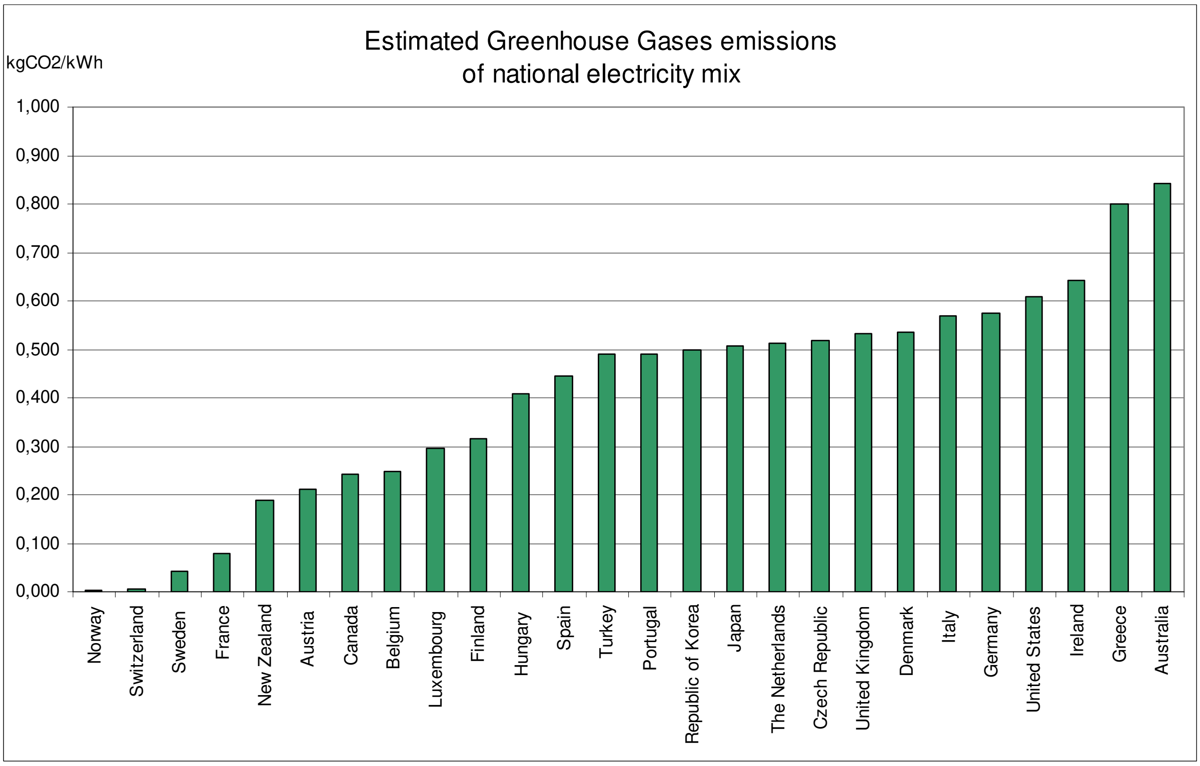

Annual Energy Output
Roof top PV system
kWh/kWp.year
2 000
1 800
1 600
1 400
1 200
1 000
800
600
400
200
0
Perth
Los Angeles
Sevilla
Ankara
Madrid
Lisbon
Sydney
Marseille
Rome
Brisbane
Athens
Houston
Washington
Barcelona
Ottawa
Wellington
Vancouver
Hiroshima
Milan
Sapporo
Seoul
Budapest
Lyon
Munich
Tokyo
Bern
Vienna
Amsterdam
Paris
Oslo
Luxembourg
Stockholm
Copenhagen
Berlin
Helsinki
Prague
Dublin
Cologne
London
Brussels
Edinburgh


Annual Energy Output
PV façade
kWh/kWp.year
2 000
1 800
1 600
1 400
1 200
1 000
800
600
400
200
0
Perth
Los Angeles
Sevilla
Madrid
Marseille
Rome
Lisbon
Ankara
Ottawa
Washington
Sydney
Athens
Wellington
Barcelona
Vancouver
Brisbane
Houston
Sapporo
Milan
Oslo
Seoul
Hiroshima
Munich
Budapest
Stockholm
Lyon
Tokyo
Bern
Copenhagen
Amsterdam
Helsinki
Vienna
Paris
Berlin
Dublin
Luxembourg
Cologne
Prague
Edinburgh
London
Brussels

Annex B : Share of electricity generation by fuel and estimated Greenhouse Gases emissions per kWh generated

See part 1.4.4 for assumptions, methodology and source of data

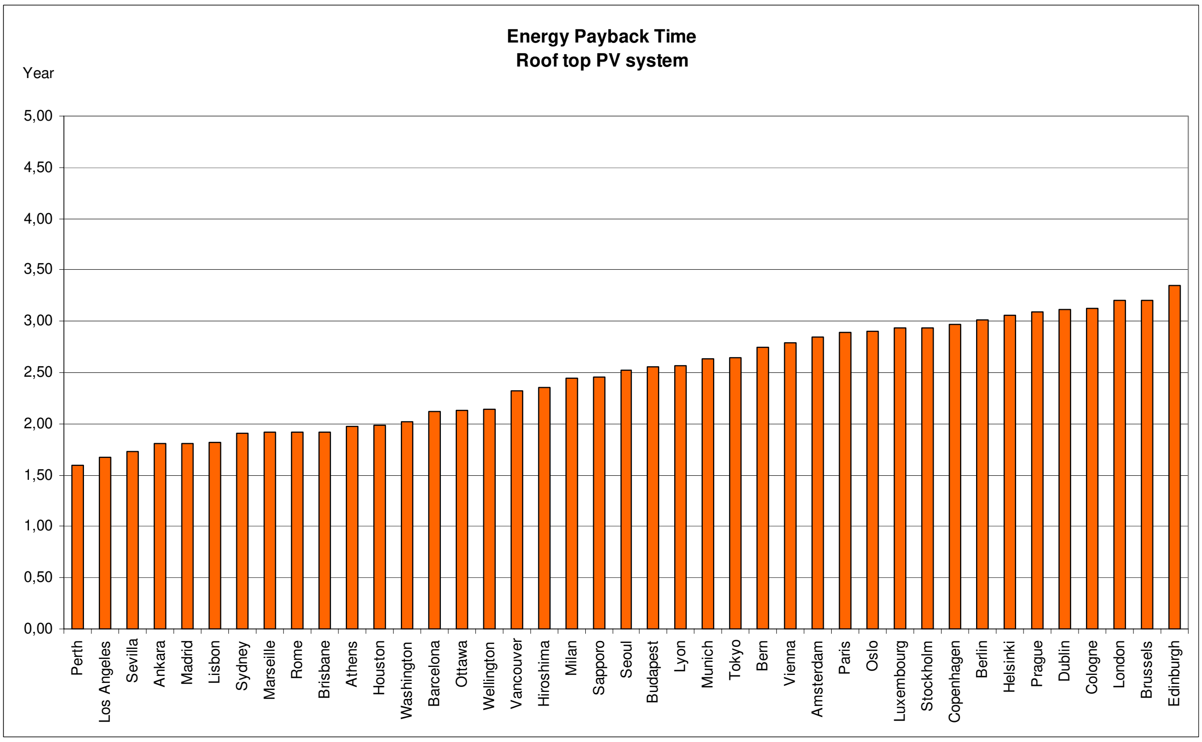
Country	Nuclear	Hydro	Coal	Oil	Gas	Geothermal, Solar, Tide, Wave, Ocean, Wind, Waste and other	Estimated Greenhouse Gases emissions per kWh generated
	-	-	-	-	-	-	[$kgCO_2$/kWh]
Australia	0%	7%	77%	1%	14%	1%	0,841
Austria	0%	61%	15%	3%	18%	4%	0,211
Belgium	56%	2%	14%	1%	26%	2%	0,248
Canada	13%	58%	19%	3%	6%	2%	0,243
Czech Republic	31%	2%	62%	0%	4%	1%	0,517
Denmark	0%	0%	55%	5%	21%	19%	0,536
Finland	27%	11%	32%	1%	17%	12%	0,315
France	78%	11%	5%	2%	3%	1%	0,080
Germany	28%	4%	52%	1%	10%	5%	0,574
Greece	0%	9%	60%	15%	14%	2%	0,801
Hungary	32%	1%	27%	5%	35%	1%	0,409
Ireland	0%	4%	32%	10%	52%	2%	0,642
Italy	0%	15%	15%	26%	40%	4%	0,569
Japan	23%	10%	28%	13%	24%	2%	0,508
Republic of Korea	37%	2%	39%	9%	12%	1%	0,498
Luxembourg	0%	25%	0%	0%	72%	3%	0,295
The Netherlands	4%	0%	28%	3%	59%	6%	0,512
New Zealand	0%	58%	8%	0%	24%	10%	0,187
Norway	0%	99%	0%	0%	0%	1%	0,002
Portugal	0%	34%	31%	13%	16%	5%	0,491
Spain	24%	17%	29%	9%	15%	6%	0,444
Sweden	50%	39%	3%	3%	0%	5%	0,042
Switzerland	41%	55%	0%	0%	1%	2%	0,007
Turkey	0%	25%	23%	7%	45%	0%	0,489
United Kingdom	22%	2%	35%	2%	37%	2%	0,532
United States	19%	7%	51%	3%	16%	2%	0,609


Estimated Greenhouse Gases emissions
of national electricity mix
kgCO2/kWh
1,000
0,900
0,800
0,700
0,600
0,500
0,400
0,300
0,200
0,100
0,000
Norway
Switzerland
Sweden
France
New Zealand
Austria
Canada
Belgium
Luxembourg
Finland
Hungary
Spain
Turkey
Portugal
Republic of Korea
Japan
The Netherlands
Czech Republic
United Kingdom
Denmark
Italy
Germany
United States
Ireland
Greece
Australia

Annex C : Energy Payback Time (EPBT)

See part 1.2 and 1.4.2 for assumptions, methodology and source of data

Country	City	Roof top PV system [year]	PV façade [year]
Australia	Sydney	1,9	3,1
	Perth	1,6	2,7
	Brisbane	1,9	3,5
Austria	Vienna	2,8	4,2
Belgium	Brussels	3,2	4,7
Canada	Ottawa	2,1	3,1
	Vancouver	2,3	3,4
Czech Republic	Prague	3,1	4,6
Denmark	Copenhagen	3,0	4,1
Finland	Helsinki	3,1	4,2
France	Paris	2,9	4,2
	Lyon	2,6	4,0
	Marseille	1,9	2,9
Germany	Berlin	3,0	4,3
	Cologne	3,1	4,5
	Munich	2,6	3,8
Greece	Athens	2,0	3,3
Hungary	Budapest	2,6	3,9
Ireland	Dublin	3,1	4,3
Italy	Rome	1,9	2,9
	Milan	2,4	3,7
Japan	Tokyo	2,6	4,0
	Hiroshima	2,4	3,8
	Sapporo	2,5	3,6
Republic of Korea	Seoul	2,5	3,7
Luxembourg	Luxembourg	2,9	4,3
The Netherlands	Amsterdam	2,9	4,1
New Zealand	Wellington	2,1	3,3
Norway	Oslo	2,9	3,7
Portugal	Lisbon	1,8	2,9
Spain	Barcelona	2,1	3,3
	Madrid	1,8	2,9
	Sevilla	1,7	2,8
Sweden	Stockholm	2,9	3,9
Switzerland	Bern	2,7	4,1
Turkey	Ankara	1,8	3,0
United Kingdom	London	3,2	4,6
	Edinburgh	3,3	4,6
United States	Washington	2,0	3,1
	Los Angeles	1,7	2,8
	Houston	2,0	3,5


Energy Payback Time
Roof top PV system
Year
5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Perth
Los Angeles
Sevilla
Ankara
Madrid
Lisbon
Sydney
Marseille
Rome
Brisbane
Athens
Houston
Washington
Barcelona
Ottawa
Wellington
Vancouver
Hiroshima
Milan
Sapporo
Seoul
Budapest
Lyon
Munich
Tokyo
Bern
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Berlin
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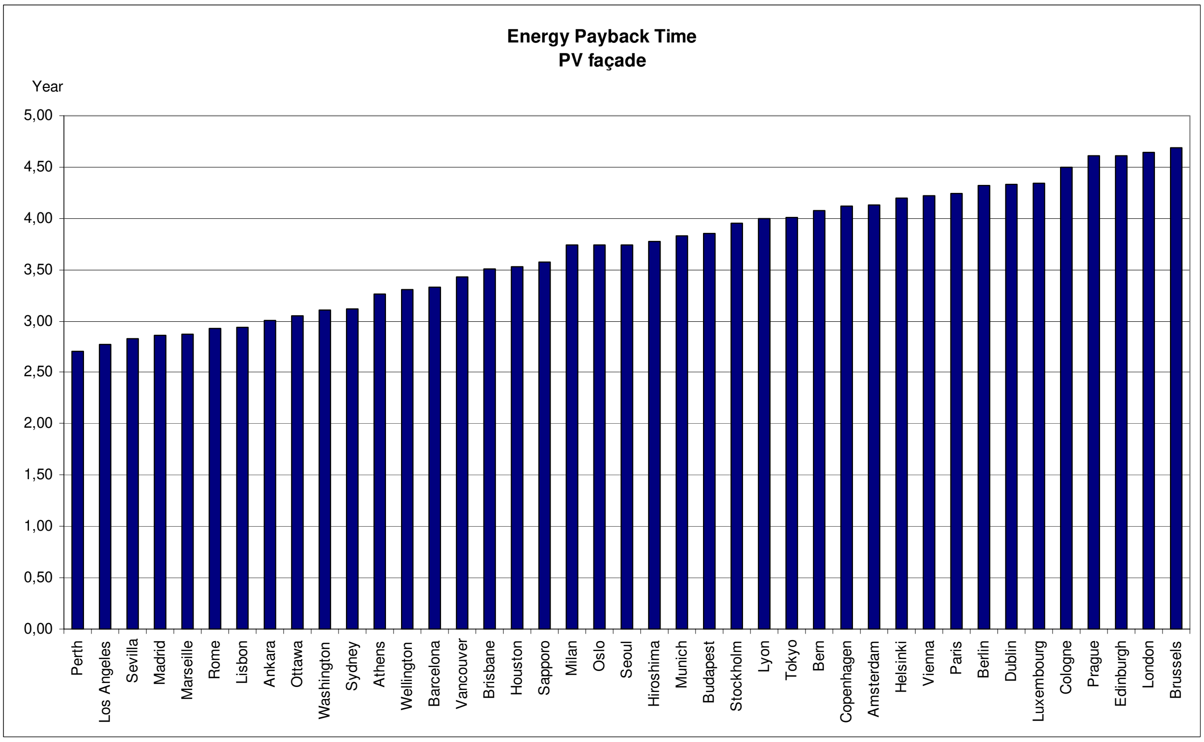
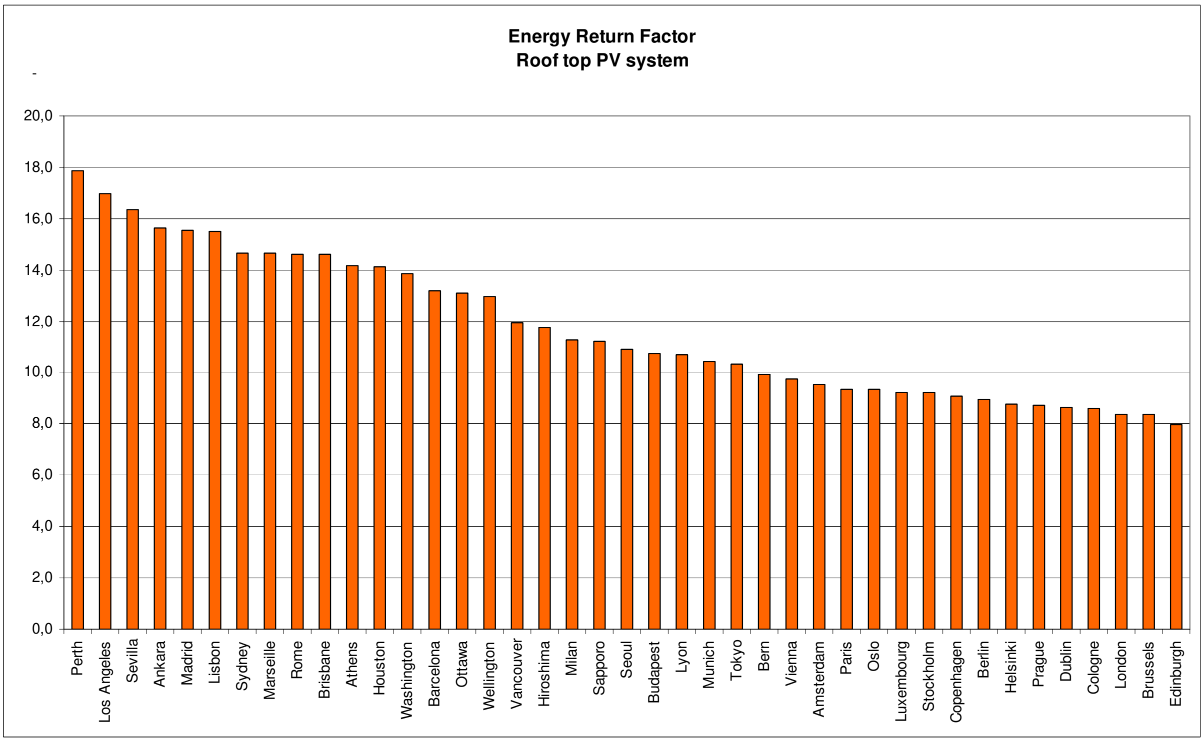
Dublin
Cologne
London
Brussels
Edinburgh

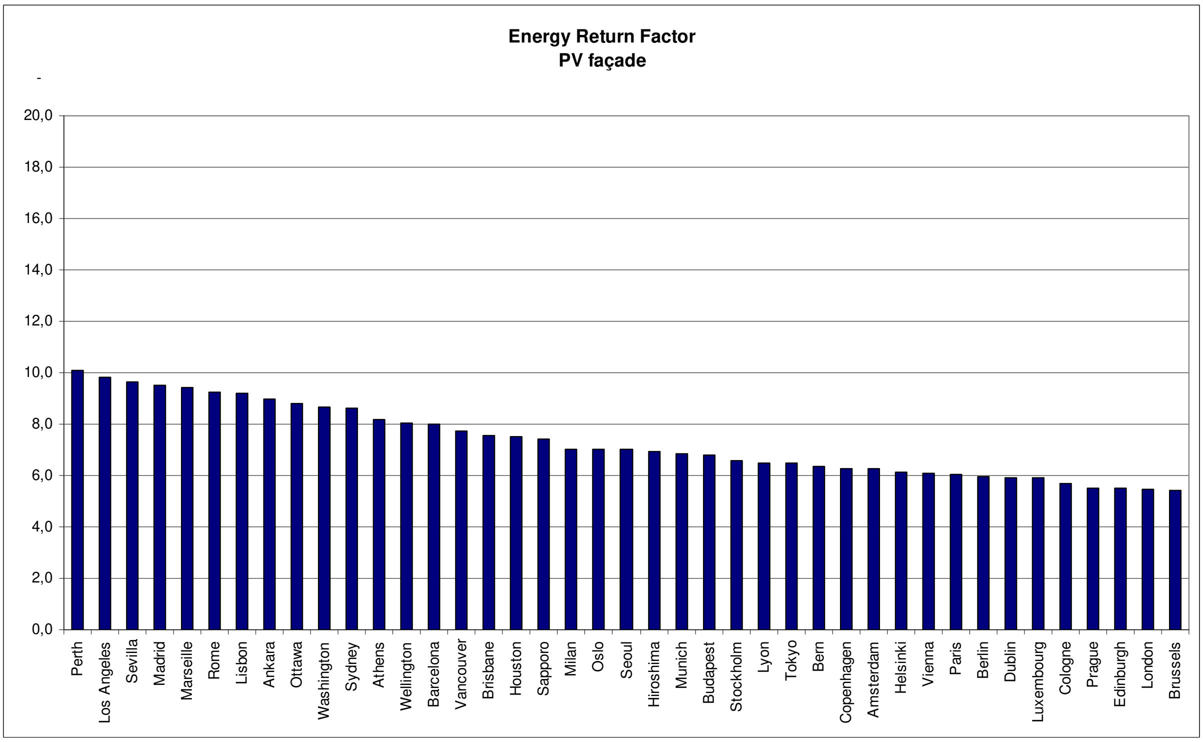

Energy Payback Time
PV façade
Year
5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Perth
Los Angeles
Sevilla
Madrid
Marseille
Rome
Lisbon
Ankara
Ottawa
Washington
Sydney
Athens
Wellington
Barcelona
Vancouver
Brisbane
Houston
Sapporo
Milan
Oslo
Seoul
Hiroshima
Munich
Budapest
Stockholm
Lyon
Tokyo
Bern
Copenhagen
Amsterdam
Helsinki
Vienna
Paris
Berlin
Dublin
Luxembourg
Cologne
Prague
Edinburgh
London
Brussels

Annex D : Energy Return Factor (ERF)

See part 1.2 and 1.4.4 for assumptions, methodology and source of data

Country	City	Roof top PV system [-]	PV façade [-]
Australia	Sydney	14,7	8,6
	Perth	17,9	10,1
	Brisbane	14,6	7,6
Austria	Vienna	9,8	6,1
Belgium	Brussels	8,4	5,4
Canada	Ottawa	13,1	8,8
	Vancouver	11,9	7,7
Czech Republic	Prague	8,7	5,5
Denmark	Copenhagen	9,1	6,3
Finland	Helsinki	8,8	6,2
France	Paris	9,4	6,1
	Lyon	10,7	6,5
	Marseille	14,6	9,4
Germany	Berlin	9,0	5,9
	Cologne	8,6	5,7
	Munich	10,4	6,8
Greece	Athens	14,2	8,2
Hungary	Budapest	10,7	6,8
Ireland	Dublin	8,6	5,9
Italy	Rome	14,6	9,2
	Milan	11,3	7,0
Japan	Tokyo	10,3	6,5
	Hiroshima	11,7	6,9
	Sapporo	11,2	7,4
Republic of Korea	Seoul	10,9	7,0
Luxembourg	Luxembourg	9,2	5,9
The Netherlands	Amsterdam	9,5	6,3
New Zealand	Wellington	13,0	8,1
Norway	Oslo	9,3	7,0
Portugal	Lisbon	15,5	9,2
Spain	Barcelona	13,2	8,0
	Madrid	15,6	9,5
	Sevilla	16,3	9,6
Sweden	Stockholm	9,2	6,6
Switzerland	Bern	9,9	6,4
Turkey	Ankara	15,6	9,0
United Kingdom	London	8,4	5,5
	Edinburgh	8,0	5,5
United States	Washington	13,8	8,7
	Los Angeles	17,0	9,8
	Houston	14,1	7,5

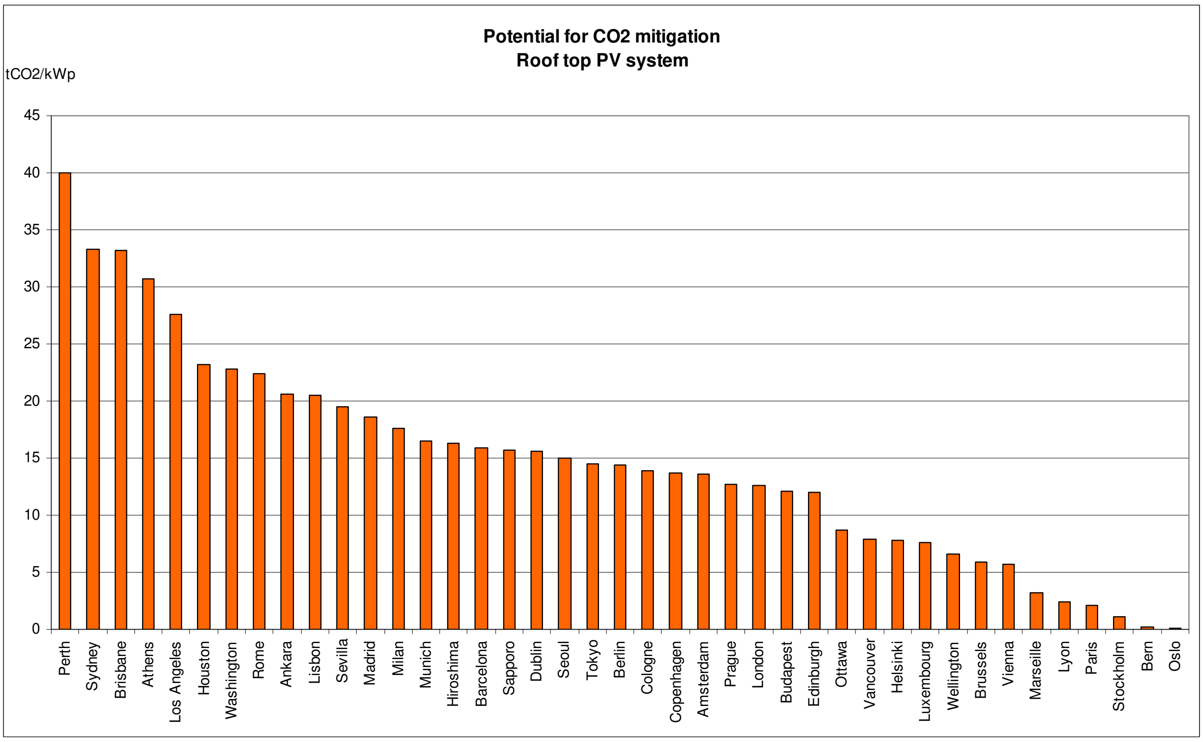

Energy Return Factor
Roof top PV system
-
20,0
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
Perth
Los Angeles
Sevilla
Ankara
Madrid
Lisbon
Sydney
Marseille
Rome
Brisbane
Athens
Houston
Washington
Barcelona
Ottawa
Wellington
Vancouver
Hiroshima
Milan
Sapporo
Seoul
Budapest
Lyon
Munich
Tokyo
Bern
Vienna
Amsterdam
Paris
Oslo
Luxembourg
Stockholm
Copenhagen
Berlin
Helsinki
Prague
Dublin
Cologne
London
Brussels
Edinburgh

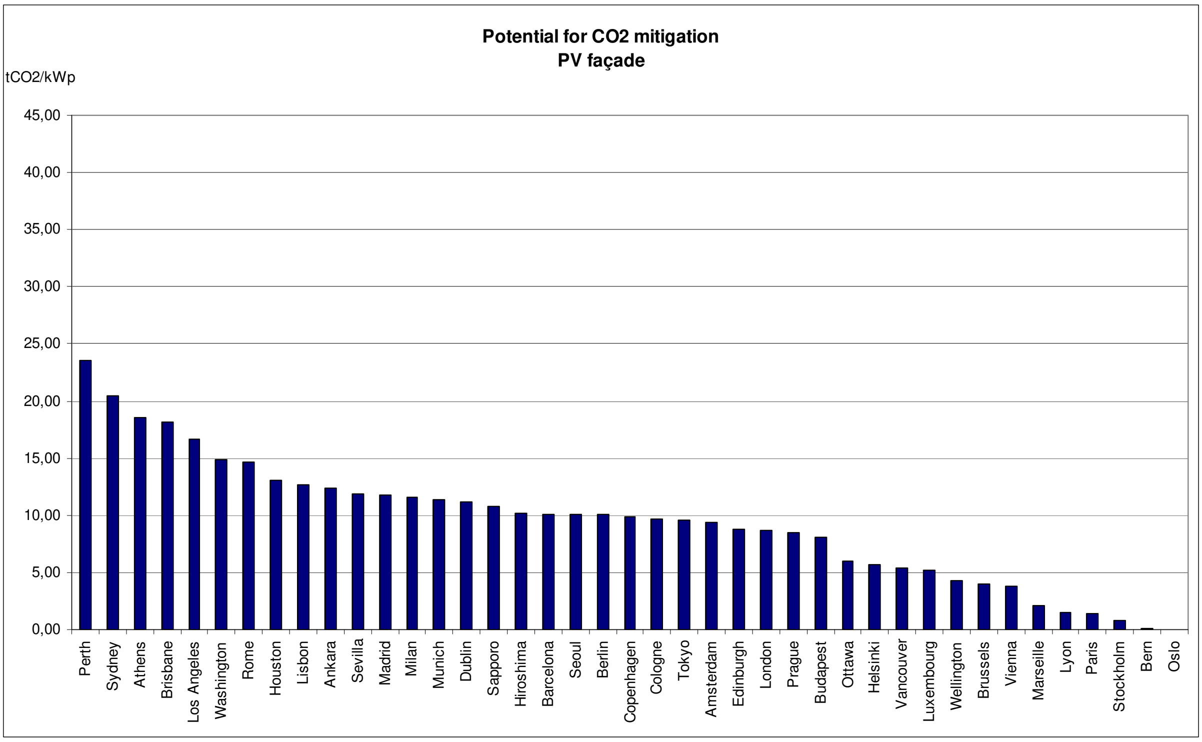

Energy Return Factor
PV façade
-
20,0
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
Perth
Los Angeles
Sevilla
Madrid
Marseille
Rome
Lisbon
Ankara
Ottawa
Washington
Sydney
Athens
Wellington
Barcelona
Vancouver
Brisbane
Houston
Sapporo
Milan
Oslo
Seoul
Hiroshima
Munich
Budapest
Stockholm
Lyon
Tokyo
Bern
Copenhagen
Amsterdam
Helsinki
Vienna
Paris
Berlin
Dublin
Luxembourg
Cologne
Prague
Edinburgh
London
Brussels

Annex E : Potential of photovoltaic systems for Greenhouse Gases Mitigation

See part 1.2 and 1.4.3 for assumptions, methodology and source of data

Country	**City**	**Roof top PV system** [tCO_2/kWp]	**PV façade** [tCO_2/kWp]
Australia	Sydney	33,3	20,5
	Perth	40,0	23,5
	Brisbane	33,2	18,2
Austria	Vienna	5,7	3,8
Belgium	Brussels	5,9	4,0
Canada	Ottawa	8,7	6,0
	Vancouver	7,9	5,4
Czech Republic	Prague	12,7	8,5
Denmark	Copenhagen	13,7	9,9
Finland	Helsinki	7,8	5,7
France	Paris	2,1	1,4
	Lyon	2,4	1,5
	Marseille	3,2	2,1
Germany	Berlin	14,4	10,1
	Cologne	13,9	9,7
	Munich	16,5	11,4
Greece	Athens	30,7	18,6
Hungary	Budapest	12,1	8,0
Ireland	Dublin	15,6	11,2
Italy	Rome	22,4	14,7
	Milan	17,6	11,5
Japan	Tokyo	14,5	9,6
	Hiroshima	16,3	10,2
	Sapporo	15,7	10,8
Republic of Korea	Seoul	15,0	10,1
Luxembourg	Luxembourg	7,6	5,2
The Netherlands	Amsterdam	13,6	9,4
New Zealand	Wellington	6,6	4,3
Norway	Oslo	0,1	0,0
Portugal	Lisbon	20,5	12,6
Spain	Barcelona	15,9	10,1
	Madrid	18,6	11,8
	Sevilla	19,5	11,9
Sweden	Stockholm	1,1	0,8
Switzerland	Bern	0,2	0,1
Turkey	Ankara	20,6	12,3
United Kingdom	London	12,6	8,7
	Edinburgh	12,0	8,7
United States	Washington	22,8	14,9
	Los Angeles	27,6	16,7
	Houston	23,2	13,1


Potential for CO2 mitigation
Roof top PV system
tCO2/kWp
45
40
35
30
25
20
15
10
5
0
Perth
Sydney
Brisbane
Athens
Los Angeles
Houston
Washington
Rome
Ankara
Lisbon
Sevilla
Madrid
Milan
Munich
Hiroshima
Barcelona
Sapporo
Dublin
Seoul
Tokyo
Berlin
Cologne
Copenhagen
Amsterdam
Prague
London
Budapest
Edinburgh
Ottawa
Vancouver
Helsinki
Luxembourg
Wellington
Brussels
Vienna
Marseille
Lyon
Paris
Stockholm
Bern
Oslo


Potential for CO2 mitigation
PV façade
tCO2/kWp
45,00
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Perth
Sydney
Athens
Brisbane
Los Angeles
Washington
Rome
Houston
Lisbon
Ankara
Sevilla
Madrid
Milan
Munich
Dublin
Sapporo
Hiroshima
Barcelona
Seoul
Berlin
Copenhagen
Cologne
Tokyo
Amsterdam
Edinburgh
London
Prague
Budapest
Ottawa
Helsinki
Vancouver
Luxembourg
Wellington
Brussels
Vienna
Marseille
Lyon
Paris
Stockholm
Bern
Oslo