



Paper to be presented at the DRUID 2011

on

INNOVATION, STRATEGY, and STRUCTURE -  
Organizations, Institutions, Systems and Regions

at

Copenhagen Business School, Denmark, June 15-17, 2011

**How do the interactions among actors influence the dynamics and evolution of electric vehicle industry in Taiwan? A sectoral system of innovation perspective**

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**Abstract**

To eliminate the problems of climate warming and oil shortage, many developed & developing countries have devoted a great deal of budgets and efforts to reduce the CO<sub>2</sub> emission and have developed sustainable or clean technology alternatives, such as photovoltaic solar, wind power and electric vehicles. Of which electric vehicles (EVs) is one of the very selective solutions. Since there are still few empirical studies and some theory gaps need to fit in the emerging technological paradigm. From the sectoral system of innovation (SSI) perspective, the paper examines three dimensions of EV SSI, namely; (1) knowledge & technology; (2) actors and networks and (3) institutions (regulations, standards & markets). Thus, this paper aims to explore the development and dynamics of the EV industry in Taiwan and how the Taiwanese governments, firms and research institutes to co-develop local EV innovation system. The paper concludes that a leading firm in Taiwan affects significantly the direction of EVs policy and the inter-organizational networks among innovation system actors as government fails to deal with radical environmental change and decide which niche technology should be invested. Some policy implications to correct these system failures and to solve these bottlenecks are provided.

Jelcodes:O21,R00

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## **Abstract:**

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**Keywords :** Electric Vehicle, Sectorial Systems of Innovation, Technological Paradigm, System Failure

## **1. Introduction**

Electric Vehicle has been a key and primary selection of many advanced countries as well as developing countries to reduce the CO<sub>2</sub> emissions and escape the shortage of fossil fuel in the future. Thus, most of them all have devoted a great deal of budgets on subsidizing non profit research institutes or firms on R&D. In addition, several incentives, such as tax reduction, installment of infrastructure, and so on have been conducted to encourage consumers to purchase EVs. In study we attempt to analyze and discuss the reasons to the formation of an EV industry. We also examine if Taiwan has build up a complete innovation systems for developing EV sector through the lens of sectoral systems of innovation approach. At the end in this paper, some suggestions will be expected to make for the Taiwan government or other countries which are shortage of resource but eager to develop their EV industries to remind them what should be paid more attention when they program and carry out the policy measures.

In the theoretic perspective, EV composes of a variety of theoretic concepts. It occupied a sustainable technology concept, for EV uses battery as the source of power, instead of traditional fossil fuel engine. EV does not solve the problem of shortage of fossil fuel, and also help to reduce a huge amount of CO<sub>2</sub> emission from fossil fuel vehicle. In addition, it also represents a clean technology concept, replacing the “end of pipe” technology. Eco-innovation is a newly

developing conceptual term, which is gradually used in the European countries and getting accepted by other countries in the world. Moreover, we are convinced by the researches who claimed the innovation systems is a good analytical tool to explore and explain the development of a emerging industry or a sector, such as the PV industry, wind power industry, and so on. However, some researchers have claimed that he advocated the Socio-technical approach broadens the concept of SSI by extending to user end (Geels, 2004 & 2007) or attempts to provide a specific solution to sustainable and emerging technology, Strategic Niche Management (Kemp 1998 & 2009). In section 2, we will introduce these related theories for EV industry respectively; In section 3 and 4, we will introduce the methodology and the empirical case study of Taiwan EV industry. And finally are followed by the discussion and conclusion.

## **2. Theoretic Review**

### **2.1. Sustainable Science and Technology Policy**

The concept of sustainable development was placed on the international agenda with the release of the report *Our Common Future* by the World Commission on Environment and Development in 1987. The definition of sustainable development in the *Our Common Future* is that “sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs(WCED, 1987). In addition, the concept of sustainable development has been widely applied in the fields of politics, society, city development, transportation, agriculture, business administration, and education since then. Lin (2005) claimed that sustainable development was embedded two aspects, namely sustainability and development, in which sustainability refers to the ability to maintain the integration of structure, forms and behavior flexibly in a dynamic environment; while development is about how to make human a better life. Generally, sustainable development requires balanced and integrated analysis from three main perspectives: social, economic, and environmental. Each viewpoint (represented by a vertex) corresponds to a domain (and system) that has its own distinct driving forces and objectives (Munasinghe, 1993). The economic view is geared towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasizes the enrichment of human relationships and achievement of individual and group aspirations. The interactions among domains (represented by the sides) are also important to ensure balanced assessment of trade-offs and synergies that might exist among the three dimensions.

In retrospect to the prior science and technology policy researches on sustainable development, which are almost focused on economic activities and policy instruments. Most of them are the incremental innovations, but not the radical innovations. They were declined to control the manufacturing process to delimit the impact to environments by improving current technologies, such as end-of-pipe. The important of such technologies can not be ignored, while technologies

on the radical innovation would play a more crucial role on sustainable development in the ongoing worse environment. Conventional environmental policy is mainly based on economic and regulatory instruments that aim to control the negative impacts of production on the environment ex post. In terms of technological change, these policies have mainly led to incremental changes in the established technologies, and to the development and use of "end-of-pipe" (EOP) technologies. The results obtained may be acceptable in some cases, but in view of the progressive deterioration of the environment we are witnessing, they are clearly not sufficient. The reorientation of the current economic system towards sustainability requires not only incremental improvements in existing technologies and systems, but more fundamental changes in the technology regime in those sectors with the greatest environmental impact ( Mulder et al., 1999, p. 8; Freeman, 1996, p. 37; Arentsen et al., 1999, p. 3). A number of authors admit that it is relatively unlikely that conventional environmental policy measures, not necessarily focused on technological change, may alone be able to bring about this radical change in technologies and practices ( Belis-Bergouignan et al., 2004, p. 202; Kline, 2001, p. 97; Smith, 2000, p. 94; Kuper and Van Soest, 1999; Mulder et al., 1999, p. 26; Kemp, 1996, p. 162; Carraro and Siniscalco, 1994, p. 546; Ayres, 1991, p. 265). While it would have a lock-in effect (sub-optimal) occurred by the conflict in between new and established technologies when the radical innovation technology policies were bringing in.

It may be deduced that faced with the possibility and/or fact of a situation of sub-optimal technology lock-in, the technology diffusion policy should (and can) go beyond establishing ad hoc economic incentives to consider new types of instruments—markedly evolutionary in nature which we have defined as techno-environmental prevention policies and techno-environmental transition policies (Carrillo-Hermosilla, 2006). Take the Japan's vehicle policy for example, the Tokyo Metropolitan Government attempted to replace diesel vehicles with low-emission vehicles, particularly, compressed natural gas vehicles, they observed in the transportation sector, when strong complementarities among the components of a complex technological system exist a failure in coordination results to a state of technological lock-in(Yarime, 2009). Thus, they play a role of coordinator on that policy implementation at the beginning, aiming to open the natural gas vehicle market aggressively. As the growth of the market has meet with the government' expectation, they turned to be as a supporter who only provides subsidies for firms.

Table 1. Elements of a techno-institutional complex

Type of lock-in	Source
Technological	Dominant design, standard tech-architectures
Organizational	Routine, hierarchies, customer-supplier relations
Industrial/System	Industry standards, technological interrelatedness, value-chain relations
Social	System socialization · adaptation of preference and expectation

Institutional Government intervention, legal framework,  
departments/ministries

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source : (del Rio & Unruh, 2007, p.1501)

Xiao (1998) attributed three fundamental reasons that the past policies failed to achieve sustainable development. They are 1) policy failure: the policy analysts and decision makers didn't put the environmental factor into the consideration at the stage of policy making seriously, or the failure of public selection, such as the interest group and agent problem, 2) market failure: when the economic activities boosting, the external effects has been internalized, resulting in market failure, and 3) insufficient institutions: it includes environment and sourcing institution as well as regulation and education, which result in the failure of achieving the planned efficiency and outcome on the sustainable development. To solve the problems mentioned above, (Nill & Kemp, 2009) assess the theoretical rationale, instrumental aspects and the coping with policy constraints of three evolutionary policy approaches which have also been used in empirical studies: strategic niche management, transition management and time strategies. Each approach has its strengths and specific problems and all three have to be further developed and tested out but they hold promise for contributing to non-incremental change with economic and environmental benefits, by shaping processes of variation, selection and retention, with the outcomes feeding back into policy.

## 2.2. Sectoral Systems of Innovation

Edquist (1997) claimed that the major knowledge links in the systems of innovation (SI) approach is useful for its making possible to describe, understand, explain, and influence the processes of innovation. Therefore, he noted that the SI approach is based on two theories. One is a main argument of interactive learning among different actors, whose innovation is seen as a collective learning process (Lundvall, 1992; Freeman, 1987) and the other is the evolutionary economic theory, which emphasize that technology change is the processes of dynamic evolution and path dependence (Nelson & Winter, 1982). Moreover, three systems of innovation approaches are identified in terms of context and boundary as below: (1) national systems of innovation (NSI) (Freeman & Soete, 1997; Nelson, 1993) ; (2) sectoral systems of innovation (SSI) (Breschi & Malerba, 1997; Malerba, 2005) ; and (3) regional systems of innovation (RSI) (Cooke, Uranga, & Etxebarria, 1997).

Chang & Chen (2004) identified and compared three existing systems of innovation approaches toward the knowledge interaction perspective, which was shown in table 2. The NSI approach stresses major knowledge links through inter-organizational knowledge creation that takes place among firms, universities and government—so-called triple-helix interactions (Etzkowitz & Leydesdorff, 2000). The generation and interaction of knowledge are always occurred in the

national boundary, the knowledge transfer facilitating through common language, social, culture codes of communication. Unlike NSI approach, SSI emphasizes the sectoral lever or industry lever, which links between firms and organizations result mainly from technological interdependence. Knowledge transfers could be sector-or technology-bounded interacted with other firms cross the country boundaries. Specifically, different sectors should develop their own strategies in terms of characteristics. Systemic links between technological systems and SSI rest on the science-technology relation and technological complementarities or synergistic inter-technology/inter-sector dependence. Third one is RSI approach, which carries on tacit knowledge sharing and social network embedness. The RSI is a response to the perceived importance of the managerial and technical skills in the local area. Knowledge transfers in RSI are mainly facilitating through co-location learning and tacit in a specific region as given. Saxenian (1991) conduct a research on the computer systems firms in Silicon Valley to illustrate how inter-firms networks account for the sustained technological dynamism of the regional economy.

Table 2. Comparing systems of innovation approaches: the knowledge perspective

Approach	Major knowledge links	Knowledge transfer facilitating factors	Systemic boundaries
NSI	Triple-helix interactions	Common language, social, culture codes of communication	Nation-bounded
TS/SSI	Inter-technological links	Technological complementarities and synergies Science and technology relation	Sector-technology-bounded, or not necessarily nation-bounded
RSI	Tacit knowledge sharing Social network	Co-location learning Tacit knowledge spillover	Region-bounded

Source : Chang & Chen (2004, p.28)

The SSI approach mainly concerns the sectoral specificity regarding on a clear understanding of the nature of technology (e.g., tacit or codified) and the relation between science and technology (Metcalf, 1995). The prior argument is really appropriate for this case of electric vehicle industry, due to the emerging EV industry involved in various actors and networks, triggering complex dynamics of learning. The following section is discussing the main analysis framework in the study.

The SSI approach is a sectoral collective learning system that links knowledge among organizations and firms in the value chain, mainly come from the interdependence and technology flows in inter-technology (Breschi & Malerba, 1997; Lundvall, 1992).

The SSI approach refers to a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and the scale of those products (Malerba, 2002).

The two major theoretic references underpin SSI approach: evolutionary theory and innovation systems approach (Malerba, 2002). Firstly, evolutionary theory is mainly focused on dynamics, process and transformation, which provides sectoral systems of innovation a broad theoretical framework on concept. In addition, there are three economic process occupied in the evolutionary approach, namely, process of variety of creation, process of replication and process of selection, which are applied by the SSI. Another source is the innovation systems approach, which advocates that innovation cannot be completed by single firm and an isolated process, but seen as an interactive and collective process among a great deal of actors (Malerba, 2002).

SSI does not only emphasize on the learning of inter-organization, but also the learning occurred in external agents in the value chain, such as universities, research centers, government agencies and financial institutions, which are the most concern in SSI. In addition, SSI complements the NSI in which more emphasis on the interaction of industrial institutions, links with the external networks, and more specific knowledge and technologies (Malerba, 2002). Therefore, this study selects a typical case of energy technology- electric vehicle, which aims to explore the learning and links of knowledge and technologies among actors in the electric vehicle industry. SSI is adopted as a research framework in this paper, and will have further discussion on its three building blocks as below: knowledge and technology, actors and networks, and institutions.

### **2.2.1 Knowledge and Technology**

Knowledge is recognized as a vital role in innovation and production for firms (Malerba, 2002). It has also asset as the most valuable resources and the primary sources of the rents it generates for firms (Liebeskind, 1996). Knowledge differs across sectors in terms of domain (Malerba, 2002). One knowledge domain refers to the specific science and technological field at the base of innovative activities in sectors (Dosi, 1998 and Nelson and Rosenberg, 1993), and the second domain concerns application, user, and the demand for sectoral products.

Firms may gain their needed knowledge from internal or external source. For particular or core knowledge and the access to complementary bodies of knowledge can be secured through internal development. Internal exploitation is the preferred choice, while the external knowledge market is imperfect (Chesbrough, 2007; Lichtenthaler, 2005; Teece, 1998); However, if the firm cannot secure access to the required complementary bodies of knowledge or the price to develop internal is too high, it may then turn to choose the external sources through the ways that exchange needed knowledge for the firm's valuable knowledge or purchase needed knowledge in external knowledge markets (Arikan, 2009). In addition, Knowledge may have different degree of accessibility (Malerba and Orsenigo, 2000). Great accessibility internal to sector implies lower appropriability: competitors may gain knowledge about new product and processes and, if competent, imitate those new products and processes. While accessibility of knowledge which is external to the industry may related to the scientific and technological opportunities, in terms of level and source (Malerba, 2002). Winter (1984) claimed that if

external knowledge is easily to gain, transformable into new artifacts and exposed to a lot of actors (such as customers and suppliers), then innovative entry may be held. On the contrary, the industry may be concentrated and formed by large established firms (Cohen and Levinthal, 1989).

In the SSI approach, knowledge and technologies constitute major role which focuses on the issue of sectoral boundaries at the center of analysis. Knowledge and technologies constitute main constraints on the full range of diversity in the behavior and organization of firms (Malerba, 2005). Searching links and complementarities among different actors in the sectoral system on innovation also plays a role in defining the real boundaries (Malerba, 2002).

### **2.2.2 Actors and Networks**

A sector is composed of a set of agents, which are organizations and individuals (e.g., consumers, entrepreneurs, and scientists) carrying out market and non-market interactions for the creation, development and diffusion of new sectoral technology and products (Malerba, 2005). The actors in the sectoral system of innovation may cover the firms and non-firms. The former are formal actors in the value chain, such as users, producers, suppliers and the later ones are non-firm actors which include the organizations of universities, financial institutions, government agencies, trade-units, and technical associations. Firms, the key actors in a sectoral system, are involved in the processes of innovation, production, sales of products, and in the generation, adoption and use of new technologies (Malerba, 2002). Non-firm actors can innovate or survive without network (DeBresson & Amesse, 1991). Hakansson (1989) sees firms at the core of networking behavior, identifying three types of behaviors: (1) vertical links in between customers and suppliers; (2) horizontal links in between competitors and others firms providing complementary assets (Teece, 1986); (3) knowledge-generating links with non-firm actors such as with universities and R&D institutions. Moreover, Holman & Jacobsson (2000) proposed a method for identifying actors in a knowledge-based cluster by using a specific "patent class", which is a set of related patents, such as patent co-classifications and patent citations. They stress that such an approach can catch more complete actors in a specific knowledge-based cluster, especially firms in a horizontal links. Malerba (2002) claimed that the most appropriate units of analysis in specific sectoral systems may not only be firms, but also include individuals, firms' sub-units (e.g., R&D center or production department) and groups of firms (e.g., industry consortia).

### **2.2.3 Institutions**

The third building block of SSI approach is the institution. The sectoral system of innovation has also influenced by the impact of institutional environments, which are laws, culture expectation, norms and conceptual systems etc. Agent's cognition, actions, and interactions are shaped by the institutions (Malerba, 2005).

In Scott's (1995) synthesis of institutional theory, three kinds of rules have been distinguished:

regulative, normative, and cognitive. Firstly, regulative institution, for example, regulations, standards, and laws ensure the stability and order of a society.

The second one is a normative institution which refers to values and social norms that govern people's behavior, for instance, the role relationship, values, behaviors norms. The cognitive institution refers to the cognitive rules that constitute the nature of reality and the frames through which meaning is made, such as belief systems, innovation agendas, problem definitions, guiding principles and search heuristics. The first two is that institutions mainly reflect the institutional perspective. When most of people are aware of taking institutions for granted, it will shape the cognition and behaviors of actors within organization, achieve the goal of legitimacy, and then affect the interactions (Nelson & Sampat, 2001).

In the SSI approach, Malerba (2005) considered the dynamic process of institutions that influence each other. In particular, the relationship between national institution and sectoral may go from the sector to the national level. Moreover, Geels (2004) claimed an interactive model of SSI approach, which interact among the different lever institution, innovation system, and actors. The interactive model with innovation system may be dual direction, not a single direction. For example, the innovation system would not only be affected by institutions or rules, but also can enact institutions or rules in turn.

In the institution environment, many institutions, such as intelligent property, standards, labor law and education system, could affect significantly the processes of sectoral innovations. Hung (2002) pointed that the structure of institution in Taiwan has provided the LCD industry a technical support and market opportunity, and it could be explained fairly why the LCD (liquid crystal display) industry has been so successful in Taiwan in recent decades. The prior findings reveal that innovation system, institutions, and actors are embedded with driving force and obstacle effects to some renewable energy industries, such as wind power and PV solar (del Rio & Unruh, 2007; Geels 2004). On contract, Institutions, meanwhile, are also possible as the major factor to make the failure in some sectors. Ancho doguy (2000) stressed that the industrial policy, keiretsu industrial groups, centralized, bank-centered financial system, education institution and employment system are likely to be a key to success in other industries, these arrangements are found to be the source of its weakness in software industry. National institutions may lead to the failure of some industries, which result from a negative effects generated in the technology diffusing process. The hard disk driver industry in Taiwan is another failure example (Hung, 2002).

### **2. 3 Socio-technical systems**

Geels (2004) claimed that the SSI does not explicitly look at the user side and its definition mainly focus on the firms, neglecting other kinds of organization; in addition, he also stressed that TIS seem to narrowed down to social systems('network of agents').

Geels (2004) provides a coherent conceptual multi-level perspective, using insights from sociology, institutional theory and innovation studies to explore transition management.

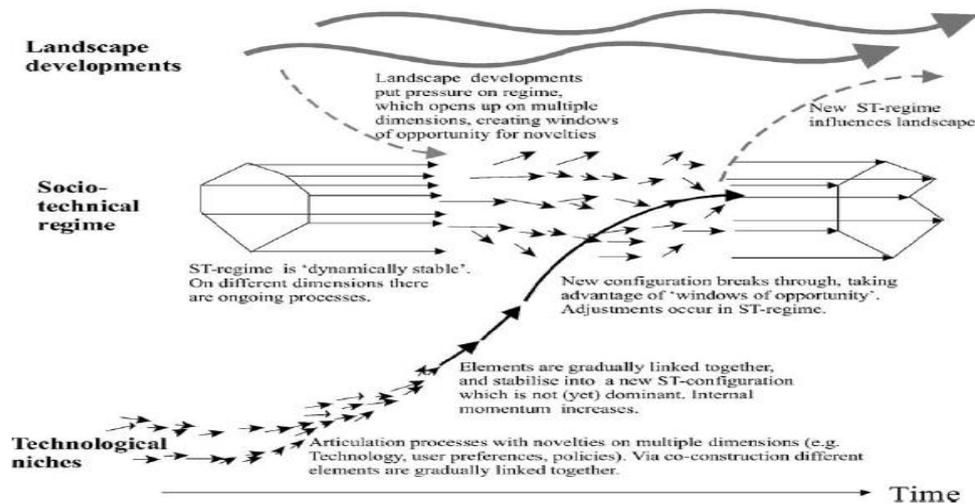


Figure 1: MLP Source from: Geels (2004)

This figure is described the multi-level perspective which proposed by (Geels, 2004). The three levels introduce the understanding of innovation systems which combines technological niches, social technical regime, and landscape developments. Three of these are dynamically interaction each other. Specifically, this study will elaborates more detail of the framework above. It can be separated into three parts. First, see the framework below, technological niches as the locus of radical innovations which are introduced by sociology of technology and evolutionary economics scholars. As the performance of radical novelties is initially low, they emerge in protected spaces to shield them from mainstream market. For example, when new technology emerges, it can trigger actors (such as firms) to explore and invest more in new technical development. Accompanied by expected problems will be produced. Some scholars call this phenomenon as diminishing returns of existing technology(Freeman & Perez, 1988). The emerged problems continue to undermine the trust in existing technology and alter expectation of new technologies. Secondly, the middle part of this framework is introduction of social-technical regime, which brings a buffer to stabilize and align the radical novelties having changes and remain the stuck in particular niches. The major importance of this part is to fulfill the societal functions and useful functionality. This needs to pay more attention to innovation and users. Moreover, firms and other relevant system will play a role to effect on new system. Some firms may lead to pressure on new emerging system and some relevant system may trigger the need for consumer pressures and regulatory measures. Thirdly, the landscape lever describes a new regime that creates major changes in the selection environment. The landscape development brings a new window of opportunity of innovation to break out of its niche. For example, the new energy or transport will be developing, which triggers the sectoral structural changes and creates a new environment in politics.

### 3. Methodology

It has been widely accepted that automobile industry has been a sector that highly depends on close social networks and long period cooperation between buyer and seller. Thus, the automobile industry and market have been long dominated by a few giant automakers such as GM, Toyota, Volkswagen, and so on. New entrants who have no niche technologies, good reputations and practical experiments would hard to be a part of their supply chain. But, EVs seems to crate a window of opportunity to many start-ups or entrants. It also attracts many governments to devote in a great deal of R&D investments on this emerging field, including China, Korea and Taiwan.

Taiwan has been widely recognized as a nation who has strong manufacturing and ICT capability in pass decades. However, none of automobile maker in this country so far can sell its own brand four wheel vehicles to the global market, but many manufacturers have been the 2<sup>nd</sup> or 3<sup>rd</sup> tier suppliers in the supply chain of automobile industry. Following the trend of EVs, Taiwan government launches many policy measures to facilitate its EVs industry or innovation system. In particular, it chooses BEV, instead of HEV, which conducted mostly by advanced countries, as the niche to develop its technological trajectory. This leapfrogging way referred to as some late-comers may be able to leap-frog older vintages of technologies, bypass heavy investments in previous technology system and catch up with foregoing countries (Keun Lee et al., 2009). With the availability of information concern as well as the specialty of its niche selection, this paper chose Taiwan EVs industry as an empirical study in a system innovation perspective.

This study mainly conducts the qualitative research method to collect necessary data or information in two steps. Firstly, we collect the secondary data from various sources, such as the EV related literatures, news, magazines, internet news, forums, web site, and so on. Those data were given to provide a basic understanding of who are the actors, the reasons why actors get involve, and the policy Taiwan government conducted to fosters this industry (part of institutions). However, it still lacks of the knowledge to the key actors, the interactions among actors and the formation of networks. The confidential proposals which have been accepted and granted by governments illustrate the formatting process of networks at the early stage of EVs development in Taiwan. With the proposals, we are able to identify the key actors and further conduct several interviews from them to explore the exchange or share knowledge with each other and to examine the validity of the government policies launched for the growth of local EVs industry.

Multiple informants reduce potential information bias not only by providing a researcher triangulation data (Miller, Cardinal, & Glick, 1997) but also adding some complementary perspectives to the analysis. Secondly, We therefore conducted interviews with the selected

persons who are working for the key players in the public or private sector in this field, including HAITEC, the subsidiary of Yulong group, represented the car maker, ITRI, the most important research institutes in Taiwan, and DoIT, MOEA, the government which is responsible for the provision of R&D subsidy to research institutes, firms and university. Their positions are senior manager, consultant, senior researcher and director. Interviews lasted from 30 minutes to one and half hours. The design of interview questions to various actors are associated the character of the actor operated in their field in EV industry. The collection of the primary data helps us to realize the interactions and dynamics among actors in depth.

#### **4. The case study of Taiwan EV industry**

##### **4.1 Global EV trends**

###### **4.1.1 The history and evolution of Global EV**

In 1838, a Scotsman named Robert Davidson built the first electric locomotive that attained a speed of four miles per hour (6 km/h) and developed almost 50 years earlier than the first internal combustion engine vehicle (ICE) built. The competition between electric vehicles (EVs) and internal combustion engine vehicles (ICEs) has lasted more than one hundred of years so far. Robin Cowan & Staffan Hulten (1996) separated the competitions into five stages: 1) the formative years of the automobile industry, 1885-1905, when no technology dominated, 2) the establishment of the ICTs as dominated, 1905-1920, 3) the consolidation of the position of ICTs 1920-1973, 4) the questioning of ICEs 1973-1998, and 5) legislated, forced introduction of large scale production of EVs after 1998.

In this paper we also try to separate the competition between EVs and ICEs into three waves and observe the evolution of EVs from different perspective and started from 1970 to date. In addition, we summarized that three factors in terms of time and magnitude have plays vital roles to influence the development of global EV industry, namely crude oil price (P), environment concern (E), and technological change (T). At the first wave (1970s-1980s), we observe that the first oil chock and the second oil shock were occurred and lasted 10 years in 1970s, while the weak environmental matters such as air pollution and the premature EV related technologies, in particular the lead-acid battery technologies, were unable to make most countries aware of the importance of developing green vehicles due to its low performance.

At the second wave (1990s), the third oil shock was occurred in 1990, millions of ICTs resulted in serious air pollution in many big cities in US, and the powerful NiMH batteries replaced the lead-acid as the power source of EVs. In 1996, the GM EV1 launched the first EV mass production and seems to start the EV era from US to the world. However, the insufficient supports from US government in regulation and the cost and performance of the NiMH batteries were still under expectation. The EVs initiative in US was failed. Until 1997, at the Conference of Parties III (COP3), Tokyo, Japan, the Tokyo conference on climate change took place.



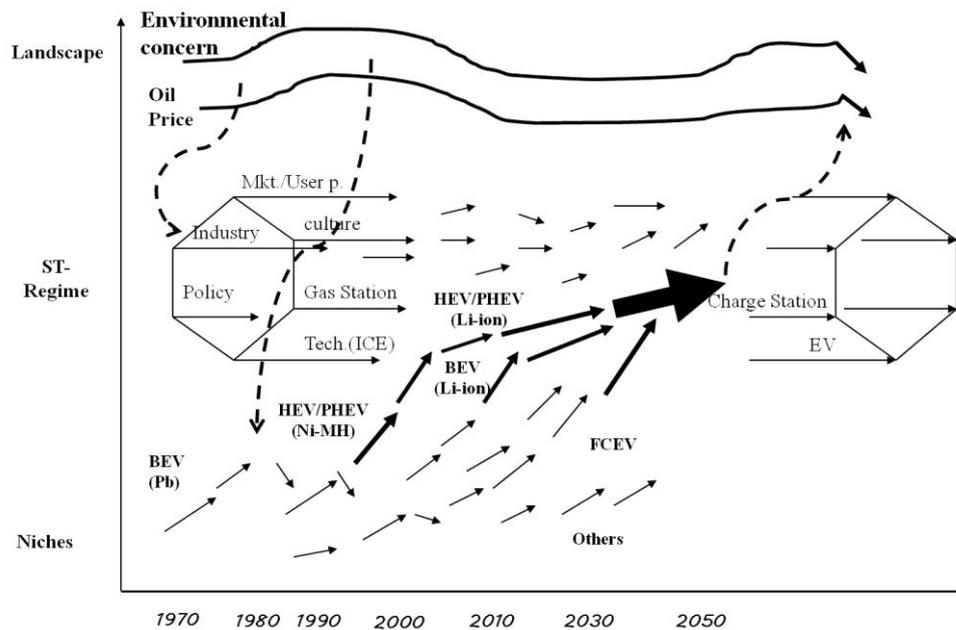


Figure 2: PET model

#### 4.1.2 The policies for advanced countries to foster their development of EV industry

Since the crude price increasing sharply and suddenly, energy shortage, and global warming are getting worse, how to develop green industries and reducing carbon emission have become the main target of many advanced countries in the world. Moreover, EV is embedded with more than 25% integrated energy efficiency, and it can reduce the consumption of gasoline by 96% and the amount of CO<sub>2</sub> emission reduction up to 72%, many major countries have chosen EV as the key selection to achieve their targets of sustainable development on the transportation perspective. The major developed countries, such as the United States, Europe, Japan, as well as the emerging and developing countries, India, Brazil and China, are devoting a huge efforts and budgets for developing the relevant researches on the EV core technology or the commercialization of the system modules applied on EV. For example, the German government approved a plan to make available €500m (US\$712m) of public funding to create an electric vehicle recharging infrastructure and to support battery R&D on August 19th, 2009. Meanwhile, Obama administration approved \$2.4 billion in EV funding to help the US reach his goal of 1 million plug-in EVs on the road by 2015.

#### 4.1.3 Global EVs market

An electric vehicle (EV), referred to as an electric drive vehicle, is a vehicle which uses one or more electric motors for propulsion. EVs are segmented mainly four types, depending on the energy source used to propel the motor as below: 1) hybrid electric vehicle( HEV);2)plug-in vehicle (PHEV);3)full performance battery electric vehicle(FPBEV or BEV); and 4) fuel cell electric vehicle(FCEV). It is also sub-classified into two types of EV, depending on the driving distance of users: one is city battery electric vehicle (CEV) and the other is neighborhood

battery electric vehicle (NEV).

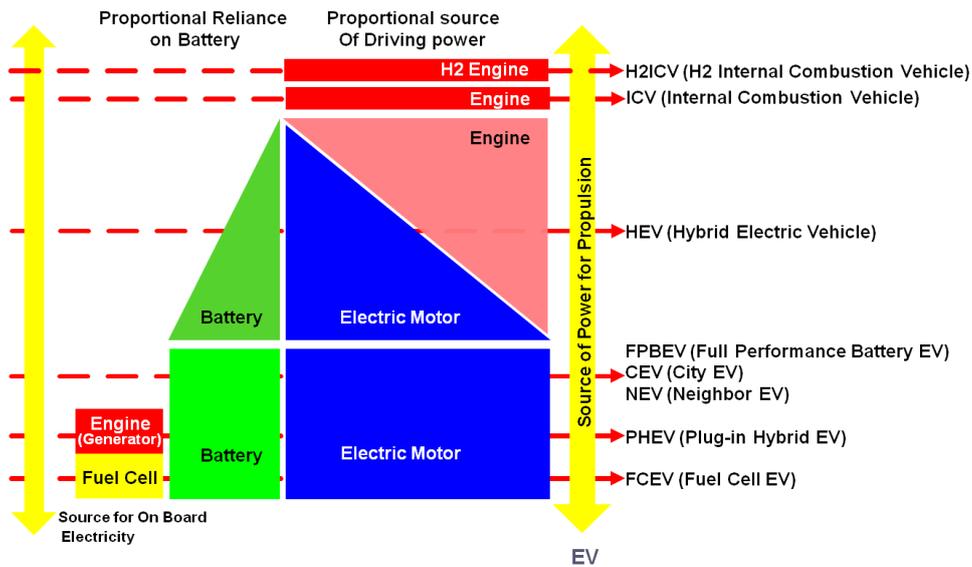


Figure 3: From ICE to EV

So far only HEV are in mass production. About 400,000 HEV were sold in 2006 worldwide, and the similar figure was 1 million in 2008, 2.1 million are expected to be sold in 2010, and 6 million in 2015.

Currently, the demand for HEV mainly comes from the U.S. and Japan, with Toyota and Honda as the major suppliers. Generally speaking, the production of HEV has become an industry, and the production capacity will be much large in the future. China also has plans for HEV, with goals to deliver an annual output of 1 million HEV by 2012, accounting for 10% of the total output of cars in China.

## 4.2 The case of Taiwan EV Industry

### 4.2.1 The history of Taiwan EVs industry

In 1974, National Tsing Hua University successfully developed the first battery electric vehicle (BEV) in Taiwan, dubbed as THEV NO.1, which was funded by National Science Council. The main components of this model include battery and motor in this model were provided by the local manufacturers. The THEV1 used **lead-acid** batteries, weighted in at 1,500 kg. Its highest speed was 80-100 km per hour, and a range of 80 km per charge. However, this project disrupted its further research after a total of 200 cars were produced for the use of the government.

In 1996, Taiwan's largest industrial conglomerate, Formosa Plastics group announced his aggressive project on the development of electric vehicle. Wang Yung-ching, the former

chairman of Formosa Plastics group, claimed that the Formosa group will invest more than tens of billion dollars on building up a complete supply chain of Taiwan EV industry. The project was cooperated with Ya-Tai Co to develop a hybrid electric vehicle (HEV) equipped with nickel metal hydride batteries. After 6 months later, the company showed its first HEV, dubbed as AP-1; However, The project discontinued for many reasons.

In 2007, Tesla, an emerging EVs manufacturer established in US, launched its first generation EV, Roadster, and chose many Taiwanese firms as the suppliers in terms of motor, controller. Meanwhile, Yulong Group, the Taiwan biggest automobile manufacturer which has used to be as the sale agency and local manufacturer of Japanese vehicle maker, collaborated with AC Propulsion (ACP), a US-based automotive technology company, in the development of a battery electric vehicle (BEV), dubbed as LUXGEN EV+. Taiwan government start to launch programs for subsidizing research institutes and firms on EVs related technologies to facilitate the development of EVs industry in Taiwan since 2009.

#### **4.2.2 The policy and the role of government**

To order to catch up the waves of global EVs, Taiwanese government adopted many measures to foster industrial innovation on EV technologies, expecting to achieve two major objectives as below,

1. Promoting Taiwan firms who position as tier 2 or tier 3 up to tier 1 suppliers of global automakers.
2. Assisting one or more local automakers to be the top 10 provider in the global EVs market in 2016.

To enhance to the R&D capability, Department of Industrial Technology (DoIT), the governmental unit that is responsible for subsidizing enterprises and research institutes, has conducted several instruments for fostering the development of EV industry in Taiwan since 2009, of which the most critical tool is the Technology Development Programs (TDP). It is well accepted that subsidies from government are highly important and useful for individual firms as well as a whole industry to facilitate emerging technologies to market at the early stage of new technology development. The TDP have been a long initiative of the DoIT aimed at pooling the research resources from research institutes, the industry and academia to maximize their effectiveness. In 2011, DoIT proposed to subsidize the research institutes such as ITRI, CSIST, ARTC and MIRDC more than US\$ 30 millions in four projects on developing battery, chases system, commercial vehicle and motor and controller module system through the way of cooperating researches among them. In subsidizing industrial part, there are ongoing five projects for 14 local firms, which focus on fostering the innovation of electric vehicle technologies and its key components.

In addition, to push Taiwan's industry to progress from manufacturing towards innovation, R&D, and service, the DoIT encouraged domestic and multinational enterprises to establish R&D centers in Taiwan. Until now, DoIT has approved more than 30 foreign enterprises to establish their R&D centers by subsidizing, of which only a few, two, are related to the EV industry for now.

To accelerate Taiwan-made EVs on the road, On April, 2010, Taiwan Executive Yuan approved a program, dubbed "Intelligent Electric Vehicle Development Strategies and Action Plan", which will focus on developing battery electric vehicle (BEV) and will be carried out in two stages and called for subsidies up to NT\$ 3 billion including pilot test, R&D subsidies and purchase subsidies to fostering the development of EV industry in Taiwan.

During the first three-year stage (2010-2013), the Industrial Development Bureau (IDB), MOEA, the responsible unit for this program, will subsidize the purchase and use of 3,000 pilot electric cars by 10 municipalities. Municipal government and automakers are encouraged to propose jointly their implementation programs to be approval by the IDB. In addition, the program has assigned the public transportation vehicles for official uses to be the first priority to use EVs as alternatives.

In the second three-year stage (2013-2016), the IDB will subsidize the purchase of electric cars directly by consumers. To make EVs more affordable to local residents to use replacing fossil fuel vehicles, Taiwan government also provide tax reduction in ways such as 25% commodity tax reduction and licensing free exemption as incentives to promote EVs. Installment and management of EV charging infrastructure in public area will be a key issue in this stage.

At the end of the program, Taiwan government expected to have capability to produce and sale a total of more than 60,000 BEVs and at least one Taiwanese EV self-brand firm can be established and become the top 10 manufacturers in global EV market.

#### **4.2.3 Knowledge and Technologies**

Differed from the traditional fossil fuel vehicle, EVs are composed of three major components, rechargeable battery, electric motor, and controller. In particular, battery is the most critical component in the EV. Thus, this paper will mainly focus on the discussion of battery in terms of knowledge and technology.

We segmented the battery technologies into three generations for EVs' use, depending on chemicals, included Pb, NiMH, and Li-ion. The first generation of battery technologies for EVs is Pb batteries, which is the cheapest and mature material applied in the battery cell manufacturing. The Pb batteries have widely used on the 3C products, while has vital problems

of low energy density, high pollution and short cycle life as they use for EVs.

Table 3: Types of Rechargeable Battery

Cell Type	Pb	NiMH	Li-ion		
			LiMn2O4	LiNiMnO2	LiFePO4
Cost	1(base)	2.4	6	6	> 10
Safety	Good	Good	Median	Poor	Excellent
Pollution	High	Median	Median	Low	Low
Patent protect	No	No	No	Yes	Yes
Energy density (Wh/L)	100	250	285	> 500	255
Discharge efficiency (W/kg)	300	800	400	300~400	2,000
Energy efficiency (%)	60	70	90	90	95
Cycle life	400	500	> 500	> 500	> 2,000
Recharge time (Hr)	8	4	2~4	2~4	< 2
EV Type	GM EV1	GM EV1s Prius (I/II)	BMW MiniE	-	-

Note: Pb: lead-acid; NiMH: Nickel metal hydride; Li-ion: Lithium

The second generation is Nickel-metal hydride batteries which is one of the most promising power sources for electric vehicles. Most of HEVs currently use the Nickel-metal hydride batteries as the resource of power, such as Toyota Prius, due to this technology has developed in mature and reliable. But the mass production of nickel-metal hydride batteries would make resources of nickel metal fall short and the rare earth for hydrogen-storage alloy would fall short too. In addition, compared with Li-ion batteries, nickel-metal hydride batteries are less energy generated and 30%-40% heavier. Li-ion batteries, the third generation, have become a new choice and conducted by many EVs, such as Tesla Roadster and GM Chevrolet Volt.

The battery system is well known to be as one of the weakest points of EVs (Affanni A. et al., 2005). Moreover, the choice of the battery system has been a critical item. And thanks to an increasing emphasis on vehicle range and performance, the Li-ion battery could become a viable candidate. The Li-ion battery technologies are segmented a number of types, depending on chemicals, included LiMn2O4, LiNiMnO2 and LiFePO4. Of which LiFePO4 has the advantage of high energy density, high discharge efficiency, high safety, long cycle life, while disadvantage of high patent protection.

Taiwan develops the battery technologies in two ways mainly. The first one is that Taiwanese firms gained the producing right from the key patents owner. As mentioned, LiFePO4 is a new

and most promising material for producing Li-ion battery in available. However, the key patents are owned by Phostech. Pihsiang, a Taiwanese manufacturer who has launched the first four-wheeled electric scooter in the world for handicapped or elderly people, has announced that Phostech has granted PHET exclusive right for manufacturing, marketing and distributing C-LiFePO<sub>4</sub> based batteries applications.

The second way is that Taiwan government funded local research institutes and firms to research and development internally. Some excellent research institutes in Taiwan equip with strong capability in machinery and motor manufacturing expertise, such as Industrial Technology Research Institutes (ITRI), the largest and most important one research unit devoting on developing many global leading high-tech in various fields, and the Chung-Shan Institute of Science and Technology (CSIST) . These institutes can be given research grant funded by the Taiwan government to do research and development in some certain field, including the battery technologies. In the Li-ion battery developing perspective, a project manager in ITRI claimed. “Regardless of plug-in hybrid electric vehicle (PHEV), hybrid electric vehicle (HEV), or battery electric vehicle (BEV), Li-ion batteries must meet the significantly higher specifications as power density or high discharge and energy density or high capacity”. The development of Li-ion battery technology in Taiwan lags behind Japan and South Korea. However, an encouraging development of technology, STOBA, was developed by the ITRI recently, a high-safety Li-battery material technology and awarded the R&D 100 Awards by the globally-renowned R&D Magazine, among other achievements by many international enterprises and research institutes. The STOBA is seems as one of the best solutions for upgrading Li-ion battery safety, especially in EV’s high-power applications. Such technological breakthrough may be an once-in-a-lifetime chance for Taiwan-made Li-ion battery technology to possibly overtake Japan and South Korea. In addition, with the grants funded by the DoIT, ITRI and other institutes are jointly searching some new materials for more efficient and high-power battery to apply on the EVs, instead of the LiFePO<sub>4</sub>. Meanwhile, many Taiwanese battery manufacturers are eager to do as the same as the institutes are doing. E-One Moli Energy Corp, a manufacturer of the LiMn<sub>2</sub>O<sub>4</sub> batteries which are used in BMW’s MiniE electric car. But the LiMn<sub>2</sub>O<sub>4</sub> batteries have problem of low safety which need to overcome. Currently, E-One proposes to transfer technology from ITRI, adding STOBA in the LiMn<sub>2</sub>O<sub>4</sub> batteries to solve the safety problem.

In this respective, we do realize so far that the protection of patents in the most promising battery technology is high. Without the permission from the patent owner, none of firms can conduct the contents of patents to produce batteries. Thus, the battery technologies in EV industry could be seems as a low accessibility and high appropriability and high cumulativeness of innovation, due to the key patents are owned and controlled by a few incumbents. Take the LiFePO<sub>4</sub> just mentioned for example, Phostech has only granted few firms to conduct their

patents to manufacturing battery for the use of HEV or BEV. Thus, many countries still have invested a great amount of money on searching alternative materials. Some experts in the filed addressed that if the Phostech offered more firms to their patents of LiFePO<sub>4</sub>, the diffusion of battery and the development of global EVs industry may go faster and widely. Furthermore, the patents to produce HEV have been owned by the well known Japanese automaker, Toyota.

An electric motor converts electrical energy into mechanical energy. Most electric motors operate through interacting magnetic fields and current-carrying conductors to generate force, although a few use electrostatic forces. The types of electric motors for electric vehicles are permanent magnet (PM) and induction motor (IM). Since the rare earth metals which are including the key components for battery and permanent magnet motors have potential shortage of supply from the China who has account for more than 90% of production in the world in 2010. To avoid the problem occurred, Taiwanese firms, such as TECO, has devoted in the development of IM.

#### **4.2.4 Actors (Firms, Research Institutes and University)**

Taiwan has strong manufacturing capabilities on the components for EVs, particularly in the battery section, where there have been a lot of local companies involving in this area. E-one is the biggest battery cell manufacturer in Taiwan, and ranks 10th in the world in 2008. E-one believes the EV industry will be high potential in future, so he announced an increased NT\$ 6 billion investment to build a new battery pack factory and EMS relevant R&D months ago. Another important actor is SIMPO, a local company who is currently the biggest battery manufacturer in 3C industry in the world. He now joins Yulong affiliated companies' "Taiwan Electric Vehicle Plan", aiming to develop the first Taiwan-made EV, accompanied other companies that produce other EV relevant components, such as electric motor, controller, inverter, power control integration system, and so on.

HAITEC who is Yulon's auto-electronic subsidiary is the only automotive-engine developer and manufacturer on the island. Three vehicles are fully developed in HAITEC, including a multi-purpose vehicle (MPV), a sport utility vehicle (SUV), and a mid-sized sedan, with other concepts on the drawing board.

Two of the premier research institutes in Taiwan, ITRI and CSIST, which are working together to develop electric vehicles (EVs), due to they are co-operated on a technology program funded by DoIT,. Both institutes have already teamed up to make various products including bathroom equipment, lighting materials, and shock-absorbing devices for vehicles moving on rails.

To make Taiwan automotives technique become an important part of international automotive

development, accelerate the development of Taiwan automotive industry, MOEA TARC (Taiwan Automotive Research Consortium) was set up in May, 2009, founded by MOEA, who is composed of MIRDC, ITRI,ARTC,CSIST, and HAITEC. TARC is delegated to integrate the capacities of industries, governments, universities, and institutes. Its major missions are to facilitate five industrial clusters, namely, electric motor and controller, EV component system, EV energy storage application system and EMS, other EV key technologies and system integration, and Niche EV.

Universities also play a very important role in the research and development of EV technologies in Taiwan. Many leading universities such as NTU, NTHU, NCKU, NCTU and others in Taiwan, which mostly granted by National Science Council (NSC), proceed the basic researches on certain fields. They have not only issued a number of valuable patents and publications in US, Europe, Japan and China, but also attributed their research results to local manufacturer, helping the latter being able to accelerate the commercialization. One project funded by the NSC is jointly carrying out by selected 16 universities to involve into the research of developing a solution for increasing the energy efficiency by making vehicles lighter.

Moreover, the universities have cultivated ten of thousands excellent undergraduate and postgraduate students in the field of electric, electronic, chemical engineering, machinery engineering, etc. for decades. Those students would enter the institutes or firms to carry out the battery, motor, controllers, and other relevant products. They also transfer EV technologies from universities to institutes or to firms. However, the linkages and cooperation between universities and research institutes or firms on EV related technologies are poor. It contributes that scholars in the universities have devoted most of efforts on publishing, instead of applying patents or creating knowhow related to EVs. Thus, most of the outcomes yielded from universities are often far behind the need of research institutes and firms.

#### **4.2.5 The interaction among actors and the formation of network**

Generally, the initial process of EVs development in Taiwan can be divided into three stages since 2007. The interaction and network among actors are shown as figure xx.

1. Technology transferring from advanced countries (2007-2008): Tesla, a US-based emerging EV company, has chose many Taiwanese suppliers as its partners of developing Roadster, the first mass production pure battery EV vehicles in the world. Those suppliers comprised a variety of firms in terms of size and products. For instance, the Fukuta is a very small and urban electric motors producer; while the Gongin and Chroma are public firms who manufacture and power controllers. Thanks to Tesla, those Taiwanese manufacturers can learn the knowhow and expertise about EVs with the automobile maker during the

co-design process. It seemed to open a window of opportunity for them to be the tier 1 suppliers in global EVs supply chain. In 2008, Yulong has also learned the knowledge and knowhow about EVs during it cooperated with ACP on the Luxgen EV+ project.

2. Projects obtained subsidy by the government (2009-2010): Taiwan government was aware of the importance of CO2 reduction and the opportunity of emerging EVs industry. DoIT conducted Technology Development Program (TPM) to subsidy local research institutes and firms to foster the EVs technologies in Taiwan since 2009. The first project obtained the grant was launched by the Yulong. This project, namely as The key industrial technologies development for systems of electric vehicle by a total amount of US\$ 8 million and last about two and half year since January 1st, 2009. Yulong Group leads other firms who have experiences in collaborating with Tesla, ACP or sufficient knowhow on related fields, such as Fujuta, Simpol, and Hua-chuang Automobile Information Technical Center Co., Ltd. (HAITEC), Tai-yu, and Tai-chen. This purpose of the project is for developing EV related technologies for preparing the commercialization of EV in next five to ten years, such as motor, power control system, and so on, and end up produce a MPV Battery Electric Vehicle model as the outcome of the project. At the early stage of the project, the cooperation between the two sides, Yulong and its other team members, was less satisfactory due to trust and technology integration issues. But the more interaction they went, the more they learned from each other.

Meanwhile, four local research institutes who supported by Taiwan government such as Industrial Technology Research Institute (ITRI), Metal Industries Research and Development Center (MIRDC), Chung-Shan Institute of Science and Technology (CSIST) and Automotive Research & Testing Center (ARTC) are also devoted to develop EV technologies.

3. A rapid growth of actors (2010-): with the launching of the action plan, more and more firms were willing to invest R&D on the EV field. Four EV related projects proposed by eight component suppliers have been approved and subsidized by DOiT, of which are strategic alliance cases in 2010. The four projects are leaded by the firms who have jointed the Yulong's project or have good reputation in manufacturing battery. In addition, with the subsidies from Taiwan government and technology transfer from local or foreign institutes, a number of local firms whoever with the knowledge or knowhow on EV technology field got involve to the emerging EV industry. Currently, there are more than 150 companies have entered the field, most of them have not collaborated with automobile makers before. Furthermore, some big Taiwanese firms, such as Foxconn, Delta, Yulong, have attempted to cooperate with China automakers on EVs projects for early penetrating the China EVs market. A SSI in Taiwan EVs industry is shown as figure 4.

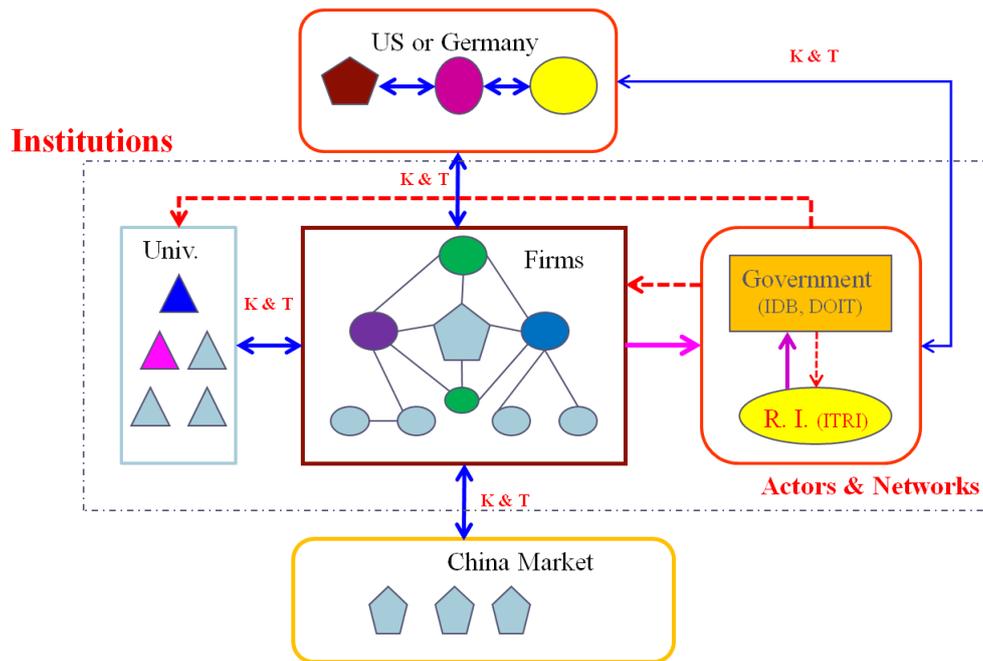


Figure 4 : A SSI of Taiwan EVs industry

## 5. Discussion and Conclusion:

The Transition from the Fossil Fuel Vehicle paradigm to the EV paradigm: the competition between the fossil fuel vehicle and EV has lasted more than one hundred years, while the earlier one has always dominated the vehicle industry as the main source of power to vehicles. Even through the EV technologies have never stopping their improvements in terms of performance for past decades, in particular, the battery technologies. But EVs technologies have always lost the battle as competed with ICEs technologies. As we have described that there are four waves of evolution from EV technologies occurred in the past five decades started in 1970s.

The transition of paradigm does not consider the environment of technology, but also the environment of “institutions”. Three waves of oil shock occurred in 1970s and 1990s revealed that the importance of reduction of the fossil fuel dependence and developing new emerging technologies, in particular, for the automobile industry. Many advanced countries then aggressively promote their EV policies and show their outlook positively to the future of EV, while the progress goes slow under expectation they did. In Geels’ socio-technical approach, three levels of factors affect the technological change, namely the niches, technological regimes, and landscapes. We argued that some sub-factors in the landscape layer, such as serious environmental matters, demand discontinuity, are important forces to push many governments adapt actions to help the transitions from ICEs regime to EVs regime.

In the sectoral perspective, this study argues that there are still many obstacles Taiwan government need to overcome in the near future and some suggestions are given.

1. There are no further cooperation between the foreign automakers and local manufacturers: it seems to be a good beginning when Silicon Valley start-up car maker, Tesla and BMW chose some of Taiwanese manufacturer as their partners to co-develop EV pilot model. The learning experiments for those manufacturers are highly valuable. However, they have been excluded from the Tesla's list to attend its following Roadster Model S project. Tesla has announced that those Taiwanese firms who have attend it's 1st generation project, Roadster will be out of the lists to joint the its Roadster Model S project. In addition, BMW selects Samsung as the battery supplier for its EVs, instead of E-one. Thus, those manufacturers should seek tier 2 or China automakers to co-design or co-produce EVs.
2. Leapfrogging policy is in doubt: The indigenous automaker is struggling to make the EV model into the mass production, due to some technical difficulties occurred in the R&D and pilot run process. It reveals that it is hard to duplicate the successful experiment from the wireless communication industry to EVs industry due to their character are various. It should reconsider to develop HEV and BEV in parallel.
3. Lacking scale of economy: reviewing the size of the actors attending in the EVs industry, most of them are small-middle enterprises (SMEs). The automobile industry is equipped with the features of capital-intensive and knowledge-intensive. SMEs have few opportunity and capability to meet the need from the giant automakers in terms of price, quality and delivery. Thus, attracting big companies to get involve the supply chain of local EVs industry are necessary.
4. Long period policy planning is needed: the information given by government indicates that none of Taiwanese firms carry out the pilot test program given by IDB yet. The only indigenous automaker influences the government policy significantly on the niche selection and push government launching the action plan including subsidies to pilot test in a short time planning. We argue that this kind of mistake should be avoided in many countries with less resource, due to the window of opportunity for new entrants does often only open one time.

This paper contributes several points. At first, it explores the technological trajectory and the evolution of global EV industry. We argued that three factors in terms of time and magnitude have plays vital roles to influence the development of global EV industry, namely oil price (P), environment concern (E), and technological change (T). One of these three factors can not make the EV industry to succeed, with single force, while only they are occurred in the same time and the strengthens are adequate, it could increase the possibilities of EVs overcome ICTs. The second is that this paper has explored the interactions among actors in the Taiwan EV industry, knowing that government plays the vital role at the early of stages developing emerging industry included EVs industry. While, none of governments can forecast which EVs technologies is the

accurate one to invest, the unique, leading firm will influence significantly the results during the programming process of policies. Thirdly, we broaden the definition of market in the SSI. We take the country, China, near Taiwan as an “extended” market. Finally, this paper also offers implication for governments that are eager to facilitate EVs industry in their countries.

## Reference:

- Affanni, A. et. al(2005). Battery Choice and Management for New-Generation Electric Vehicles. *IEEE Transactions on Industrial Electronics* 52(5),1343-1349.
- Anchordoguy, M. (2000). Japan's software industry: a failure of institutions. *Research Policy*, 29(3), 391-408.
- Breschi, S., & Malerba, F. (1997). Sectoral innovation systems: technological regimes, Schumpeterian dynamics, and spatial boundaries. In C. Edquist (Ed.), *Systems of Innovation: Technologies, Institutions and Organizations*: Routledge.
- Carlsson, B., Jacobsson, S., Holmen, M., & Rickne, A. (2002). Innovation systems: analytical and methodological issues. *Research Policy*, 31(2), 233-245.
- Carrillo-Hermosilla, J. (2006). A policy approach to the environmental impacts of technological lock-in. *Ecological Economics*, 58(4), 717-742.
- Chang, Y. C., & Chen, M. H. (2004). Comparing approaches to systems of innovation: the knowledge perspective. *Technology in Society*, 26(1), 17-37.
- Cooke, P., Uranga, M. G., & Etxebarria, G. (1997). Regional innovation systems: institutional and organizational dimension. *Research Policy*, 26(4-5), 475-491.
- DeBresson, C., & Amesse, D. (1991). Networks of innovations: a review and introduction to the issue. *Research Policy*, 20(5), 363-379.
- Etzkowizand, H., & Leydesdorff, L. (2000). The dynamics of innovation: from national systems and mode2 to a triple helix of university-industry-government relations. *Research Policy*, 29(2), 109-123.
- Freeman, C., & Soete, L. (1997). *The Economics of Industrial Innovation* (Third ed.). London: Pinter.
- Freeman, C., & Perez, C. (1988). Structural crises of adjustment: business cycles and investment behavior. In G. Dosi, C. Freeman, R. R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical change and economic theory* (pp. 38-66). London: Printer Publishers.
- Geels, F. W. (2004). From sectoral system of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6-7), 897-920.
- Hakansson, H. (1989). *Corporate Technological Behavior: Co-operation and Networks*. London: Routledge.
- Hung, S. C. (2002). The co-evolution of technologies and institutions: a comparison of Taiwanese hard disk drive and liquid crystal display industries. *R&D Management*, 32(3), 179-190.
- Kemp, R., Rip, A., & Schot, J.W., (2001) Constructing transition paths through the management of niche. In: Garud, R., Kamo, P. (Eds.), *Path Dependencies and Creation*. LEA, London, pp. 269-299.
- Kemp, R., Schot, J.W., & Hoogma, R., (1998). Regimes shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology*

Analysis & Strategic Management (10), 175-196

- Lee, K, Cho, S.J. and Jin, J. (2009). Dynamics of catch-up in mobile phones and automobiles in China: a sectoral systems of innovation perspectives. *China Economic Journal*, 1, 2009, May.
- Lynn, L. H., Reddy, N. M., & Aram, J. D. (1996). Linking technology and institutions: the innovation community framework. *Research Policy*, 25(1), 91-106.
- Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy*, 31(2), 247-264.
- Malerba, F. (2005). Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technologies*, 14(1-2), 63-82.
- Nelson, R. R. (1993). *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.
- Nelson, R. R., & Sampat, B. N. (2001). Making sense of institutions as a factor shaping economic performance. *Journal of Economic Behavior and Organization*, 44(1), 31-54.
- Nill, J., & Kemp, R. (2009). Evolutionary approaches for sustainable innovation policies: from niche to paradigm. *Research Policy*, 38(4), 668-680.
- Raven, R.P.J.M., (2006). Towards alternative trajectories. Reconfigurations in the Dutch electricity regime. *Research Policy* (35), 581-595.
- Reddy, N. M., Aram, J. D., & Lynn, L. H. (1991). The institutional domain of technology diffusion. *Journal of Product Innovation Management*, 8(4), 295-304.
- Scott, W. R. (1995). *Institutions and Organizations*. London: Sage Publication.
- von Hippel, E. (1988). *The Sources of Innovation*. New York: Oxford University Press.
- Sou, P.H. et. al(2009). Overview of the Taiwan EV National Promotion Program Driven by Clean Zone Policy. Stavanger, Norway, May 13-16, 2009
- Tsoutsos, T.D., Stamboulis, Y.A., (2005) The sustainable diffusion of renewable energy technologies as an example of an innovation-focused policy. *Technovation*, (25), 753-761.
- Van der Laak W.W.M., Raven, R.P.J.M., Verbong, G.P.J. (2007). Strategic niche management for biofuels: analyzing past experiments for developing new biofuel policies. *Energy Policy* (35), 3213-3225
- WCED (1987). *Our Common Future*. New York: Oxford University Press.
- Yarime, M. (2009). Public coordination for escaping from technological lock-in: its possibilities and limits in replacing diesel vehicles with compressed natural gas vehicles in Tokyo. *Journal of Cleaner Production*, 17(14), 1281-1288.
- 林德昌 (2005). *永續發展與聯合國二十一世紀議程*. 台北: 行政院青輔會.
- 洪世章 (2002). 結構衝突與產業劣勢: 台灣硬碟機工業之發展. *管理學報*, 19(2), 273-302.
- 蕭代基 (1998). 永續發展的意義與政策方向. *經濟前瞻*, 56, 44-49.