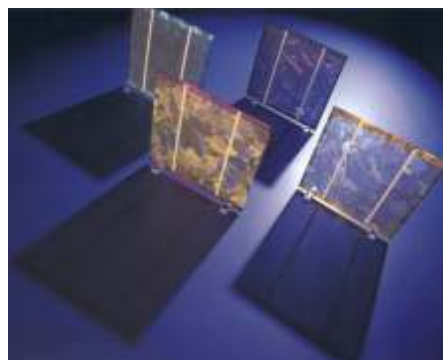




Compared Assessment of Selected Environmental Indicators of Photovoltaic Electricity in Selected OECD Cities and Malaysian Cities

Prepared by:
Malaysia Building Integrated Photovoltaic (MBIPV) Project



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Environmental Indicators of Photovoltaic
Electricity in Selected OECD Cities and
Malaysian Cities***

**Malaysia Building Integrated Photovoltaic
(MBIPV) Project**

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Foreword

In May 2006 the International Energy Agency (IEA) Photovoltaic Power Systems Programme PVPS, Task 10 prepared a comparison of environmental indicators for 41 selected cities in OECD countries [1]. The study was part of task 10's objective 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.

The Malaysia Building Integrated Photovoltaic Technology Application (MBIPV) project is a Malaysian Government initiative, funded by local government agencies and private sector sources, and supported by UNDP/GEF. The MBIPV project commenced in 2005 and will end in 2010. During the project's 5-year duration it will implement "Show-case, Demonstration and Suria 1000" programmes, which feature investment varying amounts of capital rebates to encourage investment in BIPV projects as well as to accelerate the development of the local PV market.

This paper provides the findings for selected Malaysian cities as a comparison to the results of the IEA-PVPS Task 10 report.

1 Introduction

Photovoltaic (PV) electricity generation is a renewable energy, which is clean and does not emit any greenhouse gases. It relies solely on the energy from the sun, which does not lead to depletion of energy resources or use of land such as for growing biomass fuels. However, energy is required to manufacture, install and later dismantle, recycle or dispose of PV systems. For all emerging energy technologies, especially renewable technologies, the question is often raised whether the technology requires more energy to implement it than it actually generates over its life time.

Lifecycle assessment of the energy input-output balance takes all aspects of energy consumption and generation into consideration and provides documentation for the net energy generation of the technologies concerned.

The IEA-PVPS Task 10 report that was released in May 2006 assessed the energy input into PV manufacturing, installation and disposal. This assessment was based on the latest available scientific publications at the time of writing.

The aim of the Task 10 report was to contribute to a better understanding of PV potential by closing the debate on any unjustified controversy and by providing clear and useful information to all interested parties, most importantly to national and local decision makers, who will inevitably have to deal with PV in the coming years considering its huge potential for deployment on a large scale in the short to medium term.

2 Methodology

2.1 Definition of PV systems

The PV-systems investigated in the study are standard poly-crystalline silicon modules and standard grid connected inverters. The IEA-PVPS study considered two common types of PV applications:

- 1) Roof-top application with a tilt angle of 30°, and
- 2) Façade application with a tilt angle of 90°

It was furthermore assumed that all PV systems were installed in the most favourable conditions, i.e. optimum orientation and without any shade at any hour of the day in all seasons. Thus, results found for rooftop-mounted PV systems could be considered as maximum values and results for PV façades as minimum values so that the environmental benefits of a broad range of PV systems, for instance not ideally oriented are covered.

The investigations of PV applications in Malaysia use a modified tilt angle as 30° is not optimum for locations around the Equator. Near horizontal tilt is more favourable and installations will normally have about 5 °-15° tilt angle to be efficient and still allow the PV system to follow the roof slope. In this study a tilt angle of 10° is used.

This change makes a more realistic comparison between the selected OECD cities in the IEA-PVPS study and Malaysian application as the 30° tilt angle is close to the optimum angle for the cities studied and will provide a close to optimum generation from the PV systems, while the 10° tilt angle in Malaysia will provide close to optimum generation for Malaysia.

2.2 Definition of Indicators

The study focuses on two energy indicators; the “Energy Pay Back Time” (EPBT) and the “Energy Return Factor” (ERF); and one environmental indicator, potential for CO₂ mitigation.

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 expressed in the same unit, either in primary energy or in final electrical energy. 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, which is defined to be 30 years 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 a dimensionless quantity.

The environmental indicator used is:

- the “Potential for CO₂ 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 CO₂ emissions of the local electricity generation mix (taken at national level). It is expressed in tons of CO₂ per kW_p installed.

The potential for CO₂ mitigation is only calculated on the net energy output after the energy input for the PV system has been covered. This gives a lower figure than commonly used for CO₂ mitigation assessment in for example Clean Development Mechanism projects, where the CO₂ emission reductions will be calculated based on the total energy generation while deducting any emissions from operating the system, but not from the energy consumption for manufacturing the equipment.

The potential for CO₂ mitigation is therefore conservative. However this allows for the assumption that the electricity generation mix is kept constant over the 30-years lifetime of the PV system, and the CO₂ emission factor is unchanged.

2.3 Calculation of Annual Energy Output

The annual energy output is calculated using the following formula, which is based on the CEI-IEC 61724 methodology for PV system performance monitoring.

$$E_{out} = H_i \times P_0 \times PR$$

Where:

E_{out} : Annual Energy Output in KWh/year

H_i : Global in-plane irradiation in kWh/m²/year

P_0 : Nominal power of the PV system in kW_p

PR: Performance Ratio

The global in-plane irradiation is calculated with the global horizontal irradiation database Meteonorm 4.10 in the international study and a conversion factor generated for each location is calculated by using PVSyst 3.3 to convert horizontal irradiation into in-plane irradiation (transposition factor).

For Malaysia Meteonorm 5.0 is used to calculate the global horizontal irradiation for the location in Malaysia [2]. The in-plane irradiation is calculated by optimisation of the orientation for each system at a tilt of 10°. In the international study all locations have an optimum orientation with an azimuth of 0° i.e. facing south for the northern hemisphere or north on the southern hemisphere. For Malaysia the optimum orientation of roof-top installations is either South or West depending on the local conditions with a tilt of about 10°, which provides the highest in-plane irradiation. For façades, the optimum orientation is West, which provides the highest yield. The optimisation has been made using PVSyst. 4.0 [3].

The nominal power of the PV system is 1 kW_p as the annual energy output should be calculated as kWh/kW_p.

The Performance Ratio 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.

2.4 Energy Input

The energy input figures are based on the international study, which again is based on some recent lifecycle assessments of PV manufacturing industries [1].

The energy input for multi-crystalline silicon modules are summarised below:

	Primary Energy [MJ/kW _p]	Final Energy [kWh/kW _p]
Laminate	25,606	2,205
Frame	1,061	91
Balance of System	2,660	229
Total System	29,327	2,525

The primary energy input is based on the life cycle assessment of 9 PV companies in Europe and the US. Final energy input is based on a conversion of primary energy to electricity using a grid efficiency value of 31%, which is based on the value for the Western Europe Mainland medium voltage grid.

The life cycle assessment has also been carried out for mono-crystalline modules and ribbon silicon modules. The study revealed that mono-crystalline modules requires an energy input that is 31% higher than the figures given above, while ribbon silicon modules require an energy input 21% lower than the input for multi-crystalline modules.

The assessment is only based on multi-crystalline modules as they are the most commonly used technology and it also gives a good average figure for energy input for the three technologies.

2.5 CO₂ emission factor for Grid System

The international study has used IEA published data for the electricity generation mix in the selected countries and the emission factor for various fuels and technologies has been obtained from the “RETscreen” software.

The Malaysian data is based on more precise figures obtained from the 4 main grid systems in the country. The carbon emission factors have been calculated according to the approved methodology for CDM projects for assessment of grid emission baselines. The values

calculated were based on actual dispatch of electricity to the grid systems with data for the 3 most recent years where data was available [4].

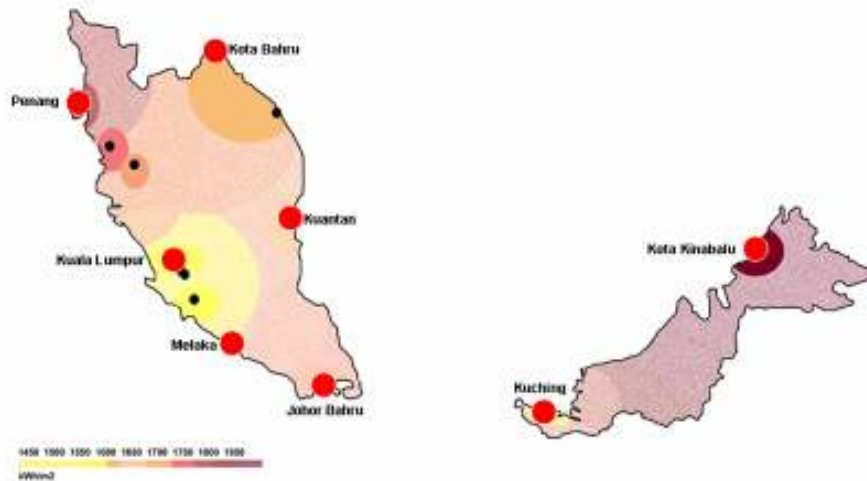
Grid system	Carbon Emission Factor [kgCO ₂ /kWh]
Peninsular Malaysia	0.63
Sarawak	1.12
West of Sabah	0.65
East of Sabah	0.80

Peninsular Malaysia and the West of Sabah grid are dominated by gas fired power plants, whereas Sarawak has increased the share of coal. The fuel emission factor for coal is 94 tCO₂/TJ, while the value for gas is 56 tCO₂/TJ, or almost half the value for coal. The East coast grid of Sabah consists solely of diesel fired plants, where the fuel emission factor is 73 tCO₂/TJ.

3 Results for Selected Malaysian Cities

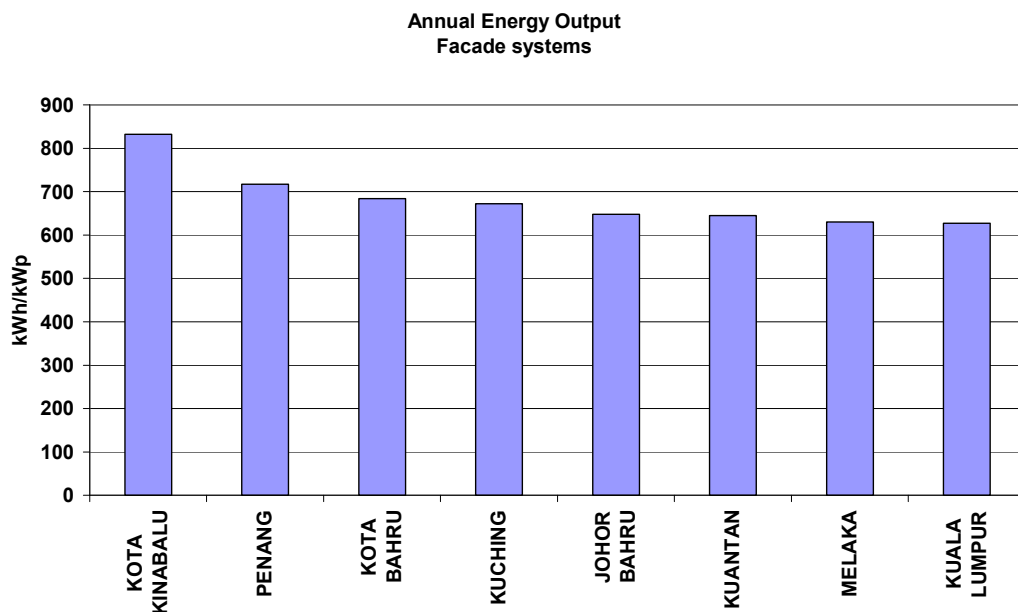
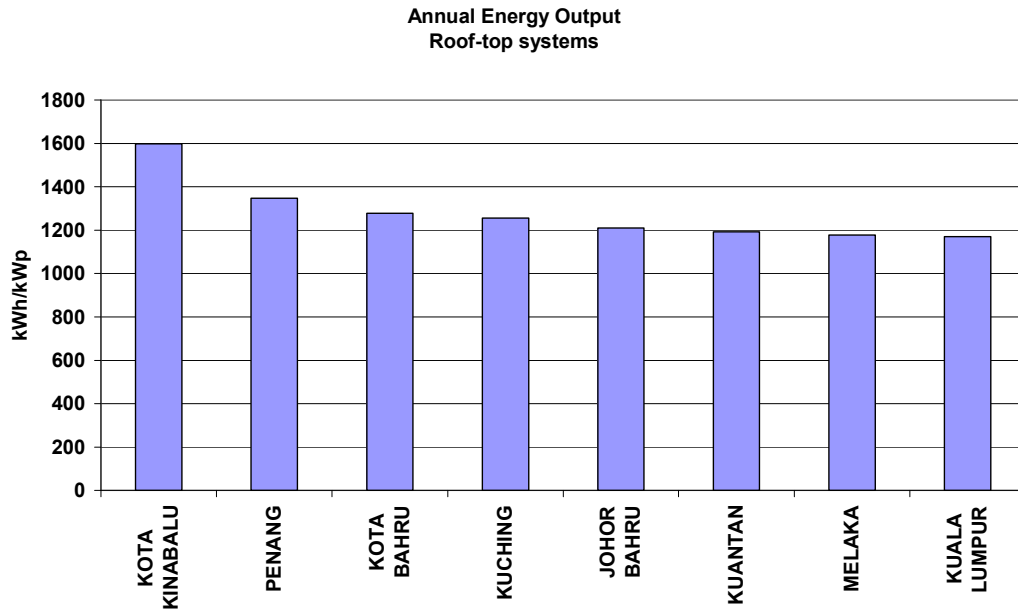
3.1 Selected Malaysian Cities

The Malaysian cities selected for this study are major cities spread over the nation, and give a good estimate of the conditions for PV in the various locations. The grid emission factors have been used for the respective grid systems the PV systems will be connected to. In the case of Kuching the system is the Sarawak grid and for Kota Kinabalu it is the West of Sabah grid. The rest of the cities are in Peninsular Malaysia and will be connected to the Peninsular Malaysia grid system.



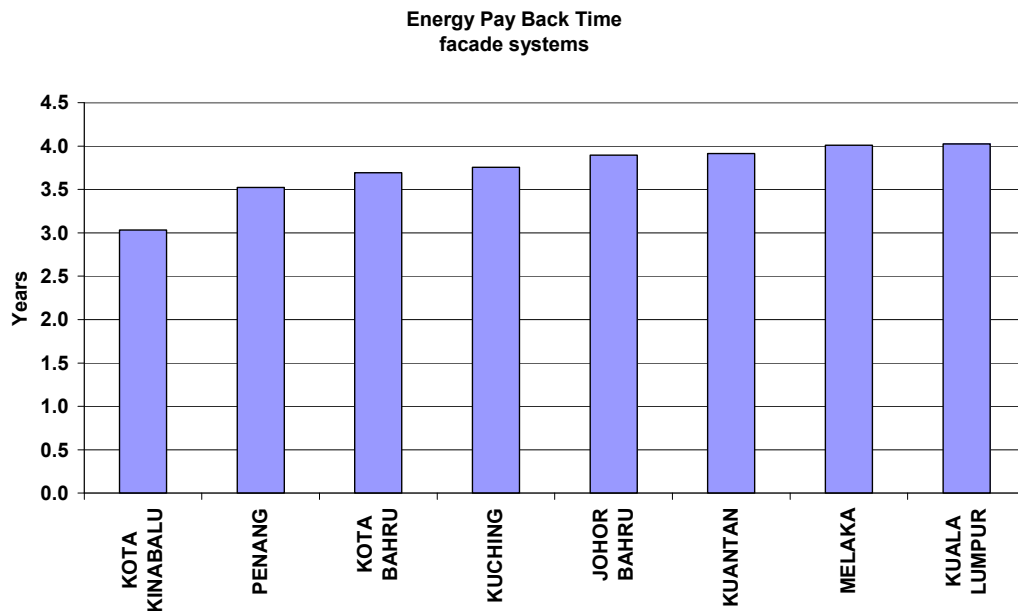
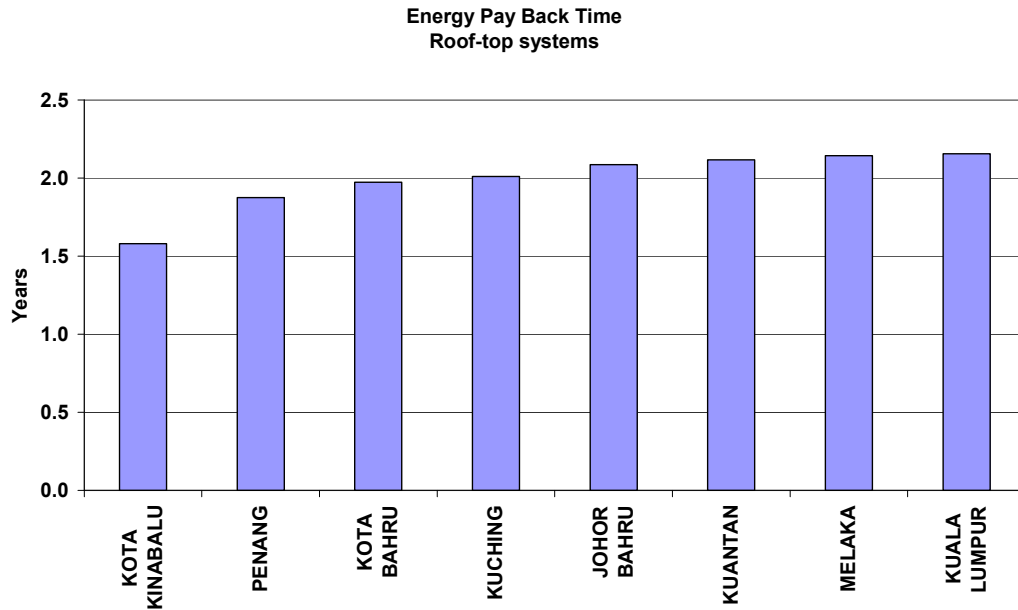
3.2 Annual Energy Output

The annual energy output for the selected cities in Malaysia varies from around 1170 kWh/kW_p to 1600 kWh/kW_p for roof-top systems, with the highest value in Kota Kinabalu. The range of annual energy output for façade systems is about half from about 630 kWh/kW_p to 830 kWh/kW_p.



3.3 Energy Pay-back Time

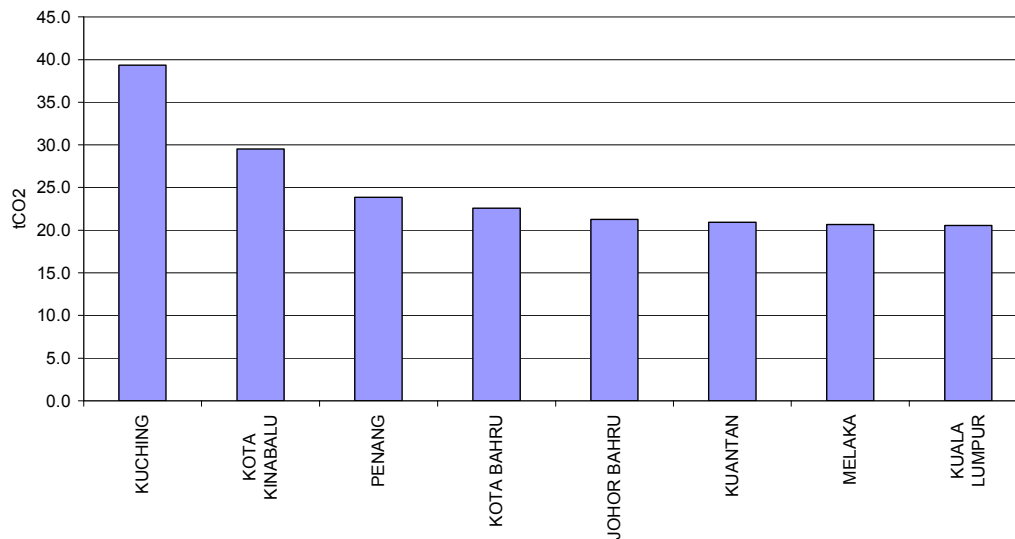
The energy pay-back times range from 1.6 to 2.2 years for roof-top systems and from 3.0 to 4.0 for façade systems, which are considerably shorter than the expected 30 years lifetime of the installations. The energy input is covered more than 18 times in the best location in Kota Kinabalu and 13 times in Kuala Lumpur.



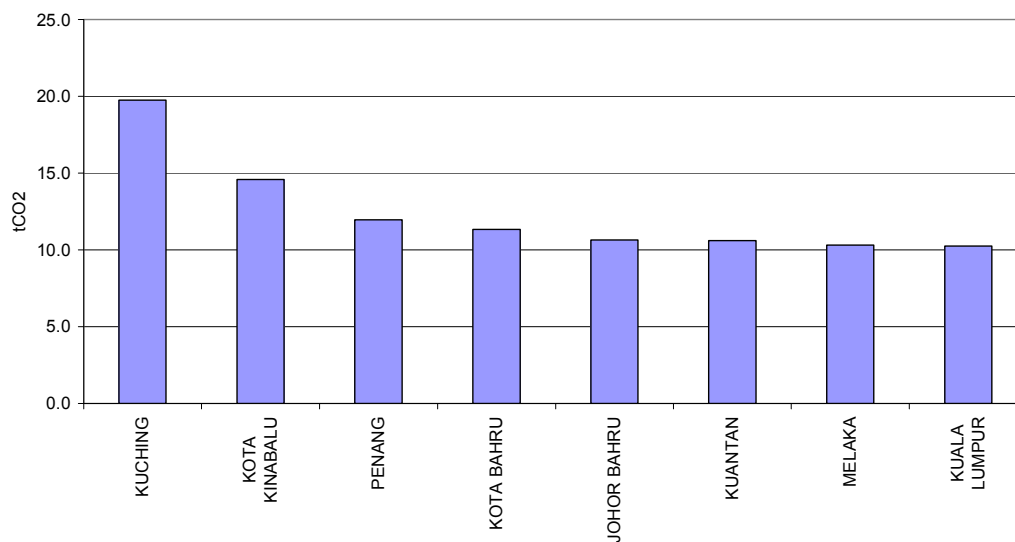
3.4 CO₂ Mitigation

CO₂ mitigation depends on the electricity generation by the systems and the grid emission factor. The CO₂ mitigation ranges from 20 tCO₂ to 40 tCO₂ for roof-top installations, with the highest mitigation in Kuching due to the high grid emission factor of the Sarawak grid system. For façade systems the mitigation ranges from 10 to 20 t CO₂.

CO2 Mitigation
Roof-top systems



CO2 Mitigation
Facade systems



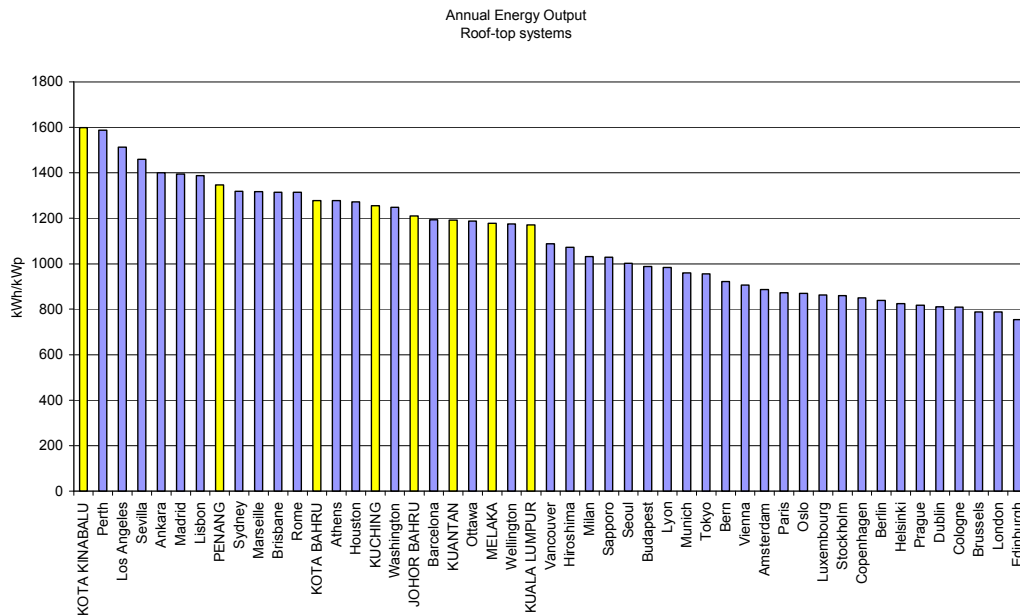
4 International Comparison

The International study compared 41 cities in 26 countries. They represent countries and cities with PV installations and provide a good comparison for Malaysia and for the assessment of the impact of the national PV programme in Malaysia.

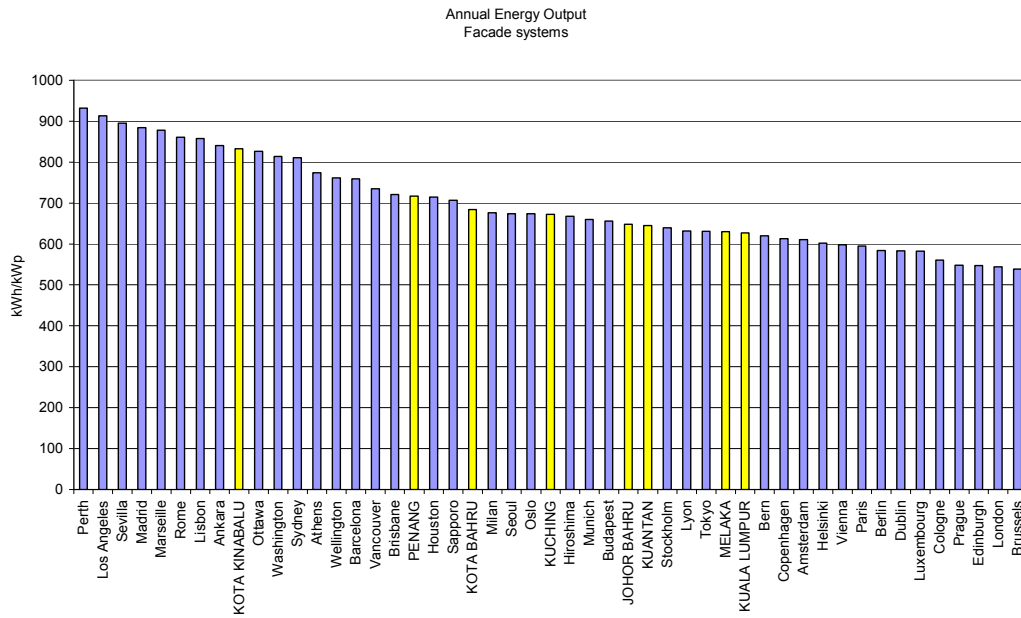
The addition of the 8 cities selected in Malaysia increases the total number of cities compared to 49 Worldwide.

4.1 Annual Energy Output

All the Malaysian cities have a high annual energy output and are in the top 50% of the studies cities. Kota Kinabalu has the highest annual energy output of the cities being ahead of Perth, Los Angeles and Sevilla.

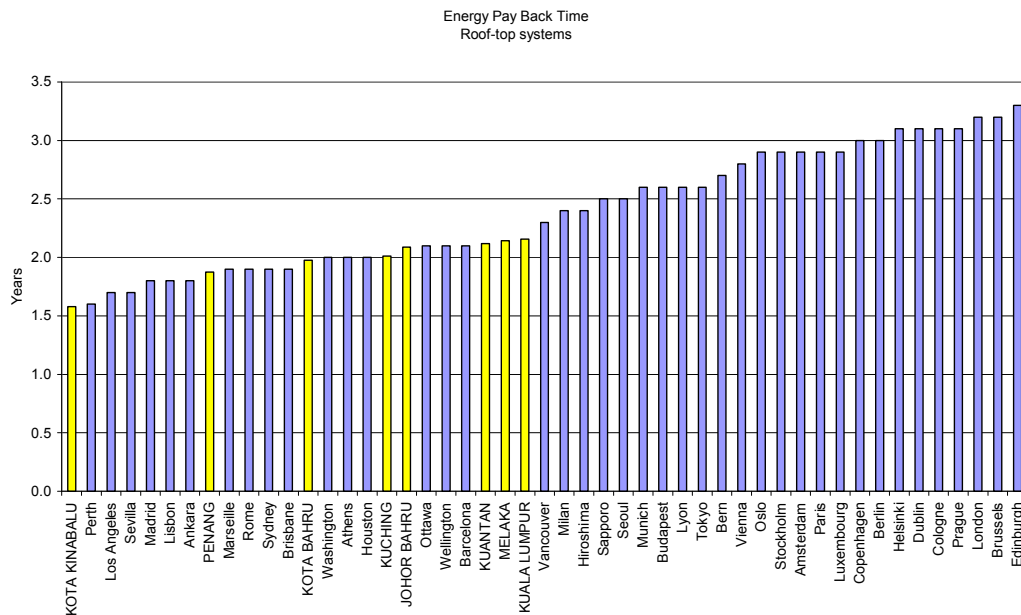


The performance of façade systems is not surprisingly a bit lower in Malaysia compared to the selected international cities, as the angle of sun above horizon is higher in Malaysia than in the other locations.

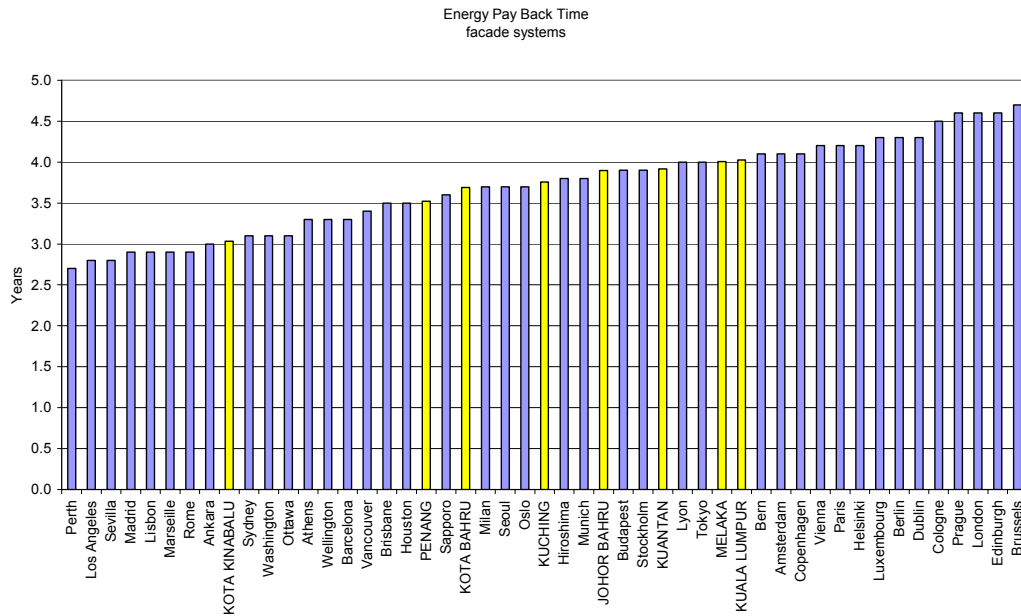


4.2 Energy Pay-back Time

Following the high annual energy output the pay-back time of the energy input is also relatively short in Malaysia. Again roof-top systems in Kota Kinabalu have the shortest energy pay back period compared to the selected cities.



However, the lower annual energy output for the façade systems makes the energy pay-back period comparatively less attractive for Malaysia. Even for Kota Kinabalu, the energy pay back period the façade systems only becomes the 9th shortest among the 49 selected cities.

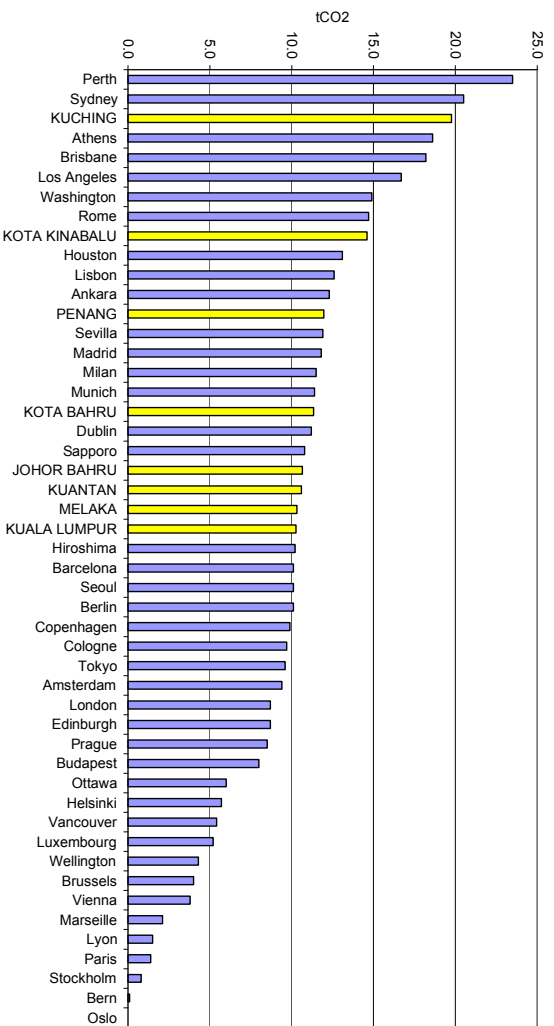


4.3 CO₂ Mitigation

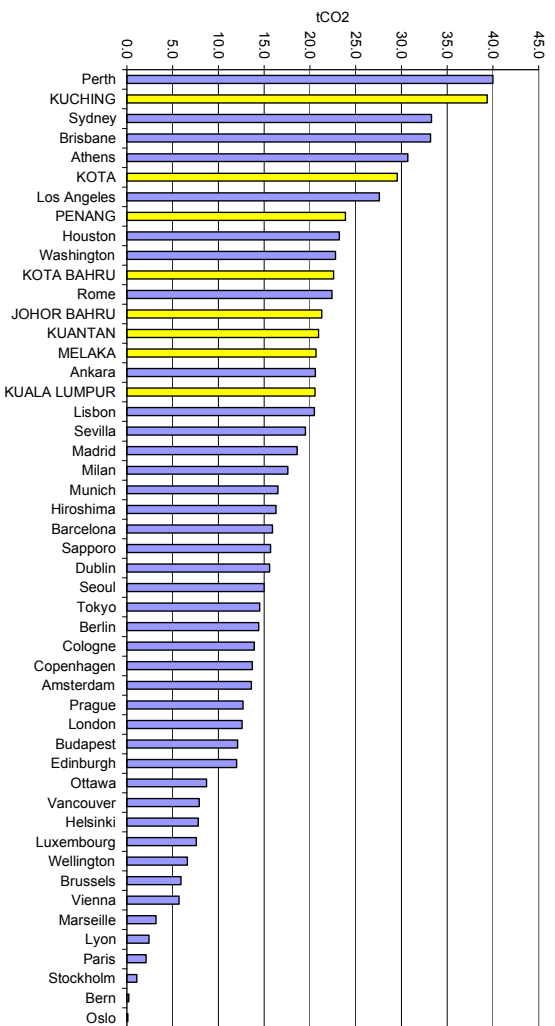
The CO₂ Mitigation depends on a combination of energy output and CO₂ emission factor for the grid systems the PV systems are connected to. Australia has a high share of coal fired power plants in the electricity generation mix and combined with the relatively high energy output from the PV systems in Perth the CO₂ mitigation is high. Kuching with a similar situation has the second highest CO₂ mitigation due to the high energy yield and high grid emission factor in Sarawak.

Roof-top systems in Malaysia have a relatively high CO₂-mitigation capability compared to the selected international cities as all the 8 selected Malaysian cities are in top 17 of the cities compared.

Again, the situation is different for the façade systems in Malaysia which have a relatively lower CO₂-mitigation capability but still fall within the mid-range of the selected international cities.



CO2 Mitigation
Facade systems



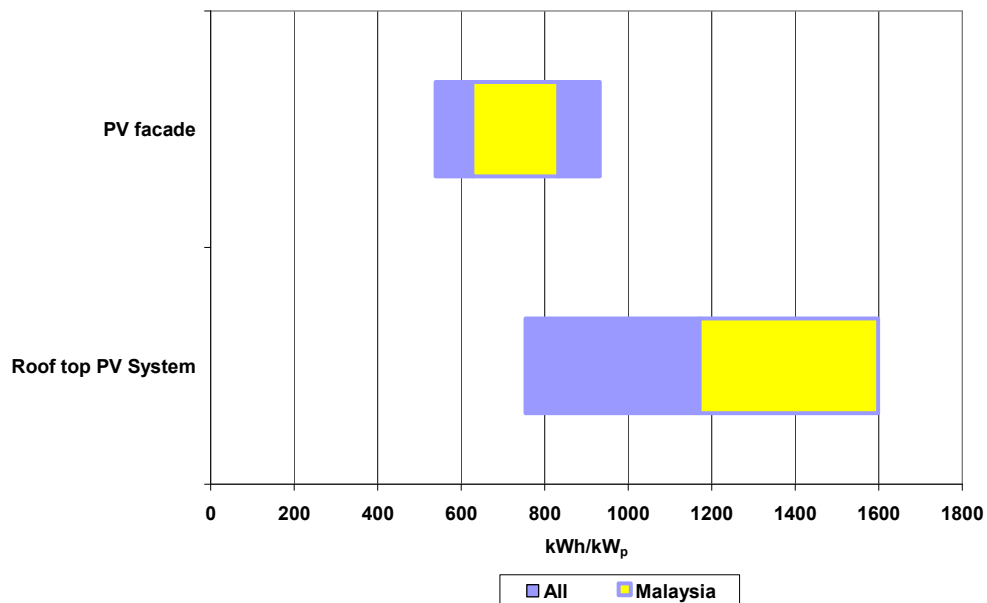
CO2 Mitigation
Roof-top systems

5 Conclusions

5.1 Annual Energy Output

An overall assessment of the Malaysian cities with the international selection of cities shows that roof-top applications in Malaysia are among the top half for the annual energy output estimated for the cities surveyed. The highest annual energy output from this study is actually for Kota Kinabalu.

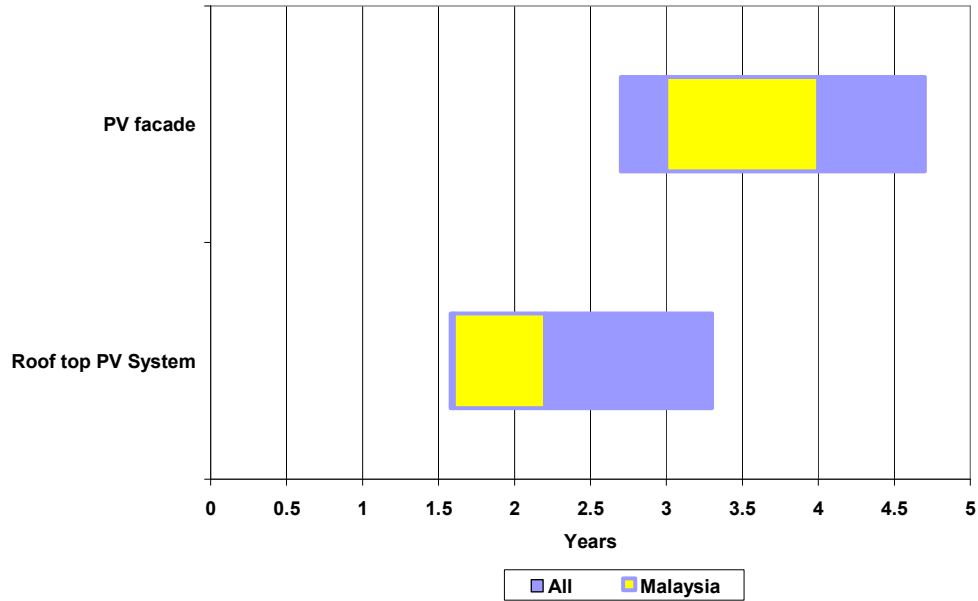
Façade systems' average performance in Malaysia falls in the mid-range for output generated, where some locations in Peninsular Malaysia have energy outputs below average, while for Kota Kinabalu it will be above average.



5.2 Energy Pay-back Time

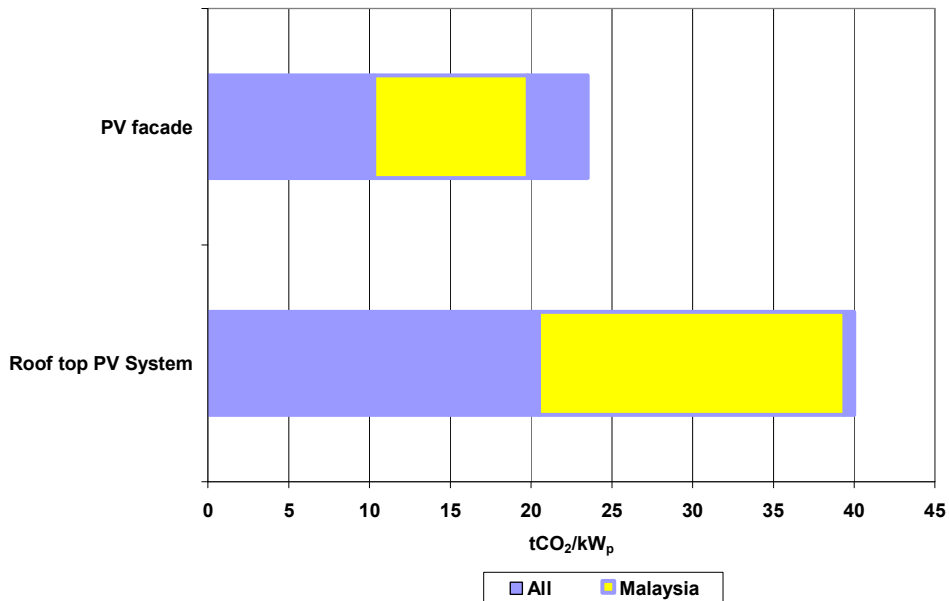
The energy pay-back time for PV systems is very short. For roof-top systems it is as low as 1.6 years but up to 4 years for façade systems. In all instances the energy input for manufacturing and installation of PV systems is recovered well before the 30 years or more of their lifetime.

Roof-top systems in Malaysia fall in the shortest portion of the payback period range, while façade systems fall in the middle of the payback period range.



5.3 CO₂ Mitigation

The CO₂ mitigation potential in Malaysia is relatively high, due to a combination of the high energy output and the high grid emission factor from Malaysian electricity grids. Especially in the state of Sarawak, where the grid emission factor is high and the PV systems will displace coal fired power, the CO₂ mitigation potential is very high. Only Perth in Australia will have a higher mitigation potential.



References

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