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Research article

Building green supply chains in eco-industrial parks towards a green economy: Barriers and strategies

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A B S T R A C T

As suggested by UNEP, the key to sustainable development is to create a “green economy” which should encapsulate all three sectors: the industry, the people, and the government. Therefore, there is an urgent need to develop and implement the green technologies into the existing facilities, especially in the developing countries. In this study, the role of green supply chains in eco-industrial parks (EIPs) towards a green economy was investigated. The strategies and effective evaluation procedures of the green economy were proposed by assessing the barriers from the perspective of institution, regulation, technology, and finance. In addition, three case studies from iron and steel-making, paper mill and pulping, and petrochemical industries were presented and illustrated for building the green supply chains. For example, in the case of Lin-Hai Industrial Park, a total of 15 efficient green supply chains using waste-to-resources technologies were established by 2012, resulting in an economic benefit of USD 100 million per year. It suggests that the green supply chains should be established to achieve both economic growth and environmental protection. With these successful experiences, building a green supply chain within industrial park should be extensively promoted to make traditional industries around the world being environmentally bearable, economic viable, and social equitable.

1. Introduction

The negative impacts of human activity on the environment have long been known; from the depletion of the ozone layer, to the destruction of various ecosystems, even to the formation of increasingly severe weather phenomena, human activity has impacted nearly every aspect of the environment. In response to climate change, several key challenges of the 21st century were identified, such as protection of the population against natural hazards, mitigation of and adaptation to global warming, and optimization of water/energy/food nexus. To prevent such destructive consequences, individuals and groups have taken concerted efforts to protect the environment beginning as early as the twentieth century. However, a major setback to the environmental protection movement is the common misconception that protecting the environment necessitates a slowdown of economic development. For example, those opposed to extensive environmental protection measures may argue that creating the national parks prevents the development of land and efforts to scale back on greenhouse gas emissions prevents industrial growth (Buckley and Carney, 2013). In recent years, international organizations such as the United Nations Environment Programme (UNEP) have moved to dispel such misconceptions by promoting a movement towards sustainable development.

Fig. 1 shows the history of important international movements towards a sustainable development and green economy. In 2009, the Global Green New Deal, released by the United Nations Department of Economic and Social Affairs (UNDESA) (UNDESA, 2009), presented a global strategy for attaining a green economy that involves a mixture of public investments and new policies. In 2011, there had been much discussion regarding the necessity of a green economy, and methods for obtaining one in recent international meetings and publications. According to UNEP (UNEP, 2011), a green economy could encapsulate all industries, people and

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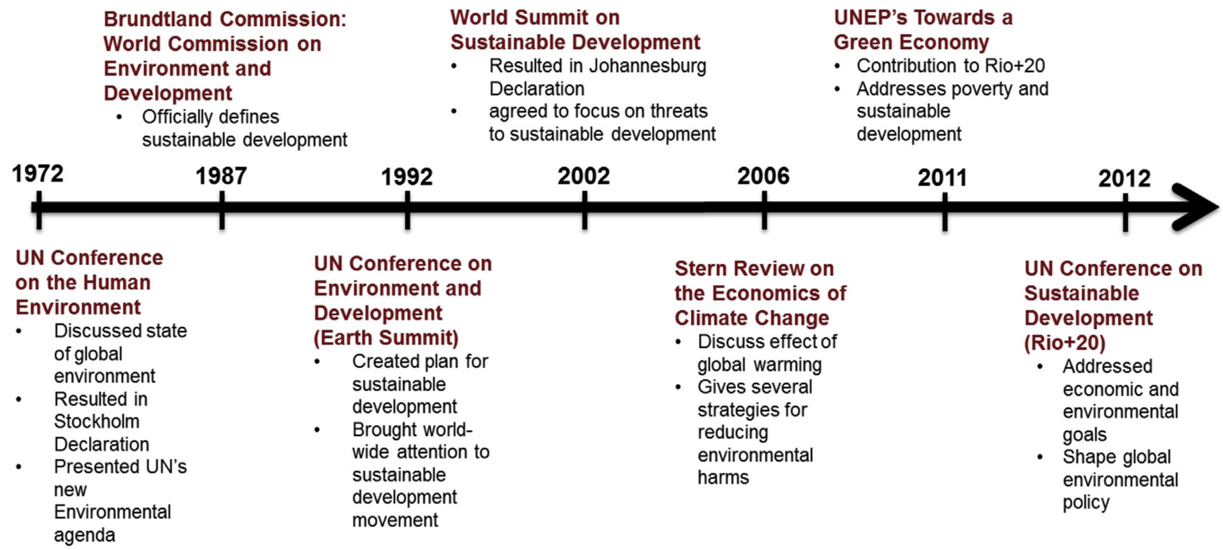

Fig. 1. Important international movement on the sustainable development and green economy.

governments, and result in "improving human well-being and social equity, while significantly reducing environmental risks and ecological scarcities". Moreover, it can support the development of technology and infrastructure that "reduces carbon dependency, promotes resource and energy efficiency, and lessens environmental degradation" (UNEP, 2011). The standard of excessive consumption is problematic as it necessitates a trade-off between economic development and environmental sustainability. However, with sustainable development, such a trade-off becomes unnecessary. Sustainable development, as defined by the World Commission on Environment and Development (WCED), is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNEP, 2012b).

Sustainable development allows for the goals established at the 1992 Earth Summit and reaffirmed at the 2012 United Nations Conference on Sustainable Development (Rio 2012) to be realized. The achievements of the "Rio+20 Summit" held on June 2012 include: (1) "Future We Want" outcome document, (2) sustainable development goals (SDGs), (3) high-level political forum on sustainable development (HLPF), (4) strengthened UNEP, (5) civil society participation and commitments, and (6) green economy. In addition, the Rio+20 passed responsibility of the "Post-2015 Dev Agenda" to two bodies: (1) UNEP Governing Council and (2) UN General Assembly. The thematic consultations of the Post-2015 process include inequalities, governance, growth and employment, health, education, environmental sustainability, food security and nutrition, conflict and fragility, population dynamics, energy, and water. Therefore, the green economy has been one of the main themes in the international debates on sustainable development towards the Rio+20 summit in 2012.

Since the sustainable development depends on a green economy, it can only be implemented if fundamental changes are made to the existing energy supply chains, especially in industrial parks (Pan et al., in press). In Taiwan, both increased exports and elevated domestic autonomous final demand levels were the main reasons for increasing CO_2 emissions, reflecting the evidence of export-oriented and continued growth characteristic in the Taiwanese economy (Huang and Wu, 2013). According to the Taiwan's sustainable energy policies, development of eco-industrial parks (EIPs) is one of the key strategies to reduce carbon emission (CO_2) intensity over 30% by 2025 (CEPD, 2004; Huang and Wu, 2013). In 2009, the "Green Energy Industry Promotion Act" announced by Ministry of Economic Affairs of Taiwan was intended to promote the renewable energy industries towards a green economy, targeting an increase of gross green industrial output value of 390 billion USD by 2015 (MOEA Taiwan, 2009).

To achieve the goal of being environmentally bearable, economic viable, and social equitable, the objectives of this paper were (1) to examine the role of green supply chains in EIPs for creating a green economy, (2) to establish the evaluation criteria to assess the effectiveness of green supply chains implemented in EIPs, (3) to identify the challenging barriers in establishing the green supply chains in EIPs, and (4) to propose the strategies for overcoming the barriers toward a green economy. In addition, three case studies of different industries including iron and steel-making, paper mill and pulping, and petrochemical industries were reviewed and illustrated.

2. Barriers and challenges

2.1. Regulatory barriers and challenges

Regulatory barriers often prevent institutions from efficiently developing technology and processes that are crucial for green supply chains. Laws regulating intellectual property rights (IPR) frequently make it difficult to share information among the industries because the laws determine who controls information and technology, making the spread of technology dependent on the groups controlling the information. This can cause a slowdown in the transformation process by posing a problem for the transfer of environmentally sound technology (Steiner, 2010). This barrier is so great that Committee of African Heads of State and Government on Climate Change (CAHOSCC) has also taken a position of calling for the removal of restrictions on intellectual property to allow African countries to develop clean energy and infrastructure (Keating, 2009).

In Taiwan, the development of renewable energy was sluggish during the period between 1996 and 2006 (Huang and Wu, 2013). Overly strict laws and regulations also prevented development and implementation of green technology and thus green supply chains. The amount of time it takes to receive permits and complete the proper procedures in order to develop and implement technology would be a main impediment factor in the expansion of renewable energy. In many countries in the European Union, for example, in France, it may take as long as eighty months to obtain the proper permits (ECORYS, 2010). Meanwhile, in the financial sector, strict laws may deter investors or insurers from developing green supply chains (UNEP, 2011). To overcome the legal barriers, it suggests that the demonstration projects should be carried out to assess the feasibility under the premises of the existing laws (Behera et al., 2012).

In addition, companies are currently experiencing obstacles in obtaining governmental approvals to use alternative fuels and materials from the recovered and/or recycled wastes (CEPD, 2004; MOEA Taiwan, 2009). For example, if a by-product is classified as a controlled waste such as fly ash, strict transportation procedures and cumbersome documentation processes are much obliged for implementation. Additionally, although some by-product synergies appear techno-economically feasible with a positive sustainability, practical implementation has been halted due to the uncertainties of the legislative framework, especially with regard to the final responsibility for approved reuse options and community concern.

2.2. Institutional barriers and challenges

Institutional barriers are pervasive when it comes to creating green supply chains. Political issues and an outdated infrastructure act as obstacles to creating an effective green economy. When drafting policy that will assist in the creation of green supply chains, it is often difficult for policymakers to decide on a common goal or strategy. Even in a single country where it is more likely that people will hold similar values and beliefs, there is difficulty agreeing on a common direction. For example, the currently grid-locked United States Congress is unable to create legislation to curb greenhouse gas emissions, forcing the country's Environmental Protection Agency (EPA) to take action instead. The difficulty that Congress has faced in resolving the environmental issues show that a shared will only emerge when attempting to coordinate international cooperation between so many countries with varying cultural practices and levels of development. For the entire globe to agree on a unified strategy will be even more difficult as there are even more cultural differences and levels of development across different continents (Keating, 2009). This struggle does not just plague the public sector: the private sector too must agree on green supply chain strategies that will fulfill the goals set forth by their government.

Once a unified plan is constructed, there may still be conflicting opinions about the specific implementation of plan. There is no doubt that many different motives, including political and financial ones, can lead to endorsements on opposite sides of a movement. For example, in 2009, South Korea began its “Four Major Rivers Restoration Project” as part of its Green New Deal policy. The ultimate goals were to combat water scarcity, improve water quality, implement flood control measures, and restore the rivers' ecosystems. While the general idea that South Korea needed to take ecological action was agreed upon, much controversy surrounded the project: the opposition decried the project, stating that it would cause habitat loss, flooding, and a contamination of the water supply. Both sides argued that their position would benefit the environment while the other would harm it (Normile, 2010). This example of a conflict in opinion suggests that the implementation of a climate change strategy is not straightforward or uncontroversial.

Outdated infrastructure, another institutional barrier, is pervasive in both developed and developing countries. Without supplanting outdated infrastructure, it is difficult to take on tasks necessary for moving towards construction of green supply chains. Without the most basic infrastructure such as roads and communication networks, developing countries cannot transfer and implement green technologies. Therefore, a necessary undertaking is the restructuring of old infrastructure which will allow for efficient development and implementation of green supply chains. Restructuring outdated infrastructure requires a large input of time and may involve significant costs, businesses and governments may be hesitant to take on such a task. Old infrastructure ultimately may not be replaced or only partially replaced, and consequently, a green economy cannot be fully achieved.

2.3. Financial barriers and challenges

The financial incentive for a particular industry and its associated businesses to invest in green technology or management may not be available at the very beginning. This may be for a variety of reasons: the cost of going green is too high in the developing countries and their industries may not have the financial resources to go green. The upfront, cost of greening supply chains may deter institutions from wanting to make such a transition. After the 2008 global financial crisis, many firms and governments no longer have the funds to invest in green technology or are reluctant to spend the money. One city in Australia was discouraged from rebuilding its water supply due to exorbitant fees it had to pay in response to the global financial crisis (Leichenko et al., 2010). In poorer countries, the upfront cost may serve as an even greater barrier as there are fewer funds with which they can invest in green technology. As a result, these countries continue to be burdened with older infrastructures and technologies. Furthermore, the payback period for implementing green supply chains may also be too great for businesses. Although the payback period for greening buildings is generally between five to ten years, this time period may be too long because of people's natural propensity for risk aversion (Leichenko et al., 2010; UNEP, 2011; van Loon-Steensma et al., 2014). In other words, the benefits of greening a business may not be apparent or immediate enough to incentivize a business or government.

Renewable energy prices are also much too expensive to be a viable energy option. According to the UNDESA (UNDESA, 2009), population with a living budget of US$ 10 per day, an amount much higher than the US$ 1.25 per day that 1.4 billion people in developing countries survive on, cannot afford renewable energy. Therefore, in the absence of any policy changes to make renewable energy affordable, these people are forced to use less desirable energy options and businesses are thus burdened with undesirable “brown” supply chains. Even if policy is available that will make renewable energy affordable, there is no guarantee that developing countries will be able to support these policies. For example, a major strategy in developing green technology and infrastructure is using subsidies to promote growth in green industries. This strategy works well for wealthy countries that can afford to subsidize various industries. However, in the least developed and developing countries, governments may not have the ability to subsidize to an effective level, given the current cost of renewable energy and sustainable materials and the low per capita income of the countries (UNDESA, 2009). As a result, environmentally harmful activities continue to be observed.

2.4. Technological barriers and challenges

The use of green technologies could control environmental pollutions and enhance resource recovery, thereby leading to better environment management system towards green economy (Styles et al., 2009; van Loon-Steensma et al., 2014). However, many local industries and enterprises lack access to green technology, and still rely on conventional technology, which is especially conspicuous in the developing countries. Institutional, regulatory, and financial barriers further exacerbate technological barriers by preventing the creation of new technology. If these barriers are not dealt with and green technology is not created, it will be even more difficult in the future to address climate change, loss of biodiversity, and other environmental problems.

Therefore, the steel mill, petrochemical, paper pulping, and cement industries would play important roles in establishing EIPs due to their unique features by utilizing a huge amount of energy and generating a great amount of wastes (Pan et al., 2012). Selection of rational sites on waste collection and reuse is essential by applying economically feasible technologies. It is noted that the demand of cooling energy in most part of Taiwan is currently supplied by the electricity. In other words, the contribution of the district cooling system in the residential and commercial areas could be negligible because only a few number of district cooling projects were established so far in Taiwan.

3. Strategies on building green supply chain

The "Global Green New Deal" presents the strategies for achieving an international green economy (UNDESA, 2009), which also addresses many existing barriers such as the difficulty to call for a global effort to "target price supports, establish policy coordination, and create an extension program to ramp up" the use of renewable energy. It specifically addresses the importance of implementing renewable energy over simply reducing emissions because "energy is the key to economic development and social wellbeing, and renewable energy is the key to a future without dangerous climate change" (Jupesta et al., 2011; UNDESA, 2009). Fig. 2 shows the visions and goals towards a green economy, which provides the rational to generate the conceptual diagram of building green supply chains. In the case of Taiwan, Taiwan possesses an abundant variety of biological resources and species. In seeking to satisfy the basic living needs, Taiwanese have abided by the moral imperative to co-exist and co-prosper with other forms of life in order to be able to maintain Taiwan's biological diversity (CEPD, 2004).

Fig. 3 presents the key aspects for achieving a sustainable development by construction of a green supply chain. The sustainable development should include economic development, environmental protection and social equity according to the suggestions provided by the CEPD of Taiwan (CEPD, 2004). Table 1 presents the barriers and strategies for constructing green supply chain, where the details are illustrated as follows.

3.1. Implementing national sustainable policy

Sustainable economic development seeks to preserve the gains from industrial capital, including man-made capital, natural capital, and human capital, to ensure the daily needs of the people while maximizing the net benefit of economic activities. To meet the major prerequisite of pursuing sustainable development, Taiwan adjusted the formerly lopsided approach to development, where predominant emphasis was given to achieving rapid economic growth and prioritizing industrial development. Currently, the industries pursue a more balanced economic development in which raising quality takes precedence over expanding quantity, placing much greater emphasis upon achieving both economic development and environment protection. In addition, Taiwan has developed the green industries, which are environmentally friendly, engage in clean production that does not threaten or pollute the environment, and promote green consumption that protects the environment (Huang and Wu, 2013).

In 2013, the National Development Council of Taiwan has implemented the "Green Economy Program" in response to the "Green Economy Policy Convention" held in Taiwan, as shown in Fig. 4. Accordingly, promotion of EIP establishment is essential to spur the development of new "green-tech" products and services for upgrading industrial technologies. Most environmental problems are global in some way; however, no countries can be forced to participate in international regulation. Therefore, several rules are suggested to make the regulation more globally acceptable: (1) involvement of a regulation context, (2) implementation of green industries by technology-forcing, guaranteed market, and economies of scale. Speed up the promotion of green supply chain in industrial parks, with a view to promote the marketability of regenerated products, help firms to publicize the sale of such products, vigorously promote green purchasing, and improve the development of marketing channels for recycled and recovered products. Meanwhile, appropriate policies should be established to foster industrial symbiosis, thereby facilitating the green

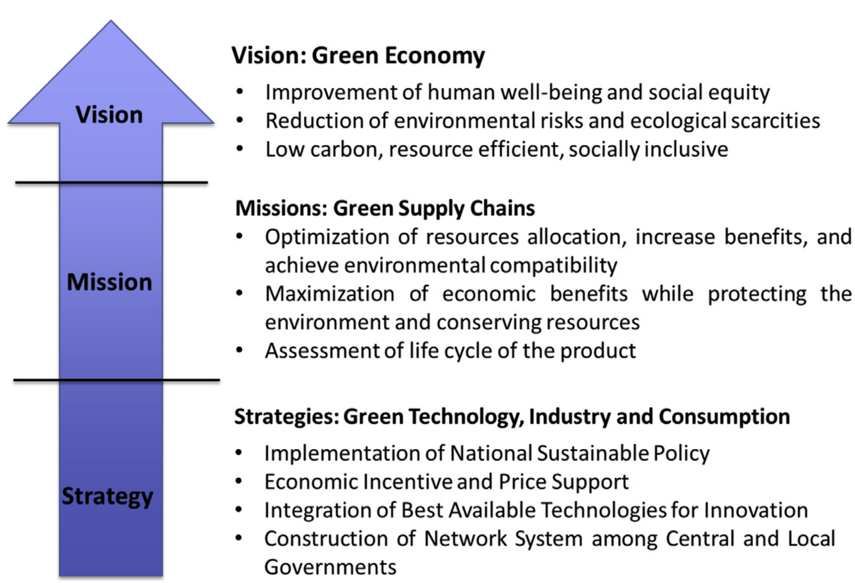

Fig. 2. Visions, missions, and strategies towards green economy.

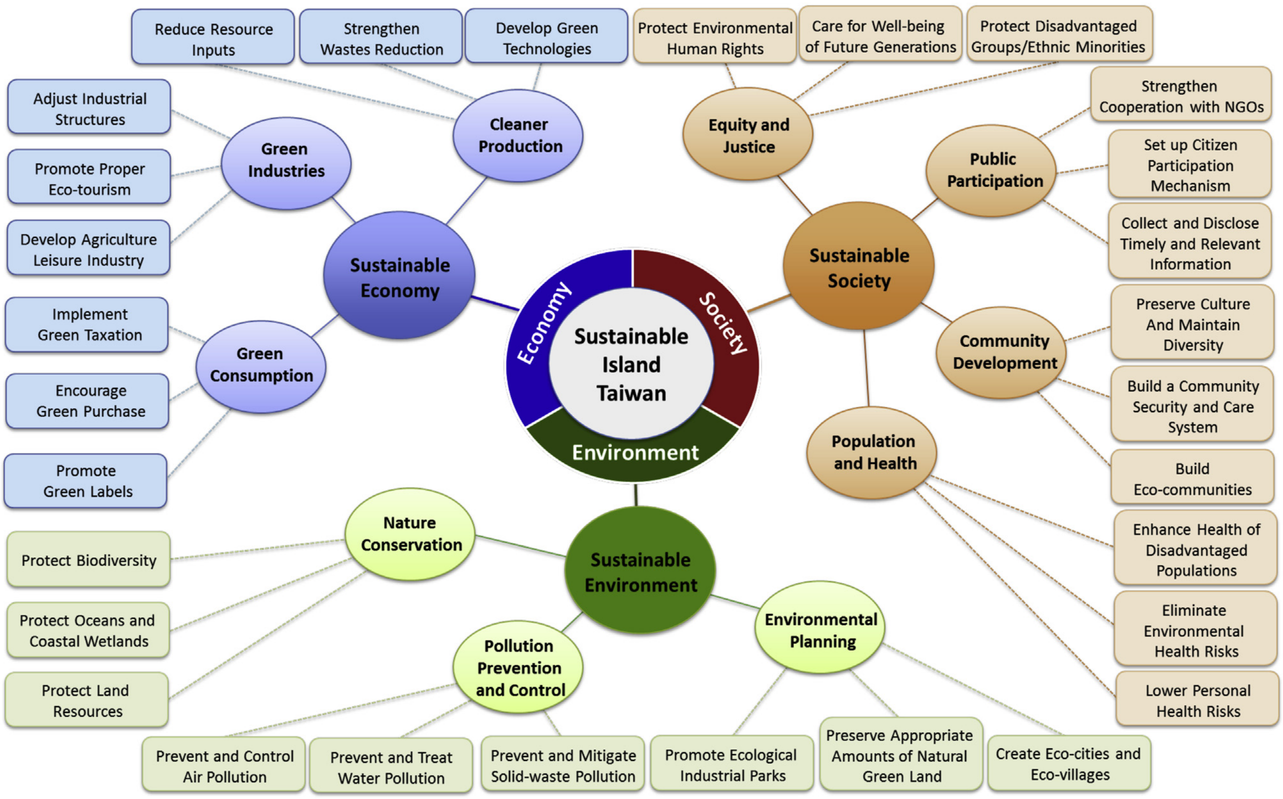

Fig. 3. Conceptual diagram of three aspects for achieving a sustainable development (Adapted from CEPD (2004)).

Table 1
Potential barriers and overcome strategies for constructing green supply chains in Taiwan.

Categories	Barrier addressed	Strategy employed to overcome barrier
Regulation	• Existing loose environmental regulations and exclusion of CO_2 as regulated pollutants • Long time required for reviewing environmental impact assessment	• New pollutant targeted regulations (e.g. carbon tax and mandatory energy audits) • Shorter authorization procedures for developing and implementing green technology
Institution	• Different focuses and concerns between central and local governments • Relatively low level of Bureau of Energy (BOE) and Environmental Protection Administration (EPA) in government hierarchy • Information availability of industries due to confidentiality and commercial issues	• Development of networking among central and local governments • Upgrade as Environment and Resource Department by merging the Environment Protection Agency, Water Resources Agency, Forestry Bureau (Council of Agriculture), Construction and Planning Agency, Central Weather Bureau • Establishment of networking platform for information exchanges
Finance	• Lack of fund and resource for construction of green supply chain • Relatively low price for utility resources discourages recycling and relatively low costs for waste disposal • Distance between companies inhibits synergies	• Providing economic incentives (e.g., price support, guarantees loans) • Implementation of feed-in tariffs (FITs) for green technologies and waste reuse and recycling • Subsidies on development of piping network for renewable energy and district heating and cooling system
Technology	• Lack of own technologies and manufacturing for key components • Existing low energy and material efficiency technologies • Availability of reliable green technologies	• Integration of best available technologies for innovation • Energy policy that targets research and development for clean and green technologies • Developments of demonstration plans for providing opportunities for new synergies

technologies for effectively material reuse and waste recycling (Dong et al., 2014; Liu et al., 2014).

3.2. Developing network among central and local governments

Governments need not to take on official pricing strategies or policy measures to persuade institutions to transition towards green supply chains. In general, unofficial measures could be equally effective, where the governments can cultivate market environments of green consumption, cultivate green enterprise culture, and encourage green technological innovation, as shown in Fig. 5. By simply publicizing and working to popularize green consumption through publicity, schools, and media outlets, it is possible to improve the green knowledge of consumers and make them push businesses to greener supply chains.

The ultimate goal of these investment and policy changes is to create a “virtuous cycle” in which an initial series of investment and policy changes will lead to accelerated industrial scaling-up, expanded markets for renewable energy and faster growth rates in production, and finally technological improvements which will further accelerate industrial scaling-up. Therefore, it will be possible to remove all subsidies and still move towards forming

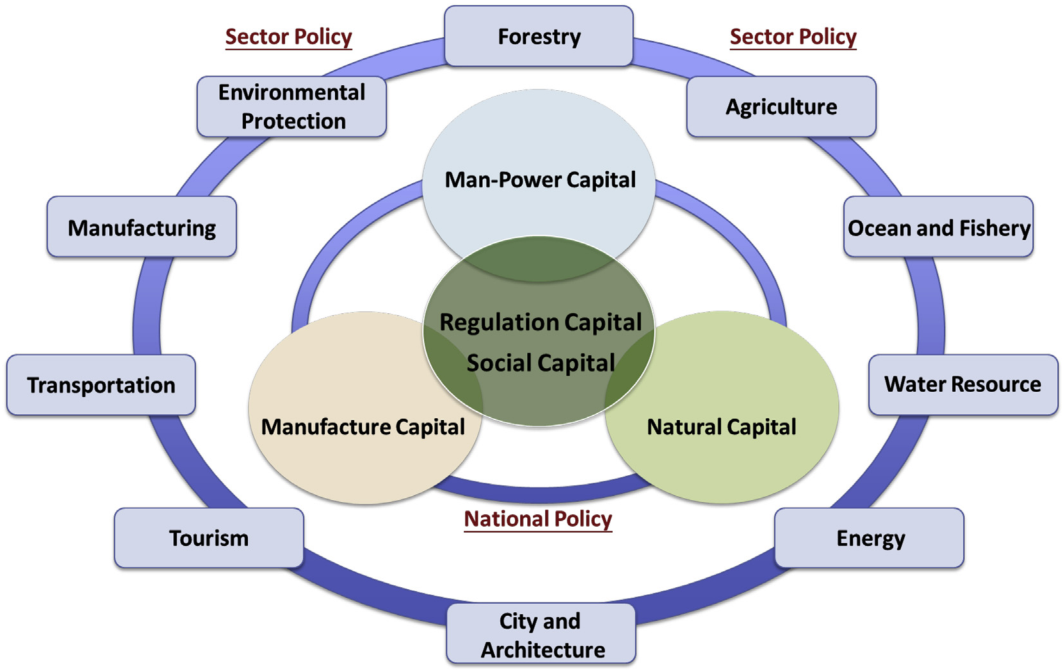

Fig. 4. "Green Economy Policy Convention" proposed by National Development Council of Taiwan (Adapted from MOEA Taiwan (2009)).

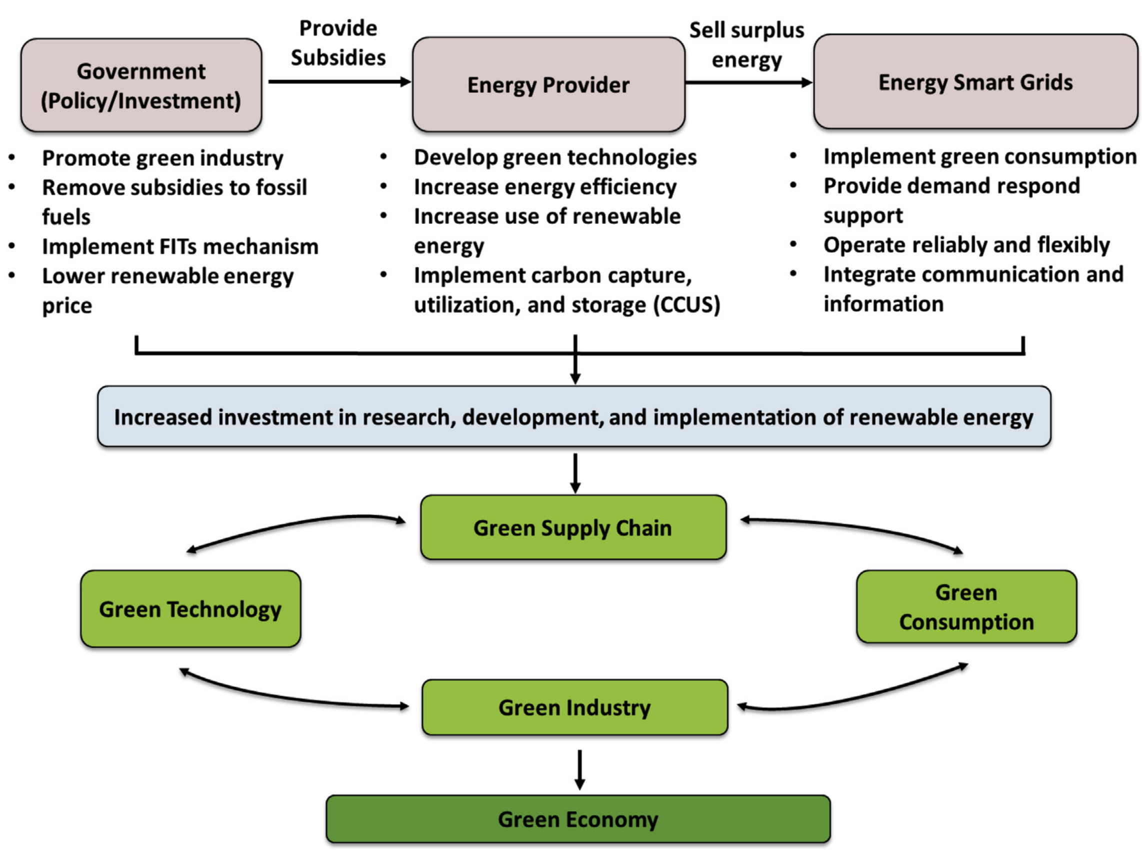

Fig. 5. Schematic diagram of price support and governance in cities for building green supply chain toward green economy.

green supply chains and a green economy in the following decade (UNDESA, 2009).

Social familiarity due to existing common cultures and trusts among the stakeholders (e.g. competent authorities of EIP, governments, communities, and other industries) is considered as the vital parameter for minimizing the uncertainties or risks of failure. Therefore, the competent authorities of EIP should help the stakeholders to build up linkages between local governments and these industrial sectors, thereby providing regulatory and financial support information (Behera et al., 2012; Dong et al., 2014). In addition, describing and outreaching policy information along with coordinating collective actions are quite important for a long term mutually beneficial success among the newly developed green businesses (Yi, 2014).

3.3. Providing economic incentives and price supports

Economic incentives such as tax exemptions and carbon credits should be implemented for creating a cost-effective green certificate market (Söderholm, 2008). Currently, the price of renewable energy in Taiwan is much too high for it to be a viable energy option. This is reasoned by that there exists many subsidies that lower the price of fossil fuels so that they are much cheaper than renewable energy. This problem can be easily solved by simply removing those subsidies to allow the international market to decide the price of fossil fuels, as shown in Fig. 5. To increase the supply of renewable energy and thus decrease its price, the primary method suggested by “Global Green New Deal” is providing international price supports through a “feed-in tariffs” (FITs) program. The goal of FITs is to increase investment in developing renewable energy in order to increase the installed capacity of renewable energy. FITs has been successfully implemented in Taiwan because of its steep learning curve: with each additional implementation of renewable energy, i.e. increasing the installed capacity, the cost of renewable energy decreases because there is “a larger market for renewable energy, greater market stability and predictability, standardization of equipment and component production, competition amongst suppliers, improved designs, and learning by doing” (UNDESA, 2009). Moreover, FIT policies that support the development of wind energy resulted in an installed wind capacity that was seven to eight times greater than the capacity generated by other pricing strategies.

Beyond policy in the form of price supports, a series of policy changes will bolster the price supports and allow them to be effective. These policies will promote already established legislation by providing additional supports to the underdeveloped countries, establishing a network of innovation centers, and developing appropriate institutional architecture (UNDESA, 2009). Assistance to the least developed countries may take the form of low interest loans, financial assistance for capacity building and institutional development, technical assistance, or subsidized access to technological information. This assistance would solve many of the institutional and financial barriers that are prevalent in developing countries and would prevent the development of green supply chains. Eventually, after the pricing strategies and policy changes make renewable energy a profitable endeavour, the pricing strategies will no longer be necessary: it will be profitable to conduct the necessary research, development, and implementation, essentially flooding the market with renewable energy thereby keeping the price low.

3.4. Integrating best available technologies for innovation

In general, technical barriers require the comprehensive and integrated strategies which include solutions from the institutional, regulatory, and financial aspects. However, some simple technologies can be available with limited resources and make significant improvements in improving economic efficiency, reducing resource use and improving human well-being (Puppim de Oliveira et al., 2013). Integrating best available technologies for innovation, i.e., energy conservation technologies, cleaner productions for energy, water and materials in industrial manufacturing processes, and adoption of efficient technology (Behera et al., 2012; Liu et al., 2014), would enable Taiwan to occupy a place in the global domain of green-technology products. For instance, the heat recovery in the incineration or manufacturing processes would not only enhance the use of district heating but also reduce the energy consumption with a better valorization of the waste (Pardo et al., 2013; Stijepovic et al., 2012). In addition, an innovative waste-heat recovery system should possess heat exchanger (Sun et al., 2014), adsorption chiller (Stanek and Gazda, 2014), transcritical CO_2 heat pump and refrigeration cycles (Ma et al., 2013), exhibiting better economic and environmental benefits.

In addition, with consideration to the life-cycle of the production process and the 5R spirit of “Recycling, Reducing, Reusing, Recovery of energy, and Reclamation of land” of Taiwan EPA, the recycling-based technologies should be promoted and implemented in EIPs. For instance, the bio-solids from the wastewater treatment plant can be converted to biogas for electricity and heat. On the other hand, the implementation of carbon capture, utilization and storage (CCUS) technologies should combat the environmental and energy issues in industries for security and sustainability, with development of appropriate value-added carbon management mechanism into fossil fuel, biomass and renewable energy technologies (Budzianowski, 2012; Mondal et al., 2012; Pan et al., 2012; Yu et al., 2012). However, the complexity of the technologies of green supply chains makes forming such supply chains difficult. It suggests that the innovation centers should adapt knowledge to make it relevant to local conditions. They will also make the knowledge available to policy makers, investors, and communities and “support national institutions and serve as a link to international experts and knowledge bases,” thereby easing the transition to the green supply chains.

4. Implementing green supply chains in Taiwan

4.1. Eco-industrial parks (EIPs) as a business model

Eco-industrial parks (EIPs), a “community of manufacturing and services companies seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water, and materials” (Côté and Cohen-Rosenthal, 1998), have been established around the world in order to meet the demands of a green economy. Most notably, they have developed in countries like Australia (Giurco et al., 2011), Denmark (Münster et al., 2012), Europe (ECORYS, 2010; Pardo et al., 2013), USA (Yi, 2014), Japan (Dong et al., 2014), China (Jung et al., 2013; Liu et al., 2014; Tian et al., 2014), Korea (Behera et al., 2012), and Taiwan (Cheng Loong Corp, 2012; Huang and Wu, 2013) to balance the environmental protection and economic development. The goals of EIPs are to promote energy conservation, carbon reduction, and green production by focusing on the implementation of green supply chains. Specifically, the objectives of EIPs are to:

1. Establish an integrated structure that embraces economic development, environmental quality, and social equity.
2. Stimulate investments in the private sector, thereby increasing employment opportunities related to resources recycling and encouraging rural and urban community developments.
3. Pursue the goal of zero emissions and building up a recycling-based sustainable society.
4. Manage waste reduction and reuse technologies to achieve goals of total recovery and zero waste.
5. Build recycling-based eco-cities and eco-villages, raise resource-recycling ratios, and reduce water and energy consumption.

To meet the objectives of EIPs, several strategies are listed below:

1. Policy makers should create policy which promotes reducing carbon emissions and improving energy efficiency.
2. Future plans should increase manufacturing efficiency while seeking cooperation between all manufacturers in the park.
3. Creation of a cost-effective integrated green certificate market. Pricing strategies such as tax exemptions and carbon credits should be implemented.
4. Information about updated manufacturing processes, supply and demand of materials and energy, resources for assistance, and human training resources should be made easily accessible.

Recently, life cycle analysis (LCA) has been extensively utilized as a structured basis for evaluating the performance of environmental impacts and benefits in EIPs (Pardo et al., 2013; Poinssot et al., 2014). Several studies on the multi-objective optimization of district heating system in EIPs can be found in the literature (Buoro et al., 2013; Jung et al., 2013). Key performance indicators (KPIs), quantifiable measures of an institution's ability to accomplish their set goals, must be developed and used for assessing progress towards the implementation of green supply chains. Table 2 summarizes the themes and KPIs for establishing the EIPs from environmental, economic and social aspects found in the literature. For instance, the UNEP has identified three primary areas that will act as the most beneficial KPIs when measuring various aspects of green economies: indicators of resource efficiency, economic transformation, and human progress and well-being (UNEP, 2012a). KPIs that measure resource efficiency can signal the aspects of a supply chain that greening strategies must target because many resource efficiency indicators (such as waste generation) are already tracked in various industries and highlight trends in the environment (UNEP, 2012b). In addition, since the scales of land areas and companies are quite different for various industrial parks, the performance of each industrial park can be compared using the annual production of energy and economic values as the basis, e.g., carbon intensity (i.e., CO_2 emission/energy production) and energy intensity (i.e., energy/GDP), respectively.

For the economic aspect, green supply chains require that investments be made in green activities that are low carbon, waste minimizing, and resource efficient. By comparing the level of investments made in environmentally friendly activities with the level of investments made in environmentally harmful activities, it is possible to successfully implement the green supply chain plan. Implementation success can also be measured by the growth of goods, services, and jobs in environmentally friendly activities (UNEP, 2012a). These economic transformation indicators often assign a monetary value to the cost and benefits of greening strategies including investments, jobs, and industrial growth.

The social indicators can be evaluated by the level of education achieved, health status, and access to social safety nets (UNEP, 2012a). Infant mortality rates, percentage of population with a primary education, literacy rate, GDP per capita, density Average distance, and betweenness centralization are suitable quantitative KPIs for the social aspect (Jung et al., 2013; Zheng et al., 2012). Human progress and well-being indicators are well suited for gauging the ultimate success of green supply chains on the formation of a green economy because they consider how well the economic development goal of sustainable development is fulfilled. When there is sufficient data available for the indicators, however, the indicators are often seen as less legitimate than the key economic indicators like GDP for making policy decisions.

4.2. Case study: iron and steel-making industry

In the case of iron and steel-making industry, China Steel Corp. (CSC), served as the center of green supply chain within Lin-Hai Industrial Park, has successfully established the business model. Lin-Hai Industrial Park (in Kaohsiung, Taiwan) has constructed the green supply chain among different industries and manufactures since 2008. Lin-Hai Industrial Park covers both Cianjhen district and Siao-Gang district in Kaohsiung. The total area of Lin-Hai Industrial Park is 1569 ha, where 89% is classified as production zone. Lin-Hai Industrial Park mainly consists of business in the fields of mechatronics, steel manufacturing, chemical engineering, and transportation, a total of 482 manufacturers. Fig. 6 shows the schematic diagram of construction of green supply chain in Lin-Hai Industrial Park.

The process waste heat from the iron and steel-making processes can be classified into various levels: (1) high quality (e.g., higher than 500 °C), (2) medium quality (e.g., 250–500 °C), (3) low quality (e.g., lower than 250 °C), which can be further utilized to generate electricity and/or steam by the combined heat and power (CHP). CHP (also known as Cogeneration), a thermodynamically efficient use of fuel, utilizes a heat engine and/or power station to simultaneously generate electricity and available heat. The high-temperature heat or steam first drives a gas or steam turbine-powered generator, and then the resulting low-temperature waste heat is used for water or space heating. The moderate temperatures of steam after through the CHP process was typically at 100–180 °C, which can be used in absorption and adsorption chillers, and/or refrigerators for cooling demand such as air conditioner.

By the end of December 2012, a total of 15 green supply chains including steam, hydrogen, nitrogen, waste alkaline solution, MSW incinerator bottom ash (BA), and electric arc furnace (EAF) dust were established. Fig. 7 shows the conceptual diagram of a building green supply chain of alkaline solid wastes such as basic oxygen furnace slag (BOFS) and EAF dust in Lin-Hai Industrial Park. For instance, the alkaline solid wastes could be utilized for carbonation process to react with CO_2 emitted from the stove or stack to form carbonate precipitation (Pan et al., 2015a). Concurrently, the physico-chemical properties of the carbonated solid waste are improved as the free-CaO content can be eliminated which is beneficial to the application as construction materials in civil engineering projects (Chang et al., 2012; Pan et al., 2012). In addition, if the alkaline wastewater was introduced, the wastewater can be finally neutralized to meet the discharge permission standard.

Table 3 presents the themes and KPIs of green supply chain in Lin-Hai Industrial Park. With this successful model, the total amount of steam supply was achieved to 2.50 million ton per year. The environmental benefits of steam supply include: a CO_2 reduction of 574,000 t/y, a SO_x reduction of 1830 t/y, a NO_x reduction of 1270 t/y and particle matter (PM) reduction of 181 t/y. On the other hand, the total amount of recycling wastes was estimated at 0.67 million t/y, corresponding to a waste utilization ratio of 84.7%. Accordingly, the total economic benefit attributed by the green supply chains was estimated at US$ 100 million per year.

4.3. Case study: paper mill and pulping industry

Cheng Loong Corp. was devoted to construct the green supply chain within Da-Yuan Industrial Park. Fig. 8 shows the paper-making process integration within Cheng Loong Corp in Da-Yuan Industrial Park (Cheng Loong Corp, 2012). The process waste from stock preparation system has been utilized in biomass energy system to produce the refuse-derived fuel (RDF) since 2009. The

Table 2
Themes and key performance indicators (KPIs) from environmental, economic and social aspects.

Aspects	Themes	Indicator titles
Environmental	Pollution prevention and control	NOx emissions
		Particles emissions
		VOCs emissions
		SO_2 emissions per unit output value increase
		Wastewater discharge per unit output value increase
		COD emissions per unit output value increase
		Target for CO_2 reduction amount
	Energy/Resource consumption	Land consumption per GDP
		Energy consumption per GDP
		Fresh water consumption per GDP
		Chemicals consumption per GDP
	Energy/Resource recycling	Energy saving efficiency
		Ratio of reclaimed industrial wastewater
		Water consumption per unit output value
		Material consumption per unit output value
		Waste recycling rate per unit output value
	Environmental Planning	Averaged PSI
		Ratio of green land
		Green building indicators
		Environmental management system
Economic	Cost reduction (Clean Production)	Measures for promoting pollution prevention and resource recovery
		Cost reduction of CO_2 emission control by waste recycling
		Ratio of material shipping expense in the total output value
	Profit increase (Green Consumption)	Gross domestic production (GDP)
		Gross industrial output value (GIOV)
		Industrial added value (IAV)
		Discounted cash flow
	Tax	Carbon tax
	Incentive	Feed-in tariff on renewable energy
		Government subsidy on construction
	Corporate image promotion (Green Industry)	Budget/expenditure of environmental protection
		Total investment for pollution control
Social	Public Participation	Number of visitors in open house events per year
		Completeness of message platform
		Publication of environmental report
		Public satisfaction of environment
		Public cognition of eco-industrial park
	Community Development	Interchange plan for public transportation system
		Plan for biking and walking route
		Social familiarity
		Betweenness centralization
		Density Average distance
	Fairness and Justice	Green park area per capital
		Number of pleaded environmental pollution events
		Compliance with laws and regulations
	Population and Health	Safety nets
		Health status

Note: This Table is summarized from the findings reported in the literature (Behera et al., 2012; CEPD, 2004; Jung et al., 2013; Tian et al., 2014; Zheng et al., 2012).

RDF is produced by shredding and dehydrating the bio-solids, e.g., organic sludge and MSW with thermal treatments. For instance, the bio-solids can be pyrolysed in the absence of oxygen at temperatures of approximately 500 °C and atmospheric pressure. With the application of RDF, the consumption of coal can be reduced by 6852 tons per month in Cheng Loong Corp, corresponding to a CO_2 emission reduction of 15,400 tons per month. Moreover, 19,800 tons of waste disposal can be avoided every year, resulting in an economic benefit of USD $1.5 million.

In addition, the organic sludge from wastewater treatment plant (WWTP) was utilized to produce biogas, which was further purified and utilized in a co-generation system. The wastewater with a high chemical oxygen demand (COD) concentration was treated though the anaerobic digestion via an up-flow anaerobic sludge blanket (UASB) reactor in the wastewater treatment plant (WWTP) to generate the bio-gas, i.e., methane. Since the produced methane gas was mixed with H_2S gas of around 65,000 ppm, the biogas should be purified by the water scrubbing tower prior to be used as a fuel in the boiler. Furthermore, it was noted that the gasification of biomass for syngas production integrated with a CHP based district heating (DH) system is technically feasible and economically affordable (Kohl et al., 2013).

Table 3 presents the themes and KPIs for green supply chain in Da-Yuan Industrial Park. A total of 11 green supply chains including steam, copper sludge, and waste electrical wire were established in Da-Yuan Industrial Park in 2012. With the successful model, the total amount of steam supply was estimated at 940,000 ton per year. On the other hand, the total amount of recycling wastes was estimated at around 284,550 ton per year. Therefore, the overall CO_2 reduction potential attributed by the green supply chains was 18,000 ton per year. The total economic benefit was estimated to be USD 2.87 million per year. It suggests that the reuse of waste solids as a resource for bio-energy production via new technological approaches can reduce the capital costs and increase the environmental benefits effectively throughout the building green supply chains.

4.4. Case study: petrochemical industry

Many petrochemical industries including Formosa Plastic Corp. and China Petroleum Corp. (CPC) were located in Lin-Yuan

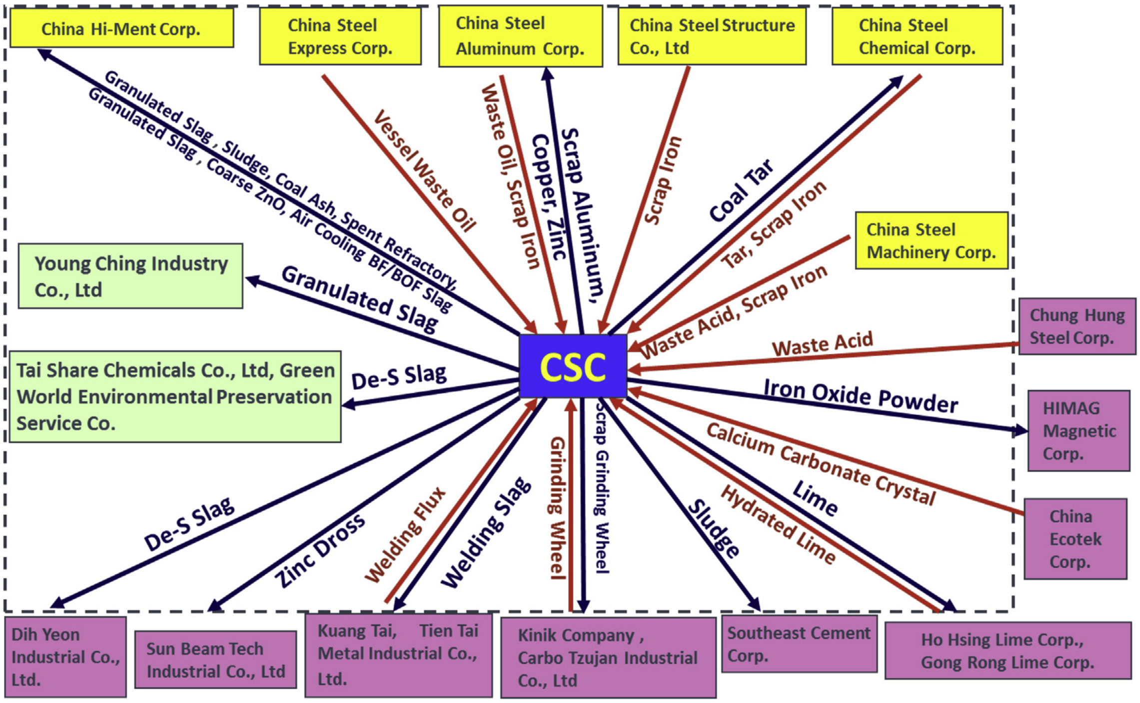

Fig. 6. Schematic diagram of building green supply chain in Lin-Hai Industrial Park (Adapted from China Steel Corp (2013)).

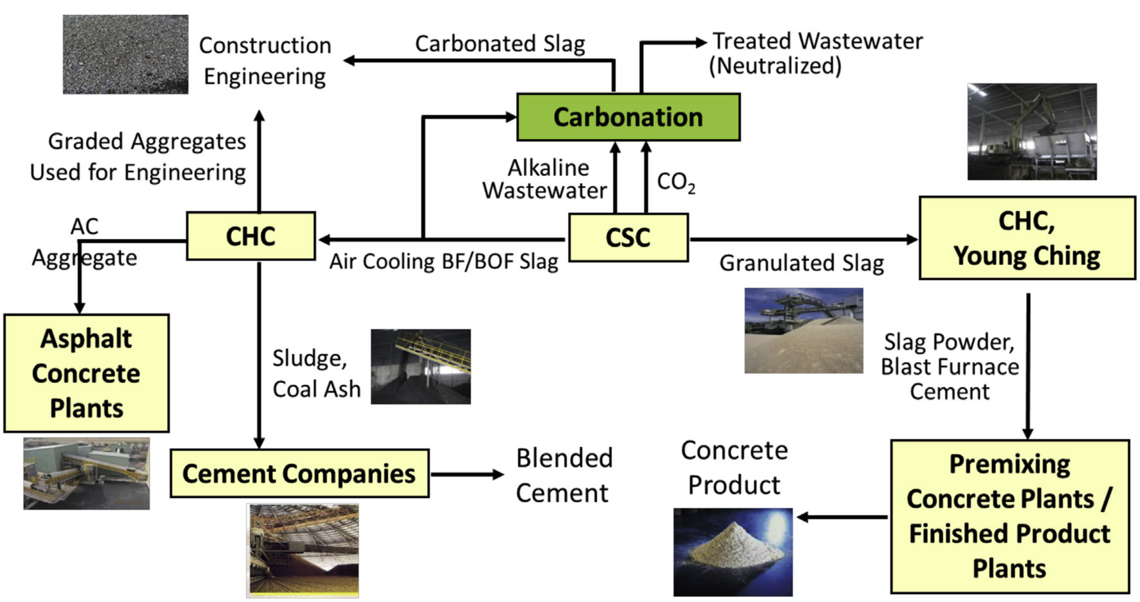

Fig. 7. Conceptual diagram of green supply chain in the case of alkaline solid wastes in Lin-Hai Industrial Park (Adapted from China Steel Corp (2013)).

Industrial Park. There are a total of 30 industries in Lin-Yuan Industrial Park, where 27 of them are petrochemical related industries. The total area of Lin-Yuan Industrial Park is 403.2 ha. Fig. 9 shows the material flow and energy flow analyses in Lin-Yuan Industrial Park. For instance, the Formosa Plastic Corp. has utilized the CHP technology to simultaneously generate electricity and steam. Four boilers with a steam capacity of 200 tons/h were installed at the Formosa Plastic Corp. The process heat with different quality was utilized to generate electricity, steam and hot water. The high-quality steam, i.e., ~3.5 kg/cm^2, was used to drive the steam turbine for electricity generation and median-quality steam supply. Since 1992, Formosa Plastic Corp. had been served as the district energy supply center for seven companies in the industrial park, with a steam supply amount of 75 t/h. Moreover, the low quality steam around 1 kg/cm^2 was utilized not only to recycle the chilled water for air-cooled heat exchanger (HE) but also generate hot gas (105 °C) delivering to high-density polyethylene (HDPE) plant for drying purpose. With the developed energy integration, the total heat efficiency increases up to 60.5% due to the steam supply chain.

On the other hand, the rain-water and wastewater were recycled into the manufacturing process use. The water recycling technologies include the membrane bio-reactor (MBR), ultrafiltration (UF) processes and reversed osmosis (RO) processes. The

Table 3
Themes and KPIs for green supply chain in Lin-Hai, Da-Yuan and Lin-Yuan industrial parks in 2012.

Aspects	Themes	Indicators	Units	Industrial Parks in Taiwan		
				Lin-Hai	Da-Yuan	Lin-Yuan
Environmental	Pollution Reduction	NO_x Emissions	t/y	1270	–	160
		Particles Emissions	t/y	181	–	15
		SO_x Emissions	t/y	1830	–	370
		CO_2 Emissions	t/y	574,000	18,000	32,300
	Resource Recycling	Ratio of Waste Recycling	%	84.7	30.6	–
		Amount of Waste Recycling	t/y	669,487	284,550	–
		Ratio of Waste Recycling	%	–	28.9	–
		Amount of Steam Supply	t/y	1,880,709	940,000	630,000
		Amount of Industry Gas Supply	t/y	116,463	–	8600
	Green infrastructure	Area of green land	m^2	57,000	5600	202,000
Economic	Energy Efficiency	Heavy Oil Reduction	kL	40,663	13,800	–
		Boiler Heat Utilization	%	–	–	60.5
	Benefits	Annual value of productions	USD/y	305 billion	105 billion	77.5 billion
		Cost Reduction	USD/y	100 million	2.87 million	5.3 million
Social	Community Development	Number of Employee per year	persons	40,717	11,027	4395
		Number of companies	units	526	168	27
		Public Satisfaction of environment	–	Excellent	Excellent	Excellent
		Cognition of eco-industrial park	–	Excellent	Excellent	Excellent

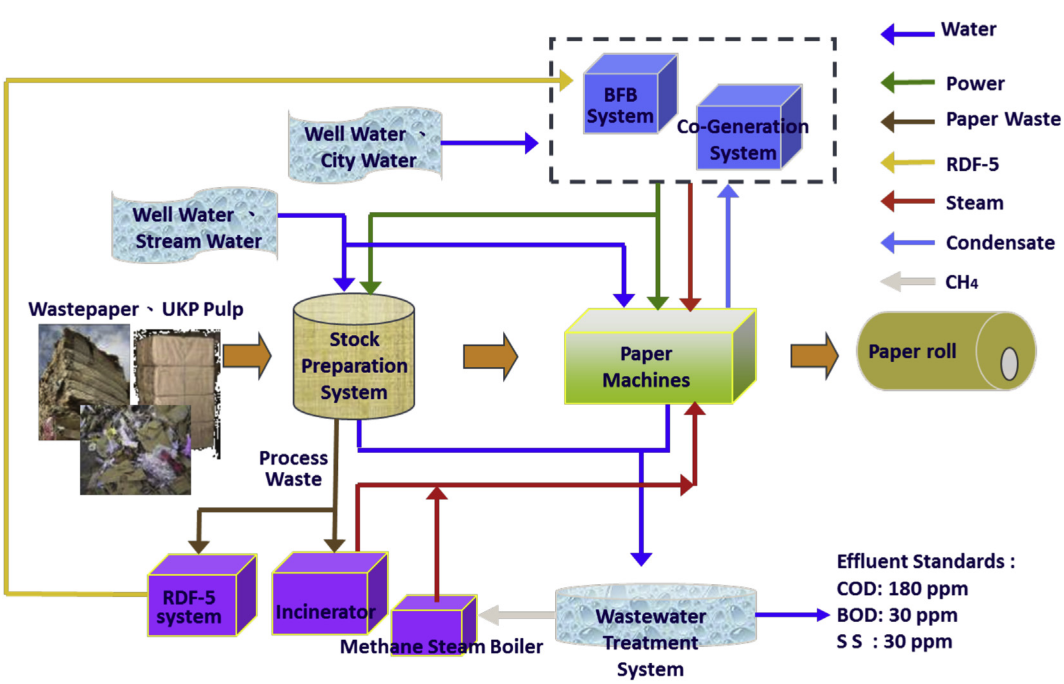

Fig. 8. Papermaking process integration within Cheng Loong Corp in Taoyuan Industrial Park (Adapted from Cheng Loong Corp (2012)).

selected membrane processes can be easily used to purify the wastewater to the levels of turbidity less than 0.2 NTU and total suspended solid (TSS) less than 1 mg/L. Furthermore, the molecules and ions in the solutions can be removed though the RO treatment because the RO membrane removes large molecules or ions except for smaller components of the solution.

Table 3 presents the KPIs for building the green supply chains in Lin-Yuan Industrial Park in 2012. By the end of 2012, a total of 7 green supply chains including electricity, steam, hydrogen, nitrogen, and bottom ash were established in Lin-Yuan Industrial Park, with a potential amount of 38,000 tons per year. The exchange of industry waste gas was estimated at 8600 ton per year. In addition, the environmental benefits of steam supply were estimated at a CO_2 reduction of 32,300 ton per year, a SO_x reduction of 370 ton per year, and a NO_x reduction of 160 ton per year. The economic benefit in the Lin-Yuan Industrial Park was estimated to be USD 5.3 million per year.

5. Conclusions

The global environment and ecosystems have numerous functions including the supplies of food, clean water, and raw material for the mankind. Therefore, it is essential for the implementation of a green economy to achieve the goals of the sustainable development. Cleaner production and environmental management play a crucial role for firm to improve the environmental performance. Recently, the green supply chain was aggressively constructed in different industrial parks around the world. The win–win benefits in both environmental and economic aspects can be achieved by implementing the “waste-to-resources supply chain” in the industrial park. Three green supply chain strategies, i.e., a low-carbon and sustainable homeland, a low-carbon industry, and low-carbon power generation, were suggested to achieve the “Low Carbon Society Vision”. In addition, it is recommended that the efficiencies

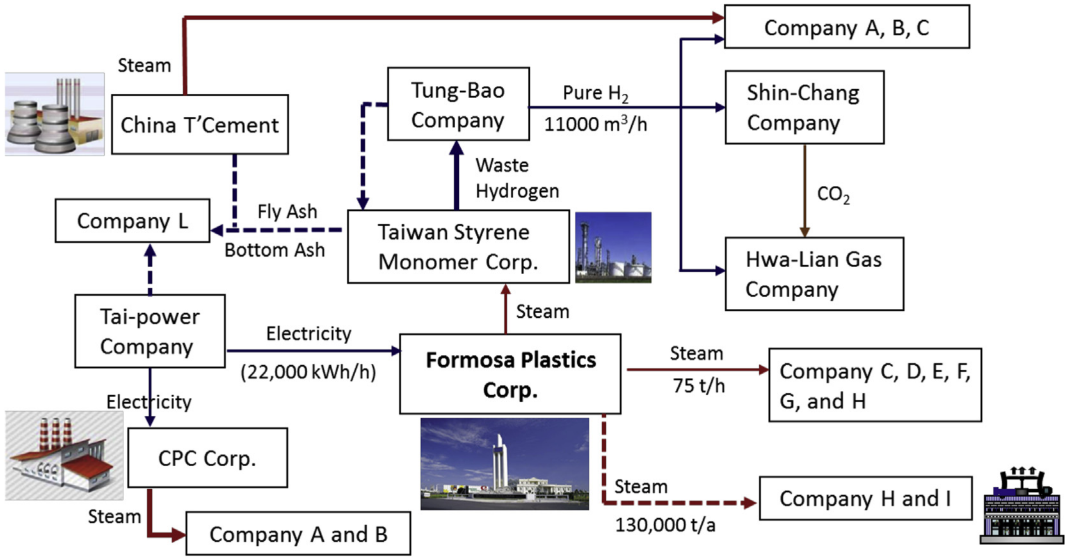

Fig. 9. Schematic diagram of construction of green supply chain in Lin-Yuan Industrial Park.

of energy and resource utilizations, the production of renewable energies, and the implementation of the carbon capture, utilization and storage (CCUS) technologies should be improved and enhanced by the public and private sectors. Once the above task is carried out and green supply chains are effectively implemented, attaining a green economy and achieving sustainable development will be more feasible than ever. It was thus concluded that the development of symbiosis networks are technically feasible, economically affordable, environmentally resilient and socially adaptable by building green supply chains in an Eco-industrial Park towards a green economy.

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