



Looking for a Framework for Analyzing Eco-innovation Dynamics

A Triple Helix Model of Innovation Perspective

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Candidate Paper for The Best Student Paper Award

Subtheme 2.6. Relevance of the Triple Helix model for sustainable development challenges

Looking for a Framework for Analyzing Eco-innovation Dynamics: A Triple Helix Model of Innovation Perspective

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Abstract: Eco-innovation is a novel fuzzy concept getting growing attentions under global climate change. It is in need of further clarification both theoretically and methodologically. Furthermore, the theoretical and methodological approach to analyze the eco-innovation process is poorly developed. This paper is an explorative study aiming to find a theoretical framework for analyzing eco-innovation dynamics. The purpose is to develop new theory rather than test the extant theories. This study follows a deductive reasoning strategy based on literature study. The public is stressed as a fourth actor in eco-innovation besides the three spheres of university, industry and government in triple helix framework. Triple helix twins and quadruple helix are both models extending the triple helix model having a fourth actor involved. Given (1) triple helix twins have a more explicit statement on the triangles of sustainable development; (2) in either innovation triple helix of university-industry government or sustainability triple helix of university-government-public, three spheres are there, which is still under the widely accepted framework of triple helix. In contrast, before employing quadruple helix framework, time and energy is in need to answer such kind of questions: Does this conceptualization help the understanding of the complex knowledge generation, diffusion and use process? how do the four spirals interact and affect in the process (the mechanisms)? Will quadruple helix be left at epistemological level again? Triple helix twins model is the preferable model for disclosing the sophisticated interactions in eco-innovation. A mini case study on the greening practices of Danish industry is organized to further support and illustrate how triple helix twins are employed in analyzing the interactions in eco-innovation.

Keywords: Eco-innovation (dynamics); ‘media and culture’ based public; Triple Helix Twins; Quadruple helix; Case Study

1. Introduction

Eco-innovation is increasingly connected to green growth under the background of global climate change (Andersen,2010), as it is supposed to be a win-win-win model (Klemmer,1999;Hemmelskamp et al.,2000). The extant study on eco-innovation are more rooted in environmental policy while ‘eco-innovation’ is still a fuzzy term and also the theoretical instrument for analyzing eco-innovation is rarely discussed and studied hitherto. This situation can also be illustrated from the statements below.

‘While innovation processes toward sustainable development (eco-innovations) have received increasing attention during the past years, theoretical and methodological approaches to analyze these processes are poorly developed’. (Rennings,2000,P.319).

‘Eco-innovation is a novel fuzzy concept used by different disciplines and in need of further clarification both theoretically and methodologically’ (Andersen,2010,P.2).

This paper is to look for the possible theoretical model for analyzing the complex interactions and feedback mechanisms within eco-innovation based on triple helix model of innovation. The basic thing is to find out whether the actors involved in eco-innovation are the same with the ones in triple helix model of innovation. If they are the same, it indicates that triple helix model might also work in eco-innovation; if there are more, or less actors, triple helix model will not be appropriate to analyze eco-innovation dynamics. Are there any other possible models or instruments for eco-innovation, with different actors compared to innovations in general? If there are, how are they connected to eco-innovation? Which would be the better one? If there are not, what is expected in the future?

To answer the questions above, a better understanding of eco-innovation itself and an analysis of the peculiarities of eco-innovation, compared to innovations in general are in need beforehand. Therefore all the stuff upcoming is organized firstly

giving an analysis of the extant definitions and understandings of eco-innovation and coming out the standpoint in this paper(Section2); and then it comes to an analysis of the characteristics of eco-innovation compared to the innovations in general(Section3); Based on section 2 and section 3, it is time to answer ‘what are the actors involved in eco-innovation’(Section4); finally it comes to discuss the possible models for eco-innovation(Section5), which depends on the actors involved.

It is an explorative study aiming to develop new theory rather than verify the extant theory. To support the conclusions drawn by the deductive analysis, a mini case study is enclosed (Section6).

2. Understandings of Eco-innovation

‘environmental technology’, ‘cleantech’, ‘environmental innovation’, ‘green innovation’ are all the alternatives of ‘eco-innovation’. Coupled with these concepts, they are the changing environmental problems and solutions. ‘Eco-innovation is currently a fuzzy concept in need of theoretical clarification’ (Andersen,2008,P.2) . Three aspects are summarized here.

Firstly, a consensus on the delimitation of ‘environmental benefit’ is absent. One proposition is from the perspective of eco-efficiency. It highlights a responsible energy consumption in the life cycle of products or in the product chain (e.g. Kemp&Foxon,2007; Europe Commission,2007;Cooke,2009); The second standpoint interprets ‘environment’ in terms of energy consumption, usage of space and preserving biodiversities (e.g. Hellström,2007).

‘to reduce the environmental impacts’, ‘to avoid the negative environmental impacts’ are the most employed expression in the extant definitions of eco-innovation. This kind of delimitation is too broad to bring it to practices level. However, it is not easy to find a way to make it more operable, as the environmental problems, the visions and solutions toward the problems, and also the actors involved are always changing.

In this paper, given the energy consumption perspective is somewhat narrow that can not illustrate the whole picture of ‘environment’, while energy, space and biodiversity are always necessary to maintain and build natural and industrial

eco-systems(Vollenbroek, 2002), environmental benefits are interpreted in terms of energy consumption, usage of space and biodiversities while without compromising the present needs. 'compared to the alternatives' is employed to make 'to reduction', 'to avoid' more concretely and comparable, which is also employed in Kemp&Foxon(2007).

Secondly, it is about whether 'environmentally beneficial normal innovations' (following Kemp &Foxon,2007) are categorized as eco-innovations. In UNU-MERIT serial working-papers, Beise&Rennings(2005),Bernauer et al.(2006), Hermosilla et al(2010), both motivated and unintentional innovations offering environmental benefits are considered as eco-innovations, as they both generate environmental benefits on the one hand; on the other hand, it is difficult to identify an environmental motivation, as in the evolutionary process of innovation, the environmental motivation for innovation probably become entangled with other motivations. Oppositely, the motivation of innovators are emphasized explicitly in Europa INNOVA Thematic Workshop(2006),Europe Commission (2007) ,OECD (2009a) and Yang et al.(2010), stressing on the intended ones.

Given the fact that 60% of innovations offer environmental benefits (Kemp &Foxon,2007) and about 80% of all innovating firms in the survey of German industry are involved in environmental-friendly innovation projects (Cleff & Rennings,1999) , this paper stresses on the intended eco-innovations. This delimitation excludes the majority of general innovations which have been widely studied and provides the possibility of paying specific and intensive attentions to the emerging and potential eco-innovation forms in the future.

Thirdly, do economy benefits created by marketization matter in eco-innovation? Few scholars discussed this before. Rennings(2000) is one of the few publications stating that eco-innovation 'can be traded on market or not'(P.322) while the majority of publications on eco-innovation stress environmental benefits and an explicit explanation on economy benefits is absent except (Fussler& James,1996),Andersen(2008) and Yang et al.,(2010). It is true that sustainable development derived from the whole society's reflection of the industrial economy

growth model, which is based on over-consumption and waste of resources and energy. Economy benefits are the core in the old economy growth system. But we also should notice that economy benefits are still one of the tri-pillars of sustainable development and the only thing is the society need to find a way of making a balance among environment benefits, social benefits and economy benefits. Eco-innovation is supposed to be the way, at least one of the ways. Therefore, economy benefits matter in eco-innovation and eco-products, eco-productions or eco-systems should be brought into market and create business value rather than 'can be traded on market or not'. Non-governmental organizations, public sectors, churches and households can be there, coupled with social innovation and institutional innovation, but finally the business value is created by marketization. Moreover, when there is no diffusion stage on market, can it be called 'innovation' according to the definition of innovation in Schumpeter(1934), which is also the main stream in innovation understanding?

In summary, Eco-innovation in this paper is interpreted as 'intended innovations toward sustainable development(**environmental-social-economic**), in which the development of novel products, productions, systems that can reduce energy consumption, usage of space and preserving biodiversity, compared to the alternative approaches'. This understanding helps to make further empirical design and theoretical development away from a blurred borderline and avoid the duplicating work toward innovations in general. Furthermore, it provides the possibility of answering 'Whether innovations towards sustainable development can be treated as normal innovations or if a specific theory and policy are needed' (Rennings2000, P.320). And also business value is highlighted, as it is the basic objective in innovation and sustainable development.

Eco-innovation dynamics is interpreted from three aspects a in this paper. Firstly, environmental problems change time and time; Secondly, the solutions for environmental problems is changing; Thirdly, the actors and stakeholders involved changed and the interaction among the actors and stakeholders are sophisticated and nonlinear. This interpretation is based on an evolutionary perspective. It keeps the understanding of eco-innovation dynamics from the generation of environmental

problems to the solutions and also the evolutionary of stakeholders and actors involved are there to reveal the interactions in the eco-innovation process at supra-national, national, regional or firm level.

3. Characteristics of Eco-innovation

Given it is to look for a theoretical model for eco-innovation based on triple helix model of innovation, the analysis upcoming is in special compared to innovations in general.

3.1 Double Spillovers

In Rennings(2000), double positive spillovers, which are generated in both innovation and diffusion stage, are underscored as the peculiarities of eco-innovation with the term ‘Double Externality Problem’ . There are two problems embedded in its elaborations on this peculiarity. Firstly, the author turned ‘positive spillovers’ to ‘double externality problem’ without an explicit illustration on the perspective he is taking. Secondly, the spillovers are limited to only diffusion stage, which might not be the truth.

‘Double Spillovers’ is employed here instead of ‘Double Externality Problem’, as eco-innovations do have double spillovers, but whether they are positive, it depends on which standpoint is taken. Firstly, eco-innovations have R&D spillovers alike in normal innovations. To other companies, particularly the ones with similar business, this kind of spillovers can be positive, but to the R&D company itself, it is another fact; Secondly, environmental benefits are the other spillovers. To the society, it can be called positive spillovers, however, it is a problem for the innovative company, as it need to pay more for the environmental-friendly solutions, for example, the extra investments on environmental technologies and alike. Secondly, the environmental benefits can not only be generated in only diffusion stage but the life cycle of the products. The environmental benefits can be from the using of recyclable materials, the cleaner production, in the using stage when the products are eco-designed and also the recycling stage when the products are designed from cradle to cradle.

3.2 Regulatory Push

In what conditions would industries take environmental concerns into business? Or how can industries be regulated or encouraged to environmental-friendly business? Numerous studies have been developed on this in the past several decades, especially during 1970s-1990s. Various soft and hard policy instruments and regulations are studied theoretically and empirically. Although there is not a consensus on what policy instruments might be the most preferable, an agreement might be there that environmental policies and regulations have strong impacts on companies' eco-innovation decisions (e.g. Porter & van der Linde, 1995a, 1995b). Furthermore, the push and support of environmental policies and regulations is in need as (1) usually neither technology push nor market pull is strong enough, and sometimes both, especially for the Small and Middle Enterprises (SMEs); (2) provide policy support to eco-products, environmental-friendly services and alike to make them more competitive on market than non-eco-products and non-eco-services. Here it is more about helping eco-companies reducing the external costs imposed by competing with non-eco-products and non-eco-services; (3) to the front runner companies, usually they are the proactive ones to influence the formulation of sector standards and regulations. This might be another kind of 'push and support'.

3.3 Public Push

In general, who would care about the environmental benefits and social benefits very much? The customers of products, the neighbors to production plants, the environmental NGOs and so on might be the ones, as environment is the classical commons shared by the whole society. The ones can be voters, pressure groups, or the supporters of pressure groups on public benefits. The NGOs, customers, neighbors to production plants (local community) are in general called 'the public'.

In the past 40 years, numerous events indicate the pushing role of public in the greening of industry. The increasing attentions paid to eco-innovation by politicians, scholars, entrepreneurs, non-governmental organizations, environmental protection agencies, business council of sustainable development and also the households can be the very example. The theme of reconciling wealth creation with environmental sustainability is addressed as early as 1972, the Stockholm Conference on the Human

Environment. Coupled, a wave of government regulations put business on the defensive until the oil-price-induced recession in 1973. In 1980s, the increasing and ambitious Action Programs of European Community indicate the renewed and expansive public interest in environmental issues. Persistent public concern coupled with intensive environmental regulations contributed to create a sense of inevitability in the business community that environment is a major and enduring issue. By the mid 1980s, the customers' growing environmental concerns began to make the companies/products with poor environmental performances punished by product boycotts. Many companies were motivated by avoiding the punishments of poor environmental performances rather than anticipating environmental successes (Howes,Skea&Whelan,1997). After mid 1980s, the public concerns on environmental problems changed from emissions, via industry emissions and waste, resource consumption to environmental impacts from life cycle of products and new chemicals and materials. End of pipe tech, cleaner production, environmental management and cleaner production were the concepts ever employed coupled with the changing environmental problems and eco-innovation is one of the highlighted concepts today.

4. Media and Culture-based Public-the Fourth Actor in Eco-innovation

As pointed out above, the public plays an important role in the greening of industry in general. In this session, the media and culture based public is stressed to be the fourth actor besides university, industry and government.

'Public' is somewhat a broad and fuzzy term. Government (institutes), university and other research institutes, non-government organizations, Environmental Protection Associations, media institutes such as British Broadcasting Corporation, Voice of America, local community, internet based virtual community, consumers and even households are all involved in the concept of 'public' (institutes). This paper will not try to give an explicit definition of 'public' and also it would be stupid and unreasonable to make it. However, it is possible to give a delimitation of what 'the public' covers. In this paper, the public is connected with all individuals or groups excluding government (institutes), university and industry. Then Non-Governmental-Organizations (NGOs), Environmental Protection Associations,

local communities, virtual communities, media systems, churches, consumers, households and so on are the public in this paper.

‘Civil Society’ is also a general term covering NGOs, Environmental Protection Associations, media systems, local communities, which usually impress people a picture of the whole society rather than some groups of individuals. Given the fourth actor discussed in this paper is not always about the whole society, the public is considered as the preferable term.

‘media and culture based’ is underscored, as on the one hand, the public’s perception of reality is mainly constructed and shaped by the mass media(system) and culture; on the other hand, the media(system) is the vehicle by which public reality is communicated. Take the construction and communication process of formulating public reality among net citizens via network based virtual community for example.

With the rapid development of internet tech and its popularity, the population of net citizens grows larger and larger. Until mid 2008, the global population of net citizens is 1.4 billion, 21% of the world population (http://www.jwb.com.cn/bhzb/html/2008-11/23/content_224451.htm). Under this background, more and more internet-based virtual communities with various functions appeared and became the popular communicating forum with strangers thousands of miles away. Facebook, Twitter, LinkedIn are the cases.

Tianya is one of the biggest virtual communities in China. There are 5267,9876 net citizens in this community hitherto. It has in total 20 columns on politics, society, finance, IT, women, fashion, entertainment, travelling and so on. It has also sub-sites in all provincial cities in China. The adjustment of oil prices announced by National Development and Reform Commission, larger and larger urban-rural gaps, medical insurance and such alike hot social topics and problems are widely discussed in Tianya virtual community. Usually the net citizens get others’ perceptions easily and follow up them with their own understandings instantly. On some specific topics, there might be millions of net citizens involved. Usually there are various perceptions among these millions of net citizen with different educations, living contexts and standpoints of interests. Sometimes there would be wars of words. During the wars,

the non-net citizens public—a broader public are involved, as the war is diffused by newspapers, TVs, radios and the net citizens themselves in the real daily life. The broader public are influenced and some may participate in the war to influence others. After rounds of being influenced and reflections, finally it comes to a collective perceptions-public reality. ‘The south China tiger incident’ in 2007; the series of influential incident happened in ‘5.12 Wen Chuan Earthquake(2008)’ such as Mourn 3 minutes at 14:28 one week later in national wide; questioning the usage of donation from individuals and parties all over the world and also the recent ‘YAO Jiabin’ incident are the very example to show how the public reality is constructed and communicated by net citizens and its diffusion among the broader public.

Moreover, in 2008 Hu jin-tao, the general secretary of the Communist Party of China central committee and president of China, had an on-line chatting with net citizens. It indicates the government’s approval of the positive effects played by net citizens; Since 2010 more and more local authorities and companies post message on Micro Blog sharing the updated information on specific topics or new products or their commitments to sustainable development. The network-based public in China has influenced and will influence the construction of a broader public reality, which is affecting the decision making of Chinese government and industries’ behavior more and more.

Besides the mass media (system) and virtual community, the public reality is also influenced by culture. Culture is the body of long term formed behavior, thinking way, value, custom, religious belief. It is intangible but embedded in people’s daily life. Usually the engineering and technical curricula in universities are more male taken while less female are interested in engineering and technical subjects. Behind this phenomenon, it is a widely accepted social image of engineering and technical subjects: they are the male’s business. And probably the public is not aware of this social value. Again, imagine there are three eco-design engineers from Denmark, China and India, and they are expected to find more possible further improvements on the package to make the products more environmental-friendly. Life cycle assessment might be employed by all of them, but the final proposals might be different because

of their different knowledge base, social value, religious belief and so on. Also, it is not surprising that the same products might impress the public within different cultures different images.

5. Triple Helix Twins or Quadruple Helix?

Triple helix is mainly a model for analyzing innovation in a knowledge-based economy (Leydesdorff &Etzkowitz,1998;Leydesdorff,2000) and it is widely studied and accepted in the past 15 years. Universities or other knowledge-producing institutes, industry and government at various levels (local, regional, national, and supra-national) are the main spheres involved in the innovation system by innovatively adapting themselves to changes(Leydesdorff &Etzkowitz,2001). It provides a theoretical framework to disclose how innovations are generated by analyzing university-industry-government interactions (Leydesdorff &Etzkowitz,1998,2001).

Compared to innovations in general, eco-innovation has one more actor besides university, industry and government. How to disclose and illustrate the more complex interactions among four actors? Based on triple helix model, triple helix twins and quadruple helix are the ones covering four actors, in which public or civil society are underlined although they have different ideas on how to locate the fourth helix.

5.1 Triple Helix Twins

‘Innovation, involving changes in physical and social environment, inevitably raises issues of sustainability.....’(Etzkowitz&Zhou,2006,P.78). Under this background, sustainability triple helix of university-public-government is proposed as a complement to the innovation triple helix of university-industry-government (see Etzkowitz&Zhou,2006). The innovation triple helix and sustainability triple helix come together to triple helix twins, in which university-industry-government works to promote innovation and economic growth, while the university-government-public serves as a balance wheel to insure that innovation and growth take place in ways that will not be harmful to the environment and health.

In this model, there is a precondition that industry and the public are with different standpoints on environmental problems and sustainable development. Government

and university are to balance the benefits of industry and the public. However, the concept of triple helix model did not receive more attention in the past 5 years and an explicit delimitation of public' is in need.

5.2 Quadruple Helix

Quadruple helix is an extension of the triple helix model, which is still disputable and somehow fuzzy. The upholders hold the idea that public (civil society or local community)'s participation should be regulated into the decision making process besides academia, industry and governments, as empirical studies implies public works in the innovation process; The opponents argue 'three helices are sufficiently complex to understand the social reproduction of the dynamics of innovation' (Leydesdorff&Henry,2003). Furthermore, public can not be considered as a fourth helix, as the public becomes decentralized and also it would 'narrow the public into another private sphere', rather than seeing civil society as the foundation of the enterprise of innovation.' (Leydesdorff&Henry,2003). It implies a basic proposition that civil society is the very substrate of innovations.

In the limited publications concerning quadruple helix or a fourth helix , it would be easy to find that the delimitation of the fourth helix is still fuzzy. Public, civil society, local community, culture, values, lifestyles, even internationalization, international-national dimension, globalization are ever proposed to be the fourth helix or N-tuple helix (e.g. Leydesdorff&Henry,2003; Leydesdorff,2011; Carayannis&Campbell,2009,2010).

5.3 Triple Helix Twins vs. Quadruple Helix?

Before coming to conclusions of which would be more close to disclosing 'eco-innovation', a comparison might be helpful.

(1) Starting Points

Eco-innovation: win-win-win of environmental-social-economical benefits;

Triple Helix Twins: The triangles of sustainability are indicated explicitly. innovation triple serving for knowledge creation and economy benefits (economical) and sustainability triple helix keeps harms to environment and health induced by industry away(environmental and social);

Quadruple Helix: It is generally connected to a better innovation while environmental benefits and social benefits are less considered (see Leydesdorff&Henry(2003); Carayannis&Campbell(2009); Leydesdorff(2011)).

(2) The Interpretability and Feasibility

Triple Helix Twins: the interactions among university, industry, government and the public are divided into university-industry-government (innovation) and university-government-public (sustainability) and eco-innovation process is the process the two helices work together. Furthermore, the interplays are kept among three spheres, which is still in the framework of triple helix interplay mechanisms. Extra explanations on the interactions mechanisms in innovation triple helix or sustainability triple helix are not in need in future study, as lots of work has been done before concerning triple helix(e.g.Ledesdorff,2000).

Quadruple Helix: if the public is considered as the fourth helix, many questions would come up, such as how do the four spirals interact and affect in the process? Does this conceptualization help the understanding of the complex knowledge generation, diffusion and use process? Will quadruple helix or N-tuple helix be left at epistemological level again? Before employing quadruple helix model, more time is in need to answer the questions above and the ones alike.

(3) The Common Problems

Both Triple Helix Twins and Quadruple Helix have a blurred delimitation of 'public'. In Etzkowitz&Zhou(2006), there is a social change history told under the subtitle 'Sustainability and Public Concerns' (P.78) while without any explanation on what Public concerns; In the publications of Quadruple Helix or the fourth helix, Carayannis&Campbell(2009) gives a more concrete delimitation, however, it also leaves what public really covers fuzzy.

Above all, triple helix twins is the preferable model to disclose and illustrate the non-linear and dynamic interactions among government, industry, government and the media and culture based public.

6. Triple Helix Twins in the greening of Danish Industry: A Case

Denmark is on the forefront globally when it comes to green products. It has a long tradition concerning clean tech development. As early as 1990s, the greening of Danish industry has been the highlight of scholars with different backgrounds (e.g. Georg, Røpke & Jørgensen, 1992; Remmen & Lorentzen, 2000; Remmen 2001). Table 1 shows the changing environmental problems, conceptions, solutions and also the actors involved, in which the eco-innovation dynamics interpreted in this paper is there.

Table 1 The greening of Danish Industry

Period	1960s-mid1980s	mid1980s-1991	1992-1996	End of 1996 -2001
Environmental Problems	<ul style="list-style-type: none"> • Emissions 	<ul style="list-style-type: none"> • Emissions and waste from companies • resource consumption 	<ul style="list-style-type: none"> • emissions and resource consumption • organizational preconditions 	<ul style="list-style-type: none"> • environmental impacts from the life cycle of products • new chemicals and materials
Conceptions	Environmental Protection	Cleaner Production Process	Environmental Management	Cleaner Products
Solutions	<ul style="list-style-type: none"> • End of Pipe 	<ul style="list-style-type: none"> • technical demonstration projects • dissemination and diffusion of solutions 	<ul style="list-style-type: none"> • continuous environmental improvements • a certified environmental management system 	<ul style="list-style-type: none"> • design criteria and life cycle screening/assessment • eco-label, environmental declarations, procurement guides
Actors	<ul style="list-style-type: none"> • Environmental Authorities 	<ul style="list-style-type: none"> • production engineers • environmental consultants • environmental authorities as a service oriented counterpart 	<ul style="list-style-type: none"> • management and employees • trade organizations, management- and environmental consultants, etc. • environmental authorities as sparring partners 	<ul style="list-style-type: none"> • designers and product developers • consumers, customers and public purchasers • government as provider of frame conditions
incentives	<ul style="list-style-type: none"> • Compliance 	<ul style="list-style-type: none"> • resource savings and eco-efficiency 	<ul style="list-style-type: none"> • internal dynamic and image • knowledge exchange and collaboration in the 	<ul style="list-style-type: none"> • product improvements from a life cycle perspective • competitive

		<ul style="list-style-type: none"> • compliance 	trade, in networks, etc.	advantage
Focus of Innovation	----	<ul style="list-style-type: none"> • Technical optimization • Good housekeeping 	<ul style="list-style-type: none"> • Organizational Collaboration within the trade 	<ul style="list-style-type: none"> • Product improvements • Product chain/stakeholders

Source : comes up based on Remmen(2001)&Remmen(2003)

In innovation triple helix of university-industry-government, the data shows a strong and effective governmental push at the very beginning and later an industry centered innovation path. In the beginning, Danish Environmental Protection Agency pushed universities, research institutes and industries to focus on the environmental problems by kinds of research, aiming to push the industries to make changes. For example, EPA required the Best Available Technology, which did push the companies to invest on R&D and innovation to the best available technology. If companies did not pursue innovation, probably they will be regulated and punished on the one hand, and they would fall behind other companies in the same sector on the other hand. When the companies realized that devoting to eco-products, eco-production and eco-services can promote the products' public image and companies' competitiveness, they will be the innovators proactively rather than polluters. Grundfos A/S(Myrdal,2010), Vestas(Lehmann, Christensen& Ma,2010)are the cases. And then it is the time that government turned to be a partner and supporter of the companies rather than pushing. An industry-centered innovation paradigm comes up then. In the project implementation process, EPA would get feedbacks from research institutions, demonstration companies and the public. As early as 1986, Danish Environmental Ministry turned to stimulate the application of cleaner technology in Danish industry by focusing on single demonstration companies. However, this was criticized by the public that it was too technology-based, expert-based and the dissemination of cleaner technologies based on demonstration projects was limited. Under the public pressure, another project named 'Employee Participation in the Introduction of Cleaner Technologies—known as the MIRT project—was carried out from 1993 to 1996, focusing on changing work routines, working behavior, or organizational structure

instead of only technology solutions (Remmen & Lorentzen, 2000). A group of scientists from the Technical University of Denmark, Aalborg University, and five companies, each representing a separate industrial sector were involved.

In sustainability triple helix of university-government-public, it is a government-push path. On the one hand, various environmental policy instruments and regulations were made to regulate industry environmental behaviors, for example, green taxes; on the other hand, government push universities to serve society by environment and sustainable development educations and trainings, being the external consultants of industries' environmental activities; developing forefront research on environmental problems, sometimes collaborating with industries. In the greening of industry, the public (institution) such as business associations, trade unions played a proactive role as mediators and translators in improving the communication between EPA and industry, increasing the diffusion of environmental management in industry sectors, in carrying out networks among companies sharing the experiences from implementing ISO 14001 or EMAS so on. There was a conflict between Danish Environmental Ministry and textile industry on green taxes. It was the business associations and trade unions that found out the misunderstandings between the two (Remmen, 2001).

7. Conclusions and Implications

7.1 Conclusions

This paper is to find a reasonable and feasible framework for eco-innovation dynamics based on triple helix model of innovation. It is argued that 'media and culture' based public is the fourth actor in eco-innovation besides university, industry and government, compared to innovations in general. Triple helix twins and quadruple helix are both models extended based on triple helix model with four actors involved. Given triple helix twins have a more explicit statement on the triangles of sustainable development and also it is still under the analyzing framework of triple helix with three actors involved in each triple helix, triple helix twins is the preferable model for eco-innovation when the research focus is on the non-linear interactions. The 'media and culture' based public is stressed because public reality is constructed

and communicated by media and culture (Carayannis&Campbell,2009). The formulation process of public reality in the internet-based virtual community, particularly in Tianya community, is elaborated to illustrate how public reality is constructed and communicated among net citizens and the broader public besides net citizens.

Eco-innovation dynamics is the process that innovation triple helix of university-industry-government and sustainability triple helix of university-government-public interplays toward a balance of environmental-social-economic benefits. What should be noted is, although four actors are divided into two groups with different functions at conceptual level, it is unpractical to have them functioned explicitly for either innovation or sustainability. It is difficult to tell exactly when government is functioned for innovation but not sustainability, so is the university, industry and the public. The blurred borderlines among university, government and industry from the perspective of function are also highlighted in triple helix framework(Leydesdorff&Etzkowitz,2001). This division and category (innovation triple helix and sustainability triple helix) is kind of conceptual idea, making the understanding of the non-linear and sophisticated interactions among four actors easier. When triple helix twins framework is employed, it is easier to keep sustainable development more concrete with focusing on the interactions among university, government and public. Also it helps to find out what the problems are in developing eco-innovations, as innovation triple helix is more about knowledge creation and wealth creation and sustainability triple helix focuses on how to make industries take environmental concerns into business proactively. The public's value toward environmental problems, life styles, costume matters.

The greening of Danish industry illustrates triple helix twins at the practical level. Danish government (Danish Environmental Protection Agency) played an important role in pushing industries to innovate and take environmental concerns into business by demonstration projects and regulations. When front-runner companies realized greening is also the approach to the promotion of competitiveness and additional business value creation, the companies tend to be in the core of eco-innovation.

Environmental NGOs, trade unions, business associations, training centers acted as mediators between government and industry.

7.2 Implications

The implications to be stressed are based on the argumentation of taking 'media and culture' based public as the fourth actor and the greening practices of Danish industry.

Firstly, taking the multi-stakeholders into the decision making process when eco-innovation is on the companies' agenda, particularly the consumers of products, the neighbors of production bases. This is coupled with the growing public environmental awareness.

Secondly, whenever developing eco-products or eco-services, take the role of media and culture in constructing and communicating public reality into consideration. It is not surprising that a pretty environmental-friendly product or service fails to be accepted by the market, as maybe the life style, the religious custom and so on are neglected, or probably the product or service fail to give the public an green image induced by the not so successful advertisements via newspaper, tv, radio or internet and so on. However, when taking the role of media and culture into consideration in eco-design, it might also be kind of obstacles. Try to jump out the culture you are familiar with. This is also one way to new ideas and innovations.

Thirdly, in the greening practices of Danish industry, government-push first and then industry-centered path is detected. There is an evolutionary process rather than forming an industry-centered innovation paradigm. To the emerging economies, it is important to notice this. On the one hand, an effective government is vital to guide and support the innovation on the right track, particularly at the very beginning; On the other hand, given the industries care about the business value most, finally the industries should be in the core of innovation for a global business competition and government is the partner and supporter.

7.3 Limitations

The public is limited to NGOs, Environmental Protection Associations, trade unions, business associations, consumers, households, local communities, virtual communities and so on in this paper. It might be challenging the definitions and

understandings of public. There might be many questions to the scholars from social science and especially the ones working on civil society and public relations alike. However, public is such a blurred and broad term and it would be stupid and unreasonable to make it clear as it is discipline dependent. Even though, it is possible to give a delimitation of what 'the public' covers in the specific contexts. This paper is a try.

The eco-innovation dynamics in this paper is interpreted as the interaction process between innovation triple helix and sustainability triple helix while how these two triple helices interact mutually is rarely discussed. And also 'in what conditions, can sustainability be achieved via the interactions between innovation triple helix and sustainability helix?' is in need of further study.

8. Discussions and Further Explanations

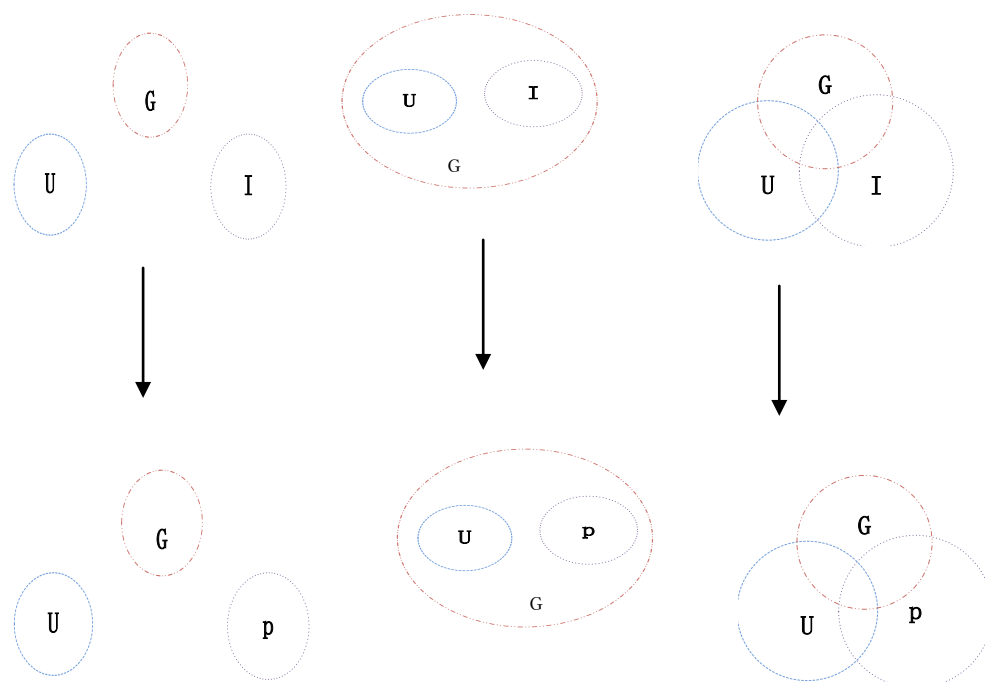
8.1 Is public as important as university, industry and government to be the fourth actor in eco-innovation?

It is an explorative study aiming to develop new theory rather than verify the extant theories. It follows a deductive reasoning strategy based on literature study. One of the most important things in this paper to argue why the 'media and culture' based public is so important to be the fourth actor besides university, industry and government. It is argued that the public are the group who cares about environmental benefits and social benefits most, especially when there are market failures and government failures. With regard to this point, it might be questioned: yes, the public such as consumers, local communities care about the environmental benefits, but it does not lead to a conclusion that the public will play an important role as university, industry and government, for example, in a society that the public usually are reactive to participate in the process of decision making.

Considering this, the role of public in the evolutionary process of eco-innovation is elaborated to further illustrate the standpoint in section 3. Also the public might be with different forms, different positions in different contexts, but they are there, reactive or proactive. If the public are proactive, the development of eco-innovation probably is better. In the greening practices of Danish industry, trade unions, business

associations, local communities, high green awareness of consumers and households are proactive and world-leading green concepts and practices are developed in Denmark. Furthermore, social innovations and institutional innovations are needed to facilitate the greening of industry and sustainable development (Remmen,2001), in which the public means more. The public participation in user innovation and open innovation can also be the proof to support the point that the public is as important as university, industry and government to be the fourth actor in eco-innovation. A further study on how and to what extent the public has affected the eco-innovation path at various levels (national, regional, industry, company) would be helpful to support this point further.

8.2 Are there also three patterns of interactions in sustainability triple helix coupled with the three innovation triple helix?



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