Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities
Electricity production based on solar photovoltaic (PV) technology 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.

These particularities make PV one of the major and most suitable options in the mid-to long term future for producing electricity worldwide in OECD and non-OECD countries.

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

Although this is no longer an issue among the scientific community and PV-related Industry, unfounded rumours still persist here and there that question the status of PV as a renewable energy, including an "infinite energy pay-back-time" and an overall negative impact on the global environment.

The purpose of the new report “Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities” published in April 2006 jointly by the International Energy Agency-Photovoltaic Power Systems Programme (IEA-PVPS), the European Photovoltaic Technology Platform and the European Photovoltaic Industry Association (EPIA) 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.
Based on a worldwide survey of existing studies concerning the energy input of PV systems, used to calculate the so-called “energy pay-back time” (defined as the time in years needed for a PV-system to “reimburse” its initial energy content) and the derived “energy return factor” (the number of times a PV system will reimburse its energy content during its commercial life cycle), and on commonly recognised and readily available data concerning pollution indicators such as CO₂ emissions in the electricity mixes of 26 OECD countries, this report provides clear and incontestable figures:

- The **energy pay-back time (EPBT)** of a complete PV system (not only panels, but also wires and electronic connexion devices) is, depending on the solar irradiation of its location, in the range of 19 months (just over one year and a half) to 40 months (three years and 4 months) for a roof-mounted system, and from 32 months (2 years and 8 months) to 56 months (4 years and 8 months) for a PV-façade.

- Based on a commonly admitted 30 year-long commercial life cycle, the **energy return factor (ERF)** is between 8 and 18 for roof-mounted systems, and between 6.4 and 10 for façades.

- Varying widely from one country to another, using the energy production mix from each country, 1 single kW of PV panels (roughly 10 square meters) can **avoid up to 40 tons of Carbon dioxide** (CO₂) during its whole commercial life cycle - 23.5 for a façade.

The complete report describes the methodology used for the calculation of the 3 indicators in relation with the location where the PV systems are installed: EPBT and ERF depend on the amount of sun at the location and the CO₂ indicator depends on the local electricity mix.

With a view to both better reflect the varying reality and to facilitate the use of the results at national and local levels by making customised figures available, the performance of PV systems is assessed in the full version 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, covering in total 41 main cities in 26 OECD countries.

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 may be located worldwide.

With the publication of this report long-awaited for by the Industry and policy-makers, and expected to be largely authoritative and consensual, the authors and the publishers hope to definitively close some unjustified controversies that still prevent the large-scale development of PV in several countries, and to provide PV supporters who are more and more numerous worldwide with proven and indisputable arguments.

The full report prepared by Hespul with the support of the French Agency for Environment and Energy Management (ADEME) can be downloaded on the IEA-PVPS website [www.iea-pvps.org](http://www.iea-pvps.org).
IEA-PVPS Task 10
The Photovoltaic Power Systems Programme is a collaborative R&D Agreement, established within the International Energy Agency, and conducting projects on the application of solar photovoltaic electricity. 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.
www.iea-pvps.org

European Photovoltaic Technology Platform
The Photovoltaic Technology Platform is an initiative which aims at mobilising all the actors sharing a long-term European vision for photovoltaic; realising the European Strategic Research Agenda for PV for the next decade(s) and give recommendations for implementation; ensuring that Europe maintains industrial leadership.
www.eupvplatform.org

European Photovoltaic Industry Association
With over 80 members drawn from across the entire solar electricity sector, the European Photovoltaic Industry Association represents over 95% of the European photovoltaic industry. EPIA represents the whole value-chain of the photovoltaic industry from silicon producers, cells and module manufacturers to system providers. The Association’s mission is to deliver to its Members a distinct and valuable service driven from the strength of a single European photovoltaic (PV) voice.
www.epia.org
Country reports
The following 26 country reports are summarizing on a country-by-country basis the results for all OECD countries. For each country, the following elements are presented:

- A map shows the location of cities that were selected for the calculation of those indicators.
- For each city, a table summarises the value of each indicator calculated within the 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 PV systems and each city, a figure gives the EPBT ranked from the shortest to the longest. It also shows the contribution of the laminate, the frame and the balance of system.
- For each city, a graph shows the net energy production over the system lifetime. 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.

The 26 countries included in the report are the following:

- Australia
- Austria
- Belgium
- Canada
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Japan
- Republic of Korea
- Luxembourg
- The Netherlands
- New Zealand
- Norway
- Portugal
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom
- United States
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

Location of studied cities

<table>
<thead>
<tr>
<th>Sydney</th>
<th>Global horizontal irradiation 1614 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>1 319</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1,91</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>33,285</td>
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</table>

<table>
<thead>
<tr>
<th>Perth</th>
<th>Global horizontal irradiation 1941 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>1 587</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1,59</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
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</table>

<table>
<thead>
<tr>
<th>Brisbane</th>
<th>Global horizontal irradiation 1686 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
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<tr>
<td>Annual output [kWh/kWp]</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1,92</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>33,174</td>
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Vienna

Global horizontal irradiation 1108 kWh/m²

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Roof-top</td>
<td>906</td>
<td>2.79</td>
<td>9.8</td>
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<td>Façade</td>
<td>598</td>
<td>4.22</td>
<td>6.1</td>
<td>3.793</td>
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Energy Payback time

Cumulative net energy production over system lifetime for Vienna
### Brussels

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation 946 kWh/m²</th>
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<tbody>
<tr>
<td></td>
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<td>Roof-top</td>
<td>Façade</td>
</tr>
<tr>
<td><strong>Annual output [kWh/kWp]</strong></td>
<td>788</td>
<td>539</td>
<td></td>
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<tr>
<td><strong>Energy Pay-Back Time [years]</strong></td>
<td>3.21</td>
<td>4.68</td>
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<td><strong>Energy Return Factor [number of times]</strong></td>
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<td><strong>Potential for CO₂ mitigation [tCO₂/kWp]</strong></td>
<td>5.861</td>
<td>4.013</td>
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</table>

**Location of studied city**

![Map of Brussels](image)

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**Energy Payback time**

Cumulative net energy production over system lifetime for Brussels.
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**CANADA**

<table>
<thead>
<tr>
<th>Location</th>
<th>Global horizontal irradiation (kWh/m²)</th>
<th>Annual output (kWh/kWp)</th>
<th>Energy Pay-Back Time (years)</th>
<th>Energy Return Factor (number of times)</th>
<th>Potential for CO₂ mitigation (tCO₂/kWp)</th>
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</thead>
<tbody>
<tr>
<td><strong>Ottawa</strong></td>
<td>1377</td>
<td>1,188</td>
<td>2.13</td>
<td>13.1</td>
<td>8.659</td>
</tr>
<tr>
<td></td>
<td></td>
<td>826</td>
<td>3.06</td>
<td>8.8</td>
<td>6.024</td>
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<tr>
<td><strong>Vancouver</strong></td>
<td>1273</td>
<td>1,088</td>
<td>2.32</td>
<td>11.9</td>
<td>7.935</td>
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<td></td>
<td></td>
<td>735</td>
<td>3.44</td>
<td>7.7</td>
<td>5.360</td>
</tr>
</tbody>
</table>

**Location of studied cities**

**Energy Payback time**

Cumulative net energy production over system lifetime for Ottawa

Cumulative net energy production over system lifetime for Vancouver

**International Energy Agency-Photovoltaic Power Systems Programme**

**European Photovoltaic Industry Association**

**European Photovoltaic Technology Platform**
### Prague

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation</th>
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<tr>
<td></td>
<td>1000 kWh/m²</td>
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<tr>
<td></td>
<td>Roof-top</td>
<td>Façade</td>
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<tr>
<td>Annual output [kWh/kWp]</td>
<td>818</td>
<td>548</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>3,09</td>
<td>4,61</td>
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<td>Energy Return Factor [number of times]</td>
<td>8,7</td>
<td>5,5</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>12,685</td>
<td>8,495</td>
</tr>
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</table>

**Location of studied city**

![Map showing location of Prague](image)

**Energy Payback Time**

Cumulative net energy production over system lifetime for Prague

![Graph showing energy payback time](image)
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**DENMARK**

**Copenhagen**

Global horizontal irradiation 985 kWh/m²

<table>
<thead>
<tr>
<th></th>
<th>Roof-top</th>
<th>Façade</th>
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</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>850</td>
<td>613</td>
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<td>Energy Return Factor [number of times]</td>
<td>9.1</td>
<td>6.3</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>13,672</td>
<td>9,868</td>
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</table>

Location of studied city

![Graph showing energy payback time for Copenhagen](image)

Cumulative net energy production over system lifetime for Copenhagen
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**FINLAND**

Helsinki

Global horizontal irradiation
956 kWh/m²

<table>
<thead>
<tr>
<th>Location of studied city</th>
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</thead>
</table>

### Helsinki

<table>
<thead>
<tr>
<th></th>
<th>Roof-top</th>
<th>Façade</th>
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<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>825</td>
<td>602</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>3.06</td>
<td>4.19</td>
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<td>Energy Return Factor [number of times]</td>
<td>8.8</td>
<td>6.2</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>7,780</td>
<td>5,683</td>
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Energy Payback time

Cumulative net energy production over system lifetime for Helsinki
FRANCE

Compares assessment of selected environmental indicators of photovoltaic electricity in OECD cities

Location of studied cities

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Paris</td>
<td>1057 kWh/m²</td>
<td>872</td>
<td>2.90</td>
<td>9.4</td>
<td>2.095</td>
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<tr>
<td>Lyon</td>
<td>1204 kWh/m²</td>
<td>984</td>
<td>2.57</td>
<td>10.7</td>
<td>2.364</td>
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<tr>
<td>Marseille</td>
<td>1540 kWh/m²</td>
<td>1317</td>
<td>1.92</td>
<td>14.6</td>
<td>3.163</td>
</tr>
</tbody>
</table>

Cumulative energy production over system lifetime for Paris

Cumulative energy production over system lifetime for Lyon

Cumulative energy production over system lifetime for Marseille

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International Energy Agency-Photovoltaic Power Systems Programme
European Photovoltaic Technology Platform
European Photovoltaic Industry Association

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

Location of studied cities

### Berlin
- **Global horizontal irradiation**: 999 kWh/m²
- Annual output [kWh/kWp]: 839 [Roof-top], 584 [Façade]
- Energy Pay-Back Time [years]: 3.01 [Roof-top], 4.32 [Façade]
- Energy Return Factor [number of times]: 9.0 [Roof-top], 5.9 [Façade]
- Potential for CO₂ mitigation [tCO₂/kWp]: 14,445 [Roof-top], 10,060 [Façade]

### Cologne
- **Global horizontal irradiation**: 972 kWh/m²
- Annual output [kWh/kWp]: 809 [Roof-top], 561 [Façade]
- Energy Pay-Back Time [years]: 3.12 [Roof-top], 4.50 [Façade]
- Energy Return Factor [number of times]: 8.6 [Roof-top], 5.7 [Façade]
- Potential for CO₂ mitigation [tCO₂/kWp]: 13,929 [Roof-top], 9,663 [Façade]

### Munich
- **Global horizontal irradiation**: 1143 kWh/m²
- Annual output [kWh/kWp]: 960 [Roof-top], 660 [Façade]
- Energy Pay-Back Time [years]: 2.63 [Roof-top], 3.83 [Façade]
- Energy Return Factor [number of times]: 10.4 [Roof-top], 6.8 [Façade]
- Potential for CO₂ mitigation [tCO₂/kWp]: 16,528 [Roof-top], 11,363 [Façade]
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**Athens**

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation 1563 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>1 278</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1,98</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
<td>14,2</td>
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<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>30,687</td>
</tr>
</tbody>
</table>

Location of studied city

**Cumulative net energy production over system lifetime for Athens**

**Energy Payback time**

International Energy Agency-Photovoltaic Power Systems Programme

European Photovoltaic Technology Platform

European Photovoltaic Industry Association
## Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**HUNGARY**

**Budapest**

### Global horizontal irradiation

<table>
<thead>
<tr>
<th>Location</th>
<th>1198 kWh/m²</th>
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</thead>
<tbody>
<tr>
<td>Budapest</td>
<td></td>
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</tbody>
</table>

### Energy Pay-Back Time [years]

<table>
<thead>
<tr>
<th>Location</th>
<th>[years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budapest (roof)</td>
<td>2.56</td>
</tr>
<tr>
<td>Budapest (façade)</td>
<td>3.85</td>
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</tbody>
</table>

### Energy Return Factor [number of times]

<table>
<thead>
<tr>
<th>Location</th>
<th>[number of times]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budapest (roof)</td>
<td>10.7</td>
</tr>
<tr>
<td>Budapest (façade)</td>
<td>6.8</td>
</tr>
</tbody>
</table>

### Potential for CO₂ mitigation [tCO₂/kWp]

<table>
<thead>
<tr>
<th>Location</th>
<th>[tCO₂/kWp]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budapest (roof)</td>
<td>12,124</td>
</tr>
<tr>
<td>Budapest (façade)</td>
<td>8,046</td>
</tr>
</tbody>
</table>

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**Location of studied city**

**Energy Payback time**

**Cumulative net energy production over system lifetime for Budapest**
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

<table>
<thead>
<tr>
<th>Dublin</th>
<th>Global horizontal irradiation 948 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>811</td>
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<tr>
<td>Energy Pay-Back Time [years]</td>
<td>3.12</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
<td>8.6</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>15,602</td>
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</tbody>
</table>

Energy Pay-back time

Cumulative net energy production over system lifetime for Dublin

Location of studied city - Dublin
### Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

#### ITALY

**Location of studied cities**

#### Global horizontal irradiation

<table>
<thead>
<tr>
<th>Location</th>
<th>Global horizontal irradiation</th>
<th>1552 kWh/m²</th>
<th>1251 kWh/m²</th>
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</thead>
<tbody>
<tr>
<td><strong>Rome</strong></td>
<td>Annual output [kWh/kWp]</td>
<td>1,315</td>
<td>1,032</td>
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<td></td>
<td>Energy Pay-Back Time [years]</td>
<td>1.92</td>
<td>2.45</td>
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<td>Energy Return Factor [number of times]</td>
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<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>22,441</td>
<td>17,608</td>
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<tr>
<td><strong>Milan</strong></td>
<td>Annual output [kWh/kWp]</td>
<td>861</td>
<td>676</td>
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<td></td>
<td>Energy Pay-Back Time [years]</td>
<td>2.93</td>
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<td>Energy Return Factor [number of times]</td>
<td>9.2</td>
<td>7.0</td>
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<tr>
<td></td>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>14,696</td>
<td>11,526</td>
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</table>

#### Energy Payback time

**Cumulative net energy production over system lifetime**

- **Rome (roof)**
- **Milan (roof)**
- **Rome (façade)**
- **Milan (façade)**

![Energy Payback time graph](chart.png)

**Legend:**
- Roof top PV system
- PV façade

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International Energy Agency-Photovoltaic Power Systems Programme

European Photovoltaic Industry Association

European Photovoltaic Technology Platform

[Site Map Link]
## Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

### Location of studied cities

- **Hiroshima**
- **Sapporo**
- **Tokyo**

## International Energy Agency - Photovoltaic Power Systems Programme

### Energy Return Factor
- **Sapporo**
  - Annual output [kWh/kWp]: 1,029
  - Energy Pay-Back Time [years]: 2.45
  - Energy Return Factor [number of times]: 11.2
  - Potential for CO₂ mitigation [tCO₂/kWp]: 15,673

- **Tokyo**
  - Annual output [kWh/kWp]: 955
  - Energy Pay-Back Time [years]: 2.64
  - Energy Return Factor [number of times]: 10.3
  - Potential for CO₂ mitigation [tCO₂/kWp]: 14,544

- **Hiroshima**
  - Annual output [kWh/kWp]: 1,073
  - Energy Pay-Back Time [years]: 2.35
  - Energy Return Factor [number of times]: 11.7
  - Potential for CO₂ mitigation [tCO₂/kWp]: 16,347

### Energy Pay-Back Time

#### Cumulative net energy production over system lifetime for Sapporo

#### Cumulative net energy production over system lifetime for Tokyo

#### Cumulative net energy production over system lifetime for Hiroshima

### Diagrams

- **Hiroshima (roof)**
- **Sapporo (roof)**
- **Tokyo (roof)**
- **Sapporo (façade)**
- **Tokyo (façade)**
- **Hiroshima (façade)**
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

REPUBLIC OF KOREA

Seoul

Location of studied city

<table>
<thead>
<tr>
<th>Seoul</th>
<th>Global horizontal irradiation 1215 kWh/m²</th>
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<tbody>
<tr>
<td></td>
<td>Roof-top</td>
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<tr>
<td>Annual output [kWh/kWp]</td>
<td>1 002</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>2.52</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>10.9</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>14,963</td>
</tr>
</tbody>
</table>

Energy Payback time

Cumulative net energy production over system lifetime for Seoul
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**Luxembourg**

- **Location of studied city:**

### Luxembourg

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation 1035 kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>862</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>2.93</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>9.2</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>7.628</td>
</tr>
</tbody>
</table>

**Energy Payback time**

- Cumulative net energy production over system lifetime for Luxembourg
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**Amsterdam**

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation</th>
<th>1045 kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roof-top</td>
<td>Façade</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>886</td>
<td>611</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>2.85</td>
<td>4.13</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>9.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>13,599</td>
<td>9,387</td>
</tr>
</tbody>
</table>
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**Wellington**

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation 1412 kWh/m²</th>
<th>Roof-top</th>
<th>Façade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td></td>
<td>1 175</td>
<td>762</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td></td>
<td>2,15</td>
<td>3,31</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td></td>
<td>13,0</td>
<td>8,1</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td></td>
<td>6,611</td>
<td>4,289</td>
</tr>
</tbody>
</table>

Location of studied city.

Cumulative net energy production over system lifetime for Wellington.
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**Oslo**

<table>
<thead>
<tr>
<th>Global horizontal irradiation 967 kWh/m²</th>
<th>Roof-top</th>
<th>Façade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>870</td>
<td>674</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>2.90</td>
<td>3.74</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>9.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>0.056</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Location of studied city

Cumulative net energy production over system lifetime for Oslo

Energy Payback time

Oslo (roof)

Oslo (façade)
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

**PORTUGAL**

**Lisbon**

**Location of studied city**

<table>
<thead>
<tr>
<th>Lisbon</th>
<th>Global horizontal irradiation 1682 kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>1388</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1.82</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>15.5</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>20,461</td>
</tr>
</tbody>
</table>

**Energy Payback time**

**Cumulative net energy production over system lifetime for Lisbon**
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

### Barcelona
- **Global horizontal irradiation**: 1446 kWh/m²
- **Annual output [kWh/kWp]**
  - Roof-top: 1193
  - Façade: 759
- **Energy Pay-Back Time [years]**: 2,12 (Roof-top), 3,33 (Façade)
- **Energy Return Factor [number of times]**: 13,2 (Roof-top), 8,0 (Façade)
- **Potential for CO₂ mitigation [tCO₂/kWp]**: 15,895 (Roof-top), 10,115 (Façade)

### Madrid
- **Global horizontal irradiation**: 1660 kWh/m²
- **Annual output [kWh/kWp]**
  - Roof-top: 1394
  - Façade: 884
- **Energy Pay-Back Time [years]**: 1,81 (Roof-top), 2,86 (Façade)
- **Energy Return Factor [number of times]**: 15,6 (Roof-top), 9,5 (Façade)
- **Potential for CO₂ mitigation [tCO₂/kWp]**: 18,579 (Roof-top), 11,778 (Façade)

### Sevilla
- **Global horizontal irradiation**: 1754 kWh/m²
- **Annual output [kWh/kWp]**
  - Roof-top: 1460
  - Façade: 895
- **Energy Pay-Back Time [years]**: 1,73 (Roof-top), 2,82 (Façade)
- **Energy Return Factor [number of times]**: 16,3 (Roof-top), 9,6 (Façade)
- **Potential for CO₂ mitigation [tCO₂/kWp]**: 19,456 (Roof-top), 11,919 (Façade)
**Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities**

### Stockholm

<table>
<thead>
<tr>
<th></th>
<th>Global horizontal irradiation 980 kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>860</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>2.94</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
<td>9.2</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>1.078</td>
</tr>
</tbody>
</table>

**Location of studied city**

[Map of Stockholm]

**Cumulative net energy production over system lifetime for Stockholm**

[Graph showing cumulative energy production]

[Bar chart for Stockholm]

**International Energy Agency-Photovoltaic Power Systems Programme**

**European Photovoltaic Technology Platform**

**European Photovoltaic Industry Association**
### Bern

<table>
<thead>
<tr>
<th>Global horizontal irradiation</th>
<th>1117 kWh/m²</th>
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</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td></td>
</tr>
<tr>
<td>Roof-top</td>
<td>922</td>
</tr>
<tr>
<td>Façade</td>
<td>620</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td></td>
</tr>
<tr>
<td>Roof-top</td>
<td>2.74</td>
</tr>
<tr>
<td>Façade</td>
<td>4.07</td>
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<tr>
<td>Energy Return Factor [number of times]</td>
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<tr>
<td>Roof-top</td>
<td>9.9</td>
</tr>
<tr>
<td>Façade</td>
<td>6.4</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td></td>
</tr>
<tr>
<td>Roof-top</td>
<td>0.180</td>
</tr>
<tr>
<td>Façade</td>
<td>0.121</td>
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</tbody>
</table>
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

Ankara

Location of studied city

<table>
<thead>
<tr>
<th>Ankara</th>
<th>Global horizontal irradiation 1697 kWh/m²</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Roof-top</td>
</tr>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>1 400</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>1,80</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>15,6</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>20,555</td>
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</tbody>
</table>

Cumulative net energy production over system lifetime for Ankara
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

UNITED KINGDOM

Edinburgh

Global horizontal irradiation 955 kWh/m²

<table>
<thead>
<tr>
<th></th>
<th>Roof-top</th>
<th>Façade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>788</td>
<td>544</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>3.21</td>
<td>4.64</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>8.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>12,571</td>
<td>8,685</td>
</tr>
</tbody>
</table>

London

Global horizontal irradiation 965 kWh/m²

<table>
<thead>
<tr>
<th></th>
<th>Roof-top</th>
<th>Façade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual output [kWh/kWp]</td>
<td>754</td>
<td>547</td>
</tr>
<tr>
<td>Energy Pay-Back Time [years]</td>
<td>3.35</td>
<td>4.61</td>
</tr>
<tr>
<td>Energy Return Factor [number of times]</td>
<td>8.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Potential for CO₂ mitigation [tCO₂/kWp]</td>
<td>12,034</td>
<td>8,733</td>
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</tbody>
</table>

Location of studied cities
Compared assessment of selected environmental indicators of photovoltaic electricity in OECD cities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington</td>
<td>1487 kWh/m²</td>
<td>1.249 (Roof-top) 1.024 (Facade)</td>
<td>2.02</td>
<td>13.8</td>
<td>22,809</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1816 kWh/m²</td>
<td>1.512 (Roof-top) 0.913 (Facade)</td>
<td>1.67</td>
<td>17.0</td>
<td>27,607</td>
</tr>
<tr>
<td>Houston</td>
<td>1615 kWh/m²</td>
<td>1.272 (Roof-top) 0.715 (Facade)</td>
<td>1.99</td>
<td>14.1</td>
<td>23,225</td>
</tr>
</tbody>
</table>

Energy Payback Time

Cumulative net energy production over system lifetime for Washington

Cumulative net energy production over system lifetime for Los Angeles

Cumulative net energy production over system lifetime for Houston