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Energy and Economic Efficiency in the Solar Power Industry

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Master's Thesis in Energy, Natural Resources and Environment

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Abstract

This thesis seeks to answer the question of how energy and economically efficient solar power industries and subcomponents are. The study delves into different forms of renewable energy sources and their applications as well as market structures in a brief fashion and tries to explain how solar power proves different and is worthy of recognition. Explaining different approaches to energy and economic efficiency, the study seeks to concretely determine the level of efficiency of photovoltaic power applications.

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1. Foreword

This thesis is a part of the Master of Science Program in Energy, Natural Resources and Environment at the Norwegian School of Economics and Business Administration. The purpose of this thesis is to apply the knowledge I have gained during my studies.

I have chosen to focus this thesis on the economic and energy efficiency of solar energy production, particularly the photovoltaic solar cell technology because I believe that renewable energy sources (and among them solar energy) is the only way to inhibit the rapid climate change move we have triggered. Additionally, there isn't much written on the efficiency of PV energy markets, and I thought exploring this facet would be interesting.

This paper does not seek to apply a nominal efficiency value for the industry but provide a stimulus towards additional research in the field. I hope that through this paper additional studies regarding PV and other solar power markets would emerge that are not localized around a specific region but which can provide a more generalized and accurate analysis for enthusiasts. Furthermore, I am interested in seeing the events that are about to unfold in the wake of a recent fossil fuel price crisis and a proliferation of "greener" policies by developed countries.

The work has been challenging and interesting, and I believe I have utilized what I have learned in my studies at NHH as well as uncover newfound knowledge presented by senior economists and fellow researchers.

I would also like to thank my thesis supervisor Kurt Jørnsten for his advice in picking topics and generating interest in the topic.

Bergen, December 2009

Onur Omer Bayraktaroglu

2. Introduction

In the wake of the recent financial crisis that put developed and developing countries alike into despair, credit and liquidity became scarcer than ever, dealing great misery to both producers and buyers, investors and savers and finally, to the trust of everyone involved in the market for money. Spillover effects included the decline in the value of stronger currencies and the rise in the price of major commodities, and the energy providing commodities like oil and coal were no exceptions.

Compounded by the rapid climate change due to the exploitation of fossil fuels, the resulting turmoil seems to have sped up the development, commercialization, and diffusion of renewable energy technologies to combat fossil fuel dependency. Policy makers around the world are becoming increasingly motivated towards shaping strategies to support a sustainable production and consumption of energy. To this end numerous trading schemes and industry subsidies were established to rear a growing market for renewable energies, with bigger targets to eliminate hazardous emissions and collaboration towards facilitating newer technologies paving the way towards a fossil-fuel-free future for generations to come.

It is however still an introductory gesture towards a "greener" future, since the majority of energy production still depends on the use of fossil fuel based methods (REN, 2009).

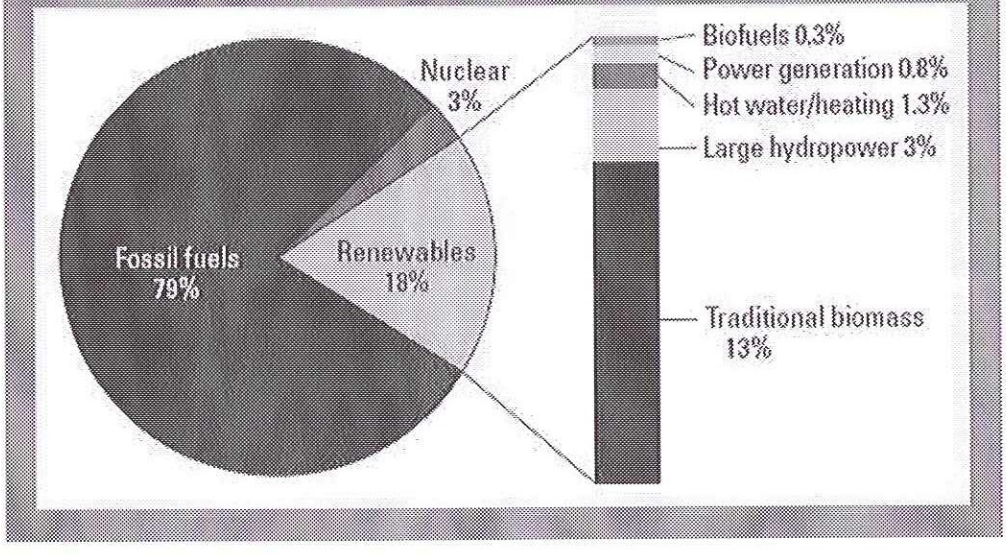


Figure 1. Renewable Energy Share of Global Final Energy Consumption, 2006

Considering the share of fossil fuel burning involved in meeting our current energy demands and that these demands are historically rising, it seems far-fetched to declare that renewable energies alone can provide for the lifestyle mankind has established for itself today. Realizing this fact has led leading countries in renewable energy technologies to strive to provide better equipment and newer methods of producing cheap, infinite and clean energy. Among the cleanest and most abundant sources of energy, solar power stands out as a natural successor to fossil fuel dominated markets. On the way to improvement, the natural stepping stone is the perfection of current methods of energy production and increasing efficiency levels to the level where no waste is produced in vain. Considering this, I pose the following research question:

What is the level of energy and economic efficiency of solar power generation, with emphasis on photovoltaic solar cell production?

This thesis investigates different methods of renewable energy generation and tries to point out why solar power deserves the attention of being the most suitable target for query on the subjects of energy and economic efficiency. By answering this question, it establishes the vehemence of providing a suitable alternative for energy generation before we have to suffer the irreversible effects of rapid climate change.

Within this study I will introduce the many facets of renewable energy generation and how solar power has the edge stand out among others. Later I will unearth methods of efficiency evaluation in theory and will try to implement them on a simplified model of photovoltaic cell production industry, demonstrating the effects of such technology on welfare.

3. Renewable Energy

According to the work of Sørensen (1991), renewable energy is defined as “a flow of energy that is not exhausted by being used”. Thus, renewable energy technologies enable the means to generate energy infinitely. Among all renewables available the sun provides us with not only a direct source of storing energy but also acts as a catalyst to indirect sources of renewables such as wind, wave and bio energy through its influence on climatic changes and growth of vegetation (Coley, 2008). Other examples of renewable sources of energy include geothermal and hydro power. The technologies available in renewable energy generation serve the common purpose of alleviating adverse effects of man’s ecological footprint on Earth and combat global warming as well as facilitate sustainability.

Contrary to common modern belief, the idea of renewable energy is age-old and has been demonstrated in various forms throughout history (Sørensen, 1991). The use of windmills in order to grind wheat in the west dates back to the 10th century (Lohrmann, 1995). Food created using plants and animals would count towards bio energy that is the end product of photosynthesis and processing.

Despite the fact that renewable energy methods are older than we think, their share in energy generation as a percentage is dwarfed by the use of fossil fuels and related finite methods (Coley, 2008). Renewable electricity generation capacity encompassed an estimated 240 GW worldwide in 2007. The largest component of this capacity is was wind power, which grew by 28%, whereas the fastest growing component was solar photovoltaics with a 50% annual increase recorded (REN, 2007). According to International Energy Agency’s (IEA) Energy Outlook figures (2009), the share of combustible renewables and waste provide 10% of the world’s total energy supply, whereas other methods including geothermal, solar and wind energy account for less than 1%. On the other hand, the adoption process of renewable energy methods is slow (Jacobsson and Lauber, 2006). Nevertheless, this comparatively smaller share in total energy generation is on the rise according to IEA (2009). It is expected that the diffusion of new renewable energy technologies will gain in popularity facing rising oil prices compounded by the peak and fall of fossil fuel generation (Aleklett, 2006).

3.1 Wind Power

Wind power is the conversion of wind energy into a useful form such as electricity by utilizing wind turbines. By the end of 2008, worldwide nameplate capacity of wind powered generators was 120.8 GW (IEA 2009). Although wind produces only about 1.5% of worldwide electricity use, it is growing rapidly, having doubled from 2005 to 2008. Reaching high levels of market penetration in several countries, wind power accounts for 19% of electricity generation in Denmark, 10% in Spain and Portugal and 7% in Germany and the Republic of Ireland. This appreciation is the result of wind power being attractive as an alternative to fossil fuels, since it is renewable, widely distributed and carries out negligible amount of emissions (Coley, 2008).

Wind energy has historically been used directly to propel sailing ships or converted into mechanical energy for pumping water or grinding grain, but the principal application of it today is the generation of electricity. Wind power, along with solar power, is non-dispatchable, meaning that for economic operation all of the available output must be taken when it is available (Holttinen et al, 2006).

3.2 Hydroelectric Power

Hydroelectricity is electricity generated by hydropower, i.e., the production of power through use of the gravitational force of falling water. It is the most widely used form of energy (Coley, 2008). Once a hydroelectric plant is constructed, the project produces no direct waste and has a considerably lower emission level of carbon dioxide than fossil fuel powered energy plants. Worldwide, hydroelectricity supplied an estimated 715000MWe in 2005. This was approximately 19% of the world's electricity (up from 16% in 2003), and accounted for over 63% of electricity from renewable resources (IEA, 2009).

Most hydroelectric power comes from the potential energy of dammed water driving a water turbine and generator. In this case the energy extracted from the water depends on the volume and the difference in height between the source and the water body's outflow. Due to its nature hydroelectric power is considered the most flexible and with potential compared to other methods of renewable energy generation (Kemp and Kasim, 2008).

3.3 Nuclear Power

Nuclear power is the use of any technology designed to extract usable energy from atomic nuclei via controlled nuclear reactions. The only method in use today is through nuclear fission, though other methods might one day include nuclear fusion and radioactive decay (Coley, 2008). All utility-scale reactors heat water to produce steam, which is then converted into mechanical work for the purpose of generating electricity or propulsion. According to IEA (2009), 16% of the world's electricity comes from nuclear power. As of 2005, nuclear power provided 6.3% of the world's energy and 15% of the world's electricity, with the US, France and Japan together accounting for 56.5% of nuclear energy generated electricity. As of 2007, there exist 439 nuclear reactors operational in 31 countries.

In the European Union as a whole, nuclear energy provides 30% of electricity generation. Nuclear energy policy differs between EU countries and some, such as Austria, Estonia and Ireland have no active nuclear plants. In comparison, France possesses 16 multi-unit stations in current use (Coley, 2008).

Solar energy generation, due to its popularity and availability across the world was chosen as the focus of this thesis.

4. Solar Energy

Today, solar power generation is recognized as the conversion of sunlight into electricity. The earliest use of the sun as a source of direct energy provider by mankind dates back to the Greek and Roman civilizations to heat buildings and water by facing dwellings towards the sun and creating pathways that received direct sunlight (Cogan, 2004). Solar power utilization directly affects a multitude of field including architecture and urban planning, lighting, agriculture, heating, water treatment and energy storage. Methods regarding electricity generation include but are not limited to concentration of solar power, use of photovoltaic panels and experimental uses of solar updraft towers and thermoelectric devices. While fossil fuels and derivative use of geothermal and tidal energy are considered as an indirect result of solar energy at work (Coley, 2008), solar power referred to in this thesis covers the utilization of sunlight only.

Solar power generation accounts for 1% of total world energy generation, whereas photovoltaic cells provide 0.4% of this share alone (REN, 2008). The comparatively low popularity of solar power generation among other renewables technologies (IEA, 2009) can be attributed to the fact that its efficiency levels were lower than expectations at the time of conception (PV Resources, 2009).

The following are the most common use of solar power generation used today.

4.1 Concentrating Solar Power

Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems in order to focus a large area of incoming sunlight into a small beam. This concentrated light is then used as a heat source for a conventional power plant or directed on photovoltaic panels (Coley 2008). Concentrating technologies that exist today include the parabolic trough, the concentrating linear Fresnel reflector, the Stirling dish and the solar power tower. Each of these systems operates based on the heating of a working fluid by concentrated sunlight and use of the fluid for power generation or energy storage (Martin and Goswami, 2005). Concentrated solar power systems can be divided into three categories; concentrated solar thermal, concentrated photovoltaics and concentrated PV and thermal.

Concentrated solar thermal is used to produce renewable electricity or heat. Innovations in the solar power tower, the Fresnel reflector and the Stirling allow the technology to become more cost effective. Concentrated photovoltaics systems function through directing sunlight on PV surfaces to generate electricity. In order to keep the focal point on the sun, solar trackers are employed to maximize concentration of incoming light. In a concentrated PV system, luminescent solar concentrators are used in improving performance of PV panels. CPV systems operate best under direct sunlight, and efficiency of systems is bolstered by the heat sinking properties of semiconductors (Coley, 2008). Concentrated PV and thermal systems operate similarly, but allow the storage of heat and electricity in the same module. Thermal heat stored in this way can be used to obtain hot tap water, heating, heat-powered air conditioning and desalination.

4.2 PV Panels

A photovoltaic cell (PV) is a device that converts light into electric current. This is established through the use of semiconductor material placed between two electrodes. As sunshine reaches the unit, free negatively charged electrons are discharged from the material, enabling conversion to electricity.

Silicon is the raw material used in production of solar cells, due to its abundance and chemical properties. With a melting point of 1420 degrees Celsius and its absence of poisonous and adverse effects to the environment, silicon has become the primary ingredient in the solar cell industry (Web Elements, 2009). The material maintains its electrical properties in high temperatures and thus provides high performance for today's PV cells.

Photovoltaic cell technology has a history of efficiency problems. The first cell introduced by Charles Fritts performed at an efficiency level of 1%, whereas Hoffman Electronics' first commercial PV cell provided only 2% efficiency. Thus, a $25 cell providing only 14mW of power meant a price per watt of $1785. Efficiency of PV cells today reaches over 20% per unit (PV Resources, 2009).

4.3 Experimental Solar Power

Experimental solar power encompasses the use of advanced systems to generate electric power. Among these, the solar updraft tower accomplishes this through utilizing a built-in greenhouse to funnel heated air inside a central tower. The rising heated air flows through a turbine, generating electricity. A 50kW prototype unit was constructed in Ciudad Real, Spain and operated for 8 years before decommissioning (Coley, 2008).

A thermogenerator converts heat directly into electricity. This is established through converting temperature differences between dissimilar materials into an electric current. The method was initially proposed by Mouchout in the 1800s, further research reappeared in the Soviet Union in the 1930s. Thermogenerators were later used by the US in powering deep space missions.

5. Efficiency

The term efficiency would in the traditional sense invoke the meaning of a state or quality being efficient or displaying competency in performance (Webster, 2009). However, this definition takes multiple forms when approached from an economic and energy related basis, leading to the discussion of energy efficiency versus economic efficiency. Using a method that is both energy and economically efficient is verily the answer to the current climate change problem we are facing, thus making primarily Western governments to undertake policies towards establishing both efficiencies in power generation (Gunn, 1997).

Energy efficiency refers to obtaining the same level and quality of energy at the end of a generation process with a lower level of input. Often confused with energy conservation, energy efficiency cannot easily be condensed into a simple difference between the current level of energy demand and the one obtained from the use of the most technological equipment available. Gunn points out (1997) that in order to decide what energy efficiency means, one has to differentiate between "maximum technical potential, the economic potential, the realistically achievable potential and the naturally occurring potential." He further mentions that "proponents of [reducing the energy efficiency gap] identify at least 5 key reasons for advocating energy efficiency:

1) saving money: by investing in those technologies between the naturally occurring potential and the economic potential;
2) reducing energy dependence: especially on imports of fossil fuels (and in countries other than New Zealand, on nuclear energy);
3) enhancing intergenerational and international equity;
4) mitigating environmental effects of global warming;
5) moving towards sustainability"

Economic efficiency, on the other hand, refers to the optimization of distribution in society's resources. This idea leads to Pareto efficiency, where efficiency occurs at the point where no individual can be made better off without making another worse off. Since Pareto efficiency occurs primarily in perfectly competitive markets and the reverse holds true, the search for perfect competition in energy markets is thus apparent. Gunn further notes (1997) that "economic efficiency comprises of

1) pricing or allocative efficiency: which requires that prices equal the marginal costs of producing those goods and/or services, throughout the entire economy,
2) technical or productive efficiency, which requires the minimization of the cost operations;
3) dynamic efficiency: which requires the optimization of investment decisions."

Complementarily, the argument that a competitive environment places pressure on firms to provide better customer service and to maximize internal efficiency through cost reduction would subsequently lower average prices (Saha, 1991) works in favour of Pareto efficiency proponents.

When we examine the solar power generation technology and solar power market in detail we can identify the implications of energy and economic efficiency. As mentioned before, the solar energy technology (solar cell in particular) started out with lower energy efficiency levels which improved over time until today, from a 1% level of efficiency to over 20% efficiency in modern silicon based PV units, making the market for photovoltaic based energy generation increasingly lucrative. The PV market has been characterized as an ever-expanding niche-market (Oliver, 1999). Thus a relatively lower efficiency value compared to other renewable energy source performances does not necessarily constitute a failing market for PV units (Hill, 1996).

In order to maintain economic and energy efficiency, various countries portray different approaches. While approaches towards economic efficiency include the use of legislation, promoting energy strategies and programs as well as trading schemes, energy efficiency is largely attributed to technological developments in the solar power generation methods.

5.1 Energy Efficiency

To facilitate energy efficiency in solar power generation (primarily in the PV cell component), alternative materials of production can be employed. One such item, Gallium arsenide (GaAs) provides over 30% efficiency in power output at the expense of increased price per watt levels, limiting its use to nice-markets such as space exploration and satellite technology. A cheaper alternative can be employed through the use of Cadmium telluride, a material primarily applied in thin-film form, however it yields far less efficiency compared to silicon based units and the material itself is poisonous. Copper indium diselenide stands out as the most promising substitute for the current silicon PV units through its thin-film application and high levels of efficiency (%20), however the technology involved is not yet commercially viable (PV Resources, 2009).

On a broader perspective commercial PV cells can be categorized under crystalline solar cells and film solar cells, which portray differences in efficiency and pricing. While crystalline application is more expensive and yields more efficiency, thin-film application provides less efficiency at a lower cost. Therefore there exists a trade-off between economic and energy efficiency in the production of PV cells.

5.2 Economic Efficiency

Economic efficiency in solar energy markets is largely established through government intervention in different countries. Since the cost of PV is generally above the cost of conventional (fossil fuel based) methods of energy generation, national governments provide incentives to the PV industry in form of subsidies, government incentive programs and feed-in tariffs (PV Resources, 2009).

The form of government incentive can take different forms. Providing tax credits to buyers of PV systems or investment subsidies where the government refunds part of the price of the PV system are common methods. Another incentive is the feed-in tariff which acts as a form of subsidy where price of the electricity generated by PV systems is guaranteed by the government. In the case where the PV installation produces more energy than it can use, the excess can be sold on the market for the guaranteed price to earn a profit.

Another tool to ensure economic efficiency by governments is the “White certificate”. These documents certify that a certain reduction of energy consumption has been attained. Just like carbon emissions trading, white certificates are also tradable and combined with an obligation to achieve a target of energy savings. Failure to adhere to the energy consumption reduction dictated by the certificate results in a penalty for the holder of the certificate. The certificate is issued whenever a producer achieves a given target reduction in energy consumption, where the producer may choose to use it for their own target compliance or sell it to targets who are unable to meet their targets (Mundaca, 2008).

6. Theoretical Framework

In order to determine the efficiency of solar power markets with emphasis on photovoltaics, several methods of determining economic efficiency in a system are available, all of which are based on the accumulated welfare decided by the market clearing equilibrium. The following is a list that portrays the most fitting methods with advantages/disadvantages.

6.1 Pareto Efficiency

Pareto efficiency applies to situations in which any (additional) change to make any person better off is impossible without making someone else worse off. Given a set of alternative allocations of goods or income for a set of individuals, a change from one allocation to another that can make at least one individual better off without making any other individual worse off is called a Pareto improvement. An allocation is defined as Pareto efficient or Pareto optimal when no further Pareto improvements can be made. An economic system that is Pareto inefficient implies that a certain change in allocation of goods may result in some individuals being made "better off" with no individual being made worse off, and therefore can be made more Pareto efficient through a Pareto improvement. Since Pareto inefficiency is considered as one or more parties getting worse off than the initial position, policy decisions that cause inefficiency are avoided (Gunn, 1997). In the case of a Pareto inefficient system, a Pareto improvement is possible, meaning that reallocating the distribution of goods and services will result in one or more parties benefiting without making anyone else worse off.

Ensuring that nobody is disadvantaged by a change aimed at improving economic efficiency requires compensation of one or more parties (Acocella, 1998). If a change in economic policy dictates that a legally protected monopoly ceases to exist and that market subsequently becomes competitive and more efficient, the monopolist will be made worse off. However, the loss to the monopolist would be offset by the gain in efficiency. This means the monopolist can be compensated for its loss while still leaving an efficiency gain to be realized by others in the economy. Thus, the requirement of nobody being made worse off for a gain to others is met.

Pareto efficiency applies to the solar power markets under the assumption that the market is perfectly competitive, allowing full information for buyers and sellers and thus establishing the best allocation of resources (Bhattacharrya, 1995). Under such circumstances it is in the government's best interest to aim for a perfectly competitive market as policy goal. However, the assumptions enveloping perfect competition markets do not entirely apply to solar power markets, as we do not have perfect information or rational behaviour for buyers and sellers, meanwhile observe the presence of externalities and larger players obtaining market power.

6.2 Dynamic Efficiency

The neo-classical theory of efficiency is defined through the use of a static efficiency model, primarily portrayed by the Pareto efficiency where at equilibrium, any effect changing the allocation of resources results in an inefficient system that requires correction. This line of thought does not take into consideration the possibility of exogenous shock effects that would eliminate a stable and rigid equilibrium that is set in stone, resulting in a market failure (McCartney, 2004).

With dynamic efficiency modelling the effects of exogenous shocks are alleviated by the idea of the equilibrium returning to its original position, since output and productivity performances are maintained. This also allows for easing the assumptions of perfect information and the neoclassical static market paradigm, providing more realistic (yet still limited) insight as to the efficiency of a system. Elimination of the market failure assumption under endogenous shocks also allows for limitation of government intervention.

Similar to the Pareto efficiency system, the commodity in question is electricity generated by the means of solar power. Dynamic efficiency is directly related to economic reform, and thus presents increased competition for businesses, forcing them to innovate and adapt in order to stay functional. Increased competition in return results in differentiated goods and presents the consumers with more choices in addition to driving prices down. The downside of this model lies in the fact that the commodity in question is not differentiable, since power generated from solar cells and fossil fuel burning provide equivalent yields.

6.3 Kaldor-Hicks Efficiency

Kaldor-Hicks efficiency is a measure of economic efficiency that captures some of the intuitive appeal of Pareto efficiency, but has less stringent criteria and is hence applicable to more circumstances. Under Kaldor-Hicks efficiency, an outcome is considered more efficient if a Pareto optimal outcome can be reached by arranging sufficient compensation from those that are made better off to those that are made worse off so that all would end up no worse off than before (ECON, 2009a). In other words, a decision that renders a group worse off but another group better off with the permission of the group that is worse off, the new equilibrium is still considered more efficient. A Kaldor-Hicks benefit then portrays a situation when a policy choice results in a net benefit (gains exceed losses, benefits exceed costs) and the new equilibrium is now a more efficient point (ECON, 2009b).

This efficiency measure is important in determining the desirability of producing public goods, such as parks, highways and reservoirs and is the theoretical foundation of the cost-benefit analysis. As a contrasting condition for attaining equilibrium to Pareto efficiency, Kaldor-Hicks efficiency provides looser assumptions to be built for a test model. With the introduction of the compromise system for those who are worse off after a policy, the system provides ways to probe hypothetical changes to a Pareto efficient but not necessarily Kaldor-Hicks efficient society. Still, a Kaldor-Hicks test operates much like a Pareto efficiency test in determining the starting point.

In terms of testing efficiency for solar power markets, primarily that of solar cells, alleviated assumptions fit well with the trade-off in PV sell construction mentioned in earlier chapters. Depending on the society in question, a trade-off between price of PV units (and therefore the system price for generated electricity) and offered quality (and thus longevity) is possible. However, since the social welfare function does not take into consideration the distribution of income but emphasizes the absolute level of it, it is not possible to determine utility gain/loss for consumers of PV cells.

6.4 Generic Social Welfare Function

A social welfare function is a real-valued function that ranks conceivable social states from lowest to highest. Inputs of the function include any variables considered to affect welfare of the society (Sen, 1970). Each social welfare function is individualistic in the fashion that variables used as inputs are unique for each purpose. The social welfare function is analogous to an indifference-curve map for an individual, except that the social welfare function is a mapping of individual preferences or judgments of everyone in the society as to collective choices, which apply to all, whatever individual preferences are. One point of a social welfare function is to determine how close the analogy is to an ordinal utility function for an individual with at least minimal restrictions suggested by welfare economics.

A simplistic welfare function demonstrating total welfare of a society based on each citizen's income level can be described as follows:

$$W = Y_1 + Y_2 + Y_3 + \dots + Y_n$$

Here W represents total welfare with each individual being denoted as Y. This function can be altered to demonstrate isolated cases.

Due to the liberty of variables that can be used in determining social welfare, this model presents the best method to determine the efficiency of solar power markets while admitting the greatest flexibility of assumptions.

7. Methodology

The purpose of this thesis is to determine the economic efficiency of the solar energy markets with emphasis on the PV cell market. In order to do this, one has to consider variables such as the effect of electrical power generation potential of PV cells, their price per watt or the costs of implementing PV cell systems, and possible harmful effects of adverse emissions during operation.

Thus I decided to run ordinary least squares (OLS) regressions to determine the nominal and real effects of changes in electricity generation potential and the cost of implementation on total social welfare. To this end, I have formulated the following model:

$$INC = \beta_0 + logKWPRI\beta_1 + \varepsilon$$

where *INC* stands for the real total income of the state of California in $million for the last 28 years and *logKWPRI* stands for the percent change in total cost of using a solar cell over 28 years, calculated by the product of the output level and price per kW given in "Borenstein, 2008" and taking the log of the resulting value. β_0 represents the available welfare for the population without the implementation of PV cells in the area.

The sample used in this thesis is from the California state only, with limited sample size for output potential and a comparatively longer time horizon to test the welfare effect of added solar power generation.

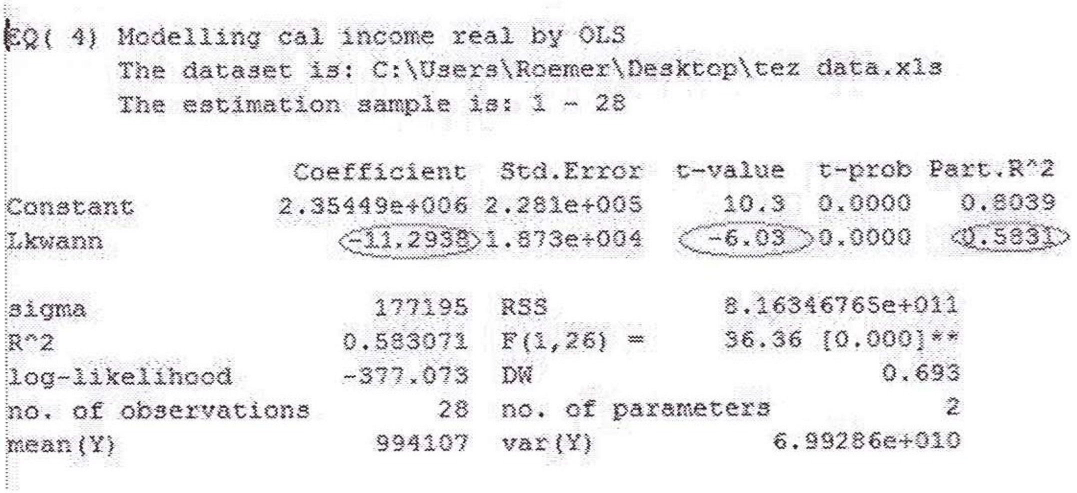
The assumptions are as follows:

1) There are no fixed costs incurred from the initial installation of PV cells and variable costs of operation are covered by the variable *PRI*.
2) PV cells generate negligible amounts of harmful emissions, thus the variable for emission potential is dropped.

The statistics software PCGive has been used for the regression analysis. Significance of coefficients is determined by using the t-test.

8. Results and Discussion

The OLS results are as follows:



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EQ( 4) Modelling cal income real by OLS
       The dataset is: C:\Users\Roemer\Desktop\tez data.xls
       The estimation sample is: 1 - 28

                  Coefficient  Std.Error  t-value  t-prob Part.R^2
Constant          2.35449e+006 2.281e+005    10.3  0.0000   0.8039
Lkwann                -11.2938 1.873e+004   -6.03  0.0000   0.5831

sigma                   177195  RSS              8.16346765e+011
R^2                   0.583071  F(1,26) =        36.36 [0.000]**
log-likelihood        -377.073  DW                         0.693
no. of observations         28  no. of parameters              2
mean(Y)                 994107  var(Y)              6.99286e+010
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The coefficient for the independent variable *logKWPRI* has a statistically significant coefficient value (at $\alpha = 0.05$) of -11.2938 and adjusted R^2 for the variable stands at ≈ 0.58. The constant for the regression equation has a value of ≈ 2.35 million.

8.1 Discussion and Interpretation

The value of the coefficient for the control variable suggests that for a 1% change in the cost of PV cell implementation results in a decrease of approximately $11.3million worth of welfare. The coefficient of determination suggests that for approximately 60% of the time the fitted values are likely to be predicted correctly. A t-value above the critical value for the given significance interval points out that the coefficient has a value that is statistically significantly different from zero.

It is certainly far-fetched to insinuate that a 1% increase in photovoltaic cell operation prices would trigger a welfare loss of over $10million, yet the implications presented by the sign of the coefficient make little sense: in a simplified instance an increase in price would imply a trade-off in favour of quality of material chosen for the photovoltaics panel and thus increase longevity and efficiency of the energy generation site (PV Resources, 2009). The reverse effect observed in the given model can be attributed to the limited sample size, choice of location and the time horizon given for the regression in the first place.

The Pareto efficiency approach might suggest that the price increase triggered a welfare loss, resulting in a market dysfunction and disequilibrium. The previous setting with no price increase was the Pareto efficient equilibrium and no change was necessary.

However, if we implement the Kaldor-Hicks efficiency approach we are presented with an alternative explanation. The increase in the price of photovoltaic panels for the area might have triggered a greater welfare loss than the benefits of efficiency better quality material would have provided. Another possible explanation could suggest that the price increase could have triggered a loss of utility that could not be conceived by the Kaldor-Hicks approach, resulting in disequilibrium shows similar effects as an endogenous shock.

8.2 US Department of Energy Calculations

According to the most recent data (EERE, 2009), US production of PV cells and modules for the year 2002 are at 121MW, which accounts for over 20% of total global production of said cells and modules. Cell efficiency stands at the 15-25% range with total system efficiency in the 5-15% intervals for the year 2003. From the operational renewable energy generation capacity, PV energy generation accounts for approximately 0.01% with 57.4MW. This value when compared to the total energy consumption by the US, accounts for a miniscule share of energy provision ($5 \times 10^{-12}\%$). While the total amounts of energy generated are calculated, the efficiency levels are largely estimates (EERE, 2009).

9. Conclusions and Summary

The results from the OLS regression suggest little of value, even when the sign of the coefficient is examined. However, different approaches to efficiency evaluation can develop new explanations towards why an increase in PV panel cost increase would create a comparatively larger negative effect.

It should be further noted that due to lack of availability in PV cost, power output, emissions and pricing data in a larger time horizon and greater samples than mere household appliances, the results of the regressions would be severely biased. Further research that can collect significantly more data can reach more accurate results that would shed more light into the issue.

However we do have to realize that phenomena can be explained by the existing theories of determining economic efficiency, including Pareto, Kaldor-Hicks and dynamic efficiency, based on the benchmarked market and setting the correct assumptions.

The PV industry has been affected negatively by the financial markets during the winter of 2007/2008. Threats of economic downturn are very much real in the face of bleak future expectations. However, the world will still need an ever-increasing amount of energy, and there will be a growing focus on supplying this energy in a cost-effective and environmentally-friendly way. And with any luck and hope of increased efficiency, this industry could turn out to be solar power.

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