

# Life-time Cost-Benefit Analysis of Solar Energy Systems in Queensland

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## ABSTRACT

The study presents a life-time cost-benefit analysis for a solar system comprising a grid-connected photovoltaic unit and a solar water heater operated at Toowoomba Queensland. The work represents technical and economic assessment of the technology at local conditions. Present solar kWh price indicate the ability of the system to provide competitive prices to cover demand peaks in Queensland. Additionally, the solar system – being located on site – offers the advantage of avoiding transmission and distribution losses throughout the electrical network. The work is addressing advantages of associating solar heaters to photovoltaic systems covering energy demands for most of conventional domestic and industrial users. Case studies for different technologies, different economic conditions and system life times are presented.

*Keywords – Evacuated Tubes Solar Water Heaters, Peak Electrical Demand, Photovoltaic, Solar Energy, Solar Water Heaters*

## INTRODUCTION

Electricity resources and infrastructure, a backbone of the contemporary human societies and economy, is currently undergoing major stresses due to constantly increased demand. Those stresses are demonstrated in high spiking peak demands and electricity prices as shown in AEMO (2009). Main reasons for those spikes could be referred back to increased energy demand in several sectors of the economy implying full reliance on electricity in most of the human needs especially in domestic usages.

EUAA (2005) described electricity consumers pay significant (and largely unseen) price for building sufficient electricity generation and networks to meet the short peaks, which can occur for only a relatively small number of hours each year. More than 5% of the network infrastructure is only used for 0.2% of the time and this under-utilized capital investment in the network is paid for by all consumers, whether they ever use it or not, due to the nature of retail and networks charges.

Obviously, those stresses could be encountered by implementing well known energy-handling methods such as raising public awareness about demand side response (DSR) measures, utilization of diverse and on-site available renewable energy sources such as solar or wind energy, energy efficiency measures etc.

A range of policy measures have been introduced to support the take-up and development of all renewable energy sources in Australia. Under a national Renewable Energy Target (RET), the government will require that 20 % of power generation comes from renewable energy sources as reported by RET (2009). Fouad Kamel (2009) showed that from a total of 52.18 TWh electrical energy consumption in the year 2008 the solar energy is able to provide 9.07 TWh of diurnal peaks above the base load; a percentage of 17.4%.

This research is presenting the economics of photovoltaic (PV) and solar water heaters (SWH) and the suitability for covering peak electrical demands in Queensland. Those technologies can only achieve effective contribution with conscious electric energy users realizing the importance of a renewable-energy-assisted electrical system.

## **SOLAR ENERGY TECHNOLOGIES USED**

The research incorporates a 1 kW-peak grid-connected photovoltaic and an evacuated tube collector (ETC) solar water heater (SWH) for supplying user's electrical and thermal demands respectively. The small SWH contains 20-tubes on an 1.37m<sup>2</sup> aperture collector area fitted to a 120 liter water tank.

Grid-connected photovoltaic generators can effectively provide users with adequate electricity at solar day times, while at night and solar-weak times the user is withdrawing electricity from the utility distribution grid. Mills (2008b) reported on photovoltaic power systems effective load carrying capacity (ELCC) as the amount of electricity PV can reliably supply as a proportion of its maximum output power. ELCC for PV is estimated to be 50-60% in Queensland. Mills (2008a) reported on economic impacts of PV embedded generation and residential air conditioning on electricity infrastructure, that 1 kW of air conditioning is estimated to impose a cost of \$1,627 in infrastructure impacts, while 1 kW of PV is estimated to provide a benefit of \$750 when installed in residential areas with an evening peak and \$1,500 when installed in commercial and industrial areas with a mid-afternoon peak.

Solar Water Heating systems are efficiently capable of providing economically and environmentally viable and sustainable thermal energy. For the purpose of this research evacuated-tube collector (ETC) solar water heaters (SWH) are chosen to tackle thermal loads for domestic and industrial applications. As reported by F. Kamel (2001) and F. Kamel (2002) ETC-SWH systems are suited to provide thermal energy at relatively high temperatures 80-90 °C and elevated efficiency of 50–60 %.

## **SCOPE OF COMBINING PHOTOVOLTAIC SYSTEMS WITH SOLAR WATER HEATERS**

Electricity is considered a high-grade energy source because its generation from fossil fuels for example, is usually accomplished at an efficiency of around 30%; it gets then transmitted and distributed at a further 80% to reach end-users at a final efficiency of  $30 \times 80 \% = 24 \%$ . Transforming electricity back into heat, at an efficiency around 50 %, makes the final transforming efficiency from heat back into heat of  $24 \times 50 \% = 12 \%$ . Hence, it seems reasonable to consistently engage photovoltaic systems with solar water heaters capable to supply thermal demands, in order to make sure photovoltaic electricity is being used specifically for electrical loads.

While grid-connected photovoltaic systems provide the ability of feeding end-users and the electrical network with solar electricity, solar water heaters provide the ability of supplying and storing thermal energy for heating and cooling purposes, otherwise produced by electricity.

Although electricity is being typically used at present for heating water during low demand periods (at night), when electricity tariffs are low, solar water heaters are offering waiving considerable part of that demand at improved efficiencies and less environmental impact. The electrical capacity relieved could be directed to supply present peak demands at improved utilization factors, reduced energy prices and enhanced reliability.

### NET PRESENT VALUE, BENEFITS AND SYSTEM LIFE-CYCLE ANALYSIS

The analysis describes the economic performance in a life-cycle analysis of a domestic solar system consisting of a 1 kW peak grid-connected photovoltaic (GC-PV) system feeding-in user's electrical loads and exporting excess electricity to the grid and evacuated tube collector (ETC) solar water heater (SWH) covering hot water demand on user's premises. Savings from the generated photovoltaic electricity and from the thermal energy produced by the SWH in kWh are deducted from total consumer's energy demand and accounted to pay back the solar system. The study is based on operational data at Toowoomba Queensland; average solar irradiation of 2008 kWhm<sup>-2</sup>year<sup>-1</sup>. Fig. 1 shows the average monthly energy yield of the combined solar system. Impact of the installed solar system on energy consumption of an average domestic user is shown in Fig. 2.

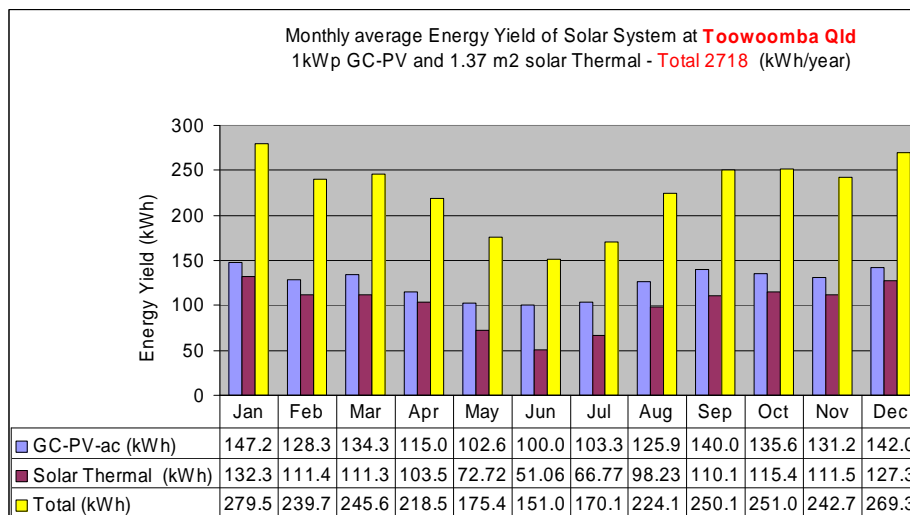


Fig. 1: Average monthly energy yield of the combined solar system

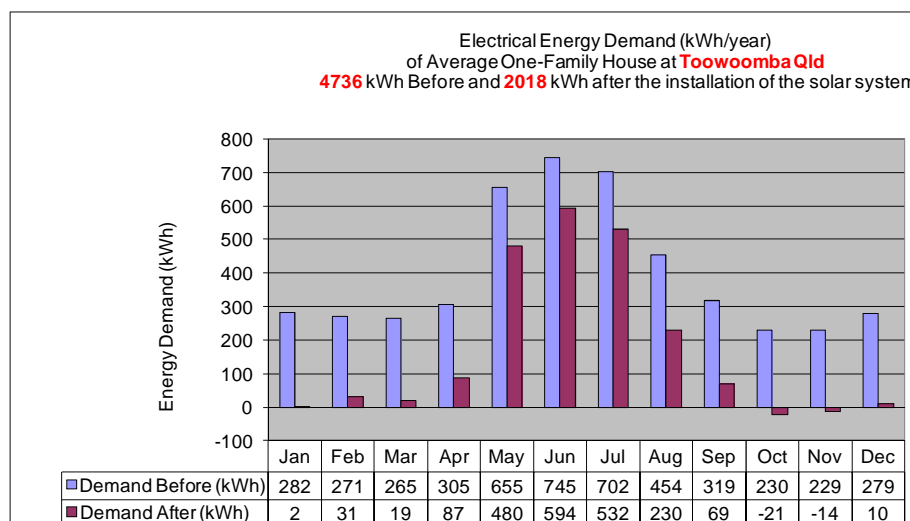


Fig. 2: Electric energy savings from the PV-SWH combined system.

Fig. 2 shows that such a simple solar system is able to strongly reduce electrical energy consumption of an average domestic user. The system demonstrates the ability to reverse electrical withdrawal, in solar-rich months, to export excess electricity back to the network.

Lifecycle analysis has been used here as described by Mierzejewski (1998) to evaluate the payback time of the solar system. In this technique cost and benefits for each operational year are projected and then discounted back to the year of installation to obtain the "net present value" (NPV). Usually, the payback time is computed as the time at which first cost and annual expenses with compounded interest equal the total savings of energy cost with compounded interest. In the following the Net Present Value of lifetime system cost and benefit will be calculated and compared. Break-even conditions are satisfied when the system capital investment is exactly met by the savings or benefits generated over system lifetime.

Market-available system cost has been used for this analysis as AUD\$8,000 for the 1 kW peak grid-connected PV system and AUD\$2,500 for the 1.37 m<sup>2</sup> 120 liter tank evacuated tube solar heater. Following assumptions have been made to calculate the Net Present Value of lifetime system cost and benefit: Interest rate 7% p.a., lifetime of the system 5-30 years, marginal tax bracket 0 % (no governmental subsidies), savings escalator 0.10, i.e. 10% p.a., operation, maintenance and insurance first year = 0.2% of invested capital and operation, maintenance and insurance increase = 5%/year.

Fig. 3 - 8 show the results of the lifecycle cost analysis for the solar system at different energy prices for the combined system GC-PV operating alongside the evacuated tube SWH. The points of intersection between the system cost and benefits represent breakeven conditions at which the total system cost equal the total benefits generated by the system operation during its entire preset lifetime. Fig. 9 through 11 are summarizing breakeven conditions at different life-time options, from 5 to 30 years, for the combined GC-PV-thermal, the GC-PV-only and the SWH-only system respectively. The figures depict solar systems are paying back the investment at a certain energy cost and a preset system life-time. At market energy prices below that level the expected benefits are lower than the system cost and consequently, on just immediate economic considerations, the system might not be justified. At higher energy prices the economic benefits generated are higher than the incurred cost i.e. the system is paying back itself before the expected lifetime.

Fig. 12 through 14 are presenting net present value calculations vs. system operating life-time. The calculations are made assuming present electricity energy price of €20/kWh, all above capital investment and expenses apply, however considering different discount rates (DR): 4, 7 and 10 %.

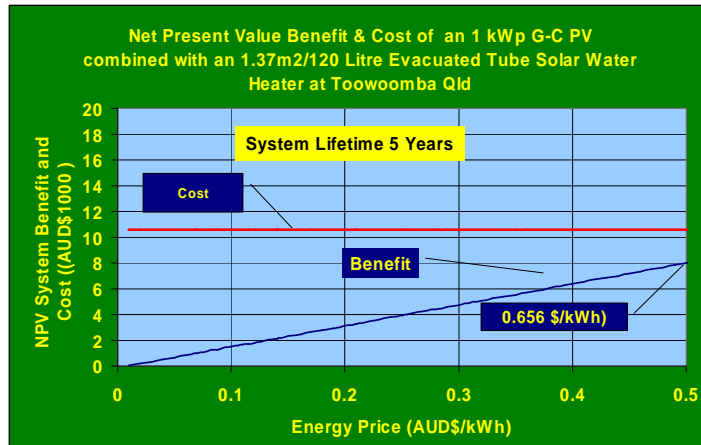


Fig. 3: Cost and benefit 5 years life time.

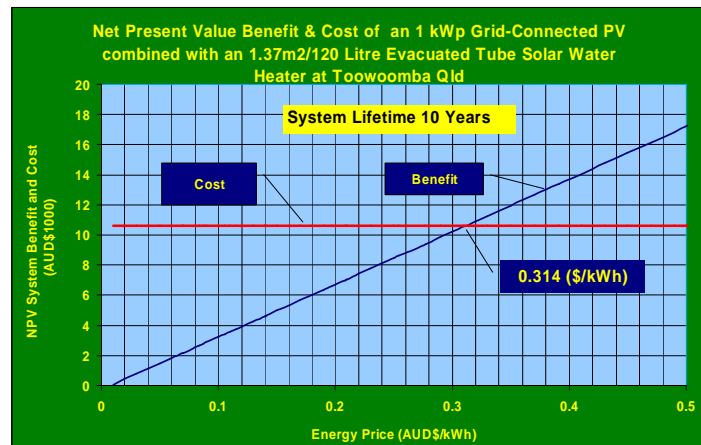


Fig. 4: Cost and benefit 10 years life time.

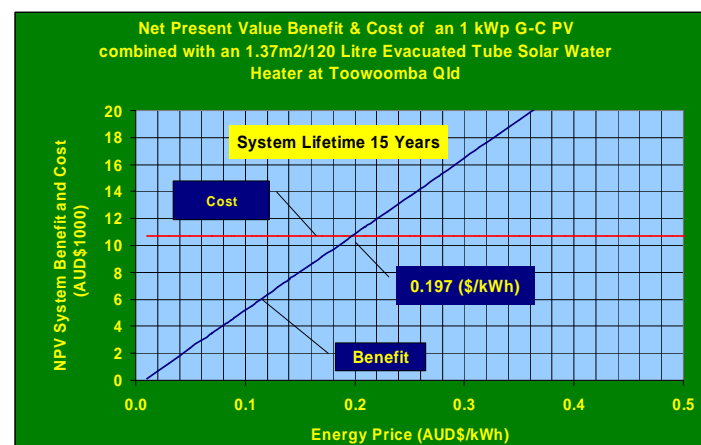


Fig. 5: Cost and benefit 15 years life time.

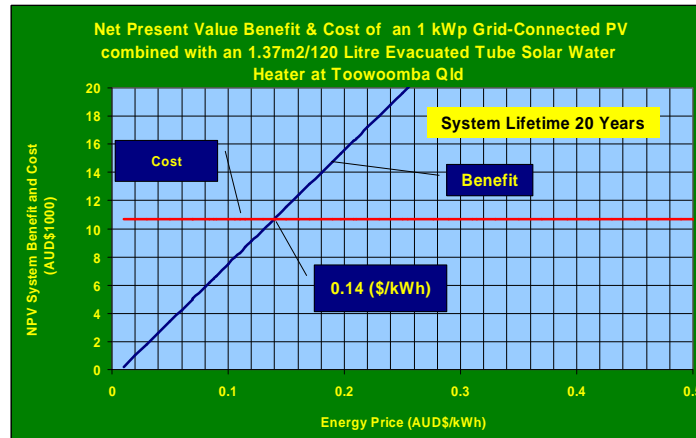


Fig. 6: Cost and benefit 20 years life time.

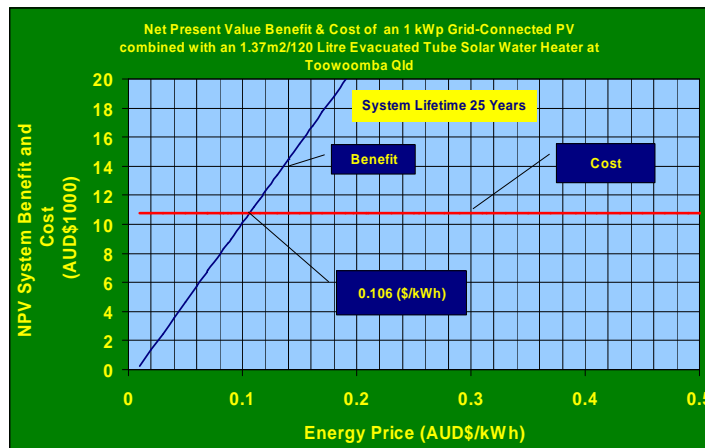


Fig. 7: Cost and benefit 25 years life time.

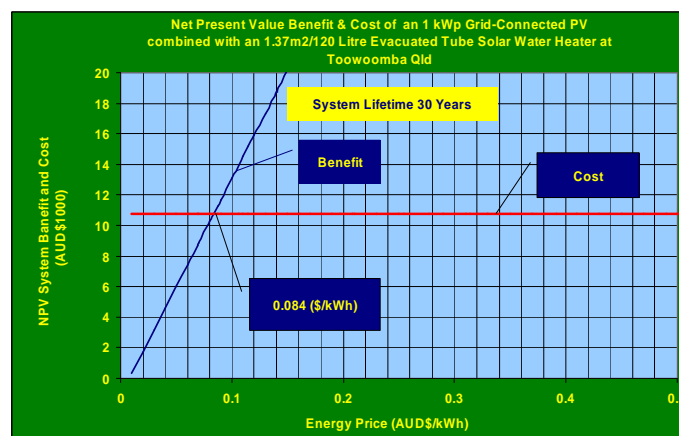


Fig. 8: Cost and benefit 30 years life time.

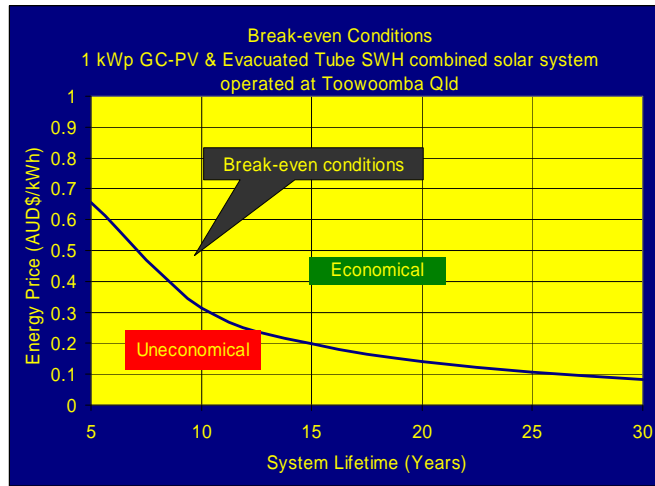


Fig. 9: Break-even conditions of the 1 kW GC-PV operating alongside a 1.37m<sup>2</sup>/120 Litre evacuated tube SWH system.

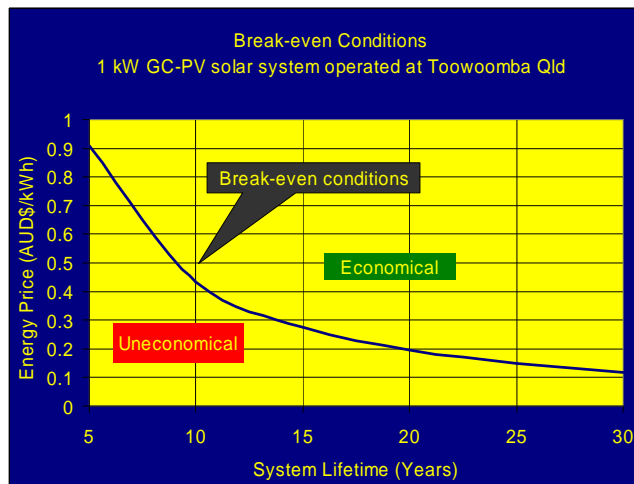


Fig. 10: Break-even conditions of the 1 kW GC-PV system.

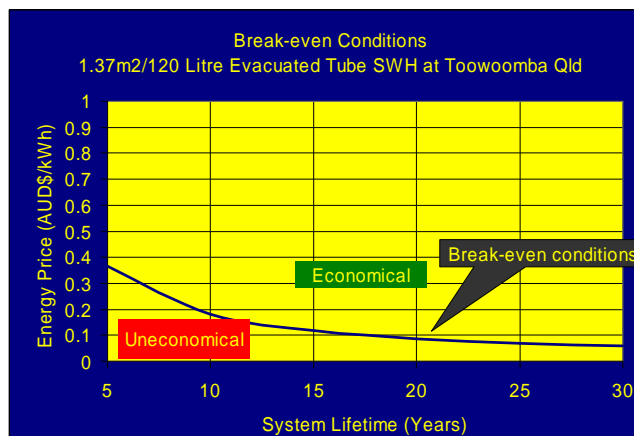


Fig. 11: Break-even conditions of the 1.37m<sup>2</sup>/120 Litre evacuated tube SWH system.

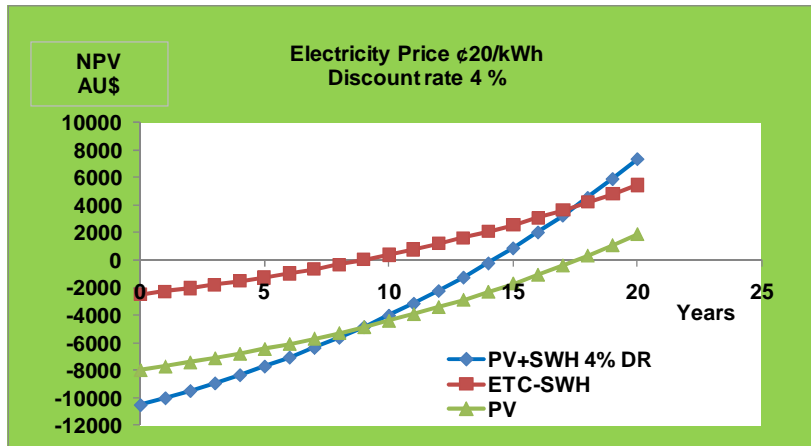


Fig. 12: Net present value of solar system vs. system operating life-time at a discount rate 4 %.



Fig. 13: Net present value of solar system vs. system operating life-time at a discount rate 7 %.



Fig. 14: Net present value of solar system vs. system operating life-time at a discount rate 10 %.



## DISCUSSION

The analysis demonstrates that the system consisting of just the solar water heater provides the shortest payback time and the lowest kWh cost compared to the two other alternatives, the combined system and the GC-PV-only system. However the combination of both the GC-PV with the SWH still gives economic advantages in terms of lower ¢/kWh and shorter payback time compared to the GC-PV-only system. Solar favorable locations are expected to show better economics with lower cost of energy and shorter payback time.

The cost of the produced energy can be calculated from the total present cost of the system divided by the total energy expected to be produced from the system over its lifetime. The payback time, in contrast, is calculated taking into consideration the total present cost of the system as well as the total revenues created from the system during its lifetime (discounted to the present). The point at which the cost equals the benefits is considered the break-even point as illustrated in Fig. 3 - 8.

The study shows that such a simple solar system is able to strongly reduce electrical energy consumption at an average domestic user, as depicted in Fig. 2. The system is even able, in solar-rich months, to totally eliminate electrical withdrawal from the utility grid and export excess energy feeding the electrical supplier.

Fig. 9 shows the ability of the combined solar system to provide energy price at end-user premises of ¢14/kWh (\$140/MWh) for 20 years life-time. Likewise, an electricity market energy price of about ¢20/kWh is able to make the system break even in just 15 years. The same readings could be made for the SWH-PV combined system in Fig. 10, and for the sole SWH Fig. 11.

Fig. 12, 13 and 14 are depicting the solar heating system is paying back in 9, 10 and 11 years for DR of 4, 7 and 10 % respectively, the combined system is paying back in 14 and 17 years for DR of 4 and 7 % respectively; however is unable to pay back below 20 years lifetime for DR of 10 %. The photovoltaic system is paying back in 18 years at DR of 4 %, however unable to pay back before 20 years for DR of 7 and 10 %. This indicates that solar systems are today already able to cover diurnal peak demands at competitive market prices.

## CONCLUSIONS

The analysis presented in this paper describes the economics of a combined solar system including a grid-connected photovoltaic (GC-PV) unit covering electrical loads alongside a solar water heater system covering thermal loads. The results show such a system presenting realizable economic benefits at present equipment and energy prices. The calculations demonstrate a system consisting of just a solar water heater is providing the shortest payback time and the lowest cost per kWh compared to the two other alternatives, the combined system and the GC-PV-only system. Once the generated benefits over the system lifetime have exceeded the incurred cost the system would have paid itself back and start generating just benefits at little maintenance running cost. The higher the energy prices at the site of operation the higher the benefits and consequently the shorter the payback time. Solar systems at present prices indicate the technical and economic ability to reduce peak electrical demands on the national grid.

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