Potential Contribution of Solar Energy Towards Electrical Peak Demands in Queensland

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ABSTRACT

Given, heavy diurnal electricity peak demands causing high volatility in electricity prices, this study shows evident economic benefit in assigning part of diurnal loads to photovoltaic and solar water heating systems. Besides covering demand peaks, the solar system – being located on site – offers the advantage of avoiding transmission losses and voltage drops throughout the network. Life-time cost calculations for solar kWh indicate the ability of the solar system to provide competitive prices to cover demand peaks. The project incorporates a 1kW (peak-power) grid-connected photovoltaic and an evacuated tube solar water heater SWH. The unit represents an initial technical and economic assessment of the technology at local conditions. The results quantify the power able to be waived by using solar systems in Queensland. It is advisable to consistently join photovoltaic (PV) equipment with solar water heaters in order to ensure the PV electricity is not being used to supply thermal loads.

INTRODUCTION

Electricity resources and infrastructure, a backbone of the contemporary human societies and economy, is currently undergoing major stresses due to constantly increased demand. Evident indications for those stresses are extreme peak demands translated into high spikes in electrical energy prices. Main reasons for those spikes can be easily referred back to increased energy demand in several sectors implying full reliance on electricity in most to all of human needs especially in domestic usages. **Figure 1** shows a typical day energy price and demand in Queensland and **Figure 2** peak price of electricity in Queensland 2008-09; data extracted from the Australian Energy Market Operator AEMO (2009).

EUAA (2005) pp16 is describing electricity consumers pay significant (and largely unseen) price for building sufficient electricity generation and networks to meet the short demand peaks, which can occur for only a relatively small number of hours a year. More than 5% of the network infrastructure is only used for 0.2% of the time and this under-utilised 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 might be encountered by implementing well known energy-handling methods such as raising public awareness about the issue, 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 per cent of power generation comes from renewable energy sources" as reported in RET (2009).
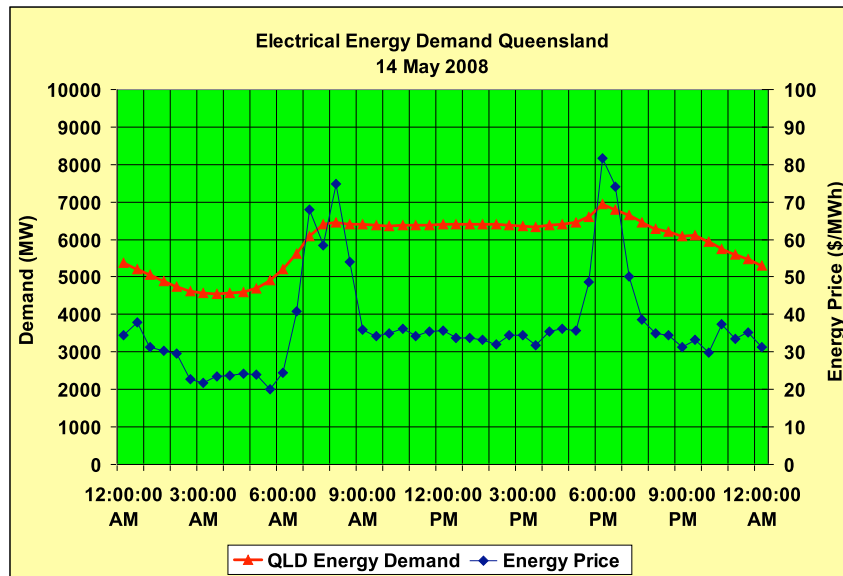
**Electrical Energy Demand Queensland
14 May 2008**

**Figure 1 Demand and Price of Electricity for Queensland on14 May 2009; data
extracted from the Australian Energy Market Operator AEMO (2009).**

**Average peak price (7:00am to 10:00pm EST weekdays excluding NEM holidays)
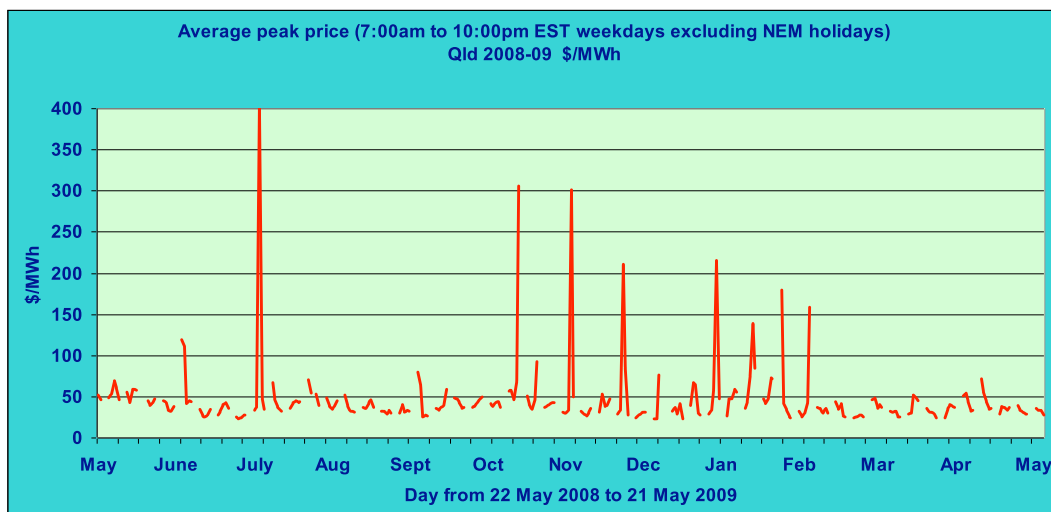Qld 2008-09 $/MWh**

**Figure 2 Fluctuation of Average regional peak price in Queensland, data extracted
from the Australian Energy Market Operator AEMO (2009).**

This research is handling the contribution photovoltaic (PV) and solar water
heaters (SWH) might offer to mitigate 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.

WHY COMBINING PHOTOVOLTAIC SYSTEMS WITH SOLAR WATER HEATERS?

Electricity generation from conventional prime energy sources (e.g. oil, gas or
coal) is usually accomplished at an end efficiency of around 35% EECA (2000).
Electricity transport is separated into long distance transmission and more local
distribution. Each stage of the energy supply train can result in energy losses. In
New Zealand these losses are around 8-10 PJ per annum (or around 7% of the
total electricity produced) EECA (2000); this is an efficiency of 93 %. Accordingly,
electricity is effectively reaching end-users at a final efficiency of 35% x 93 % ≅

32.5 %. This means, to obtain electrical energy the economy has lost around 67.5 % of the prime energy source. A justification for this lays in the fact that modern technologies e.g. automation, communication, lighting and controls are based in a contemporary society mainly on electricity. Therefore electricity is considered a high-grade and expensive energy source. **Figure 3** show common electricity supply chain losses as published by EECA (2000). The figure is depicting total losses of 64 % (generation), 4 % for transmission and 5 % for distribution before reaching the end-user. Further losses are usually expected for the type of utilization of electricity at the end-user premises as depicted in the figure.

Electricity Supply Chain Losses arising from Thermal Generation (Gas)
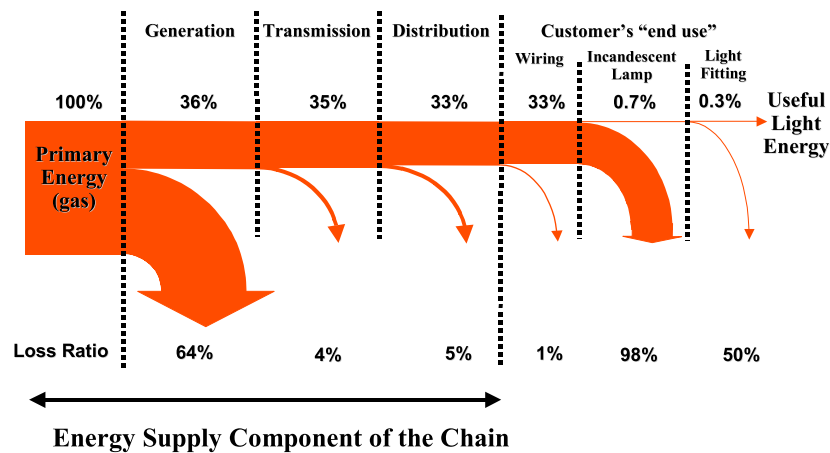
Figure 3 show common electricity supply chain losses EECA (2000).

In the contemporary technology, it became conventional to use electricity for heating purposes, among others for water heating and cooking. Using electricity for heating purposes occurs usually with losses depending on the application. Efficiency of electrical heating storage water tanks depends on the level of insulation of the tank, piping and on the distance between the tank and the tape on use. Losses for heat transfer between heating plate and cooking containers besides other heat losses transferred to the surroundings are representing further reduction in the efficiency of utilization of electrical stoves.

Assuming an arbitrary but realistic average figure for the electricity into heat transformation as 80 % means, the use of electricity for heating purposes is being fulfilled at a best efficiency of 32.5 % (from the above) x 80 % $\cong$ 26 %. This implies throwing away around 74 % of the prime energy source in form of thermal waste causing increased global warming. In other terms, the well economically and environmentally expensive oil, gas or coal get used at 26 % efficiency while 74 % of those natural resources are dissipated in the environment contributing only to a further global warming and have no contribution to an economic development.

The above portray leads to the simple conclusion that, thermal usages need to be satisfied directly from a thermal source, avoiding so the use of electricity as a medium for energy storage and transportation. Such a conduct presents a direct energy usage at around 60-70 % efficiency in contrast to the above described electrical scenario of 26 %.

The use of thermal solar energy to satisfy thermal demands is offering an excellent opportunity to avoid both the above described scenarios. In such a case no burning of fossil fuel is involved, immediate storage and usage of solar thermal energy is guaranteed and finally no transportation of energy is needed because solar energy is already distributed and used where and when it is required.

Photovoltaic solar electric systems have demonstrated to be a reliable, efficient and economic energy source. Market-available photovoltaic solar systems are transforming solar irradiation directly into electricity at peak efficiencies of around 15%. However, based on the above, if the photovoltaic solar electricity is being used for heating purposes, the use of photovoltaic solar electricity gets totally out of a sustainable context, because photovoltaic panels are sophisticated and quite expensive technologies made to produce electricity not thermal energy. Solar thermal systems are much cheaper technologies providing to the opposite a direct and affordable thermal energy.

SOLAR ENERGY TECHNOLOGIES USED

The research incorporates 1 kWp grid-connected photovoltaic and a 1.37 m^2 (aperture area) 120 litre-tank evacuated tube collector (ETC) solar water heater for supplying user's electrical and thermal loads respectively. The small ETC 20-tube unit has a 1.37m^2 total aperture collector area fitted to a 120 litre 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 common distribution grid. Mills (2008) 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. And in Mills (2008) reported on economic impacts of PV embedded generation and residential air conditioning on electricity infrastructure, that I 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 described by Kamel (2001) ETC-SWH systems can be best suited to provide thermal energy at quite elevated efficiency of 50–60 % at relatively high temperatures 80 – 90 °C .
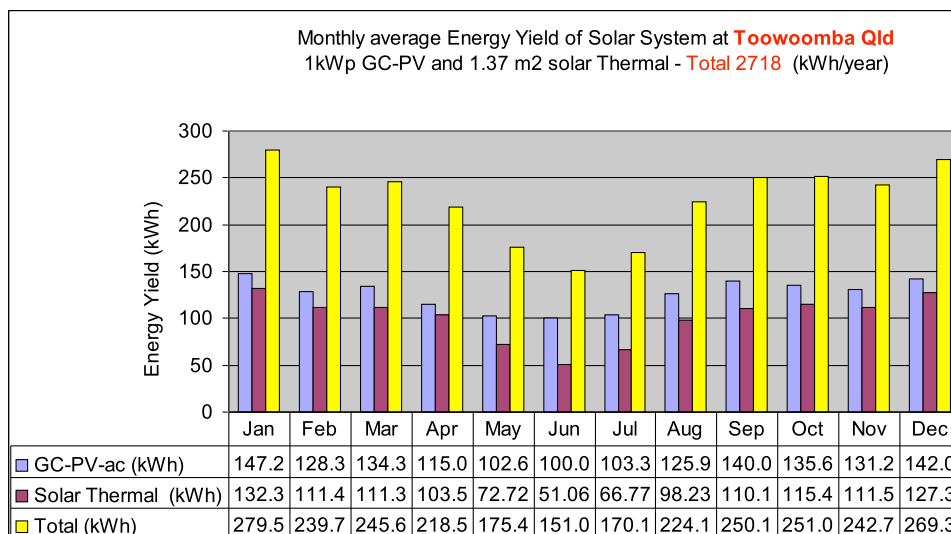
ECONOMIC ANALYSIS

The analysis describes the economic performance of a domestic solar energy system consisting of photovoltaic and a solar water heating devices in a life-cycle analysis. Savings from the generated photovoltaic electricity and from the thermal energy produced by the SWH in kWh are deducted from total consumer

energy demand and accounted to pay back the solar system. The study is based on operational data at Toowoomba Queensland at an average solar irradiation of 2008 kWh/m^{2}year. **Figure 4** shows the average monthly energy yield of the combined solar system. Impact of the installed combined solar system on energy consumption of an average domestic user is shown in **figure 5**. The contribution made by the PV system added to that of the solar thermal system results in the total reduction in the energy demand from the utility grid.

Figure 5 shows that such a simple solar system is able to strongly reduce electrical energy consumption of an average domestic user. The system is even able, in solar-rich months, to totally eliminate electrical withdrawal from the utility grid and rather to export excess energy to the electrical supplier.

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". 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.
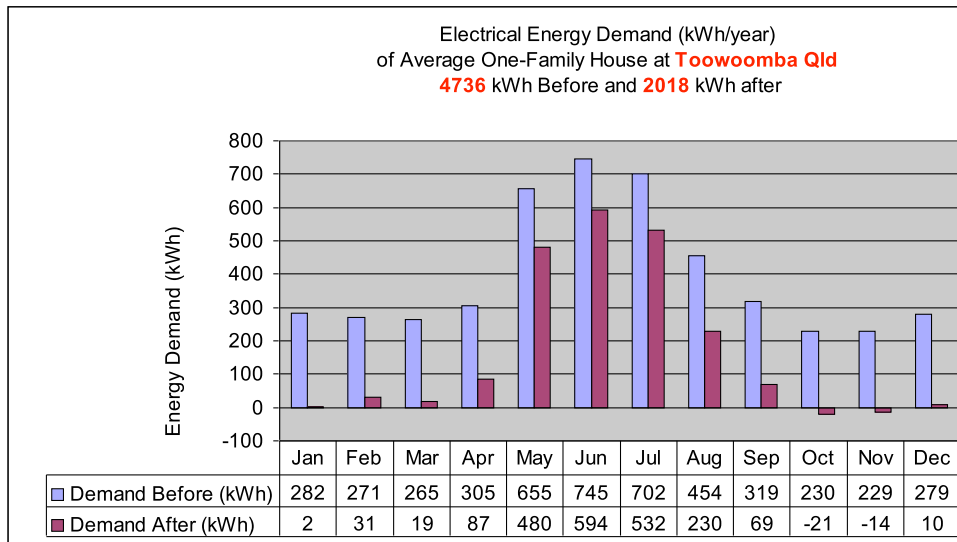

Monthly average Energy Yield of Solar System at **Toowoomba Qld**
1kWp GC-PV and 1.37 m2 solar Thermal - Total 2718 (kWh/year)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GC-PV-ac (kWh)	147.2	128.3	134.3	115.0	102.6	100.0	103.3	125.9	140.0	135.6	131.2	142.0
Solar Thermal (kWh)	132.3	111.4	111.3	103.5	72.72	51.06	66.77	98.23	110.1	115.4	111.5	127.3
Total (kWh)	279.5	239.7	245.6	218.5	175.4	151.0	170.1	224.1	250.1	251.0	242.7	269.3

Figure 4 Average monthly Energy yield of the GC-PV-SWH combined solar system.

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^2 120 litre 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 Kamel (2002).

Figures 6 show breakeven conditions of the solar system under three different conditions: 1) the photovoltaic grid connected unit alone, 2) the solar system GC-PV and SWH combined, and 3) the solar water heater system alone. The

analysis shows the system is paying back the investment at a certain energy cost and system operating 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.

Electrical Energy Demand (kWh/year)
of Average One-Family House at Toowoomba Qld
4736 kWh Before and 2018 kWh after

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand Before (kWh)	282	271	265	305	655	745	702	454	319	230	229	279
Demand After (kWh)	2	31	19	87	480	594	532	230	69	-21	-14	10

Figure 5 Electric energy savings from the GC-PV-SWH combined solar system.

The analysis demonstrates e.g. that the PV-SWH system at present market conditions is able to produce energy at actual competitive prices of 20, 14, 10 and 8 cent/kWh at 15, 20, 25 and 30 years life-time respectively. This corresponds to 200, 140, 100 and 80 $/MWh. Comparing those solar energy cost with **AEMO** electricity prices in **figures 1 and 2** indicate the system is already now able to economically cover peak loads (at peak prices) at competitive prices. Furthermore, systems bought today shall produce energy at a constant price to the end of their life, while electricity prices are constantly rising. Saving electrical transmission and distribution losses happening on the conventional network and offering more energy supply security, solar energy is thus representing convincing option to cover peak diurnal demands.
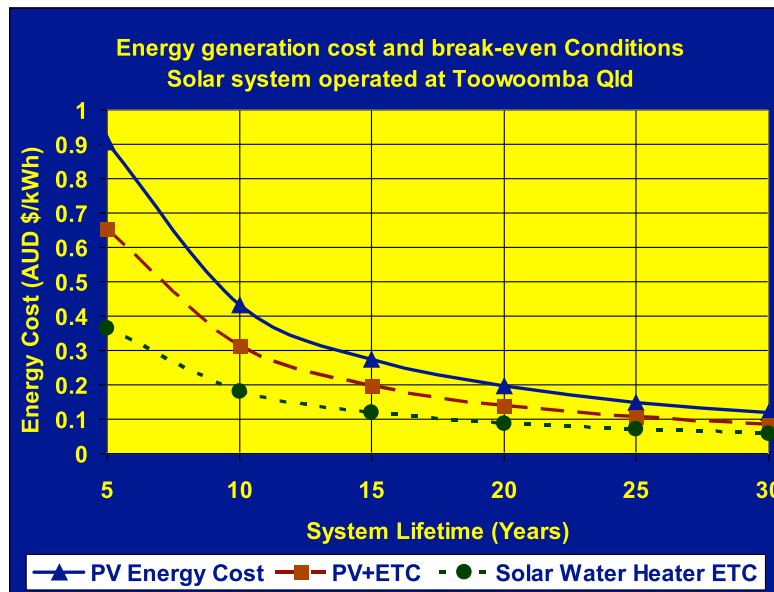
Figure 6 Energy generation cost and break-even conditions of the 1 kW GC-PV system and the evacuated tube SWH system.

THE SOLAR SYSTEM COVERING PEAK DIURNAL DEMAND

This work presents a simulation of electrical demand of the 14th May 2008 in Queensland (**figure 1**) with solar energy covering diurnal peaks above a base load of 4100 MW (for the year 2008). Base load is left to be covered by conventional power stations operating throughout the year at a capacity factor of unity providing best economic operating conditions at least possible energy price. A graph of the simulation is presented in **figure 7**.

DISCUSSION

A look at the AEMO peak demand prices in **figure 2** shows an average of around AUD $40/MWh (4 ¢/kWh) wholesale price (transmission and distribution cost not yet included); peaks at times are exceeding AUD $400/MWh (40 ¢/kWh). Historical reports are indicating energy prices incidents of as high as AUD $6,622/MWh (¢660/kWh) AEMO (2009). The solar system in consideration shows ability to provide energy price at end-user premises of ¢14/kWh ($140/MWh) (**figure 6)** for 20 years life-time. This provides evidence that solar systems composed of photovoltaic grid-connected and solar water heating units are today already able to cover diurnal peak demands, particularly those above the base-load. Base load is left to be covered by low-cost power plants throughout the year, since those are producing the most economic operation.
Figure 8 and 9 are showing quantitatively the amount of contribution solar systems might make by covering diurnal electrical peaks. From a total of 52.18 TWh/year for 2008 the solar energy is able to provide 9.07 TWh; a percentage of 17.4%.
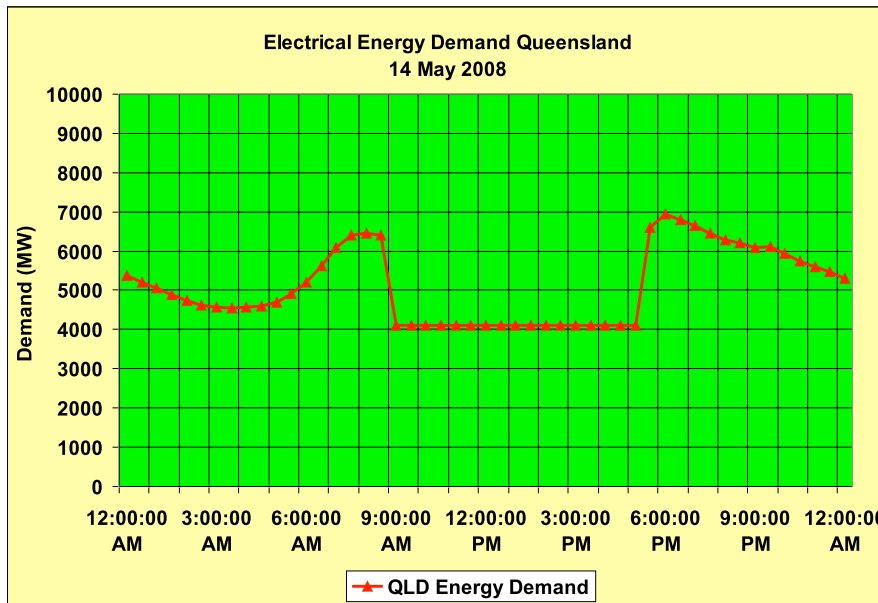
Figure 7 Implementation of solar systems to cover peak demands in all Queensland.

CONCLUSIONS AND RECOMMENDATIONS

The analysis presented in this paper for a combined solar system including a grid-connected photovoltaic (GC-PV) array associated with a solar water heater shows such a system presenting realizable economic benefits and the ability to cover diurnal electrical peak demands at competitive prices. From a total of 52.18 TWh of electricity in 2008 the solar energy is able to provide 9.07 TWh; a percentage of 17.4%. Further on the system, being installed on user's premises is saving transmission and distribution losses, besides offering a long-term energy supply security. It is recommended to consistently engage photovoltaic solar systems with solar water heating systems so that the photovoltaic is supplying essential electrical loads while solar heaters are covering thermal loads.
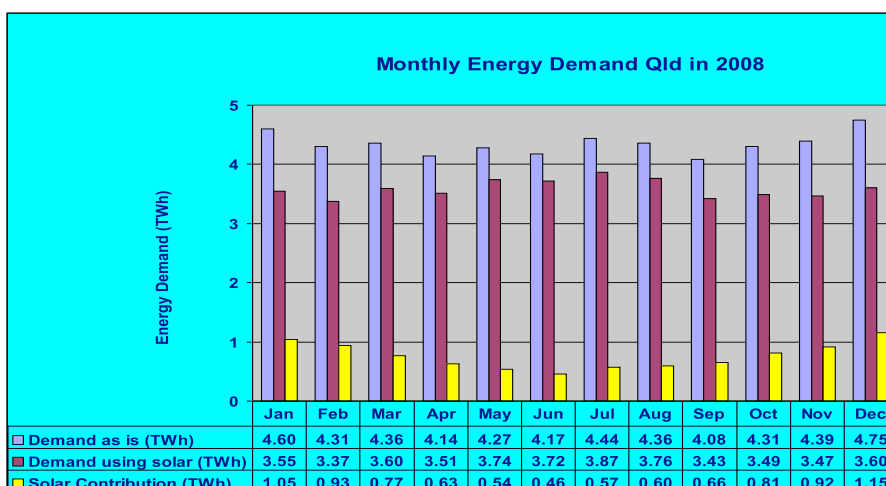

Monthly Energy Demand Qld in 2008

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
☐ Demand as is (TWh)	4.60	4.31	4.36	4.14	4.27	4.17	4.44	4.36	4.08	4.31	4.39	4.75
☐ Demand using solar (TWh)	3.55	3.37	3.60	3.51	3.74	3.72	3.87	3.76	3.43	3.49	3.47	3.60
☐ Solar Contribution (TWh)	1.05	0.93	0.77	0.63	0.54	0.46	0.57	0.60	0.66	0.81	0.92	1.15

Figure 8 Possible savings achieved by solar energy covering diurnal electrical peak demand.

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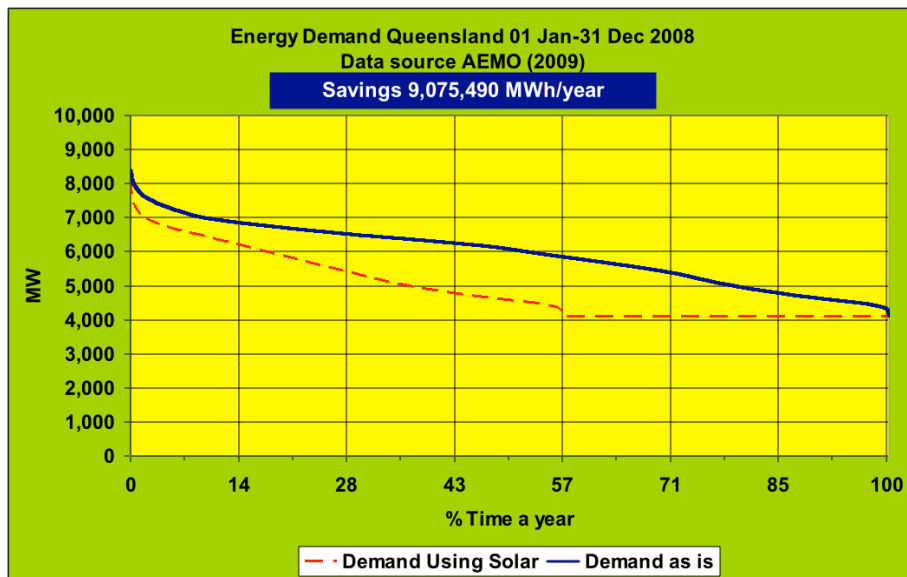Kamel
Full Paper Peer Reviewed

Figure 9 Solar energy contributing covering diurnal electrical peak demand in Queensland.

REFERENCES

AEMO, 2009, Australian Energy Market Operator Price & Demand Data Sets,
    http://www.aemo.com.au/data/price_demand.html

AEMO, 2009, Australian Energy Market Operator, Electricity Market Price &
    Demand Data Sets, http://www.aemo.com.au/data/price_demand.html

EECA, 2000, The dynamics of energy efficiency trends in New Zealand; A
    compendium of energy end the analysis and statistics P.110,

EUAA, 2005, Demand Side Response in the National Electricity Market Case
    Studies End-Use Customer Awareness Program, http://www.euaa.com.au/
    publications/papers/files/DSR%20Case%20Studies%20Final
    %20Draft3.3%20RF%201.8%20Clean%20(LOW%20RES).pdf

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INTERNATIONAL CONFERENCE

Potential Contribution of Solar Energy Towards Electrical Peak
Demands in Queensland
Kamel
Full Paper Peer Reviewed

F. Kamel, 2001, Assessment of domestic evacuated tube direct solar water heater, pp 6, http://eprints.usq.edu.au/3999/1/Kamel_Wilson_ISES_2001_Paper_2.pdf

F. Kamel, 2002, Cost of kWh produced and payback time of a pv-solar-thermal-combined rooftop collector at different locations in New Zealand, pp 9, http://eprints.usq.edu.au/4086/1/Kamel_Wilson_EEA_2008.pdf

T. Mierzejewski, 1998, Analysis For Residential / Commercial Photovoltaic Systems Intertied With New Zealand Electricity Networks, NZ Energy Efficiency and Conservation Authority

D. Mills, 2008, Economic Impacts of PV Embedded Generation and Residential Air Conditioning on Electricity Infrastructure, Discussion Paper presented at the PV Solar Future Workshop, Brisbane, hosted by Ergon Energy and the Queensland Environmental Protection Agency, 14 November 2008, Dr David Mills Sustainability Innovation Department of Environment and Resource Management

D. Mills, 2008, Photovoltaic Power Systems Effective Load Carrying Capacity, Discussion Paper presented at the PV Solar Future Workshop, Brisbane, hosted by Ergon Energy and the Queensland Environmental Protection Agency, 14 November 2008 Dr David Mills Sustainability Innovation Department of Environment and Resource Management

RET, 2009, Energy White Paper, National Energy Policy - Framework 2030 Strategic Directions Paper, http://www.ret.gov.au/energy/Documents/Energy%20Security/Strategic%20Directions%20for%20Energy%20White%20Paper%20March%202009.pdf

BIOGRAPHY

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