Paper to be presented at
the DRUID16 20th Anniversary Conference
Copenhagen, June 13-15, 2016

National technological innovation systems: Taiwan's biodiesel innovation system (1997–2015)

CHAO CHEN Chung
National Cheng Kung University
Department of Political Science
chaochen.chung@gmail.com

Abstract

This study explores the biodiesel innovation system in Taiwan from the perspective of its established framework called the national technological innovation system (NTIS). We analyse the evolution of biodiesel in Taiwan, and discover existing blocking mechanisms in its system through an evaluation of present research as well as the consistency and appropriateness of technology, development and innovation (RTDI) policies for the functional dynamics of the system. We suggest that the undoubted potential of biodiesel in Taiwan could be achieved, provided that (1) the government maintains the consistency of a set of interrelated RTDI policies over time, and (2) design these policies comprehensively according to the dynamics of the functional pattern of biodiesel by NTIS.

Jelcodes:O21,-

National technological innovation systems: Taiwan's biodiesel innovation system (1997–2015)

Abstract

This study explores the biodiesel innovation system in Taiwan from the perspective of its established framework called the national technological innovation system (NTIS). We analyse the evolution of biodiesel in Taiwan, and discover existing blocking mechanisms in its system through an evaluation of present research as well as the consistency and appropriateness of technology, development and innovation (RTDI) policies for the functional dynamics of the system. We suggest that the undoubted potential of biodiesel in Taiwan could be achieved, provided that (1) the government maintains the consistency of a set of interrelated RTDI policies over time, and (2) design these policies comprehensively according to the dynamics of the functional pattern of biodiesel by NTIS.

Keywords: Taiwan, biodiesel, innovation system, policy

1. Introduction

Bio-diesel is capable of replacing fossil fuels and extensively reducing the emission of greenhouse gas (GHG). The first generation of biodiesel, currently in widespread production, is derived from a variety of feed stocks such as used cooking oil, while second generation biodiesel, only a few of which are close to large-scale commercialisation, are derived from multiple feed stocks and refining technologies such as algae (Harvey and Pilgrim 2011).Since the United Nations Framework Convention on Climate Change (UNFCCC) was signed in 1992 and the Kyoto Protocol was opened for signature in 1997, governments all over the world have encouraged the production and innovation of biodiesel as a solution to reduce GHG emissions. Until now, however, the global production of biodiesel has really been concentrated in specific countries of particular regions. In 2014, 27 European countries manufactured around 40% of the world's biodiesel supply while approximately 30% was produced by the USA, Brazil and Argentina in North and South America. However, in East Asia, China manufactured about 0.8% of the world's production of biodiesel. While other East Asian countries, that have also launched biodiesel policies, are presently not among the top global producers (as shown in Table 1)(REN 21 Steering Committee 2014).

Taiwan is one of the few East Asian countries that have launched policies to encourage the production and innovation of biodiesel to reduce GHG emissions in response to the Kyoto Protocol. In fact, policy support for biodiesel in Taiwan only emerged after the opening of signature for the Kyoto Protocol in 1997. From 1998 to 2014, the Taiwanese government held three National Energy Conferences in tandem with the progress of the Kyoto Protocol (as shown in Figure 1). These conferences provided general policy guidance for establishing an innovation system for biodiesel and led to the promotion of more concrete policies, including those for R&D and regulations, to accelerate industry development. Yet, Taiwan's biodiesel production only hit a maximum of 96,234 kl in 2013,a long way from the levels of the top biodiesel producers globally. And since 2014, Taiwan's biodiesel innovation system has struggled to grow despite continued governmental policy support (as shown in Table 2).

Taiwan's experience indeed raises both empirical and theoretical issues that are worthy of further exploration. Empirically, Taiwan's biodiesel policies were originally prompted by the Kyoto Protocol and subsequently led to the emergence of the country's biodiesel innovation system. However, Taiwan's biodiesel innovation has needed the continued support of these governmental policies. The contrasting influence of governmental policies on the ups and downs of Taiwan's biodiesel industry can provide important lessons for biodiesel policy implementation in other countries. However, it is difficult to theoretically explain Taiwan's empirical experience using existing literature, which seldom discusses the international dimensions of national policies. These dimensions, also recognised as international factors in this study, include international political and economic events as well as treaties (such as the Kyoto Protocol), norms (like technical standards) and diverse inter-governmental organisations (Gallagher 2012). In fact, the approaches of innovation systems tend to focus on the influence of national research, technology, development and innovation (RTDI) policies on the evolution of innovation systems within national borders. Nevertheless, nations are a part of the international arena and thus, international factors would frequently motivate national governments to promote particular RTDI policies as a response to them. The process through which international factors influence national RTDI policies—that, in turn, further shapes the dynamics of innovation systems within national borders—remains unknown.

To fulfil the theoretical gap and intensively explore the empirical development of biodiesel in Taiwan, this study aims to make an original linkage between three variables—international factors, governmental RTDI policies and innovation system development—within national borders (See Figure 2). Guided by this theme, we examine three research questions: (1) How could international factors shape national

RTDI policies?(2) How should governments respond properly to international factors? and (3) How does a government's response further influence the evolution of innovation systems within national borders?

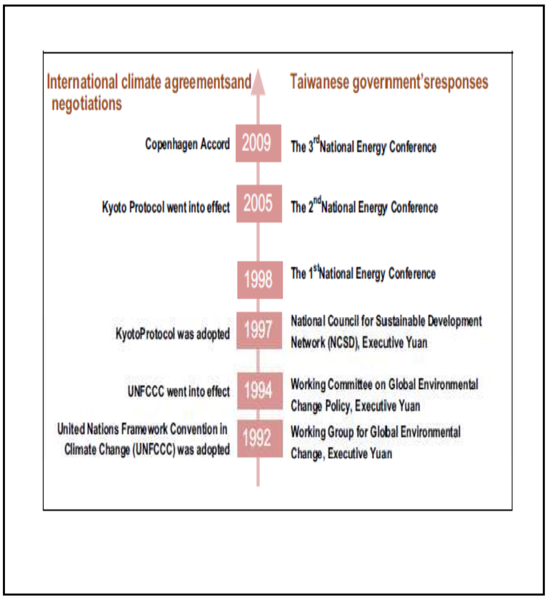
This study is structured as follows. Section 2 establishes the analytical framework while Section 3 details the methodology. Section 4 provides the results and Section 5 discusses the consistency and appropriateness of Taiwanese biodiesel policies. This is followed by the conclusion in Section 6.

Table 1 Bio-fuels global production (Top 16 countries and EU-27), 2013

COUNTRY	FUEL ETHANOL	BIODIESEL	HVO	TOTAL	COMPARISON WITH TOTAL VOLUMES PRODUCED IN 2012
			billion litres		
United States	50.3	4.8	0.3	**55.4**	+1.2
Brazil	25.5	2.9		**28.4**	+4.1
Germany	0.8	3.1		**3.9**	+0.2
France	1.0	2.0		**3.0**	+0.1
Argentina	0.5	2.3		**2.7**	-0.3
The Netherlands	0.3	0.4	1.7	**2.5**	no change
China	2.0	0.2		**2.2**	-0.1
Indonesia	0.0	2.0		**2.0**	+0.2
Thailand	1.0	1.1		**2.0**	+0.5
Canada	1.8	0.2		**2.0**	+0.1
Singapore	0	0.93	0.9	**1.8**	+0.9
Poland	0.2	0.9		**1.2**	+0.3
Colombia	0.4	0.6		**0.9**	no change
Belgium	0.4	0.4		**0.8**	no change
Spain	0.4	0.3		**0.7**	-0.2
Australia	0.3	0.4		**0.6**	no change
EU-27	**4.5**	**10.5**	**1.8**	**16.8**	**1.3**
World	**87.2**	**26.3**	**3.0**	**116.6**	**7.7**

Source: REN 21 Steering Committee 2014

Figure 1 The progress of Kyoto Protocol and the government response



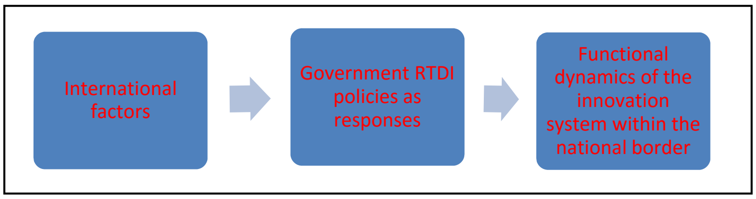
Source: Shyu 2014

Table 2 The domestic production of bio-diesel in Taiwan (2005-2015

Year	Production (kL)
2005	679
2006	1876
2007	3717
2008	19,088
2009	31,620
2010	43,774
2011	56,939
2012	82,872
2013	96,234
2014	42,590
2015 (Jan-May)	0

Source: Bureau of Energy, 2015

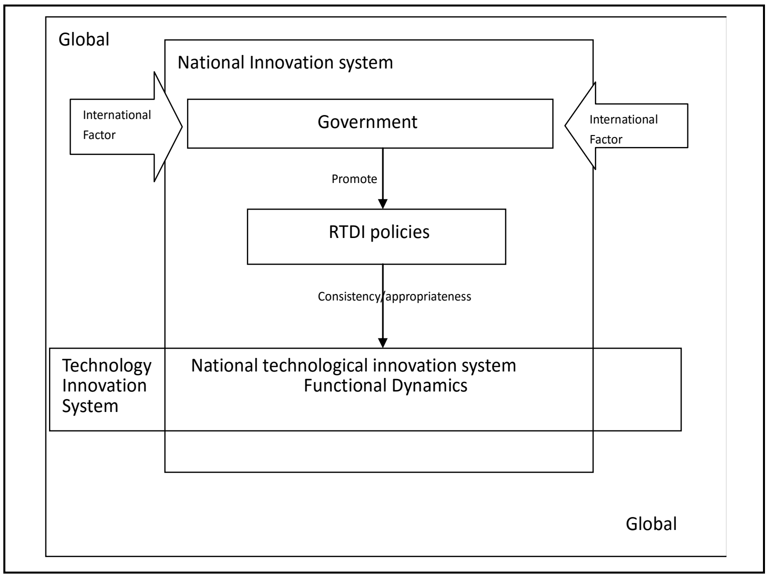
Figure 2 The theme of the article



2. Analytical framework

This study establishes a new analytical framework, called the national technology innovation system (NTIS), to analyse Taiwan's empirical experience. This framework integrates the contributions of both the national innovation system (NIS) and the technology innovation system (TIS). While NIS recognises an innovation system according to the geographical boundary of a nation (Freeman 1987; Nelson and Rosenberg 1993), TIS examines an innovation system from the perspective of a knowledge field developed globally (Carlsson et al. 2002). The intersection of a national and a technological innovation system is defined as a NTIS (as shown in Figure 3).The NTIS following Jacobson (2008) comprises three elements: actors, networks and institutions. The actors include individuals and organisations, such as firms and universities. These actors within the networks would interact with each other to generate, diffuse and utilise the technology. Their interactions are deeply shaped by national institutions, whether formal (i.e. regulations and laws) or informal (i.e. culture and routines). In fact, as described by Bergek et al. (2008), governmental RTDI policies as a special form of national institution, influence the dynamics and performance of the TIS within a nation, thus giving rise to the NTIS. Since the NTIS is the intersection of a national and a technological innovation system, international factors that influence TIS dynamics in a global context will also affect the development of the domestic NTIS. Thus, international factors would frequently motivate national governments to promote particular RTDI policies as a response to them. Howa government responds to these international factors, i.e. through the promotion of specific RTDI policies will have further impact on the dynamics of the domestic NTIS. Thus, the NTIS framework would been riched by related research on the effects of international factors and the analysis of RTDI policies.

Figure 3 The analytical framework



Gee and McMeekin (2011) made one of the first attempts to analyse the effects of international factors on national RTDI policies. The two authors described how distinctive governmental responses to international factors would eventually shape the divergent technological trajectories of innovation systems in different countries. Studying the bio-ethanol industries in the United States and Brazil, the authors investigated the impact of three international factors: two energy crises in the 1970s (the Arab Oil Embargo in 1973 and the OPEC Oil Crisis in 1979) and the threat of climate change addressed by the Kyoto Protocol in the 2000s. Both the US and Brazilian governments responded differently to each of the three international factors and this ultimately led to the evolution of bio-ethanol industries that were very different in each country. The distinctive responses of each government as described by Gee and McMeekin (2011) were driven by the particular institutional arrangements of each country's political system and technological competences. Such distinctive policy responses would then lead to specific policy objectives and instruments that would have a significant impact on the direction and momentum of the system evolutionin each country. Nevertheless, the authors only considered the sequence of international factors and each government's distinctive responses; they did not formulate substantial policy guidance to aid government officials in deciding on the appropriate RTDI policies as suitable responses to international factors.

Other analyses of RTDI policies provide rich insights, with consistency and appropriateness recognised as the two main guidelines for setting governmental policies. Indeed, governments should maintain consistency in their RTDI policies over time, to maximise public support for the innovation systems.

According to Chung (2013), consistency can be examined from two aspects. First, the objectives and instruments of the set of interrelated policies should not be contradictory, but ideally should complement each other and offer no paradoxical incentives to feed the dynamic development of the innovation system. And second, the direction for the implementation of each policy should be complementary to its objectives. Moreover, RTDI policies should be appropriate in that they match the system's functional dynamics. The functions of an innovation system as expressed by Jacobson and Johnson (2000) are the contributions of a component or a set of components to the system's performance. Such a functional pattern is unique compared to those of other systems, and evolves over time (Bergek et al 2008). In fact, there are seven key functions of an innovation system as identified by Hekkert et al (2007), i.e. Entrepreneurship Activities (Function 1), Knowledge Development (Function 2), Knowledge Diffusion (Function 3), Guidance of Search (Function 4), Market Formulation (Function 5), Resource Mobilisation (Function 6), and Legitimation (Function 7). Table 3 provides the definitions of each of these functions.

Based on the literature above, we adopt the NTIS framework for analysing Taiwan's biodiesel innovation system. The analytical framework as exhibited in Figure 3assumes that international factors will influence governments to promote particular RTDI policies as a response to them.

To respond properly to international factors, governments should maintain the consistency of their RTDI policies while at the same time implement these policies to appropriately match the functional pattern of the NTIS. In this way, the RTDI policies could play a positive role in supporting the NTIS's functional dynamics. Since there has been little discussion among existing literature (such as Huang and Wu 2008) on Taiwan's experience in developing its biodiesel industry, we have chosen it for an in-depth empirical study.

Table 3 Definitions of functions

System Functions	Definition
Function 1: Entrepreneurship Activities	The presence of active entrepreneurs is a prime indication of the performance of the innovation system. The entrepreneurs' risky experiments are necessary to cope with uncertainties for new combinations of technological knowledge and applications and markets. Entrepreneurs can either be new entrants or incumbent companies.
Function 2: Knowledge Development	Mechanisms of learning are at the heart of innovation process. The activities of research and development and knowledge accumulation are prerequisites within the innovation system.
Function 3: Knowledge Diffusion	The essential function of networks is the exchange of information. Network activity could be regarded as precondition to 'learning by interacting'.
Function 4: Guidance of Search	Guidance of the search refers to the activities within the innovation system which can positively affect the visibility and clarity of specific wants among technology users. When various technology options co-exist, specific foci are chosen for further investment. The process of selection is not simply a matter of market or government, but an interactive process of exchanging ideas between different actors.
Function 5: Market Formulation	New technology often has difficulty to compete with embedded technologies. Thus it is important to create protected space for new technologies. The protected space could by established by the formulation of temporary niche markets, the creation of competitive advantage by favorable tax regimes and minimum consumption quotes.
Function 6: Resource Mobilization	Resources, both financial and human capitals, are necessary as a basic input to all activities within the innovation system. The resources could be made available by industry or government.
Function 7: Legitimation	The advocacy coalition can function as a catalyst to create legitimacy for new technology trajectory. Legitimation refers to social acceptance and compliance with relevant institutions. The actors' response to policies, agreement or opposition, are revealed through lobbying activities or the compliance with the policy implementation. Such responding activities could be practiced by particular interest groups or individual actors.

Sources: Hekkert et al (2007)

3. Methodology

Data for this study is collected through two rounds. The first is through a historical event analysis, while the second round uses in-depth expert interviews. Each round of data collection is introduced below.

In the first round, the historical event analysis is conducted through desk research. This method, established by Negro et al. (2008),is adopted to map the historical background of the interplay between the Kyoto Protocol (the international factor) and Taiwan's biodiesel policies, their contents as well as the structure and functioning of its biodiesel innovation system. The main events researched are the activities revealing the functional pattern of the biodiesel NTIS in Taiwan (as shown in Table 4), with the information sourced from written documents including newspapers, journals, government reports and websites.

In the second round of data collection, we conduct in-depth expert interviews to seek information which are not found in written documents. Since this study also aims to understand the consistency and appropriateness of policy implementation, we select interviewees who could reveal the actual conditions of policy implementation as well as the stakeholders' attitudes towards the implemented policies. We interviewed 13 experts who have been deeply involved in the innovation and production of biodiesel in Taiwan. They comprise five government officials, six industrial experts and two academics. We use semi-structured questionnaires for each interview and adjust supplementary questions according to each interviewee's character and role, to gain additional research value from each interview.

4. Results

The biodiesel industry in Taiwan emerged after 1997, but has faced interruptions since mid-2014. In this section, we divide the development of the Taiwanese biodiesel industry into three phases: emergence and initial expansion (1998–2008), continued expansion (2009–2013) and industry stagnation (2014–2015). Table 5 contains a summary of the relevant government policies, to provide a better understanding of their contents, i.e. policy objectives and instruments.

4.1 First Phase: Emergence and initial expansion (1998–2008)

The preliminary biodiesel policy guidance was initially revealed at Taiwan's First and Second National Energy Conferences held in response to the Kyoto Protocol. The First National Energy Conference was convened in 1998after the signing of the Kyoto Protocol in 1997. It concluded that by 2020, Taiwan's CO2 emissions should be reduced to 2000 levels, and that new renewable energy should account for 1%–3% of the country's total energy consumption (Bureau of Energy 2009). To reduce CO2 emissions, the government also directed the Ministry of Economic Affairs and the National Science Council to fund research projects that would systematically evaluate the potential of the mass production of first generation biodiesel made from used cooking oil (F2, F6) (MOEA 1999; NSC 1999).Subsequently in 2005, the Second National Energy Conference was convened when the Kyoto Protocol came into effect. The target of reducing CO2 emissions was decreased; since the government conceded that it was difficult to reduce CO2 to 2000 levels by the year 2020, it established a new schedule stating that from 2005 to 2025, the average growth rate of CO2 could be as much as 1.5% and that it be reduced to 1%, the same level as OECD countries, only after 2025 (Bureau of Energy 2005, 86, 90). Even though this schedule was considered to be a slight concession for the reduction of CO2 emissions, Taiwan still maintained its vision of low carbon and sustainable development (F4). Concrete R&D and regulatory policies were launched to support the new emergence of biodiesel, in accordance with the policy guidance revealed in the two National Energy Conferences. The government also reaffirmed that its policies would continue to support the development of first generation biodiesel made with used cooking oil as a measure to reduce CO2 emissions.

R&D policies were promoted before the regulatory ones. Indeed, since 2000, the Ministry of Economic Affairs through the Technology Development Program, has allocated research funding to the Industry Technology Research Institute (ITRI), a public research institute under the Ministry, to support the process innovation of biodiesel (F6). ITRI refined biodiesel with used cooking oil and successfully constructed the first trial biodiesel refinery factory in 2004, which was able to produce 3,000 tonnes per year (F2) (NSC 2013). The implementation of ITRI's Technology Development Program was positively received by private small and medium enterprises (SMEs) (F7). ITRI's innovation was initially transferred to Taiwan NJC Corporation, the country's first biodiesel company, in 2004 (F1, F3). The company, a joint venture between the domestic NICE Group and New Japan Chemical Corporation (F6), established the first formal biodiesel refinery factory in Taiwan through technology transfer from ITRI (TNJC 2014). Hereafter, several newly set-up SMEs also transferred the same process innovation from ITRI to establish new factories (F1, F3). Several established chemical oil companies, such as Chant Oil Corporation, also expanded their business and invested in the recycling service of used cooking oil with partial support from the Technology Development Program (Chant Oil 2014),to provide raw materials for the refinery factories (F1, F6). In 2007, in cooperation with the Ministry of Economic Affairs, the Environmental Protection Administration also established a system to recycle used cooking oil (Environmental Protection Administration Waste Management Office 2013). Consequently, the public system and private companies were able to recycle 100,000 tonnes of used cooking oil annually, which could maximise the blending ratio between biodiesel and oil to turn them into B2 oil[1]. In reality, the refinery factories utilised the recycled used cooking oil to produce B100 oil, which was purchased by the public oil company, China Petrol Corporation. The Corporation, which (F7) had been investing in the biodiesel business since 2007 in support of the Ministry of Economic Affairs (F6), blended the B100 oil to turn it into B1 oil and delivered this to its own petrol stations (Chen et al.

[1] B2 oil is the blending ratio between 2% biodiesel and 98% oil.

2008).

China Petrol Corporation also invested in genetic modification to improve the genes of non-edible energy crops, such as Jatrophacurcas and microalgae (F6). To accelerate the accumulation of related knowledge (F2), they cooperated with universities to develop second generation biodiesel from the beginning (F3). For example, the Corporation has collaborated with National Kaohsiung Marine University since 2007 to evaluate the possibility of feeding Cyanobacteria in Taiwan's west seashore (Editorial Office 2007).

The regulation of the blending ratio between biodiesel and oil was formally launched in 2008 when the domestic biodiesel production system was established. In the same year, the Ministry of Economic Affairs implemented new clauses of the Act, compelling all domestic vehicles to be refuelled with B1 oil (Bureau of Energy 2014). This regulation, in fact, formulated a stable market for the biodiesel industry (F5).

4.2 Second Phase: Continued expansion (2009–2013)

The policy guidance revealed at the Third National Energy Conference continued to guide the growth of biodiesel in Taiwan (F4). In 2009, the Third Conference was held to follow-up on the progress of the Copenhagen Accord in the same year. Following the Conference, the government once again adjusted the emissions target, this time to reduce emissions of CO_2 to 2008 levels between 2016 and 2020, and to achieve 2000 levels only by 2025. The government, once again, reaffirmed its vision to reduce CO_2 emissions and ensure sustainable development. Moreover, to fulfil this vision, the government further encouraged the innovation of second generation biodiesel made with algae (Bureau of Energy 2009).Guided by the policy announcement, substantial regulatory and R&D policies were simultaneously implemented to support the steady expansion of the biodiesel industry.

The Act was amended with new clauses in 2009 and on this basis, the Ministry of Economic Affairs forced all domestic vehicles to refuel with B2 oil in 2010 (Bureau of Energy 2014). Such a regulation was expected to increase the domestic market for the biodiesel industry. However, in 2011, a group of biodiesel SMEs complained to the Legislative Yuan that China Petrol Corporation did not have the rights to purchase domestic biodiesel among its highest priorities. Only 35%–45% of China Petrol Corporation's biodiesel was acquired from domestic SMEs, while the remaining55%–65% were low-priced imports from the United States that had been generously subsidised by the US government to promote renewable energy. In other words, a significant part of the domestic market was enlarged for imports (-F5). The SMEs that could not supply biodiesel to the China Petrol Corporation filed for bankruptcy and by 2011, only five out of 11 SMEs remained in the biodiesel industry (-F1). From the SMEs' perspective, the competition with imports was unfair (Ho and Low 2011), and their lobbying prompted positive response from the Ministry of Economic Affairs and the China Petrol Corporation (F7). Until 2013, 96% of the biodiesel used in Taiwan was domestically produced (Bureau of Energy 2014). With the domestic market for biodiesel enlarged by the regulation of B2 oil, private SMEs were able to remain in the biodiesel industry, which rapidly increased domestic production to almost 70%from 2011 to 2013 (F1). The Ministry of Economic Affairs also put forth plans to launch a new regulation on the use of B5 oil in 2016, expecting to further increase the domestic market for biodiesel (F5) (Chen 2011).

Also during this period, the R&D policy on the 'National Energy Program' (now known as the National Program) was promoted to fund universities conducting research on second generation algal biodiesel (F6). The universities (F7) have responded positively to this move by the National Program to support them in the accumulation of knowledge on algal biodiesel (F2). As an example, the National Yang-Ming University received National Program funding and successfully simulated the genetic modification of blue-green algae that would release more carbonic anhydrase and thus absorb more CO2 (NYMU 2012).

The simultaneous implementation regulatory and R&D policies was greatly supported by China Petrol Corporation (F7), which launched new investments with expectations that the biodiesel market would be enlarged. In 2009, the Cooperation signed a memorandum of understanding (MOU) with the Indonesian government on plans to cultivate Jatrophacurcas in Indonesia on a large scale (Tang 2009). Although the MOU was eventually not put to practice due to a disagreement with the Indonesian government, the Cooperation continued investing in new research projects such as the genetic modification of algae and the technologies of interesterification (F2) (Wu 2012). The results of these projects were expected to contribute to the innovation and production of second generation biodiesel.

4.3 Third Phase: Industry stagnation (2014–2015)

The conclusion of the Third National Energy Conference continued to guide the promotion of regulatory and R&D policies after 2014. Yet the actual implementation of these policies was not successful; while the National Program was executed according to its original plan, the regulation of the Act was suspended. There was in fact no consistency in the implementation of the two types of policies.

The 2010 regulation of the Act's new clauses compelling all vehicles to refuel with B2 oil was abruptly terminated in mid-2014, after complaints from several tour bus enterprises that their buses using with B2 oil would occasionally stall and potentially cause traffic accidents (-F7). The Ministry of Economic Affairs went on to mandate that all petrol stations should provide pure diesel, thus obliterating the market for biodiesel, which in turn had an impact on the development of its industry (-F5) (Tang2014). The Ministry of Economic Affairs issued directives for existing stocks of biodiesel already produced by SMEs to be supplied to China Petrol Corporation, which would convert them into low-priced fuel oil. Nevertheless, since fuel oil was similarly priced to biodiesel, the Corporation no longer had any incentive to purchase biodiesel from the SMEs, which eventually exported their stock of used cooking oil—used as the raw material for biodiesel—to Europe. Shortly after, Taiwan totally ceased to produce biodiesel (-F1) (Huang 2014).

The R&D policy on the National Program continued to be implemented to encourage the innovation of second generation algal biodiesel, even though the regulation of the Act was suspended. In fact, since 2014 the National Program has involved more companies in its research projects and encouraged them to transfer more second generation biodiesel technologies from universities (F2, F3) (MOST 2015). Yet, since there was no longer a market for biodiesel in Taiwan, it was quite difficult to persuade public and private companies to transfer the knowledge of second generation biodiesel for further innovation and production (Hsu 2014).

5. Discussion

This section discusses the consistency and appropriateness of Taiwan's biodiesel policies. As mentioned above, Taiwan has not been able to maintain the consistency of its regulatory and R&D policies for biodiesel, which in turn have not been very appropriate for the growth of its biodiesel innovation system. We discuss these issues further in the following paragraphs, keeping in mind the definitions of consistency and appropriateness noted in Section 2 of this study.

The consistency of Taiwan's regulatory and R&D policies for biodiesel was maintained during the First (1998–2008) and Second Phases (2009–2013) of its industry's development; however, it was not maintained in the Third Phase (2014–2015). In the First Phase, the policies' objectives and implementation were both consistent. The objectives of the regulatory policy contained in the Act—to promote 'sound development of the oil industry' and 'at the same time give equal consideration to environmental protection'—were not contradictory to the R&D policy of the Technology Development Program, whose objectives included the intention to 'initiate R&D innovation' and to 'break ground on industrial technology development'. In fact, in response to the Kyoto Protocol, both the regulatory and R&D policies tended to promote biodiesel as the industry that would supply innovative renewable energy to the country and help it reduce GHG emissions. The two kinds of policies were also consistently implemented. The R&D policy was initially implemented to establish the supply chain for biodiesel, and only until the establishment of the domestic supply chain, while the regulatory policy guided the distribution of biodiesel in the domestic market. Moreover, in the Second Phase the objectives and implementation of the regulatory and R&D policies were also consistent. The objectives of the regulatory policy contained in the Act were complementary to the R&D policy on the National Program that aimed to achieve 'security, efficiency and cleanliness of energy'. Both types of policies were intended to develop the biodiesel industry to supply the country with renewable energy, and were promoted together. However, by the Third Phase, there was a contradictory implementation of the regulatory and R&D policies. The regulatory policy of the Act was terminated and this squeezed the domestic biodiesel market, while the National Program was still funding the innovation of second generation biodiesel and encouraging companies to transfer such technologies. Given that companies subsequently lost interest in the innovation and production of biodiesel, it is difficult to say that both the Act and the National Program have successfully supported the development of Taiwan's biodiesel industry, to help reduce its GHG emissions in response to the Kyoto Protocol.

The set of interrelated biodiesel policies—regulatory and R&D—were only appropriate in the First and Second Phases and not in the Third Phase. In the First Phase, the policy guidance which was revealed at the First and Second National Energy Conferences *guided the search* for biodiesel (F4). The R&D policy of the Technology Development Program *mobilised resources* (F6) to encourage *knowledge development* (F2) and *technology transfer* (F3) from the ITRI to private SMEs, and the regulatory policy of the Act *formulated the market* for B1 oil (F5). Such implementation of the policies was *legitimised* by companies (F7), while private

SMEs were newly setup (F1). Both private SMEs and a public company, China Petrol Corporation, initiated new investments into the production and distribution of biodiesel (F6). The policies continued to be appropriate in the Second Phase of the industry's development. The Third National Energy Conference continued *guiding the search* for biodiesel (F4). The regulatory policy of the Act expanded the *formulated market* for B2 oil (F5), and the R&D policy of the National Program *mobilised resources* (F6) to encourage the *knowledge development* (F2) of algal biodiesel in universities. The implementation of the two types of policies was *legitimised* by universities and companies (F7). The private SMEs remained in the industry, expanding their production of biodiesel, while the China Petrol Corporation initiated new investments in research projects related to second generation biodiesel (F1, F6). Nevertheless, the appropriateness of such policies was dramatically reduced in the Third Phase. The regulatory policy of the Act that once expanded the market forB2 oil was terminated, and therefore eliminated the *formulated market* (-F5). Even though the National Program continued *mobilising resources* (F6) to encourage universities to *develop knowledge* of algal biodiesel (F2) and persuade companies to *transfer technologies* from the universities (F3), the National Program alone could not stimulate companies to develop second generation algal biodiesel. As a result, both types of policies were not very appropriate for the biodiesel innovation system.

In sum, the Taiwanese government promoted a set of RTDI policies to develop biodiesel as a response to the Kyoto Protocol. However, the consistency of these policies was only maintained in the First and Second Phases of the development of its biodiesel industry, and the policies were sufficiently appropriate for the emergence and continued expansion of the biodiesel innovation system. However, in the Third Phase, the originally consistent policies were not implemented in a complementary direction, and they eventually were very limited in their appropriateness and even caused the industry's stagnation.

In fact, Taiwan's empirical experience in the development of its biodiesel industry draws some theoretical insights for the analysis of RTDI policies. Following the sequence of research questions noted in Section 1, in this section we refer to three policy implications that could contribute towards the development of RTDI policies for renewable energy industries.

First, international factors could actually motivate the promotion of national RTDI policies. We noted in Section 1 that the international dimensions of national policies have seldom been discussed by existing literature on innovation systems. Through exploring Taiwan's experience in developing its biodiesel industry, however, we find that the direction and principle of international factors will shape the objectives of national RTDI policies which play a functional role in guiding the search for technological trajectories of the NTIS. For instance, even if a country is not a signatory of a particular international treaty, it is still governed by the treaty. In other words, the international treaty would play a role in guiding the search that eventually shapes the functional dynamics of technology innovation systems in countries across the world.

Second, the government should properly respond to the international factors with consistent RTDI policies that appropriately match the functional dynamics of the NTIS. We review Gee and McMeekin (2011)'s study in Section 2 and find that it has not provided concrete policy guidance for governments to promote their policies as a suitable response to international factors. Thus, in this study, we offer substantial policy guidance in that governments should maintain the consistency of a set of interrelated RTDI policies that match the functional patterns of the NTIS. However, since different NTIS possess unique functions, each of them should be supported by different sets of RTDI policies. Policies that are replicated from another NTIS in the country or from other countries would not be effective. In practice, different NTIS in the field of renewable energy should be supported by different RTDI policies. A policy copied from a particular NTIS of renewable energy will not match the functional dynamics of another. For example, the policies that are effective for the innovation of solar energy will not fit the development of bio-energy.

Finally, government RTDI policies that could be motivated by international factors influence the performance of the NTIS. As we have shown with Taiwan's example, government policies were able to initiate the emergence—but also cause the stagnation—of a new renewable energy industry. The positive and negative effects of the policies on the NTIS change over time. Therefore, governments should take note of changing dynamics of the NTIS and maintain the consistency of their policies over time.

6. Conclusion

This study has both theoretical and empirical contributions. Theoretically, this study establishes a new integrated framework intended to explore how international factors could influence national RTDI policies, which, in turn, would further shape the dynamics of the NTIS within national borders. Empirically, this study analyses the biodiesel industry in Taiwan, which has received little attention from the academic community till date.

However, this study also has two limitations. First, we only apply the framework of the NTIS to the empirical example of the Taiwanese biodiesel industry. More empirical examples are needed to further explore the analytical framework. Second, we only adopt a qualitative method in our study. More scholars, applying divergent methodologies, are needed to achieve an in-depth analysis of the NTIS framework.

Acknowledgement
The authors are grateful for the research funding from the Ministry of Science and Technology (MOST102－2410 － H－ 006－044 －).

References

Bergek, Anna, Staffan Jacobsson, Bo Carlsson, Sven Lindmark, and Annika Rickne. "Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis." *Research Policy* 37 (2008): 407-29.

Carlsson, Bo, Staffan Jacobsson, Magnus Holmén, and Annika Rickne. "Innovation Systems: Analytical and Methodological Issues." *Research Policy* 31 (2002): 233-45.

Carlsson, B. , and R. Stankiewicz. "On the Nature, Function, and Composition of Technological Systems." *Journal of Evolutionary Economics* 1, no. 2 (1991): 93-118.

Chant_Oil. *About Chen Oil*. Chant_Oil http://www.chantoil.com.tw/e-all.php?fname=p1&top=1 (accessed 18 Dec, 2014), 2014.

Chen, Ming-de. "The Plan for Overall Suply of B5 Oil " In *Energy Knowledge Library* edited by Industrial Technology Research Insitute. Bureau of Energy: http://km.twenergy.org.tw/KnowledgeFree/knowledge_more?id=101 (accessed 17 July, 2015), 2011.

Chen, Wen-qin , Nan-ming Wu, Guo-di Chen, and Wen-zheng Lu. "Application and Production of Bio-Diesel in Taiwan." [台灣地區生質柴油生產及應用現況.] In *2008 Conference on Environmental Polution* edited by Yuanpei University. Yuanpei University: Yuanpei University, 2008.

Chung, Chao-chen. "Government, Policy-Making and the Development of Innovation System: The Cases of Taiwanese Pharmaceutical Biotechnology Policies (2000–2008)." *Research Policy* 42, no. 5 (2013): 1053-71.

Energy, Bureau of, ed. *The Conclusion and Implementation of National Energy Conference in 1998 (87年全國能源會議結論執行成效與檢討)*. Taipei: Bureau of Energy 2009.

———. *The Development of Sustainable Renewable Energy--Bio-Fuels [發展永續的再生能源--生質*

能]. Bureau of Energy http://web3.moeaboe.gov.tw/ECW_WEBPAGE/webpage/book1/page3.htm (accessed 15 Dec, 2014), 2014.

———. *The Monthly Report of Bureau of Energy* edited by Bureau of Energy Bureau of Energy http://web3.moeaboe.gov.tw/ecw/business/web_book/WebReports.aspx?book=M_CH&menu_id=142 (accessed 18 July, 2015), 2015.

———, ed. *The White Book of Energy Policy* Taipei: Bureau of Energy 2005.

Freeman, Christopher *Technology Policy and Economic Performance : Lessons from Japan* London Pinter, 1987.

Gallagher, Kelly Sims, Arnulf Grubler, Laura Kuhl, Gregory Nemet, and Charlie Wilson4. "The Energy Technology Innovation System." *Annual Review of Environment and Resources* 37 (2012): 137-62.

Gee, Sally, and Andrew McMeekin. "Eco-Innovation Systems and Problem Sequences: The Contrasting Cases of Us and Brazilian Biofuels." *Industry and Innovation* 18, no. 3 (2011): 301-15.

HARVEY, M. , and S. PILGRIM. "The New Competition for Land: Food, Energy, and Climate Change." *Food Policy* 36 (2011): S40–S51.

Ho, Mengkuei, and Y.F. Low. "Biodiesel Producers Seek Government Subsidies, Support." *Central News Agency* 18 July, 2011, no. 18 July, 2011 (2011).

Hsu, Elizabeth. "Food Safety: How Fuel Policy Impacts Food Safety." *Central News Agency* 22 Dec (2014).

Huang, Xu-sheng "Used Cooking Oil for Bio-Diesel Is Exported." [廢食油煉生質油 從內銷轉外銷.]*CNA NEWS* (2014): http://www.cna.com.tw/news/afe/201409160367-1.aspx (accessed 11 Feb, 2015).

Huang, Yun-Hsun, and Jung-Hua Wu. "Analysis of Biodiesel Promotion in Taiwan." *Renewable and Sustainable Energy Reviews* 12 (2008): 1176–86.

Jacobsson, Staffan. "The Emergence and Troubled Growth of a 'Biopower'innovation System in Sweden." *Energy Policy* 36 (2008): 1491–508.

Jacobsson, S., and A. Johnson. "The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research." *Energy Policy* 28, no. 9 (2000): 625–40.

MOEA. "Mission of Doit." edited by Ministry_of_ Economic_Affairs. http://www.moea.gov.tw/Mns/doit_e/content/Content.aspx?menu_id=5436 (accessed 20 Feb, 2015), 2015.

———. *Research and Development of New and Clean Energy Report. [新能源及潔淨能源研究開發規劃總報告.]* Taipei: Ministry of Economic Affairs 1999.

Petroleum Administration Act.

MOST. "Overall Objectives of National Energy Program ", edited by Ministry_of_Science_and_Technology.

http://www.nepii.tw/language/en/about-nep-ii/overall-objectives/ (accessed 20 Dec, 2014), 2014.

MP Hekkert, RAA Suurs, SO Negro, S Kuhlmann, and R Smits. "Functions of Innovation Systems: A New Approach for Analysing Technological Change." *Technological forecasting and social change* 74, no. 4 (2007): 413-32.

Negro, Simona O., and Marko P. Hekkert. "Explaining the Success of Emerging Technologies by Innovation System Functioning: The Case of Biomass Digestion in Germany." *Technology Analysis & Strategic Management* 20, no. 4 (2008): 465-82.

Negro, Simona O., Roald A.A. Suurs, and Marko P. Hekkert. "The Bumpy Road of Biomass Gasification in the Netherlands: Explaining the Rise and Fall of an Emerging Innovation System." *Technological Forecasting & Social Change* 75 (2008): 57-77.

Nelson, Richard, and Nathan Rosenberg. "Technical Innovation and National Systems." In *National Innovation Systems: A Comparative Analysis* edited by Richard Nelson. Oxford: Oxford University Press, 1993.

NSC, ed. *Long-Term Development of Energy Technology Plan.[能源科技長程發展計畫.]* Taipei: Natioal Science Council, 1999.

———. *The Report on the Implementation of the National Proram (2009-2013) [「能源國家型科技計畫第一期程(2009~2013)目前執行內容與成效」專案報告]*. http://www.taiwan921.lib.ntu.edu.tw/mypdf/twnen2013.pdf (accessed 18 Dec, 2014): Legislative Yuan 2013.

NYMU. "Nymu Particpated in the National Program and Discovered the Genetic Modification of Blue-Green Algae "[陽明大學能源國家型科技研究成果卓越 微藻捕碳研究躍國際.]. *NYMU* (2012): http://web.ym.edu.tw/front/bin/ptdetail.phtml?Part=news-10108-04&Rcg=1 (accessed 11 Feb, 2015).

Office, Editorial. "Th Introduction of Domestic Energies ". *Energy Monthly* March (2007): 38.

Office, Environmental Protection Administration Waste Management. *The Used Cooking Oil Should Be Recucled by Cleaners* Environmental Protection Administration: http://ivy5.epa.gov.tw/enews/fact_Newsdetail.asp?inputtime=1021029175314 (accessed 18 Dec, 2014), 2013.

REN_21_Steering_Committee. "Renewables 2014 Global Status Report ", edited by REN 21. REN 21: http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf (accessed 12 Feb, 2015), 2014.

Shyu, Chian-Woei. "Development of Taiwanese Government's Climate Policy after the Kyoto Protocol: Applying Policy Network as an Analytical Framework." *Energy Policy* 69 (2014): 334-46.

Suurs, RoaldA.A., and MarkoP. Hekkert. "Competition between First and Second Generation Technologies: Lessons from the Formation of a Biofuels Innovation System in the Netherlands." *Energy* 34 (2009): 669–79.

———. "Competition between First and Second Generation Technologies: Lessons from the

Formation of a Biofuels Innovation System in the Netherlands." *Energy* 34 (2009): 669–79.

Tang, Pei-jun "Cpc Paid 36 Billlion to Cultivate Jatrophacurcas in Indonisia to Stablize Raw Materials of Bio-Diesel ". *Central News Agency* 02 Sep, 2009 (2009).

Tang, Yu-lin. *Bio-Diesel Is in Bad Quality and Stopped by Policies. [生質柴油品質差 政策喊卡.]* China Times http://www.chinatimes.com/newspapers/20140506001400-260102 (accessed 18 Dec, 2014), 2014.

TNJC. *Biodiesel Introduction*. TNJC: http://www.tnjc.com.tw/page/biodiesel (accssed 18 Dec, 2014), 2014.

Wu, Zong-rong. "The Research of Bio-Energy in China Peroleum Corperation ", edited by Green Technology Research Institute. China Peroleum Corperation: http://www.ctci.org.tw/public/Attachment/210511343171.pdf (accessed 17 July, 2015), 2012.