Feasibility Study for the Design of an Industrial Park with Low Energy Consumption

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Yi Yang

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Abstract
China is in the period with rapid development and great economics growth. Unsustainable development made China face the energy crisis and environmental problems. In the last two decades, over 100 industrial parks supported by the Chinese central government were built in over 20 provinces. And the number of the industrial parks supported by local governments (at the level of provinces and cities) is much higher. However, most of the industrial parks have not been systematically optimized with considerations of integrated solution with low energy consumption. On the other hand, since the introduction of the industrial ecology concept by Frosch and Gallopolos in 1989, and the apparent success of the Kalundborg Industrial Symbiosis project, attention to planned eco-industrial park (EIP) development projects has grown all over the world. Furthermore, there are a great number of companies producing the solar energy equipment in China. This project is a feasibility study for the design of an industrial park with low energy consumption and energy integration between the manufacturing and residential buildings, which is supported by the Asia Pro Eco Program that aims to promote sustainable solutions for the environment between Europe and Asia. In this paper, the situation of EIP development in the world and China is introduced. By analyzing the EIP development and the situation of the industrial park in China, the solutions for China to gain the sustainable development are introduced. As the result, the feasibility study will focus on solar energy system that will be used in the Himin Industrial park. In this park, the solar energy is used to provide the energy for the district heating, hot water and air conditioning in the residential buildings and the workshops. Furthermore, the photovoltaic products can provide the electricity for the light in the workshop and the road lamp. Therefore, as the solar energy replaced the fossil fuel that provides heat by combustion, the park can decrease the consumption of the fossil fuel and reduce the environmental impact of industrial activity. At the same time, the cost on this industrial park will be much less than the generic industrial parks in China.

Key words: Industrial park, Eco-industrial park, Circular economy, Renewable energy
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1 Introduction

This project is a feasibility study for the design of an industrial park with low energy consumption and energy integration between the manufacturing and residential buildings. In addition, the diffusion of low energy consumption buildings concepts in China might promote a technology transfer from the EU to Asian countries with benefits in both continents: in Europe there might be a push to develop and export new technologies and in China new technologies and living standards might be introduced, promoting their diffusion and creating additional chances of investment and occupation.

This project derives from Asia Pro Eco Programme that aims to promote sustainable solutions for the environment between Europe and Asia. Asia Pro Eco is designed to strengthen the environmental dialogue between Asia and Europe through the exchange of policies, technologies and best practices that promote more resource-efficient, market driven, and sustainable solutions to environmental problems in Asia. The program aims to support a series of preventive and corrective actions, which materialise in technical solutions that contribute to both quality of life and economic prosperity in Asia.

This project is financed by the European Development Fund and is supervised by the European Commission. The project will be undertaken by the Institute of Engineering Thermophysics, Chinese Academy of Sciences (IET, CAS) and the partners that consists of Malardalen University of Sweden (MdU), University of Perugia of Italian (UNIPG) and Dongguan University of Technology of China (DGUT).

2 Background

With the high-speed development of industry, the energy crisis brings serious problems for the companies. And on the other hand, the environment problems brought by the industrial pollution become the great drawback for the development of the companies. The pollution is intimidating the life of the human. The investment for cleaning the polluted air, water and soil is much higher than the income from the industry development.

2.1 The Situation of the Industry in China

The industrial park is an improvement of industrial areas and residential buildings that is beneficial for the workers, who will be working in more environmentally friendly workplaces and live in a less polluted environment in the vicinity of industrial activities. In the last two decades, over 100 industrial parks supported by the Chinese central government were built in over 20 provinces. However, most of the industrial parks have not been systematically optimized with considerations of integrated solution with low energy consumption. For instance, there are nearly 1000 sets of stand-alone diesel engine with capacity of 1000kW without any thermal energy recovery from the exhausted gases. Industrial parks with low energy consumption are of importance for the local government’s strategy for the sustainable development. The developers of industrial and residential areas may offer more attractive working spaces and housing, which is a need of people, when they reach a higher level of income. The improvement of living conditions for workers has been demonstrated a new trends to attract qualified workers. In addition, a high environmental quality of the buildings which are offered to potential industrial activities may attract foreign investors from Europe, the US and Japan with the possible future legislation on emission trading, for which it will be
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possible to gain a bonus on greenhouse gases emissions if energy saving interventions are realized in countries with more stringent limits to comply with the Kyoto protocol.

2.2 The Energy Consumption and the Environmental Problems
China is the most populous country in the world and the second largest energy consumer after the United States. Production and consumption of coal, its dominant fuel, is the highest in the world. Coal makes up 65% of China’s primary energy consumption, and China’s coal consumption in 2003 was 1.53 billion short tons, or 28% of the world total. China’s demand for coal is rising rapidly as its economy grows. See Figure 2.1.

![Coal Consumption in China](image)

**Figure 2.1 Coal Consumptions in China from 1990 to 2003**
(Data resource from (Paul Crompton and Yanru Wu))

Furthermore, with 12.7% of the world’s total, China is the second largest emitter of energy-related carbon dioxide emissions after the United State. This means China’s efforts to reduce the greenhouse-gas emission will bring great benefits for the global environment.

![Energy-Related Carbon Emissions](image)

**Figure 2.2 Energy-Related Carbon Emissions**

On the other hand, the oil consumption is increasing rapidly to meet the requirement of rapid industry development. China has become the world’s second largest consumer of petroleum...
products since 2004, having surpassed Japan for the first time in 2003, with total demand of 6.5 million barrels per day. (From EIA) As the source of around 40% of world oil demand growth over the past four years, Chinese oil demand is a key factor in world oil markets.

With the great energy consumption, the energy intensity of use is still high, even though there is a dramatic decline in energy intensity of use because China initiated its economic reform program in the late 1970s. The energy intensity is measured by energy consumption relative to constant dollar shipments of manufactured products (See figure 2.5)
From all these diagrams above, we can see the China influence on the world energy market and environment. Now the energy crisis and the environmental issue are the main problems for China, so it is time for China to braze a new trail in building a new mode of consumption and production in line with sustainable development. There were hundreds of industrial parks built in the past decades in China, as mentioned above, but few of them are systematically optimized with the consideration of low energy consumption and reducing environmental impact. Furthermore, the workers are requiring a good living condition in the park for instance of providing the hot water and cooling system, which means that the energy consumption will increase for providing these services. So a good solution should be found for the design of industrial park in China.

2.3 Development Strategy in China: Circular Economy (CE)
China is the only country that has rapid economic growth with the greatest population in the world. The rapid industrialization in the last decades has engendered serious problems of depletion of natural resources, degradation of major ecosystem, and pollution extending far beyond its borders. This kind of unsustainable model development is not possible for China. The resources are not available to provide a growing population with higher standard in a western lifestyle of consumption. This ambitious development target is to raise the majority of China’s population into “the all-round well-being society”. This means that by 2050 a larger population of 1.8 billion would reach a per capita GDP of US$ 4000 per year, five times the current level. Some estimate that this increase could occur within the next 30 years. This demands a tremendous increase in production and multiplies pressure on natural resources and the environment. Research by the State Environmental Protection Administration indicates that China’s economy will need to achieve at least a seven-fold increase in efficiency of resource use to achieve the goals set for 2050, while maintaining environmental quality. The China Council for International Co-operation for Environment and Development (CCICED) states that an increase such as tenfold will be required (Lei and Qian 2003).
To meet the needs for development while restoring the health of ecosystems, the only option is to follow a development path different from the industrialization model of the West. China’s leaders see that continuing the present massive exploitation of natural resources and inefficient production practices cannot continue. Their conclusion is to adopt the Japanese and German Recycling Economy approaches and set higher goals than either.
3 The Objectives of My Thesis Work and Methodology

3.1 The Objectives
The aim of this project is to find a good solution for China’s sustainable development on the industry park. A lot of industrial parks have been built in the past decades, and there must be more in the future. Not only the energy system

Therefore, the objective of my thesis work is:
To design an Industrial Park which is suitable for China with consideration of Energy Consumption, better living conditions, also some other factors like economy and environmental impact

3.2 The Methodology
The methodology that will be used in this thesis work is:

1. Collect the information for the analysis for the book, articles and some companies;
2. Analyze the situation of IP development in China;
3. Find the good solution for the sustainable development bases on the analysis;
4. Do the feasibility study;
   ● calculating based on the certain data;
   ● arrange the energy system to reduce the fossil fuel consumption;
   ● making the economic evaluation;
5. Draw conclusions and give some recommendations.
4 Industrial Park Development

An industrial park is defined as “a large tract of land, sub-divided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms”. Types and synonyms of industrial parks include industrial estates, industrial districts, export processing zones, industrial clusters, business parks, office parks, science and research parks, and bio-technology parks. Eco-industrial parks have now been added to this list.

As I mentioned before, there are hundreds of industrial parks built in China in the past few decades, but few of them have considered about the low energy consumption. And this number is increasing rapidly. Now the leaders of China had made a decision to build the circular economic strategy. So the eco-industrial park could be a good solution for the industrial park development in the future, because one of the key strategies in China’s Circular Economy (CE) initiative is to use eco-industrial parks to help generate much higher productivity and efficiency of resource utilization. The China government started up the eco-industrial park projects in 1999.

On the other hand, the renewable energy could be a good substitute for the fossil fuel. Now the solar energy could be the best one for China, because there are a great number of companies producing the solar energy equipment in China, and they have the intention and capability to build this kind of industrial park.

4.1 The Eco-Industrial Park

The eco-industrial park is based on the concept of low energy and raw material consumption, and environment friendly. The eco-industry is a kind of industrial system that is managed by the ecology. In this kind of eco-industry Park, there are some factories and plants that are connected with each other like a food chain, which means the waste from one factory is the raw material for another factory, so that these factories form a closed ecosphere. The eco-industry park can efficiently decrease the pollution and increase the material utilization. On the other hand, the companies do not need to spend much money on the transportation for the material because the factories are in the same region. This will bring the company benefits to gather together and make the park possible.

4.1.1 The Definition of Eco-Industrial Park (EIP)

There are several definitions of the term eco-industrial park. The following definition was put forward by Lowe [1]:

"An eco-industrial park or estate is a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance."
"The goal of an EIP is to improve the economic performance of the participating companies while minimizing their environmental impacts. Components of this approach include green design of park infrastructure and plants (new or retrofitted); cleaner production, pollution prevention; energy efficiency; and inter-company partnering. An EIP also seeks benefits for neighboring communities to assure that the net impact of its development is positive."

Indigo Development introduced this concept of eco-industrial parks (EIP) to pollution prevention staff at the US-EPA (Environmental Protection Agency) in 1993. The Agency then embodied this concept in an Environmental Technology Initiative project, which led to the President's Council on Sustainable Development adopting EIPs as demonstration projects in 1995.

In the EIPs, the critical elements are the interactions among the park’s member businesses and community’s relationship with its community and natural environment.

4.1.2 Eco-industrial Park Development in the World

We are in an era of exponential change in world systems; availability of resources for development, destruction of natural capital, release of an increasing variety of toxic materials, climate change, and the impacts of all of these forces on human and natural systems. For instance, plastics from ocean dumping of garbage are disintegrating to a molecular level and entering into food chains. The ocean waters in northern seas are becoming less saline due to ice melting as the result of a warming atmosphere. Therefore, every country in the world is now facing the great challenges to develop their industry and economy without demolishing the natural environment and with low energy resources consumptions at the same time. Many countries including the developed countries like USA, Japan, and Germany etc. and the developing countries like China, Indonesia and Thailand etc. have built many different kinds of eco-industrial parks in the past decades.

An initial focus was upon the concept of eco-industrial parks (Lowe, 1997). Eco-industrial parks (EIP) are based on Industrial Ecology (IE) concepts and aim to increase business performance and competitiveness by integrating the social, economic and environmental aims in a concrete form while reducing raw material consumption, pollution and waste and creating jobs, improving the work conditions. Industrial Ecology (IE) attempts to understand the potential environment improvement in industrial by using an analogy of industrial system to natural ecological system. In a successful industrial ecosystem, the material flows should be closed into loops of recycle and reuse, then effluent and waste from one process serve as the input material for other process or are recycled for further production. Therefore, Eco-industrial Parks based on the industrial ecology have following benefits:

- Waste products from one industry provide the inputs for another, reducing input cost;
- Reduced waste streams mean lower waste disposal costs;
- Waste now has an economic value, increasing profits;
- The creation of a larger and more varied economic base;
- The potential for job creation from firm formation;
- Reduced emissions means less need to separate industrial and residential land uses and consequently reduced movement cost between two;
According to the IE concept, the eco-industrial park of Kalundborg in Denmark is the most successful example. Much of the work on EIPs has drawn upon this example as providing evidence of what could be achieved through implementing industrial ecology concepts.

A web of waste and energy exchanges occurs in Kalundborg between the city, a power plant, a refinery, a fish farm, a pharmaceuticals plant and a wallboard manufacturer. The heart of this park is the power station which provides process steam to Statoil Refinery and Novo Nordisk, and it also provides the residual heat to the municipality and fish farms. In 1993 Asnæs power station installed a desulphurization unit to remove sulfur from its flue gases, which allows it to produce gypsum. This is the main raw material in the manufacture of plasterboard at Gyproc. Excess gas from the Statoil refinery is treated to remove sulfur, which is sold as a raw material for the manufacture of sulfuric acid, and the clean gas is then supplied to power station and to Gyproc as an energy source. So these companies form a perfect industrial ecosystem.(the details about this eco-industrial park is in the appendix 3)

While the Kalundborg example developed organically over a long time period and as a result of voluntary co-operation between the companies involved, there have been attempts to recreate key features of Kalundborg through policy intervention, particularly in Western Europe and North America. The example of Kalundborg was one factor behind a strong drive to establish EIPs in the USA, where the President's Council on Sustainable Development (PCSD) formed a task force on eco-industrial parks.

### 4.1.3 Eco-Industrial Park Development in China

One of the key strategies in China’s Circular Economy (CE) initiative is to use eco-industrial parks to help generating much higher productivity and efficiency of resource utilization. The Circular Economy approach to resource-use efficiency integrates cleaner production and industrial ecology in a broader system encompassing industrial firms, networks or chains of firms, eco-industrial parks, and regional infrastructure to support resource optimization. State
owned and private enterprises, government and private infrastructure, and consumers all have a role in achieving the CE.

Nowadays, there are two kinds of solution that are suitable for China to build an eco-industrial park. One is to redesign the existent industrial parks and build the network of byproduct exchange to connect the enterprises with each other so that the park can achieve the low energy and material consumption. The other is to build a new eco-industrial park with one or several anchor companies.

There have been some successful EIPs in China in the past few years. For instance, the Guitang Sugarcane Eco-Industrial Park is one of the most successful EIPs in which the Guitang Group has created a cluster of companies in Guigang to reuse its by-products and reduce its pollution. The complex includes: an alcohol plant, pulp and paper plant, toilet paper plant, calcium carbonate plant, cement plant, power plant, and other affiliated units. The sugarcane from the farm is sent to sugar refinery to produce sugar, and the spent sugar juice and bagasse & slag are respectively sent to the alcohol plant and the paper mill to produce alcohol and paper. Then the spent alcohol from the alcohol is sent to the fertilizer plant to produce the fertilizer for the farm and the white sludge from the paper mill is sent to the cement kiln to produce cement. (See Appendix 5)

The other successful projects are: Zaozhuang EIP initiative in Shandong Province in North China, with key feature of transforming a traditional industrial zone to eco-industrial park; Quzhou EIP Initiative in Zhejiang Province in East China, with key feature of constructing web of material exchanges among dozens of chemical plants of various sizes; and Nanhai EIP initiative in Guangdong Province in South China, with key feature of developing environmental protection industry in a greenfield.

4.2 The Industrial Park with Renewable Energy

Renewable energies are inexhaustible, clean, such as solar, wind and hydraulic energies. They have been used since many centuries before our time and their applications continued throughout history and until the "industrial revolution", at which time, due to the low price of petroleum, they were abandoned. During recent years, due to the increase in fossil fuel prices and the environmental problems caused by the use of conventional fuels, we are reverting back to renewable energy sources.

Renewable energy can not totally replace the conventional fuels in the industry park due to the technology. Renewable energy can only be used as an assistant energy resource in the industrial park, but it can reduce the fossil fuel consumption and environmental impact.

There are also some successful examples in the world, for instance the Dyfi Valley Community Renewable Energy Project which is located in Unite Kingdom. This project aims to benefit the community’s 12,500 or so resident by encouraging the local people to engage with energy issue, establishing some community-based renewable energy installation. Furthermore, the project wanted to improve understanding and support for renewable energy by maximizing the local benefits.

The total installed capacity of completed renewable energy schemes was 205 kW electrical capacity (hydro, wind, solar) and 150 kW heat capacity (solar, wood, heat pump). And now
the people in the valley do not need to buy any energy from the other companies outside the park. (See Appendix 4)

In China, few industrial parks use the renewable energy as one of the energy resources. But nowadays, there are a lot of companies producing the products related to the renewable energy like solar heating water system. Himin Group is one of the biggest company which produces solar energy equipment, and now it wants to build an industrial park by using its own produces. So this will be a good example for the industrial park design in the future.

Therefore, except the eco-industrial park, the park with renewable energy could be another solution for China’s sustainable development.
5 Comparison and Discussion

To decide which kind of industrial park is better, the comparison and discussion are needed. For these two kinds of solutions, they all have advantages and disadvantages.

Table 5.1 the Advantages and Disadvantages of EIP and IP with Renewable Energy

<table>
<thead>
<tr>
<th></th>
<th>Eco-Industrial Park</th>
<th>Industrial Park with renewable energy (e.g. solar energy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>- Increase the energy and material use efficiency;</td>
<td>- Reduce the fossil fuel consumption;</td>
</tr>
<tr>
<td></td>
<td>- Reduce the environment impact;</td>
<td>- Using renewable energy is good for the environment;</td>
</tr>
<tr>
<td></td>
<td>- Save the cost for the material transportation;</td>
<td>- There are a lot of companies producing the solar energy equipment in China;</td>
</tr>
<tr>
<td></td>
<td>- Reduce the fossil fuel consumption;</td>
<td>- Easier to achieve comparing with the EIPs;</td>
</tr>
<tr>
<td></td>
<td>- Using renewable energy is good for the environment;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- There are a lot of companies producing the solar energy equipment in China;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Easier to achieve comparing with the EIPs;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Need much area for solar collectors;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Not good to meet the energy requirement in production process</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>- To build an EIP is a long time work;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- The investment for the exchange network is big;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- There is a great risk if one of the company is bankrupt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- The companies must be joined in “closed loop”.</td>
<td></td>
</tr>
</tbody>
</table>

For advantages, these two kinds of industrial park can all reduce the fossil fuel consumptions. In the eco-industrial park, the energy can be saved by the increase the energy use efficiency, but in the industrial park with solar energy, the fossil fuel consumption can be reduced by replaced by the solar energy. Furthermore, they are both friendly to the environment.

For disadvantages, the eco-industrial park is much harder to achieve than the industrial park with solar energy.

Why Eco-Industrial Park is hard to achieve? Developing an eco-industrial park integrates many fields of design and decision-making. Success depends on the high level cooperation among the public agencies, design professions, project contractor and the companies located in the park. Eco-industrial parks have been primarily described in the industrial ecology literature as a means of managing material and energy flows with attention to the possibility of particular chemical linkages. So the companies that located in the park must have the capability to be connected by the industrial network according to the chemical linkages. These companies are sometime hard to find and to be collected together to build an eco-industrial park. And some companies are not used to work “in community” and may fear the interdependence this creates.
On the other hand, the old Industrial parks IPs have been aroused to make rational adjustment in the distribution of small and medium enterprises (SEMs) in towns or cities in China since 1980s. Over the years two kinds of IPs have been developed in the country. The first is the parks with one or several anchor companies. The second is the parks composed of SEMs from many distinct business sectors but without anchor enterprises, which account for the main part of the total IPs. The challenges of guiding the second IPs onto eco-industrial parks might be that a series of obstacles, e.g. irregular layout of enterprises site, less available mass-byproduct-water for reuse, short of the conditions for energy cascading use and weak in information exchange among the enterprises and park administration.

Furthermore, companies using each other’s residual products as inputs face the risk of losing a critical supply or market if a plant closes down. This will break the whole industrial network so that the park will not survive any more, which will lead a big economic loss.

Comparing with EIP, the industrial park with solar energy is much easy to achieve in China. It does not need so many companies connected together. And the company like Himin Group which produces the solar energy equipment has the capability to build this kind of industrial park by itself, and it will bring great benefit for the company and the workers who work there.

In conclusion, the industrial park with the renewable energy is a feasible choice for this project.
6 Feasibility Study for Himin Eco-industrial Park

6.1 Introduction to Himin Solar Energy Group

Himin Solar Energy Group was established in 1996 in Shandong province of China. During the past ten years, Himin Solar Energy Group produced 8 millions square meters of solar collectors. Now they have over 5000 franchisers all around China. Its products are evacuated tubes, solar water heaters, solar collectors, photovoltaic products, and the Winpin low-e glass etc.

Figure 6.1 The Compact Solar Water Heater and the Split Solar Water Heating System (The Main Products of Himin Solar Energy Group)

Compact solar water heater is a kind of solar water heating system that solar collector and storage are connected with the cylinder storage on the top and with the collector panel on the bottom. There is no need of pump to push the fluid and no need of pipeline between the collector and storage. This kind of solar water heater relies on the natural circulation of water between the collector and the tank or heat exchanger. As water in the vacuum tubes is heated it rises naturally into the tank, while cooler water in the tank flows down to the bottom of the vacuum tubes, causing circulation throughout the system. It is a simple and safe solution to get heat power from the sun. This kind of solar water heater is used by millions of families in China because it is cheap and easy to be installed in the buildings.

Figure 6.2 The Working Principle of Compact Solar Water Heater
Split solar water heating system uses electric pump, valves, and controllers to circulate water or other heater-transfer fluid through the collectors. They are usually more expensive than compact solar water heater. A split solar water heating system is generally easier to retrofit than a compact solar water heater because their storage tanks do not need to be installed above or close to the collectors. This kind of solar water heating system can produce much more hot water than the compact solar water heater.

![Advanced collector tube](image)

**Figure 6.3 The Working Principle of Split Solar Water Heating System**

Except all these water heating systems, Himin photovoltaic division is devoted to the productions and promotion of solar photovoltaic products including solar lamps and solar modules. At present, the production capability has reached 10MW.

![The Solar Lamp and Solar Modules](image)

**Figure 6.4 The Solar Lamp and Solar Modules**

Himin has many partners from all around the world, not only for the business, but also in the technical field, which includes the University of Sydney and Chinese Academy of Sciences.

### 6.2 Introduction to Eco-industrial Park with Himin Solar System

The Himin eco-industrial park is located in Dezhou of Shandong Province at the longitude of 116°E and the latitude of 37.5°N with the annual average temperature at 12.9°C. With total area of 3,000,000m², Himin Eco-industrial Park has 50,000 employees and 1,000,000m² per year solar products including domestic solar thermal collectors, solar electricity equipments and energy saving glassed, whose production value is one hundred million USD per year.
The eco-industrial park is divided into two parts: one is workshop area and the other is living area. The workshop area is about 7,200m² contenting 1,150 workers. All the producing sections and commercial constructions are in this area. The living area includes 7,640m² living community with 179 families. The blueprint is shown at right.

The aim of this project is to replace the electricity or natural gas with solar energy. To achieve this target, the solar water heating system will be used in the workshop and the community buildings. On the other hand, the solar photovoltaic modules will provide the light electricity for the park.

In the community of the park, there will be the expert buildings, the employee relation buildings, the dormitory, the villas, the library, and indoor swimming pool etc. This is the eco-industrial park combined with science and technology, the architecture esthetics, the culture and environmental protection.
6.3 Calculating the Available Solar Energy for Himin Park during a Year

The efficiency of a solar heating system is directly connected to the available solar radiation at the specific location of the system. Due to the earth’s orbit around the sun and its rotation around its own axis, the solar radiation on the ground varies on a daily and on an hourly basis. The sunshine reaching the ground also depends on the weather; on clear and sunny days a solar heating system is able to absorb more energy than on cloudy days.

In this project, we used empirical predictive equations that link the values of solar radiation with other meteorological parameters whose values are known for the location under consideration to calculate the available solar radiation on the collectors for Himin Eco-industrial Park. The detailed solution for the calculation of available solar energy is shown in Appendix 1.

Table 6.1 The Input Data for Calculation

<table>
<thead>
<tr>
<th>Dezhou Coordinates</th>
<th>Collector’s Position</th>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude (L)</td>
<td>Tilt (β)</td>
<td>45°</td>
</tr>
<tr>
<td>Latitude (φ)</td>
<td>Rotation (γ)</td>
<td>0°</td>
</tr>
<tr>
<td>Altitude</td>
<td>Ground Albedo (ρ)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Note: 1. Rotation 0° of the collector means the front surface of the collector is directly towards the south.
2. Assuming the altitude of Dezhou is at the sea level.
3. Assuming the ground albedo is 0.2.

According to the input data, we calculated the total available solar radiation through a year. The result is 4992MJ/m²/year. Because the daylight varies during a year, the solar radiation is much more in summer than in winter. The result of calculation is shown in the following table and figure.

Table 6.2 The Available Solar Radiation During a Year.

<table>
<thead>
<tr>
<th>Month</th>
<th>Solar Energy [MJ/m²/month]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>265.52</td>
</tr>
<tr>
<td>February</td>
<td>284.24</td>
</tr>
<tr>
<td>March</td>
<td>379.27</td>
</tr>
<tr>
<td>April</td>
<td>420.06</td>
</tr>
<tr>
<td>May</td>
<td>467.89</td>
</tr>
<tr>
<td>June</td>
<td>541.11</td>
</tr>
<tr>
<td>July</td>
<td>555.23</td>
</tr>
<tr>
<td>August</td>
<td>537.68</td>
</tr>
<tr>
<td>September</td>
<td>484.86</td>
</tr>
<tr>
<td>October</td>
<td>447.10</td>
</tr>
<tr>
<td>November</td>
<td>363.49</td>
</tr>
<tr>
<td>December</td>
<td>245.46</td>
</tr>
<tr>
<td>Total</td>
<td>4991.90</td>
</tr>
</tbody>
</table>
As the figure 6.8 shows, the available solar energy varies during the year.

### 6.4 Energy Balance with the Solar Energy System

There are two parts in the Himin Eco-industrial Park; one is the workshop area and the other is the residential building area. The energy consumptions are different in these two parts. In this design, the solar energy will meet the requirement of the hot water at first.

#### 6.4.1 The Residential Building Area

In the residential building area, the energy consumptions consist of the electricity, the district heating system and the hot water. The residential building area is 7640m² with 179 families. The energy consumptions are shown in the table below;

<table>
<thead>
<tr>
<th>Energy Consumptions in Residential Buildings</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity for air cooling (COP=2.5)[kWh/year]</td>
<td>142104</td>
</tr>
<tr>
<td>Hot Water [kWh/year]</td>
<td>10696</td>
</tr>
<tr>
<td>District Heating [kWh/year]</td>
<td>65704</td>
</tr>
</tbody>
</table>

Note: These values are calculated based on the data that Himin Group provided.

In this project, the solar energy is the assistant energy recourse. With the efficiency of 50%~60% of the vacuum tube solar collectors, the solar heating water system will provide the hot water at 45°C and 70°C in winter. It can also provide the water at 90°C as the heating source for an absorption refrigeration cycle in summer. The absorption chiller operates in a temperature range of 80-120°C [15]. The reason we use the absorption chiller is that the absorption chiller can take use of the energy from the solar system and it can also save a lot of electricity compared to the electric chiller. The absorption chiller only requires some electricity for pumping. The theory of the absorption refrigeration cycle is shown in Appendix 2. So due to the available solar energy varies during the year and the heating water and the
air-cooling are only needed in winter and summer separately, the energy distribution should be decided.

### Table 6.4 The Energy Distribution in the Residential Building

<table>
<thead>
<tr>
<th>Month</th>
<th>Hot Water [kWh]</th>
<th>Heating [kWh]</th>
<th>Cooling [kWh]</th>
<th>Total [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>3562</td>
<td>218781</td>
<td>0</td>
<td>222342</td>
</tr>
<tr>
<td>Feb</td>
<td>4452</td>
<td>218781</td>
<td>0</td>
<td>223233</td>
</tr>
<tr>
<td>Mar</td>
<td>6233</td>
<td>0</td>
<td>0</td>
<td>6233</td>
</tr>
<tr>
<td>Apr</td>
<td>8904</td>
<td>0</td>
<td>0</td>
<td>8904</td>
</tr>
<tr>
<td>May</td>
<td>10685</td>
<td>0</td>
<td>0</td>
<td>10685</td>
</tr>
<tr>
<td>Jun</td>
<td>12465</td>
<td>0</td>
<td>0</td>
<td>12465</td>
</tr>
<tr>
<td>Jul</td>
<td>14246</td>
<td>0</td>
<td>118420</td>
<td>132666</td>
</tr>
<tr>
<td>Aug</td>
<td>13356</td>
<td>0</td>
<td>118420</td>
<td>131776</td>
</tr>
<tr>
<td>Sep</td>
<td>11575</td>
<td>0</td>
<td>118420</td>
<td>129995</td>
</tr>
<tr>
<td>Oct</td>
<td>10685</td>
<td>0</td>
<td>0</td>
<td>10685</td>
</tr>
<tr>
<td>Nov</td>
<td>7123</td>
<td>0</td>
<td>0</td>
<td>7123</td>
</tr>
<tr>
<td>Dec</td>
<td>3562</td>
<td>218781</td>
<td>0</td>
<td>222342</td>
</tr>
</tbody>
</table>

Note: 1. Assuming the months that need the heating service are January, February and December;
   2. Assuming the months that need the cooling service are July, August and September;
   3. The COP for the electricity air conditioning is 2.5;

In the residential buildings, the district heating is the largest part of energy consumption. And the requirement of hot water will vary during the year. The requirement in summer will be more than in winter because people need more hot water to shower in summer. From the table 6.4 we can see that the largest energy demand is in the winter, so to meet the total energy demand, the area of the solar collectors can be calculated. In order to use solar energy for the cooling demand, the absorption cooling system is needed. The table 6.5 shows the results:

### Table 6.5 The Energy Distribution in the Residential Building

<table>
<thead>
<tr>
<th>Month</th>
<th>Available [kWh]</th>
<th>Hot Water [kWh]</th>
<th>Heating [kWh]</th>
<th>Cooling [kWh]</th>
<th>Total [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>241727</td>
<td>3562</td>
<td>238165</td>
<td>0</td>
<td>222342</td>
</tr>
<tr>
<td>Feb</td>
<td>258770</td>
<td>4452</td>
<td>254318</td>
<td>0</td>
<td>223233</td>
</tr>
<tr>
<td>Mar</td>
<td>345288</td>
<td>6233</td>
<td>0</td>
<td>0</td>
<td>6233</td>
</tr>
<tr>
<td>Apr</td>
<td>382421</td>
<td>8904</td>
<td>0</td>
<td>0</td>
<td>8904</td>
</tr>
<tr>
<td>May</td>
<td>425967</td>
<td>10685</td>
<td>0</td>
<td>0</td>
<td>10685</td>
</tr>
<tr>
<td>Jun</td>
<td>492628</td>
<td>12465</td>
<td>0</td>
<td>0</td>
<td>12465</td>
</tr>
<tr>
<td>Jul</td>
<td>505487</td>
<td>14246</td>
<td>0</td>
<td>169171</td>
<td>132666</td>
</tr>
<tr>
<td>Aug</td>
<td>489507</td>
<td>13356</td>
<td>0</td>
<td>169171</td>
<td>131776</td>
</tr>
<tr>
<td>Sep</td>
<td>441415</td>
<td>11575</td>
<td>0</td>
<td>169171</td>
<td>129995</td>
</tr>
<tr>
<td>Oct</td>
<td>407042</td>
<td>10685</td>
<td>0</td>
<td>0</td>
<td>10685</td>
</tr>
<tr>
<td>Nov</td>
<td>330919</td>
<td>7123</td>
<td>0</td>
<td>0</td>
<td>7123</td>
</tr>
<tr>
<td>Dec</td>
<td>223471</td>
<td>3562</td>
<td>219910</td>
<td>0</td>
<td>222342</td>
</tr>
</tbody>
</table>
Note: 1, Assume the absorption chiller is single-effect machine. So the COP for the absorption cooling system is 0.7 [16];
2, The efficiency of the collectors is 55%.

In conclusion, from the figure shown above, it will save all of natural gas and electricity by using the solar energy comparing with that without solar energy in the residential buildings.

### 6.4.2 The Workshop Area

The production procedures of the solar thermal collector mainly include the molding section, the drying section, the plating section, the vacuum section and the seal section. The energy consumptions for each section are showed in the table 6.6. As we can see from the table, electricity is the main energy consumption in production processes, which is mainly consumed by driving engines and plating. Furthermore, the solar system can not provide the heating at the temperature above 100°C to meet the heating demand in the production process. So the solar energy is not good for the production process.

**Table 6.6 The Energy Consumptions in the Production Process**

<table>
<thead>
<tr>
<th></th>
<th>Molding Section</th>
<th>Drying Section</th>
<th>Plating Section</th>
<th>Vacuum Section</th>
<th>Seal Section</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8116.5</td>
</tr>
<tr>
<td>(kW)</td>
<td>38.3</td>
<td>431.9</td>
<td>4983.6</td>
<td>2615.0</td>
<td>47.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lighting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.7</td>
</tr>
<tr>
<td></td>
<td>10.8</td>
<td>2.9</td>
<td>8.2</td>
<td>18.0</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30.4</td>
</tr>
<tr>
<td>(M³/h)</td>
<td>29.6</td>
<td></td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

But there are still heating and cooling demands in the workshop area:

**Table 6.7 Energy Consumptions in Workshop Area**

<table>
<thead>
<tr>
<th>Energy Consumptions in Residential Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity for air cooling (COP=2.5)[kWh/year]</td>
</tr>
<tr>
<td>District Heating [kWh/year]</td>
</tr>
</tbody>
</table>

Note: These values are calculated based on the data that Himin Group provided.

So in the workshop area the main part of energy consumption is also the district heating and we assumed there was no hot water demand because people do not need to take shower at the working place and there are enough extra solar energy in the months except winter for the hot water demand.
So in the workshop area the district heating is also the main part of the energy consumption, and then according to this, the area of solar collectors for workshop can be calculated as:

**Table 6.8 The Energy Distribution in the Workshop Area**

<table>
<thead>
<tr>
<th>Month</th>
<th>Heating [kWh]</th>
<th>Cooling [kWh]</th>
<th>Total [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
<tr>
<td>Feb</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
<tr>
<td>Mar</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Apr</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Aug</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Sep</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Oct</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nov</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dec</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
</tbody>
</table>

So to use the solar energy to replace all the energy demand for the district heating, hot water and cooling in both residential building area and workshop area, the area of the solar collectors should be around 12000m².

**Table 6.9 The Energy Distribution in the Workshop Area**

<table>
<thead>
<tr>
<th>Month</th>
<th>Available [kWh]</th>
<th>Heating [kWh]</th>
<th>Cooling [kWh]</th>
<th>Total [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>259330</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
<tr>
<td>Feb</td>
<td>277614</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
<tr>
<td>Mar</td>
<td>370432</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Apr</td>
<td>410270</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>456987</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>528502</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>542297</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Aug</td>
<td>525155</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Sep</td>
<td>473560</td>
<td>0</td>
<td>111600</td>
<td>111600</td>
</tr>
<tr>
<td>Oct</td>
<td>436684</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nov</td>
<td>355018</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dec</td>
<td>239745</td>
<td>239745</td>
<td>0</td>
<td>239745</td>
</tr>
</tbody>
</table>

Note: 1. The COP for the absorption cooling system is 0.7; 2. The efficiency of the collectors is 55%.
7 Economical Evaluation

The target of this project is to build an eco-industrial park with very low energy consumption in China. So we mainly focus on the energy factor in the whole park system.

7.1 The Basic Data

The life span of the solar energy system that we used in this eco-industrial park is about 15 years. In China, the boilers that use the fossil fuel as the energy resource supply the district heat and hot water, and the life span of them is about 15 years.

Table 7.1 The Price of the Natural Gas and the Electricity.

<table>
<thead>
<tr>
<th></th>
<th>Natural Gas</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (RMB)</td>
<td>1.5 [RMB/m³]</td>
<td>0.54 [RMB/kWh]</td>
</tr>
<tr>
<td>Price (USD)</td>
<td>0.186 [$/m³]</td>
<td>0.067 [$/kWh]</td>
</tr>
</tbody>
</table>

Note: 1USD=8.07RMB

Table 7.2 The Investment of the equipment

<table>
<thead>
<tr>
<th></th>
<th>Boiler</th>
<th>Electric Air Conditioning</th>
<th>Solar Energy System</th>
<th>Absorption Air Conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (RMB)</td>
<td>5250[RMB/100m²]</td>
<td>300[RMB/m²]</td>
<td>1000[RMB/m²]</td>
<td>57% of electric chillers</td>
</tr>
<tr>
<td>Price (USD)</td>
<td>651[USD/100m²]</td>
<td>37[USD/m²]</td>
<td>124[USD/m²]</td>
<td>-</td>
</tr>
</tbody>
</table>

The depreciation of the equipment is the investment divided by the fix number of life span. The repairing cost is the depreciation multiplied by 2% (according to the experience). So for comparing the economics effect between the boiler and the solar energy, the investment and operational cost are calculated.

7.2 Comparison and Discussion

In order to know whether using the solar energy is a good choice or not, we need to compare these two cases:

Case 1:

This case is to use the natural gas to provide the heat for the park without the solar energy system. So in this case, the boiler should be built and the central air-conditioning with the electric compressor needed to be installed. Therefore, the investment includes the cost for buying and installing the equipment. The operating cost includes the cost of the natural gas, the electricity, the water and the cost of maintenance.
Table 7.3 The Investment and Yearly Cost for Case 1 (Unit: US$)

<table>
<thead>
<tr>
<th>Residential Buildings Without Solar Energy</th>
<th>Boiler</th>
<th>Air conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment 1</td>
<td>96,543</td>
<td>551,673</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>648,216</td>
</tr>
<tr>
<td>Operation cost per year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NG cost</td>
<td>27,584</td>
<td>0</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>2,874</td>
<td>18,470</td>
</tr>
<tr>
<td>Water cost</td>
<td>3,572</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2,758</td>
<td>736</td>
</tr>
<tr>
<td>Labor cost</td>
<td>2,391</td>
<td>0</td>
</tr>
<tr>
<td>Total cost per year</td>
<td></td>
<td>58,384</td>
</tr>
<tr>
<td>Cost in 15 years</td>
<td></td>
<td>1,523,977</td>
</tr>
</tbody>
</table>

Note: 1, the investment for the boiler includes the building, the equipment and the network construction.

Case 2:
The second case is to build 6000m² of solar collectors so that the solar energy can totally meet the energy requirement of the residential building area. So the investment only includes the solar energy system and the absorption air-conditions system.

Table 7.3 The Investment and Yearly Cost for Case 2 (Unit: US$)

<table>
<thead>
<tr>
<th>Residential buildings with 12000m² collectors</th>
<th>Collectors</th>
<th>Absorption air-condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>892,193</td>
<td>314,454</td>
</tr>
<tr>
<td>total</td>
<td>1,206,647</td>
<td></td>
</tr>
<tr>
<td>Operation cost per year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NG cost</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>0</td>
<td>1,521</td>
</tr>
<tr>
<td>Water cost</td>
<td>3,525</td>
<td>0</td>
</tr>
<tr>
<td>Repairing cost</td>
<td>1,190</td>
<td>419</td>
</tr>
<tr>
<td>Working cost</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total cost in 1 year</td>
<td>6,655</td>
<td></td>
</tr>
<tr>
<td>Cost in 15 years</td>
<td>1,306,472</td>
<td></td>
</tr>
</tbody>
</table>

Note: 1, the investment for the solar collectors is based on $124/m².

Normally, the cost for the absorption cooling system is much higher than the compression cooling system. But the major part of the cost for the absorption cooling system is the solar collectors; the percentage could be 88% of the total cost for the cooling system [17]. However, in China the solar collectors are very cheap than the other countries and in this project the company produces the solar collectors. So in this project we assume that the investment for the absorption air-condition is normally 60% of the investment for the air-conditioning with electric compressor.

So from the calculation above, the difference of these two cases can be found easily. In the case 2 too much area solar collectors is needed, and the investment is too big, although the
cost in 15 years is a little less than the case 1. Therefore, using the solar energy to cover all
the energy demand for district heating, hot water and cooling is not a good choice. So next we
will calculate how many solar collectors is the best. To find out how many collectors is the
best, the following figure is made according to calculation with different area.

First, the situation of residential buildings is analyzed; the following figures show the
difference of cost in 15 years with difference area of solar collectors. In this calculation, the
boiler and the electric air conditioning were included to cover the energy demand except the
part that was provided by the solar system.

![Figure 7.1, Cost in 15 Years with Different Area of Collectors in Residential Building](image)

![Figure 7.2, Energy Saved with Different Area of Collectors in the Residential Buildings](image)
From these two figures, it can be found that the best solution is to build about 2500m$^2$ of solar collectors. With 2500m$^2$ of solar collectors, the electricity for cooling in the summer can be totally saved, which means the absorption air conditioning is used to meet all the cooling demand. The investment and the operating cost per year are the lowest.

For the workshop area, the same calculation was done. The results are shown in the following figures.
In the workshop area the same thing happened, using the solar energy to cover the total energy demand for the cooling system is the best choice. From these two figures, it can be found that the best solution is to build about 2200m² of solar collectors.

For the workers, the solar energy system can bring them a lot of benefits. For instance, each family can pay less money for the electricity and the heat and pay less investment on the boiler and air conditioning equipment. And the environment of the living area is better.

### 7.3 The Final Results

In conclusion, it is better to use solar energy to cover the energy requirement for the hot water and cooling system. So the total area of solar collectors should be about 4700m². Then how much energy could be saved can be calculated. According to the table 7.1, the cost that will be saved by the NG and electricity reduction is 48974US$/year, so the payoff time for this industrial park with 4700m² of solar collectors will be around 13 years.

<table>
<thead>
<tr>
<th>Without solar system</th>
<th>With solar system of 4700m² collectors</th>
<th>Comparison, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment, [US$]</td>
<td>648,216</td>
<td>658,772</td>
</tr>
<tr>
<td>Total Cost in 15 years, [US$]</td>
<td>1,523,977</td>
<td>717,240</td>
</tr>
<tr>
<td>NG, [m³/year]</td>
<td>148400</td>
<td>81701</td>
</tr>
<tr>
<td>Electricity, [kWh/year]</td>
<td>318980</td>
<td>46023</td>
</tr>
<tr>
<td>CO₂ emission, [ton/year]</td>
<td>618</td>
<td>212</td>
</tr>
<tr>
<td>NOₓ emission [kg/year]</td>
<td>606</td>
<td>87</td>
</tr>
<tr>
<td>SO₂ emission [kg/year]</td>
<td>893</td>
<td>128</td>
</tr>
</tbody>
</table>

Note:
1. The electricity is bought from the coal based power plant;
2. According to the experience, the efficiency of power generation is about 33%;
3. The investment with 4700m² includes the combined boiler and the absorption cooling system.
8 Conclusion & Recommendation

To build an industrial park with very low energy consumption can benefit not only China but also the world. It is a good solution for China to solve the problems of energy crisis, and it can also reduce the green house gases emission, which will benefit the environment of the world.

As we analyzed above, there are two types of industrial Park that are suitable for China

1. Build an eco-industrial park by connecting the companies located in the park with the exchange network so that the ecology concept could be achieved;
2. Build an industrial park with an anchor company that dedicates to the renewable energy so that the target of decreasing the fossil fuel consumption and environmental impact could be achieved.

Comparing these two types of IP, the second one is easier to achieve because the most important and difficult problem is to build deep trust among the companies and the investment for the construction of exchange network is also a problem for the first type. Normally the investment will be provided by the local government. But for the second type, the anchor company can provide the technology and finance support for the eco-industrial park. At the same time, the company can also apply for the finance support from the government because this industrial park is a good sustainable solution for China’s circular economics. Furthermore, Himin Group is a great company whose main production is the solar energy system in China, which is another advantage to build the IP with renewable energy as one of the energy recourse.

In this project, the solar energy is the main energy resource for hot water, district heating and air-cooling in the park. The photovoltaic products are used as the road lamp and the light resource in the workshop. So the company can save the spending on the natural gas and electricity. At the same time, using solar energy as the energy resource reduces CO2 emission.

As discussed above, the advantages of IP with solar energy are:
- IPs using solar energy as the energy resource are easier to achieve than building IPs with the exchange network based on the ecology;
- By integration of boiler and solar energy, natural gas can be reduced by 45%, and 86% electricity can be saved;
- At the same time, the total cost can be saved 53% and CO2 emission can be reduced by 57%, NOx and SOx emission can be reduced by 86%.
- Less operating cost;

However, there are still some disadvantages:
- The technology of solar energy cannot meet the requirement of energy demand of production process;
- A large area is needed for collecting enough solar radiation;

The recommendation:
- It is better to use solar energy for the hot water and cooling system.

In conclusion, the eco-industrial park using the solar energy as the energy resource is a good choice for China’s sustainable development for the future.
9 Reference List


Appendix 1

Solar Irradiation Calculation on the Collector in the Himing Park

In order to know how much energy we can save by using solar energy, the irradiation from the sun per year should be calculated according to the position of park and the climate. To decide how much heat the collector can absorb, we need to know the variation of the average solar irradiation on the collector over a year. This is calculated by first estimating the hourly radiation flux on the collector for the mean day of month (see table 1.1) and then multiply the daily total radiation (the sum of all hours) by the number of days in that month.

<table>
<thead>
<tr>
<th>Month</th>
<th>Day of Month</th>
<th>For the Average Day of the Month</th>
<th>n, Day of Year</th>
<th>δ, Declination</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>i</td>
<td>17</td>
<td>17</td>
<td>-20.9</td>
</tr>
<tr>
<td>February</td>
<td>31 + i</td>
<td>16</td>
<td>47</td>
<td>-13.0</td>
</tr>
<tr>
<td>March</td>
<td>50 + i</td>
<td>16</td>
<td>75</td>
<td>-2.4</td>
</tr>
<tr>
<td>April</td>
<td>90 + i</td>
<td>15</td>
<td>105</td>
<td>9.4</td>
</tr>
<tr>
<td>May</td>
<td>120 + i</td>
<td>15</td>
<td>135</td>
<td>18.8</td>
</tr>
<tr>
<td>June</td>
<td>151 + i</td>
<td>11</td>
<td>162</td>
<td>23.1</td>
</tr>
<tr>
<td>July</td>
<td>181 + i</td>
<td>17</td>
<td>198</td>
<td>21.2</td>
</tr>
<tr>
<td>August</td>
<td>212 + i</td>
<td>16</td>
<td>228</td>
<td>13.5</td>
</tr>
<tr>
<td>September</td>
<td>243 + i</td>
<td>15</td>
<td>258</td>
<td>2.2</td>
</tr>
<tr>
<td>October</td>
<td>273 + i</td>
<td>15</td>
<td>288</td>
<td>-9.6</td>
</tr>
<tr>
<td>November</td>
<td>304 + i</td>
<td>14</td>
<td>318</td>
<td>-18.9</td>
</tr>
<tr>
<td>December</td>
<td>334 + i</td>
<td>10</td>
<td>344</td>
<td>-23.0</td>
</tr>
</tbody>
</table>

Table 1.1 Day numbers and standard mean day of the month

The extraterrestrial radiation flux, $G_{0n}$, measured on a plane normal to the radiation on the n$^{th}$ day of the year is given in terms solar constant as follows:

$$G_{0n} = G_{sc} (1 + 0.033 \cdot \cos \frac{360n}{365}) \tag{1.1}$$

$G_{sc}$ — Solar Constant: The solar constant means the solar irradiance falling on the atmosphere, and it is defined as the energy from the sun, per unit time, at the earth’s mean distance from the sun. The value of the solar constant is 1367 W/m$^2$, based on the recent measurement from space.

Calculating the declination angle $\delta$

The declination is the angle between the line joining the centers of the sun and the earth and it's projection on the equatorial plane at solar noon (Figure 1.1). The declination angle is due to the rotation of the earth about an axis that makes an angle of 66.55° 2 with the plane of rotation (which means that its axis is inclined at an angle of 23.45° from an “upright” position). It is because of this axis tilt that the day length changes over the year.
Calculating Local Solar Time

The solar time is based on the apparent angular motion of the sun across the sky, with solar noon denoting the time the sun crosses the meridian of the observer. The difference in minutes between solar time and standard time is:

\[
\text{SolarTime-StandardTime} = 4(L_{st} - L_{loc}) + E
\]  

(1.3)

Where \( L_{st} \) is the standard meridian for the local time zone (for China this is 120°), \( L_{loc} \) is the longitude of the location in question and the equation of time (in minutes) is given as:

\[
E = 229.2 - (0.000075 + 0.001868 \cos 0.032077 \sin 2 + 0.04089 \sin 2) 
\]  

(1.4)

Where \( B = (n-1) \frac{360}{365} \)

The hour angle is then calculated as:

\[
\omega = 15(SolarTime - 12)
\]  

(1.5)

The hour angle \( \omega \) is an angular measure of time and varies by 15° per hour from -180° directly after midnight to +180° just before next midnight.

Angle of Incidence \( \theta \)

By using the computed position angles from the above expressions, the angle of incidence, \( \theta \), between the incident sun beam and the surface normal may now be estimated. The general expression for solar radiation falling on a surface of tilt \( \beta \), and azimuth \( \gamma \) on the latitude \( \phi \) and during a time when the declination is \( \delta \) and the hour angle is \( \omega \), is:

\[
\cos \theta = \sin \delta \cdot \sin \phi \cdot \cos \beta - \sin \delta \cdot \cos \phi \cdot \sin \beta \cdot \cos \gamma + \cos \delta \cdot \cos \phi \cdot \cos \beta \cdot \cos \omega + \cos \delta \cdot \sin \phi \cdot \sin \beta \cdot \cos \gamma \cdot \cos \omega + \cos \delta \cdot \sin \beta \cdot \sin \gamma \cdot \sin \omega
\]  

(1.6)
Then calculating the zenith angle $\theta_z$. This angle varies between 0° and 90°. When the zenith angle is outside these boundaries, this means that the sun is below the horizon, and hence there is no solar radiation on the location. The zenith angle is the angle of incidence of sunbeam on a horizontal surface. It can be calculated by:

$$\cos \theta_z = \cos \phi \cdot \cos \delta \cdot \cos \omega + \sin \phi \cdot \sin \delta$$  \hspace{1cm} (1.7)

**Total Radiation on a Horizontal Surface**

Firstly we need to estimate the hourly clearness index, $K_T$, by using the mean cloudiness, $C$, in each month that can be obtained from the weather bureau or some related units.

$$K_T = 0.803 - \frac{(0.916 \cdot C + 0.34)^2 - 0.34^2}{1.832}$$  \hspace{1cm} (1.8)

This is an empirical correlation and the mean cloudiness is defined as the part of sky covered by cloud, its range is between 0% and 80%.

Calculating the total hourly radiation, $I$, from the extraterrestrial radiation and $K_T$. At any day the solar radiation incident on a horizontal plane in each hour outside the atmosphere is:

$$G_0 = G_{0a} \cdot \cos \theta_z$$  \hspace{1cm} (1.9)

And then

$$I = G_0 \cdot K_T$$  \hspace{1cm} (1.10)

The total hourly radiation, $I$, includes the direct beam radiation from the sun that is decided by the geometrical problem and the diffuse radiation, $I_d$, that comes from some part of the sky dome other than the sun. Hence we need to calculate the diffuse radiation from the sky dome. Here, we will assume that the diffuse radiation is evenly distributed all the sky (“isotropic sky”). For hourly globe radiation data, the usual approach for finding the beam and diffuse fraction of the radiation is to correlate $I_d/I$ with $K_T$:

$$\frac{I_d}{I} = \begin{cases} 
1.0 - 0.09k_T & \text{for } k_T \leq 0.22 \\
0.9511 - 0.1604k_T + 4.388k_T^2 & \text{for } 0.22 \leq k_T \leq 0.80 \\
-16.638k_T^3 + 12.336k_T^4 & \text{for } 0.80 \leq k_T \\
0.165 & \text{for } k_T \geq 0.8 
\end{cases}$$  \hspace{1cm} (1.11)

And then according to this ratio and total hourly radiation, $I$, we can get the value of the diffuse radiation $I_d$. So the beam radiation, $I_b$, that comes directly from the sum is:

$$I_b = I - I_d$$  \hspace{1cm} (1.12)

**Radiation on Sloped Surfaces**

The total radiation on a tilted surface is the sum of the incident beam and diffuse radiation and the part of the solar radiation that is diffusely reflected from the ground onto the surface.

*Beam Radiation on a Tilted Surface*
The beam component of the radiation on a tilted surface can be calculated directly if the angle of incidence, $\theta$, is known. The ratio $R_b$ is used for determining the fraction of the total horizontal radiation that is incident on the surface, and is defined as:

$$R_b = \frac{I_T}{I} = \frac{I_a \cdot \cos \theta}{I_a \cdot \cos \theta_T} = \frac{\cos \theta}{\cos \theta_T}$$  \hspace{1cm} (1.13)

Here, the subscript $T$ denotes Tilted surface. The beam contribution of the total radiation on the tilted surface is hence $I_b \cdot R_b$.

**Diffuse Radiation on a Tilted Surface**

When estimating the fraction of the diffuse radiation that is incident on a tilted surface, the diffuse radiation from the sky is assumed being distributed uniformly over the hemisphere. Under this assumption, it can then be shown that the fraction of this radiation on a surface with a tilt of $\beta^\circ$ from the horizontal plane is $(1+\cos \beta)/2$.

**Ground-Reflected Radiation Received by a Tilted Surface**

As the global radiation hits the ground, some of it is reflected out to the sky in all directions. The reflectance of the ground is also called albedo. The earth’s mean reflectance is about 0.3, which means that 30% of the incoming solar radiation is reflected. More exact data on the ground reflectance is given in the table below:

<table>
<thead>
<tr>
<th>Vegetation / Ground cover</th>
<th>Albedo, $\rho_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>0.05-0.20</td>
</tr>
<tr>
<td>Field</td>
<td>0.15-0.25</td>
</tr>
<tr>
<td>Mud</td>
<td>0.20-0.35</td>
</tr>
<tr>
<td>Water</td>
<td>0.21</td>
</tr>
<tr>
<td>Snow</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The fraction of the ground reflected radiation that is incident on a tilted surface is $(1-\cos \beta)/2$.

**Total Radiation on a Tilted Surface**

When the fraction of the beam, diffuse and reflected radiation has been calculated, the total hourly radiation incident on the tilted surface and be calculated as:

$$I_T = I_b \cdot R_b + I_d \cdot \left(\frac{1+\cos \beta}{2}\right) + I \cdot \rho_g \cdot \left(\frac{1-\cos \beta}{2}\right)$$  \hspace{1cm} (1.14)

Sum the hourly radiation over the day. This is the monthly mean radiation per square meter and day, $H_{Tm}$ [Wh/m$^2$.day]. Then multiply $H_{Tm}$ with the number of the days in each month, we can get the total solar radiation in each month.
Appendix 2

Refrigeration Cycle Descriptions

The basic cooling cycle is the same for the absorption and electric chillers. Both systems use a low-temperature liquid refrigerant that absorbs heat from the water to be cooled and converts to a vapor phase (in the evaporator section). The refrigerant vapors are then compressed to a higher pressure (by a compressor or a generator), converted back into a liquid by rejecting heat to the external surroundings (in the condenser section), and then expanded to a low-pressure mixture of liquid and vapor (in the expander section) that goes back to the evaporator section and the cycle is repeated.

The basic difference between the electric chillers and absorption chillers is that an electric chiller uses an electric motor for operating a compressor used for raising the pressure of refrigerant vapors and an absorption chiller uses heat for compressing refrigerant vapors to a high-pressure.

The basic absorption cycle employs two fluids, the absorbate or refrigerant, and the absorbent. The most commonly fluids are water as the refrigerant and lithium bromide as the absorbent. These fluids are separated and recombined in the absorption cycle. In the absorption cycle the low-pressure refrigerant vapor is absorbed into the absorbent releasing a large amount of heat. The liquid refrigerant/absorbent solution is pumped to a high-operating pressure generator using significantly less electricity than that for compressing the refrigerant for an electric chiller. Heat is added at the high-pressure generator from a gas burner, steam, hot water or hot gases. The added heat causes the refrigerant to desorb from the absorbent and vaporize. The vapors flow to a condenser, where heat is rejected and condense to a high-pressure liquid. The liquid is then throttled through an expansion valve to the lower pressure in the evaporator where it evaporates by absorbing heat and provides useful cooling. The remaining liquid
absorbent, in the generator passes through a valve, where its pressure is reduced, and then is recombined with the low-pressure refrigerant vapors returning from the evaporator so the cycle can be repeated.
Appendix 3

Case Review: The Symbiosis Institute at Kalundborg in Denmark

The example of Kalundborg in Denmark strictly speaking is an example of an industrial network, and not an industrial estate. However, as a case study it is an excellent illustration of the application of an Industrial Ecology approach and is certainly relevant to an industrial estate. The example of Kalundborg is often quoted in the literature, perhaps because it is simple enough to allow the idea of an industrial ecosystem to be appreciated and yet sufficiently sophisticated to give a feeling for the enormous potential of this approach.

2.1 The History of Kalundborg EIPs

The history of Kalundborg really began in 1961 with a project to use surface water from Lake Tissø for a new oil refinery in order to save the limited supplies of ground water (Christensen, 1999). The city of Kalundborg took the responsibility for building the pipeline while the refinery financed it. Starting from this initial collaboration, a number of other collaborative projects were subsequently introduced and the number of partners gradually increased. By the end of the 1980's, the partners realized that they had effectively "self-organized" into what is probably the best-known example of a working industrial ecosystem, or to use their term - an industrial symbiosis.

2.2 Industrial Symbiosis

Symbiosis means co-existence between diverse organisms in which each may benefit from the other. In this context, the term is applied about the industrial co-operation taking place in Kalundborg between a number of companies and Kalundborg Municipality, all of which exploit each other’s residual or by-products mutually.

The Symbiosis co-operation has developed spontaneously over a number of decades and today comprises some 20 projects. The exchange of residual products between the companies is laid out in the diagram.

![Figure 5: Material and Energy Flows in the Kalundborg Industrial Ecosystem](http://www.symbiosis.dk/)
The Industrial Symbiosis of Kalundborg is built as a network co-operation between six processing companies, one waste handling company and the Municipality of Kalundborg.

The philosophy behind the Symbiosis is that the six companies: **Energy E2** Asnæs Power Station, the plasterboard factory **BPB Gyproc A/S**, the pharmaceutical plant **Novo Nordisk A/S**, the enzyme producer **Novozymes A/S**, the oil refinery **Statoil A/S**, **Bioteknisk Jordrens Soilrem A/S** as well as the waste company **Noveren I/S** and **Kalundborg Municipality** - exploit each other's residual or by-products on a commercial basis.

One company's by-product becomes an important resource to one or several of the other companies. The outcome is reduced consumption of resources and a significant reduction in environmental strain.

The collaborating partners also benefit financially from the co-operation because the individual agreement within the Symbiosis is based on commercial principles.

### 2.3 Exchange of Resources

#### Steam and Heat

Asnæs Power Station produces heat for the city of Kalundborg and process steam for the Statoil Refinery, Novo Nordisk A/S and for Novozymes A/S. The combination of heat and power production results in a 30% improvement of fuel utilization compared to a separate production of heat and power.

Approximately 4,500 households in Kalundborg receive district heat from Asnæs Power Station. District heat has replaced approx. 3,500 small oil-fired units.

Statoil Refinery receives process steam and water from Asnæs Power Station. The steam covers about 15% of the refinery’s total consumption of steam. The refinery uses the steam for heating oil tanks, pipelines etc. Novozymes A/S and Novo Nordisk A/S use steam from Asnæs Power Station for the heating and sterilization of the processing plants.

Some of the cooling water from Asnæs Power Station is used by a fish farm producing 200 tones of trout and salmon on a yearly basis. The fish have better growth conditions in the heated water.

#### Water

The Kalundborg Region as well as the industrial companies is large consumers of water. This is why the Symbiosis companies are seeking to recycle as much water as possible. Asnæs Power Station has, for example, reduced its total water consumption by 60%. Previously Asnæs Power Station used ground water for its power and heat production only. The ground water has now been substituted by surface water from the lake of Tisso and treated wastewater from Statoil. These efforts have enabled Asnæs Power Station to reduce its ground water consumption by 90%. Earlier, Novozymes A/S also used ground water exclusively for processes requiring drinking water quality. 1 million cubic metres of ground water have now been substituted by lake water from Tissø whose water has been processed up to drinking water quality by Kalundborg Municipality.
As the water from Tissø is not an unlimited resource, the consumption of lake water has gone down by 50%. Asnæs Power Station has accomplished this reduction by recycling its own wastewater.

**Wastewater**
The wastewater is led to a recycling reservoir together with the runoff from the surrounding fields and surplus water from Tissø in the winter period. The recycling reservoir has a capacity of 220,000 cubic metres of water, which are used in the power station processes.

The wastewater from Novozymes A/S and Novo Nordisk A/S is part of a genuinely symbiotic relationship: Novozymes A/S treats all wastewater up to a level corresponding to the wastewater of an ordinary household. From Novozymes A/S, the treated wastewater is pumped to the treatment plant of Kalundborg Municipality where a final treatment process takes place.

The Novozymes A/S wastewater is of a relatively high temperature making it easier for the municipal treatment plant to treat its wastewater. In this collaboration process, the environment is also the winner as the overall discharge of nitrogen into Jammerland Bugt is very limited. Wastewater is also discharged from Asnæs Power Station into the treatment plant of Kalundborg Municipality.

**Refinery Gas**
An “eternal” flare of surplus gas is part of the safety system in any refinery. Statoil's refinery flare has been reduced to a mere night-light, because the refinery now exploits its own surplus gas internally. Formerly a large portion of the gas was transported by pipeline to BPB Gyproc and Asnæs Power Station to be used in their production.

**Gypsum**
The desulphurization plant of Asnæs Power Station, which removes sulphur dioxide (SO2) from the flue gas, produces about 200,000 tones of gypsum on a yearly basis. Desulphurization is a chemical process in which sulphur dioxide (SO2) is removed while forming the by-product gypsum. The gypsum is sold to BPB Gyproc A/S, a company that manufactures plasterboard products for the construction industry. The gypsum from the power station reduces the import of natural gypsum significantly. Being more uniform and purer than natural gypsum, power station gypsum is therefore well suited for the plasterboard production.

Gypsum stemming from the municipal recycling station of Kalundborg is delivered to BPB Gyproc A/S, thereby contributing - on a smaller scale - to reducing imports of natural gypsum and the amounts of solid waste for land filling.

**Sludge**
Sludge is a major residual product stemming from the municipal water treatment plant in Kalundborg. The sludge is utilized at A/S Bioteknisk Jordrens Soilrem as a nutrient in the bioremediation process. In this way, a waste product from one process is applied as a useful resource in another process.

**Other Waste**
Noveren I/S collects waste from all Symbiosis companies. Waste that is an integral part of various processes. In return, the participating companies receive raw materials. Noveren I/S
produces electricity on the basis of landfill gas. This electricity is resold to power companies. In addition, Noveren I/S delivers a total of approx. 56,000 tones of combustible waste on a yearly basis corresponding to an energy consumption of approx. 6,500 private households in terms of power and district heating.

24 Profits

Such an approach can lead to a significant reduction in the environmental impact, as is shown in Table 1 (Erkman, 1998):

<table>
<thead>
<tr>
<th>Reduction in consumption of resources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>45,000 tons/year</td>
</tr>
<tr>
<td>Coal</td>
<td>15,000 tons/year</td>
</tr>
<tr>
<td>Water</td>
<td>600,000 m³/year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reduction in waste emissions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>175,000 tons/year</td>
</tr>
<tr>
<td>Sulfur Dioxide (SO₂)</td>
<td>10,200 tons/year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Valorisation of &quot;wastes&quot;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>4,500 tons/year</td>
</tr>
<tr>
<td>Calcium sulfate (gypsum)</td>
<td>90,000 tons/year</td>
</tr>
<tr>
<td>Fly ash (for cement etc)</td>
<td>130,000 tons/year</td>
</tr>
</tbody>
</table>

Table 1: Environmental Aspects of the Symbiosis [Erkman, 1998].

On the other hand, this symbiosis also reduced the cost. Each exchange is based on a separate contract between the two partners involved, revenues can be estimated as coming from selling the waste material and from reduced costs for resources. The partners estimate that they have "saved" $160 million so far (Christensen, 1999). The payback time of a project is less than 5 years on average. Therefore, a more rational utilization of resources can save money.

2.5 Conclusion

According to the analysis above, we can find a number of advantages from the symbiosis that is used in the EIP of Kalundborg.

- Recycling by-products. The by-products from one company become the resource of another company;
- Reduced the consumption of resources, e.g. water, coal, oil, gypsum, fertilizer etc.;
- Reduced the environmental strain. Reduced CO₂ and SO₂ emission, reduced discharges of wastewater and less pollution of wastewater etc.;
- Improved utilization of the energy resources. Waste gases are used in the energy production;
- Reduced the investment cost and shorten the payback time.

On the other hand, the symbiosis still has one disadvantage that in such a carefully planned and integrated industrial system the individual parts would be too closely linked and dependent on each other, rendering it fragile and hence likely to collapse.
Appendix 4
Case Review: Dyfi Valley Community Renewable Energy Project in UK

3.1 Introduction
This project is located in Dyfi Valley, near Machynlleth, mid Wales of United Kingdom. The aim of this project that was supported by several organizations is to enable the local people to carry out small-scale schemes using various renewable energy technologies.

The project began in earnest in June 1998. The initial funding was for three years and the elements of it have been extended until 2002. The Dyfi Eco Valley Partnership that is a company limited by guarantee managed the project. It was created by Powys and Gwynedd county councils, Dulas Ltd (a leading specialist renewable energy company based in Machynlleth), the Centre for Alternative Technology, the Welsh Development Agency and Snowdonia National Park. It has drawn in other partners and local people in becoming the sustainable community regeneration body for the area. It is now managed by a board of local people.

For the fund, the European Commission provided 35% of the funding from the European Regional Development Fund through the Objective 5b structural funding program. The Welsh Development Agency, Powys County Council, Dulas Ltd and the Shell Better Britain Campaign all contributed. Investments by local private sector participants/owners in individual schemes counted as part of the matching funding for the EC support. Ceredigion County Council and Cymad (a regeneration body for Gwynedd) provided additional funding for feasibility studies.
3.2 The Aim and Achievement of the Project

The Dyfi Valley Community Renewable Energy project aims to benefit the community’s 12,500 or so resident by encouraging the local people to engage with energy issue, establishing some community-based renewable energy installation. Furthermore, the project wanted to improve understanding and support for renewable energy by maximizing the local benefits.

The total installed capacity of completed renewable energy schemes was 205 kW electrical capacity (hydro, wind, solar) and 150 kW heat capacity (solar, wood, heat pump).

Schemes completed to date include:

- A 120kW grid-connected hydro-electric unit, installed by a farmer;
- Three 800–1000W (domestic) solar electric installations, one of which powers a ground-source heat pump;
- A 1.4kW solar electric array at Dyfi Eco Park;
- Two 690W solar electric arrays at schools;
- 124m² solar thermal array, plus heat transfer main installed at the Center for Alternative Technology;
- Two domestic wood stove/solar water heating systems;
- 10 solar hot water systems installed by Solar Club members.

3.3 Benefits

The benefits from this project spread through the local economy and community through the following means:

- Reduced expenditure on the energy supplied from outside the community keeps more money circulating in the local economy;
- Equipment supply, technical support, civil engineering and maintenance was supplied commercially from local SMEs or solar traders;
- Each scheme contributes to the credibility of a green local economy whose existence can be promoted and replicated elsewhere, again drawing on local SME services. Reduced consumption of fossil fuels reduces emissions of carbon dioxide, alleviating globe climate change;
◆ One job has been created directly from this project and a further 8 job safeguarded.

Many people in the community are now more aware of the economic and environmental implications of energy use and this influences their behavior in subtle way, from being more careful to switch off unused electrical to use public transport.
Appendix 5
Case Review: The Guitang Group and Guigang Eco-Industrial City

China produces 10.5 million tons of sugar annually from 539 sugar industries, the majority from sugar cane. Over the last few years, the sugar industry in China has experienced a significant economic decline. This industry has to increase its productivity to remain competitive with Brazil, Thailand, and Australia, three major sugar-producing countries. Low prices for sugar on world markets in recent decades have eliminated the industry in former leading countries, including Hawaii and Puerto Rico in the US. Sugar production is becoming much less competitive in the Philippines.

The Guangxi Zhuang Autonomonous Region, in the far south of China, is the largest source of sugar, producing more than 40% of the national output. The cost of producing sugar is high in Guangxi. Most farmers have small landholdings, productivity is low, and sugar content of the canes is low. Most refineries are smaller scale and fail to utilize their by-products. This gap causes them to lose secondary revenues and generate high levels of emissions to air, water, and land. The farmers burn the cane leaves every harvest season, generating air emissions. Ning Duan estimates that there are 70,000 families growing sugar in the Region and that there are 100 sugar mills. The economy of the town of Guigang is 50% dependent upon sugar related industries. (Duan 2001)

The Guitang Group is a state-owned enterprise formed in 1954 that operates China’s largest sugar refinery, with over 3800 workers. The Group owns 14,700 ha’s land for growing cane. Though the sugar industry in China is generally responsible for high levels of emissions, this company has created a cluster of companies in Guigang to reuse its by-products and thereby reduce its pollution. The complex includes: an alcohol plant, pulp and paper plant, toilet paper plant, calcium carbonate plant, cement plant, power plant, and other affiliated units. The goal of the initiative is “to reduce pollution and disposal costs and to seek more revenues by utilizing by-products.” (Duan 2001 and The Guitang Sugarcane Eco-Industrial Park Project website) The following chart shows the present flows of materials and water.

Based on Duan 2001
Duan identifies in this chart two primary eco-chains that Guitang has established, each of which has additional members and some internal feedback loops.

The output of the Guitang complex of companies is: 120,000 tons of sugar, 85,000 tons of paper, 10,000 tons of alcohol, 330,000 tons of cement, 25,000 tons of calcium carbonate, 30,000 tons of fertilizer, and 8,000 tons of alkali per year. In the late 1990s the secondary products accounted for 40% of company revenues and nearly as large a portion of profits and taxes paid.

The Guitang Group’s plans for the future include expansions of the industrial ecosystem and changes in processes at various stages. This innovative plan includes:

- Construct a new beef and dairy farm using dried sugarcane leaves as feed.
- Construct a milk-processing factory to make fresh milk, milk powder and yogurt for the local market.
- Construct a beef-packing house to process beef, oxhide, and bone glue.
- Build a biochemical plant to make amino acid based nutrition products and other bio-products using the byproducts from the beef packing house.
- Develop a mushroom growing company—using manure from the new dairy and beef farm.
- Process residue from the mushroom base to use on sugarcane fields as natural fertilizer.

China’s expected entry into the World Trade Organization poses a major threat to the economy of Guangxi. With barriers to lower-priced imports lowered, the economy of this Region could be injured profoundly. So Guitang Group’s eco-industrial initiative has strategic importance for this and other sugar producing regions in China.

**City of Guigang Plans to Become an Eco-Industrial City**

The Group’s example has inspired the town of Guigang to adopt a five year plan to become an Eco-Industrial City. The heavy dependence of its economy on the sugar industry makes it important to improve the efficiency of its many processing plants. The plan calls for smaller sugar producers to send their by-products to Guitang’s eco-industrial complex and sets targets for high by-product utilization. (Targets for the city: “utilization of sugarcane slag reaches more than 80%, use of spent sugar-juice reaches 100%, use of spent alcohol reaches 100%.”) The plan also calls for consolidation of cane growing land into larger holdings. (It will require a transition for small farmers into other crops or into industrial employment.) It includes training of industry and government managers in eco-industrial principles and methods and broader dissemination of Cleaner Production strategies. Some of the long-term goals of this plan are:

- Develop an eco-sugar cane park to enable planting of organic cane, increases in sugar content of canes, increase in production per mu of land, and extend the harvest period.
- Enlarge the paper mill with a goal of increasing production to 300,000 tons per year in 3 phases.
- Switch some production from sugar to fructose, which has a strong market.
- Build a facility to produce fuel alcohol from spent sugar juice and sugar (capacity 200,000 tons per year). This product will help reduce air pollution from vehicle exhaust.
- Adopt low chlorine technology to bleach pulp. Paper made by this technology will be much whiter than the paper made by traditional technologies. (The Guitang Sugarcane Eco-Industrial Park Project website)

Guitang and the leadership of the town are supported by China’s State Environmental Protection Bureau (SEPA) and the China National Cleaner Production Center (CNCPC). Ning Duan, Deputy President of the Chinese Research Academy of Environmental Sciences, has been a key advisor to the Guitang Group. Financing is from the financial bureau of Guigang City. The local tax administration will return 50% of the agriculture tax to construction of irrigation systems for sugarcane farms.