Volume 4, No.2 (2016)

International Review for Spatial Planning and Sustainable Development

SPSD Press Since 2010

SPSD Press since 2010

International Review for Spatial Planning and Sustainable Development

For investigation regarding the impact of planning policy on spatial planning implementation, International Community of Spatial Planning and Sustainable Development (SPSD) seeks to learn from researchers in an integrated multidisciplinary platform that reflects a variety of perspectives—such as economic development, social equality, and ecological protection—with a view to achieving a sustainable urban form.

This international journal attempts to provide insights into the achievement of a sustainable urban form, through spatial planning and implementation; here, we focus on planning experiences at the levels of local cities and some metropolitan areas in the world, particularly in Asian countries. Submissions are expected from multidisciplinary viewpoints encompassing land-use patterns, housing development, transportation, green design, and agricultural and ecological systems.

IRSPSD INTERNATIONAL
ISSN 2187-3666 (Online)

International Review for Spatial Planning and Sustainable Development
https://www.jstage.jst.go.jp/browse/irspsd
http://spsdpress.jimdo.com/volumes/
http://dspace.lib.kanazawa-u.ac.jp/dspace/bulletin/irspsd

International Review for Spatial Planning and Sustainable Development

Volume 4, No.2, 2016

SPSD Press Since 2010

International Review for Spatial Planning and Sustainable Development, Volume 4 No. 2, 2016

Content

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 1-2
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_1

Editorial Introduction

Special Issue on "Environmental Planning"

Guest Editors:

Yan Li[1*] and Jen Te Pai[2]
1 College of Asia Pacific Studies, Ritsumeikan Asia Pacific University
2 Department of Land Economics, National Chengchi University
** Corresponding Author, Email: yanli@apu.ac.jp*

Received 21 August, 2015; Accepted 15 November, 2015

The natural environment is where our human societies are based on and draw resources from. We breathe air, drink water, reside on land, harvest the crops and manufacture the goods that we need with biotic and abiotic matters from the environment. It also absorbs the wastes that we discharge, forming ecosystems that have enveloped us for millions of years (Donald, 2009). However, due to the rapid population increase, industrialization and excessive use of fossil fuels in the past two centuries, severe environmental problems have emerged, among which energy and climate change are amongst the most concerned (Harris, 2012). Meanwhile, besides the geologic hazards such as earthquake, volcano eruptions and landslides that have always presented threats to human beings, atmospheric hazards such as floods and draughts are now intensified due to climate changes induced by human activities (IPCC, 2014). This special issue addresses on these three key issues: disaster mitigation, energy and climate change.

The first two papers examine the issue of disaster mitigation focusing on different disasters and different target groups. Nguyen, Imamura, and Iuchi (2016) review much literature and point out that tourists are vulnerable to disasters because they are transient people who usually lack knowledge of local hazards and perceive risks differently. Moreover tourists face communication barriers, and local emergency management systems are often focused on the preparedness and response phases of local communities. The authors use the case of coastal tourism destinations and suggest social learning as a possible means to address this disaster management gap. Targeting governmental policies, Yamashita et al. (2016) carried out a questionnaire survey to evaluate the effectiveness of municipalities in utilizing the registration scheme for their watershed management which is promoted by the Japanese government. The study indicates that municipalities are not so active in promoting runoff reduction by subsidizing private facilities, and that the public involvement should be strengthened in some planning processes.

The following paper by authors Tantiwatthanaphanich and Zou (2016) is a case study of a rural village in Thailand called Na Duang that was chosen for the implementation of a biomass utilization plan under an international cooperation scheme. After introducing the current status of energy demand, national plans, potential for biomass and biogas utilization, as well as relevant policies at the national level, the Na Duang project is described in detail and an analysis of its strengths, weaknesses, opportunities, and threats (SWOT) is performed.

For the climate change research field, Yang, Li and Xu (2016) study the city-level greenhouse gas (GHG) inventory of China. A GHG inventory is a framework for measuring a city's GHGs from all sources in the city and it provides scientific evidences for mitigation policies and actions. Yang, Li and Xu (2016) reviews recent published works of urban GHG inventory in China and compares the methodology frameworks, gas types, emission scopes and geographical boundaries. This paper shows that the city-level GHG inventory studies in China are still in the exploratory stage and facing many difficulties.

Some of the papers in this issue were presented at the Biennial International Conference on Spatial Planning and Sustainable Development held on 7-9 August at Taipei University of Technology, Taiwan. We would like to express our sincere gratitude to researchers who joined the conference and submitted their works to our journal. We also give special thanks go to reviewers who granted us their most generous support with their time and valuable comments. We hope all our efforts will enhance the knowledge for a sustainable human-nature relationship.

REFERENCES

Harris, F. (2012). *Global environmental issues*. Chichester, West Sussex: John Wiley & Sons.

J. Donald Hughes. (2009). *An environmental history of the world: humankind's changing role in the community of life*, London; New York: Routledge.

IPCC (2013). *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, available from http://www.ipcc.ch/report/ar5/wg1/ (last accessed on January 15, 2016).

Nguyen, D. , Imamura, F., and Iuchi, K. (2016). "Disaster Management in Coastal Tourism Destinations: The Case for Transactive Planning and Social Learning", *International review for spatial planning and sustainable development*, 4(2), 3-17.

Yamashita, S. , Matsuda, S. , Watanabe, R.and et al. (2016). "A Registration System for Preventing/Mitigating Urban Flood Disasters as One Way to Smartly Adapt to Climate Change in Japanese Cities", *International review for spatial planning and sustainable development*, 4(2), 18-29.

Tantiwatthanaphanich, T. and Zou, X. (2016). "Empowering the Local Community via Biomass Utilization: A Case Study in Thailand", *International review for spatial planning and sustainable development*, 4(2), 30-45.

Yang, F., Li, Y., and Xu, J. (2016). "Review on Urban GHG Inventory in China", *International review for spatial planning and sustainable development*, 4(2), 46-59.

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 3-17
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_3

Disaster Management in Coastal Tourism Destinations: The Case for Transactive Planning and Social Learning

David Nguyen[1*], Fumihiko Imamura[2] and Kanako Iuchi[2]
[1]Department of Civil and Environmental Engineering, Graduate school of Engineering, Tohoku University
[2]Tsunami Engineering, International Research Institute of Disaster Science,Tohoku Univeristy
** Corresponding Author, Email:nguyen.david.ngoc.t8@dc.tohoku.ac.jp*

Received 12 June, 2015; Accepted 25 October, 2015

Key words: Tourism, Disasters, Urban Planning, Social Learning

Abstract: Due to its intrinsic scenery, many tourism destinations are located in areas that are exposed to various natural hazards such as tsunamis, volcanic eruptions, and high winds. In particular, coastal tourism presents numerous risks unique to the tourism sector due to differences in the type of vulnerabilities faced by tourists compared to other types of communities. Tourists are transient, may lack knowledge of local hazards, perceive risks differently, and may present various communication barriers. Physical mitigation may also be limited as local communities rely on the preservation of the area's natural assets. Research on the effects of disasters in tourism destinations have generally fallen into the categories of emergency management, which is focused on the preparedness and response phases, or solutions, adopting a structural engineering approach. Long-term solutions that utilize non-structural approaches have been acknowledged as vital towards mitigation in various literatures, but in reality, have been scarcely applied. As disasters can constitute a wicked rather than tame problem, long-term solutions should include the input of multiple stakeholders striving towards a working solution that is constantly updated through feedback loops. Urban planning can provide such theoretical backgrounds that are missing from tourism planning studies, but have thus far, been limited to the needs of the permanent communities and not the transient community. This paper examines literature on disaster management planning in coastal destinations and bridges the gap between the fields of urban planning, disaster management and tourism planning, by suggesting the utilization of social learning to address disaster management gaps found in existing literature.

1. INTRODUCTION: COASTAL TOURISM AND NATURAL HAZARDS

Tourism is a major source of income, investment, and employment for coastal communities. The World Trade Organization believes that tourism has the capacity to stimulate development, economic growth, and create new opportunities for poverty alleviation and self-governance, especially in regions that are resource scarce or have limited livelihood options (World Tourism Organization, 2005). Regions in economic decline as well as remote areas, such as islands, have used tourism as a means to revitalize their economies, promote investment into the region and job creation.

However the tourism economy contains a number of vulnerabilities that are unique to the industry. As many tourism products rely on the intrinsic assets of the local environment, tourism sites are often located near areas that are exposed to natural hazards such as high winds, volcanic activity, storm surges, tsunamis and sea level rise. As tourism is a major user of local infrastructure which includes transportation networks, electrical systems and water supply systems, disruption to these services can have negative repercussions for tourism, both short and long-term, leading to eroding destination image (Byrd, 2007; Huan, Beaman & Shelby, 2004).

In December 2004, a magnitude 9.1 earthquake occurred southwest of Sumatra Island generating massive tsunamis that directly devastated six countries in the Indian Ocean. In the case of Thailand, the tsunami contributed to the country's worst natural disaster with over 5,300 confirmed deaths, nearly 3,000 missing, and losses accounting nearly a quarter of the national GDP (Rosa, 2012). Heavily dependent on the tourism industry, the tsunami was a major blow to the Thai economy as half of the confirmed deaths consisted of tourists (Thanawood, Yongchalermchai & Densirisereekul, 2006). The loss of tourism confidence led to a sharp decline in tourism, affecting locals whose livelihoods relied on the visitor industry. Factors contributing to large loss of life include limited utilization of tsunami sirens, lack of tsunami signage, poor hazard knowledge of tourists, limited evacuation training and conflicts over responsibilities (Calgaro & Lloyd, 2008).

Tourism represents a paradox as on the one hand, the industry relies heavily on positive images of safety, stability and low risk, but on the other, the intrinsic aspects that the industry is built upon are often vulnerable to natural hazards. In other words, tourism is considered a risky industry (Sonmez, Apostolopoulos & Tarlow, 1999). In order to reduce this risk, disaster management planning should prioritize improving the destination's resiliency. In clarifying the differences between resistance and resilience, Jonientz-Tristler describes resistance as actions where the effects of a disaster can be opposed. In contrast, resilience implies that efforts, products, and policies can promote the ability of a community to bounce back from an inevitable disaster event. Although natural hazard events are uncontrollable, its outcomes can be managed (Jonientz-Trisler, 2001).

2. VULNERABILITIES IN COASTAL TOURISM

Lindell's Disaster Impacts Model identifies three characteristics that provide insight into how hazards influence physical and social vulnerabilities. First, hazard characteristics identify the degree of exposure of natural hazards to a particular area. Next, physical vulnerabilities examine what type of structures, infrastructure and natural environments are susceptible to damage and loss based on the interaction between exposure and physical characteristics. Finally, social vulnerability examines the impacts of a disaster on a community group and their type of susceptibility (Lindell, Prater & Perry, 2006). Building upon these three characteristics, Table 1, below, modifies and summarizes it within the context of coastal tourism.

Table 1. Vulnerabilities in coastal tourism

Categories of Local Vulnerabilities in Coastal Tourism	
Hazard Characteristics	Tsunami inundation zones Flood zones Some areas also at risk of landslides Some areas also at risk of volcanic activity
Physical Vulnerabilities	Structures (Houses, Buildings, etc) Infrastructure (Transportation, Emergency services, Electricity) Natural structures (Coral Reefs, Wetlands, Parks)
Social Vulnerabilities	Tourists are mobile and difficult to account for Tourists lack knowledge of local hazard risk and evacuation Tourists may possess language barriers Tourists' risk perceptions may differ significantly High reliance on tourism creates significant risk for local communities and businesses

Hazard characteristics discuss the types of natural hazard vulnerabilities a coastal tourism area may be exposed to. Each area's hazard characteristics vary from one another due to their unique geography. For example, Hilo City in the State of Hawaii has experienced multiple tsunamis, leading to the city declaring much of its coastal zone a tsunami evacuation area. However, other coastal cities such as Beppu, in southern Japan, are exposed to both volcanic and tsunami risks due to its proximity to the Pacific Ocean and Mount Tsurumi, an active lava dome.

Physical vulnerabilities examine the exposure of natural and built structures to the aforementioned hazard characteristics. As tourism relies on sites to generate consumption, a number infrastructure found in the destination are also exposed to hazards. For example, coastal tourism may include a number of beaches, which in turn rely on the creation of nearby transportation infrastructure for accessibility, businesses to provide services and accommodation to be provided in the hazard area. In addition to built structures, the condition of natural structures can also influence vulnerability as the lack of mangroves, coral reefs, wetlands and open areas can increase an area's susceptibility to inundation (Klee, 1998).

Social vulnerabilities in coastal tourism examine both the transient population and the long term population which, while sharing the same hazard characteristics, may differ in social vulnerabilities. Tourists themselves present unique vulnerabilities as they are mobile, difficult to account for, may present communication and language barriers and are not easy to reach with relevant information such as warnings (Byrd, 2007). Tourists' risk perceptions may also differ as personal experiences with certain types of disasters may lead to higher risk aversion leading to reluctance to take action during a disaster event.

Communities dependent on the tourism economy are vulnerable to external shocks such as fluctuations in energy prices, currency rates, conflict, epidemics, or externally generated disaster (Table 2, below). Shocks can cause simultaneous losses for household, community, regional and national actors, diminish investment confidence, lower rates of job creation, slow economic growth and reduce GDP (Calgaro & Lloyd, 2008; Ritchie, 2009). In the case of Japan, tourism numbers decreased following the invasion of Iraq in 2003, the SARS epidemic in 2003, the Great East Japan Tsunami and Earthquake in 2011, and increased tension over the Senkaku Islands dispute in 2012 (Cooper, 2005; Kimura, 2012). In terms of recovery, tourism industries can struggle to rebuild its branding or image. The terrorism incidents in Bali, and more recently in Tunisia, deterred many tourists from returning and instead opt for alternate destinations that offer similar environments (Prideaux, Laws & Faulkner, 2003). For communities reliant on the tourism economy, prospects for recovery are delayed as the working force struggles to return to their old professions and may be forced to adopt new ones.

Table 2. Five factors that explain vulnerabilities of tourism economies to external shocks. Adapted from Calgaro & Lloyd (2008)

1.	Place-specific nature of tourist activity
2.	Fragility of destination images to negative perceptions of risk
3.	High dependency on tourism as a primary livelihood
4.	Heavy reliance on the marketing strategies of international tour operators
5.	High levels of seasonality

Despite these vulnerabilities, several factors contribute to the persistence of communities residing in areas exposed to natural hazards. The first detriment of people's behavior in the face of hazards is often livelihoods. People may choose to risk living in a hazardous area for the assurance of a better everyday life because it allows access to sustainable livelihoods (Dove, 2007; Kelman & Khan, 2013). Even in developed countries, people can move out of the city towards hazardous areas in search for a better quality of life (Chester, 2005).

Cultural and historical factors also contribute to people's attachment to a particular area despite a history of natural hazard risks. Residents living near volcanic hazard areas in Martinique demonstrate that the spatial dimension of risk perception is closely related to experience or memory of past eruptions (D'ercole & Rancon, 1994). A wide range of studies by anthropologists further show how traditional societies are strongly bonded to the volcano they live on and how their perception of associated risk is biased (Quesada, 2007). In the case of the Tohoku region of Japan, some residents who relied on the fishing industry were reluctant to relocate to higher ground, opting to stay closer to the industries near the coastline (Ranghieri & Ishiwatari, 2014).

For business owners in coastal tourism destinations, literature has identified numerous problems in the implementation of disaster management policies. First, the tourism industry tends to be poorly prepared for natural disasters, taking almost fatalistic or passive approaches (Cioccio & Michael, 2007; Faulkner, 2001; Prideaux, et al., 2003). Gaps in awareness and implementation of these policies stem from negative attitudes towards crisis planning, perceived lack of responsibility for dealing with crises, lack of money, lack of knowledge, lower risk perception, small size of organisations and perceived lack of cohesiveness due to firms being private (Wang & Ritchie, 2013). In addition, tourism operators are concerned with false alarms which affect destination image and businesses more so in their sector than compared to others (Becken & Hughey, 2013; Murphy & Bayley, 1989). For example, in 1990 local businesses in Mammoth Lakes, California, reacted negatively after geologists issued a false alarm, by stating that they would rather take their chances with a restless volcano than yield into fears that could harm the economy (Blakeslee, 1990).

Businesses that are willing to cooperate may lack sufficient resources to accommodate tourists' needs during disasters, or maintain knowledge of hazard risks and evacuation procedures. Tourism planning literature suggests that much of the current disaster plans in tourism are focused on post-disaster phases, and should shift from response and recovery to reduction and readiness (Ritchie, 2009). Long term strategies should not only include long-term disruptions caused by inundation, which in turn are caused by tsunamis, but also sea level rise and swells that cause major floods (Carlsen, 2006).

Managing these risks requires good governance to be efffective, essentially confidence in the rule makers by those to whom the replies. Effective risk management requires engagement at all levels in identifying, prioritizing, warning, and informing, or in other words, building capacity, about potential risk (O'Brien, O'Keefe, Gadema, & Swords, 2010). As risk is a social construct, its relationship to the various stakeholders represents a chain of interconnectedness between them. Distancing an actor in the chain lessens the effectiveness of risk management (O'Brien, et al., 2010).

3. APPROACHES TO DISASTER MANAGEMENT IN COASTAL TOURISM

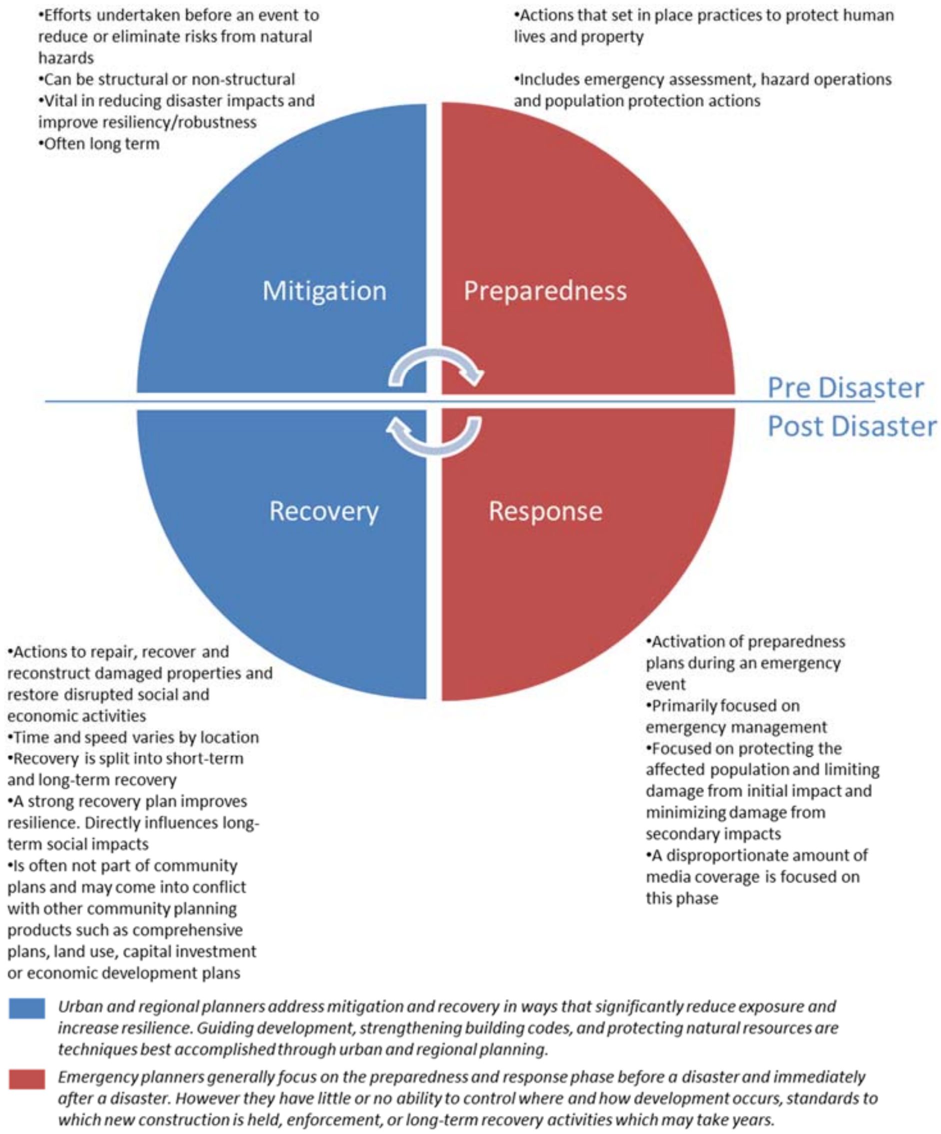

Figure 1. Four Disaster Phases. Modified from Masterson, et al. (2014) and UNEP (2007)

Literature on disaster management categorizes disasters into four phases: hazard mitigation, disaster preparedness, disaster response and disaster recovery (Queensland Government, 2015). Additional variants of the disaster phases cycle exist, such as Faulkner's Disaster Management Framework, Robert's Disaster Crisis Model and Fink's Crisis Management Cycle, which expand from the original four to a larger number of phases that offer greater detail into the disaster cycle, especially in the emergency management aspect (Faulkner, 2001).

Masterson et al. offer detailed explanations of the four phases. Firstly, hazard mitigation is defined as actions taken to reduce or eliminate risk from natural hazards. Mitigation strategies can be structural or engineering solutions, such as seawalls, or non-structural, such as land-use policies, zoning and education. Following mitigation, preparedness refers to practices that protect lives and property with threats that cannot be achieved by mitigation or are partially controlled. Preparedness strategies include various emergency management functions such as emergency assessment, hazard operations, warning and evacuation training (Figure 1) (Masterson et al., 2014).

Between the preparedness and response phase is a disaster event. The response phases are actions focused on the protection of an affected population, limiting damage from initial impact and to reduce the damage from further impacts. The ability to prepare and respond varies depending on the lead time of a natural hazard. For example, tropical storms offer more time for communities to prepare than sudden disasters such as earthquakes. Following response is the recovery phase which is further broken down into short and long-term recovery. Generally, the recovery phase focuses on actions seeking to prioritize the reconstruction and recovery of damaged properties, especially vital infrastructure and restoration of disrupted social and economic activities. Short term recovery focuses on the immediate restoration of infrastructure and services needed by society to function at a basic level, however long term recovery focuses on social and economic vulnerabilities that can last years after the disaster event (FEMA, 2004). A strong recovery plan improves resilience and directly influences long-term social impacts (Masterson et al., 2014).

Although Figure 1 suggests equal emphasis on the different phases of the cycle, Masterson states that in practice, emphasis is often placed on the response. Reasons for the bias stem from the proliferation of media coverage that focuses primarily on the disaster event and the following responses which generate the most interest. In contrast, long term recovery, mitigation and preparedness generate considerably less, if any media interest.

Masterson identifies four types of capital whose accessibility directly influences a community's resilience to natural hazards: social, economic, physical and human. Social capital consists of social organizations, such as networks and social trust, that facilitate coordination and provides an informal safety net during disasters while assisting the community in accessing resources. Economic capital is economic resources that increase the ability and capacity of individuals and the community to absorb disaster impacts and influences the speed of the recovery process. In general, those with greater access to financial resources recover more quickly from disasters. Physical capital refers to the structural environment such as buildings and dams. Hazard literature suggests that physical capital is one of the most important resources contributing to a disaster-resilient community and a lack of such resources may have a direct negative impact on a community's ability to prepare, respond and recover to a disaster event. In terms of disaster resiliency, human capital refers to the education and health of the working population. The knowledge and skills on types of hazard, hazard history and risks can be important assets in building community disaster resilience. Literature suggests that human capital determines a person's level of disaster resilience more than other types of capital (Burby, 1998; Masterson et al., 2014).

Table 3. Addressing vulnerabilities in tourism

Addressing vulnerabilities in Tourism	
Built	Hard-mitigation structures such as seawalls, embankments and evacuation towers
	In areas where such structures cannot be built, utilize dual use structures such as hotels, schools and public areas for evacuation
	Hotels can serve as both evacuation towers and short term recovery centers due to structure and capacity
Natural	Preservation of beaches and reefs, among others, that can reduce the impact of tsunamis
	Preservation of trees and open spaces that can reduce the impact of tsunamis, floods and high winds
Social	Improve hazard knowledge of local community and tourists
	Disaster hazard and evacuation signage and pamphlets
	Training in businesses and facilities in hazard/evacuation areas
	Early warning sirens and other communication

Utilizing the Lindell's three characteristics of vulnerabilities, Table 3 adapts them in the context of coastal tourism destinations. The table identifies vulnerabilities tourism destinations may face in terms of built/physical, human and social assets. These take into consideration the place-centric nature of the tourism economy, unique vulnerabilities of the transient tourist population and the reliance of the local community upon the visitor industries.

First, in terms of the built environment, much of the existing mitigation strategies implemented in coastal tourism destinations have focused on structural mitigation strategies. While such actions contribute to the decrease and, in some cases, outright elimination of natural hazard risks, it can in other cases contribute to increased risk. The presence of structures such as seawalls can create a false sense of security as well as promote development into hazardous areas. In cities such as Miyako, Japan, seawalls were not designed for a 1,000 year interval tsunami (Onishi, 2011). The presence of such seawalls may simply push storm surges elsewhere and transplant the hazard risk to another city (Masterson et al., 2014). For many tourism destinations, there may simply be a lack of space to develop structural mitigation strategies as they compete with the presence of hotels and businesses. Structural mitigation can be expensive and may not present the most cost effective solution. More importantly, coastal destinations rely on the preservation of natural assets such as coastlines, beaches, reefs, mangroves and forests. Cities can be reluctant to adopt structural mitigation strategies which can negatively impact its scenery and thus, its economy.

In terms of social vulnerabilities, as mentioned previously, tourists are mobile, may lack knowledge of local hazard risks and evacuation routes, may perceive risks differently and may face communication barriers. While the local community in a destination may possess better knowledge of hazard risks and evacuation strategies, their reliance on the tourism industry can create vulnerabilities during the recovery phase as visitor numbers decline. A tourism destination's recovery is highly influenced by the destination image and branding which in turn is based on the ability of a destination to convince visitors that the situation is safe and under control (Ritchie & Crouch, 2003).

In response to these vulnerabilities, long term mitigation strategies should utilize a number of built, natural and social capital in creating structural and non-structural mitigation strategies. However, due to the limitations of many tourism destinations' abilities to promote structural mitigation strategies, non-structural approaches to mitigation should be further examined.

To address physical vulnerabilities, hotels can serve as sites for evacuation during a disaster and as a place of refuge during the response and recovery phases. Hotels have been identified by the United Nations Environment Programme (UNEP) as containing one of the strongest physical structures in a coastal destination. Their large size and large room capacity combined with their tendency to maintain energy generators and food supplies make them ideal locations for evacuation (UNEP, 2007). The Maldives has enacted a One Island-One Resort concept which is used to mitigate damage and casualties caused by tsunami. Each resort maintains its own emergency response plans for an entire island, which include food stock, emergency generators, and a large amount of rooms, allowing them to reduce dependency on national or international relief efforts (Carlsen, 2006).

For cities which rely on beach tourism for its primary economy, such as Ishigaki and Atami in Japan, the lack of space prevents the city from developing evacuation towers as well as limiting the development of seawalls to a few locations. As a result, the cities cooperate with hotels in identified hazard risk zones to function as an evacuation shelter during the event of a tsunami or typhoon. The utilization of hotels as a mitigation strategy requires cooperation with the private sector, land use planning and zoning to ensure hotel structures in hazard risk zones are capable of withstanding multiple disasters, and regular collaboration to ensure that all stakeholders are able to achieve identified standards and goals.

Land use planning also applies to natural capital, such as the protection and sustainability of natural assets. In some cases, these features can actually serve as a form of structural mitigation, such as open parks near the coast, coral reefs and bay islets. Examples of land use planning that protects natural capital include: reducing or preventing beach erosion, parks with mangroves or trees and zoning that limits development in these areas. The continued functionality of these features after a disaster is vital in promoting economic recovery as well as serving as a form of mitigation.

Social vulnerabilities in among the tourism population rely heavily on improvements in education and communication in order to increase resiliency. The presence of natural hazard signage can communicate to visitors the hazard risks of an area as well as evacuation information. As tourists may lack the ability to speak the local language, signage should be multi-lingual, containing the languages of the most frequent foreign visitors in the area. Signage should also clearly identify the direction of the evacuation route and location of refuge areas. These signs should be located in hazard risk areas with high tourism traffic, such as transportation entry/exit points, popular attractions and shopping areas, and at accommodation. Pamphlets with simple to understand multi-lingual disaster information should be made available in hotels, tourism information kiosks and transportation centers. In the case of tsunamis, sirens have proven to be a useful tool in alerting tourists and local residents of an impending tsunami, creating lead time for individuals to prepare for evacuation (Atwater et al., 1999).

4. DISASTERS AS WICKED PROBLEMS

The reluctance to adopt certain disaster mitigation measures by coastal destination stakeholders reflects the need to further examine obstacles influencing their implementation. In order to properly utilize a destination's human capital to improve resiliency, stakeholders require a platform or procedure where they can engage each other and produce more effective collaboration through regular meetings and discussions. The goals of these collaborations are to allow each stakeholder the ability to give input towards a specific disaster mitigation goal and to create a working solution based on the feedback from the discussion. Two theories utilized in urban planning, transactive planning and social learning, are utilized to gauge the process of collaboration between stakeholders.

Lew (2012) describes the limitation of tourism planning which often draws upon concepts from urban and regional planning, especially in the area known as rational planning. In practice, some problems can be addressed by a more pure rational planning approach while others require a more incremental approach (Lew, 2012). Transactive planning was developed as a response to the perceived deficiencies of rational planning and advocacy planning. It is based on social learning theory and interaction where the planner brings process knowledge to facilitate shared understanding among people or clients who bring their personal experience and knowledge of local conditions to the planning process. A mutual learning process occurs as the planner and client are recognized for the equal value and importance of the knowledge they contribute (Lew, 2007). However, the limitations to this approach are the level of time and personal commitment that is required by the planner.

The need for transactive planning is a reaction to problems that Rittel & Webber (1973) refer to as 'wicked problems'. Wicked problems are those that are considered resistant to resolutions. These problems are often social and are characterized by perceptions of significant change, difficult quantification, few methods or rules, uncertainty as to when a problem is solved, no true/false decisions, but rather better or worse ones and no opportunity for trial and error. Any mix of these conditions requires a more incremental approach over a comprehensive approach (Rittel & Webber, 1973). In contrast, tame problems are primarily facility and infrastructure based and can often be addressed very well by engineering solutions (cite).

As wicked problems are highly uncertain, a single solution is considered impractical. Urban planning, whether tourism or disaster management focused, is often tasked with the difficulties of changing the mindsets and behaviours of a large number of people in order to achieve or promote change in policy or governance. As such, many disaster events, whether sudden on-set disasters such as earthquakes and tsunamis, or slow onset disasters such as climate change, are considered wicked problems due to the long term planning requirements and political processes involved (Heugten, 2014).

5. SOCIAL LEARNING

By defining sustainable development as a wicked problem, Rittel and Webber (1973) suggest that resolution to these problems are influenced by the capacity of the stakeholders to communicate, negotiate and reach collective decisions. The concept of "social learning" was based upon Rittel's acknowledgement of the role deliberation played in solving problems, and in accordance with urban planning theories, such as Habermas' communicative rationality and Forrester's deliberative democracy (Forester, 1999; Habermas, 1985). Social learning has been proposed to support participatory planning in various literatures such as on climate change, sustainability, impact assessments, natural resource management and disaster prevention (Roosli & O'Brien, 2013; Siebenhuner, 2004; Wal, et al., 2013; Webler, Kastenholz, & Renn, 1995).

It provides insight that certain complex societal and/or socio-ecological problems require shared problem identification, which can only be constructed through raised awareness among actors of each other's different mandate and, sometimes, goals and perspectives. The expected final outcomes of such processes are to find the best solutions through cooperative agreements as support for sustainable decision making and actions. Real decision making and actions are though left for the participants to deal with in their subsequent ordinary working processes (Johansson, Nyberg, Evers & Hansson, 2013).

Social learning is increasingly used in environmental or resource management. It is regarded as a promising approach for collective decision making in societal processes characterized by complexity, uncertainty and multiple social perspectives in overcoming building resilience. It is also important in policy implementations at the local level, as in a modern context, it is an overarching and normative concept where individuals and organizations learn from and about each other through exchange, dialogue or even conflict. Learning occurs when people engage and share their perspectives and experiences to develop a common framework of understanding and basis for joint action (Johansson et al., 2013).

Social learning's greatest value comes from its practical framework for exploring the critical elements of complex problem solving that are characterized by complexity, uncertainty and multiple perspectives (Johansson et al., 2013; Kilvington, 2007). Insight on complex societal and/or socio-ecological problems that require shared problem identification can only be constructed through raised awareness among each other's mandates, goals and perspectives. Societal learning is an iterative and ongoing process that comprises several loops and enhances the flexibility of the socio-ecological system to respond to change. The governance context is shaped both by cultural factors, macro economical and regulatory frameworks which are subject to change during the multi-scale social learning processes (Pahl-Wostl et al., 2008).

The social learning process promotes an environment where awareness of each stakeholder's goals and perspectives allows for reciprocity and reflection, leading them to reach collective decision making in their solutions. Pahl-Wostl (2008) states that the process includes social involvement and interaction, which are considered to be as important as content management, problem analysis and the development of a solution. These two aspects cannot be separated (Pahl-Wostl et al., 2008). Social learning can be done through site visits, as small group work with an egalitarian atmosphere. The process requires repeated meetings that allow for unrestricted opportunities to influence the process, political support for the process and direct links to formal decision making opportunities. This allows all stakeholders a chance to discuss any topic that comes to mind, debate, provide and dissect expert opinion, visit sites and improve relational qualities (Pahl-Wostl et al., 2008). Learning occurs when people engage and share perspectives and experiences to develop a common framework of understanding which leads to a basis for joint action (Johansson et al., 2013). The problems that were identified, information exchanged and solutions developed are a result of this interaction.

The outcomes of this deliberative process are to reach the most optimal solution through cooperation and agreement to support sustainable decision making and actions. Real decision making and actions are left for the participants to deal with in their subsequent ordinary working processes. The competence of the final decision is higher when local knowledge is included and when expert knowledge is publicly examined. Secondly, the legitimacy of the final outcome is higher when potentially affected parties can state their own case before their peers and have equal chances to influence the outcome. Third, public participation is identified with proper conduct of democratic government in public decision making activities (Webler et al., 1995). The participation of local stakeholders makes social learning key in policy implementation at a local level (Johansson et al., 2013).

6. LESSONS LEARNED

In the case of Khao Lak, Thailand, which has been cited in disaster literature as a case study where the lack of appropriate disaster risk reduction measures in both the city and tourism industries has led to high casualty rates, significant improvements have been made. In 2005, a National Disaster Warning Center was established in Thailand. In Khao Lak, multiple non-structural measures were achieved, which include the development of evacuation routes and maps, establishment of evacuation shelters and increasing hazard risk education and awareness of the area. This was achieved through the collaboration between the government and private sectors (Srivichai, Supharatid & Imamura, 2007). In the case of Khao Lak, Srivichai et al. have also identified the need to utilize hotels for vertical evacuation in certain areas of Khao Lak due to congestion.

The need to increase collaboration between the government and private sector was also noticed in Japan as a result of the 2011 Great East Japan Earthquake and Tsunami. The author has visited several coastal tourism destinations to review changes in their disaster management plans since 2011. Atami, a coastal city located 100 kilometers south of Tokyo, developed multi-lingual tsunami signage found throughout the city, multi-lingual hazard map and evacuation routes in tourism brochures and increased cooperation with private businesses and hotels in order to secure buildings that could be used for vertical evacuation. Atami city officials have expressed reluctance in further developing structural mitigation measures due to a lack of space and concerns over its costs and negative impacts to tourism. Similar sentiments were echoed in Okinawa Prefecture which, in 2015, began developing new tsunami mitigation measures in coastal cities and facilitating annual discussions with local governments, transportation and accommodation industries on how to proceed with their next disaster management plans for tourism.

Despite acknowledging the importance of improving disaster resiliency in the tourism sector and identifying the need for private-public collaboration, there has been some resistance. Attempts to modify land-use through urban planning to reduce hazard risks was met with resistance by locals in Phi Phi Island, Thailand (Srivichai et al., 2007). In the Tohoku Region of Japan, which was the most affected by the 2011 disasters, much attention has focused on reconstruction and recovery. Although prefectural disaster management plans have identified the need to work with the private sector on a number of non-structural measures, actual implementation has been limited. For example, in Miyagi Prefecture many hazard maps of the cities and towns identify only public infrastructure as sites for tsunami evacuation, despite the presence of tall hotels or other privately owned buildings which have, in the past, offered their sites for evacuation purposes. Multi-lingual hazard and evacuation maps/guides have been produced but are not widely disseminated, especially in businesses, accommodation and transportation gateways in tourism destinations. Both local government and private businesses in the interview stressed an interest and desire to work together and better implement such non-structural measures, both sides have stated a lack of time, money and man power as the reasons for limited collaboration.

7. CONCLUSION

Coastal destinations are often located in areas that are exposed to various natural hazards, such as tsunamis, flooding and high winds, among others. The tourism industry maintains a number of unique vulnerabilities ranging from physical vulnerabilities, such as limited ability to utilize structural mitigation measures, to social vulnerabilities, such as external shocks in tourism, mobility and communication challenges among tourists and economic vulnerabilities of the local community reliant on this industry. Non-structural mitigation strategies could provide a viable alternative in the face of natural hazard risks, such as hazard education, hazard and evacuation signage and laws and policies that promote resiliency.

Despite such hazard risks, some stakeholders in coastal destinations have displayed limited adoption of non-structural mitigation strategies, if at all. Reasons stem from stakeholders' perceived limited abilities, differences over stakeholder roles, financial and human resource concerns, and fears over harming destination image and branding. Thus the question becomes, if lack of cooperation between stakeholders serves as a barrier in the implementation of non-structural mitigation policies, what can overcome this?

Literature in the field of Urban Planning, particularly focusing on transactive planning theory, has identified social learning as a promising approach for collective decision making. Social learning is a process that allows different sources of knowledge and experiences to come together to learn about and form decisions about wicked problems. In application, such processes require a shift from a reactive, top-down approach to an inclusive approach that proactively reduces risk of disasters occurring and to minimize negative consequences for human lives and economic activities (United Nations, 2005).

Public participation can initiate social learning processes which translate uncoordinated individual actions into collective actions that support and reflect collective needs and understanding. However, there is a tendency for people to want to pursue egoistic aims before collective ones and it has to be responsible for contributing in a positive way to the democratic quality of our societies (Webler et al., 1995). Another limitation involves the time consuming process of deliberation and frequent updates to the working solution that may deter some stakeholders from fully participating in the process.

Despite these challenges, major disaster events such as the 2004 Indian Ocean Tsunami, the 2009 Samoan Earthquake and Tsunami, the 2011 Great East Japan Earthquake and Tsunami and the 2013 Super Typhoon Haiyan, have led to the United Nations developing the Sendai Framework 2015-2030. Based on the experiences gained from these disaster events, the agreement identifies and prioritizes the need for both the government and businesses to collaborate together in order to promote structural and non-structural mitigation strategies. The tourism sector itself has been identified as a target for the promotion and integration of disaster management due to the heavy reliance of some cities on tourism as a key economic driver (United Nations, 2015). For cities that continue to face disjointed collaboration between the multiple levels of government, tourism businesses, tourists and local community, the establishment of processes that allow for deliberation and contribution of these stakeholders can promote social learning leading to the basis for collaboration and, ultimately, the creation of policies that improve the destination's resiliency to disasters.

REFERENCES

Atwater, B. F., Cisternas, M., Bourgeois, J., Dudley, W. C., II, J. W. H. & Stauffer, P. H. (1999). *Surviving a Tsunami - Lessons from Chile, Hawaii, and Japan*. Hilo: United States Geological Survey.

Becken, S. & Hughey, K. F. D. (2013). Linking tourism into emergency management structures to enhance disaster risk reduction. *Tourism Management,* 36(0), 77-85.

Blakeslee, S. (1990). Wrong Once, Expert Keep Quiet On Volcanic Activity in California. *New York Times*, from http://www.nytimes.com/1990/09/11/science/wrong-once-expert-keep-quiet-on-volcanic-activity-in-california.html

Burby, R. J. (1998). *Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities*: Joseph Henry Press.

Byrd, E. T. (2007). Stakeholders in sustainable tourism development and their roles: applying stakeholder theory to sustainable tourism development. *Tourism Review,* 62(2), 6-13.

Calgaro, E. & Lloyd, K. (2008). Sun, sea, sand and tsunami: examining disaster vulnerability in the tourism community of Khao Lak, Thailand. *Singapore Journal of Tropical Geography,* 29(3), 288-306.

Carlsen, J. (2006). Post-Tsunami Tourism Strategies for the Maldives. *Tourism Review International, 10(1-2)*, 69-79.

Chester, D. K. (2005). Volcanoes, society, and culture. In J. Marti & G. G. J. Ernst (Eds.), *Volcanoes and the Environment* (pp. 404-439). Cambridge: Cambridge University Press.

Cioccio, L. & Michael, E. J. (2007). Hazard or disaster: Tourism management for the inevitable in Northeast Victoria. *Tourism Management,* 28(1), 1-11.

Cooper, M. (2005). Japanese Tourism and the SARS Epidemic of 2003. *Journal of Travel & Tourism Marketing,* 19(2-3), 117-131.

D'ercole, R. & Rancon, J.-P. (1994). La Future Eruption De La Montagne Pelee: Risque et Representations. *Mappe Monde*.

Dove, M. R. (2007). Volcanic eruptions as metaphor of social integration: a political ecological study of Mount Merapi, Central Java. In J. Connell & E. Waddell (Eds.), *Environment, Development and Change in Rural Asia-Pacific: Between Local and Global* (pp. 16-37). Routledge, London.

Faulkner, B. (2001). Towards a framework for tourism disaster management. *Tourism Management,* 22(2), 135-147.

FEMA (2004). Dimensions of Recovery. In F. E. M. Agency (Ed.), *Holistic Disaster Recovery: Creating a More Sustaianble Future*. Emmitsburg: United States Department of Homeland Security.

Forester, J. (1999). *Deliberative Practitioner: Encouraging Participatory Planning Processes*. The MIT Press, Cambridge.

Habermas, J. (1985). *The Theory of Communicative Action, Volume 1: Reason and the Rationalization of Society*. Beacon Press, Boston.

Heugten, K. v. (2014). *Human service organizations in the disaster context*. Macmillan Publishers, New York.

Huan, T.-C., Beaman, J. & Shelby, L. (2004). No-escape natural disaster: Mitigating Impacts on Tourism. *Annals of Tourism Research,* 31(2), 255-273.

Johansson, M., Nyberg, L., Evers, M. & Hansson, M. (2013). Using education and social learning in capacity building - the IntECR concept. *Disaster Prevention and Management: An International Journal,* 22(1), 17-28.

Jonientz-Trisler, C. (2001). *The Mitigation Strategic Implementation Plan: Toward tsunami-resistant communities.* Paper presented at the 2001 International Tsunami Symposium, Washington DC.

Kelman, I. & Khan, S. (2013). Progressive climate change and disasters: island perspectives. *Natural Hazards,* 69(1), 1131-1136.

Kilvington, M. (2007). Social learning as a framework for building capacity to work on complex environmental management problems

Kimura, S. (2012). Chinese tourists skip Japan over Senkakus dispute. *The Asahi Shimbun*, from http://ajw.asahi.com/article/behind_news/social_affairs/AJ201210190081

Klee, G. A. (1998). *Coastal Environment, The: Toward Integrated Coastal and Marine Sanctuary Management*. Upper Saddle River: Prentice Hall.

Lew, A. A. (2007). Tourism Planning and Traditional Urban Planning Theory: The Planner as an Agent of Social Change. *Journal of the Canadian Association of Leisure Studies,* 31(2), 383-392.

Lew, A. A. (2012). *Planning Theory, Sustainable Cities and Sustainable Tourism*. Paper presented at the Sustainable Tourism in Urban Environments.

Lindell, M., Prater, C. & Perry, R. (2006). *Disaster Impact Model*. Emmitsburg: Federal Emergency Management Agency.

Masterson, J. H., Peacock, W. G., Zandt, S. S. V., Grover, H., Schwarz, L. F. & Cooper, J. T. (2014). *Planning for Community Resilience: A Handbook for Reducing Vulnerability to Disasters*, Island Press.

Murphy, P. E., & Bayley, R. (1989). Tourism and Disaster Planning. *Geographical Review,* 79(1), 36-46.

O'Brien, G., O'Keefe, P., Gadema, Z. & Swords, J. (2010). Approaching disaster management through social learning. *Disaster Prevention and Management: An International Journal,* 19(4), 498-508.

Onishi, N. (2011). In Japan, Seawall Offered a False Sense of Security. *New York Times*, from http://www.nytimes.com/2011/04/02/world/asia/02wall.html

Pahl-Wostl, C., Tabara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E. et al. (2008). The importance of social learning and culture for sustainable water management. *Ecological Economics,* 64(3), 484-495.

Prideaux, B., Laws, E. & Faulkner, B. (2003). Events in Indonesia: exploring the limits to formal tourism trends forecasting methods in complex crisis situations. *Tourism Management,* 24(4), 475-487.

Queensland Government (2015). Disaster management phases, from http://www.disaster.qld.gov.au/About_Disaster_Management/Management_Phases.html

Quesada, C. (2007). Vivre dans un ile-volcan: approche anthropologique des relations entre hommes et volcan a Niuafo'ou (Tonga, Polynesie Occidentale). Ecole des Hautes Etudes en Sciences Sociales.

Ranghieri, F. & Ishiwatari, M. (2014). Relocation in the Tohoku Area *Learning from Megadisasters: Lessons from the Great East Japan Earthquake*: World Bank.

Ritchie, B. (2009). *Crisis and Disaster Management for Tourism*. Bristol: Channel View Publications.

Ritchie, B. & Crouch, G. I. (2003). *Qualifying and amplifying determinants*. Cambridge: Cabi Publishing.

Rittel, H. W. J. & Webber, M. M. (1973). Dilemmas in General Theory of Planning. *Policy Sciences,* 4, 155-169.

Roosli, R. & O'Brien, G. (2013). Social learning in managing disasters in Malaysia. *Disaster Prevention and Management: An International Journal,* 20(4), 386-397.

Rosa, D. (2012). The Boxing Day Tsunami and its Effects on Thailand's Tourism: Neumann University.

Siebenhuner, B. (2004). Social learning and sustainability science: which role can stakeholder participation play? *International Journal of Sustainable Development,* 7(2), 146-163.

Sonmez, S. F., Apostolopoulos, Y. & Tarlow, P. (1999). Tourism in Crisis: Managing the Effects of Terrorism. *Journal of Travel Research,* 38(1), 13-18.

Srivichai, M., Supharatid, S. & Imamura, F. (2007). Recovery Process in Thailand after the 2004 Indian Ocean Tsunami. *Journal of Natural Disaster Science,* 29(1), 3-12.

Thanawood, C., Yongchalermchai, C., & Densirisereekul, O. (2006). Effects of the December 2004 Tsunami and Disaster Management in Southern Thailand. *Tsunami Society.*

UNEP (2007). *Disaster Risk Reduction in Tourism Destinations*. Paris: United Nations Environment Programme.

United Nations (2005). *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communties to Disasters*. Kobe: United Nations.

United Nations (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030* Sendai: United Nations.

Wal, M. v. d., Kraker, J. D., Offermans, A., Kroeze, C., Kirschner, P. A. & Ittersum, M. v. (2013). Measuring Social Learning in Participatory Approaches to Natural Resource Management. *Environmental Policy and Governance,* 24(1), 1-15.

Wang, J. & Ritchie, B. W. (2013). Attitudes and perceptions of crisis planning among accommodation managers: Results from an Australian study. *Safety Science,* 52(0), 81-91.

Webler, T., Kastenholz, H. & Renn, O. (1995). Public participation in impact assessment: A social learning perspective. *Environmental Impact Assessment Review,* 15(5), 443-463.

World Tourism Organization (2005). Tourism and Poverty Alleviation, from http://step.unwto.org/content/tourism-and-poverty-alleviation-1

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 18-29
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_18

A Registration System for Preventing/Mitigating Urban Flood Disasters as One Way to Smartly Adapt to Climate Change in Japanese Cities

Sampei Yamashita[1*], Sadanori Matsuda[1], Ryoichi Watanabe[2], Yukihiro Shimatani[3], Toshiyuki Moriyama[4], Hironori Hayashi[3], Hiroki Iyooka[2], Teruki Hamada[2], Terukazu Yamashita[5], Kumiko Kakudo[5] and Tomoko Minagawa[6]

1 Department of Civil and Urban Design Engineering, Kyushu Sangyo University
2 Department of Civil Engineering, Fukuoka University
3 Department of Urban and Environmental Engineering, Kyushu University
4 Department of Socio-Environmental Studies, Fukuoka Institute of Technology
5 NPO Minamihata Dam Chosuisurukai
6 Department of Environmental Management and Planning, Kumamoto Univsersity
** Corresponding Author, Email: samp@ip.kyusan-u.ac.jp*

Received 5 July, 2015; Accepted 11 November, 2015

Key words: Watershed management, Urban flooding, Rainwater retention, Smart adaptation

Abstract: Intensive rainfall and frequent inundation have become a serious problem in urban areas all over the world. Climate change and heat island effect may be the cause of the phenomena. Widespread impervious pavement/surface of the ground makes things worse. In order to promote an effective river basin management in urban areas and reduce runoff, a registration system called "Safety Plan for 100mm/h-Rainfall" ("100mm/h Anshin Plan" in Japanese), a scheme for preventing and mitigating inundation caused by extremely heavy, short-term rainfall (such as 100mm/h-rainfall) was established in April 2013 by the central government in Japan. This study carried out a questionnaire survey to examine how municipalities effectively utilize the registration scheme for their watershed management. As a result, it is found that there are municipalities who have started/revised subsidizing installation of private rainwater retention/infiltration facilities in association with the registration system; however, municipalities in general are not so active in promoting runoff reduction by subsidizing private facilities. In addition, in the plans emphasizing public works for runoff reduction, public involvement is not so active, whereas in the plans devised with relatively new committees of watershed management, public involvement as well as private retention activities tend to be active. Based on the results, prospects of how a safety plan should be utilized in an urban watershed are discussed and examined from practicality's point of view.

1. INTRODUCTION

Intensive rainfall and frequent inundation have become a serious problem in urban areas all over the world. Climate change and heat island effect may be the cause of the phenomena. Widespread impervious pavement/surface of the ground makes things worse. Measures such as dredging rivers, increasing the capacity of the rainwater drainage system and constructing flood walls are not always effective. It should be necessary for people to reduce direct runoff by retaining/infiltrating rainwater within the entire urban watershed as there are a number of private properties and enterprises situated there. Harvesting the retained rainwater may contribute to recovering a sound hydrologic cycle in urban areas, which must be one way to smartly adapt to climate change.

In order to promote effective river basin management in urban areas and reduce runoff, a registration system called "Safety Plan for 100mm/h-Rainfall" ("100mm/h Anshin Plan" in Japanese), a scheme for preventing and mitigating inundation caused by extremely heavy, short-term rainfall (such as 100mm/h-rainfall) was established in April 2013 by the central government in Japan (MLIT (Ministry of Land, Infrastructure, Transport and Tourism), 2013).

A national policy for comprehensive flood control in the face of rapid urbanization in the city has been enforced since 1977 in Japan. The policy is focused not only on river-system/drainage management but also on surface-runoff reduction by retaining/infiltrating rainwater in the watershed. However, the policy has been applied to only 17 rivers and their watersheds from 1977 up until 2015. 12 of them are managed directly by the central government; and thus, they tend to depend on the rainwater retention/infiltration function from public facilities and properties in spite of the policy's emphasis on runoff reduction involving private-sector collaborations (Shimatani, Y., Yamashita, S. et al., 2010).

Moreover, storm-water management incorporating green infrastructure involving the private sector has been implemented, especially in recent years, in developed countries because of its cost effectiveness in maintenance (NYC Environmental Protection, 2014; Furumai, H., 2015); this approach is critical in a society with population decline like Japan. The registration system of "Safety Plan for 100mm/h-Rainfall" was established in these circumstances.

This study is to get information directly from the municipalities that have their officially-registered schemes and to contribute to subsequent planning for flood control in other urban areas.

2. METHOD

2.1 The registration system

"Safety Plan for 100mm/h-Rainfall" was introduced in April 2013 by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). This has much to do with one of the policies the Japanese government has implemented to tackle flood disasters especially in urban areas in a comprehensive way since the late 1970s (MLIT, 2013). The plan is intended to mitigate food damage in urban areas not only by improving river channels and drainage systems but also by installing rainwater retention/infiltration facilities/functions all over the urban river basin. It expects river and drainage-system administrators, residents and private firms to collaborate and mitigate flood disasters by reducing surface runoff and sharing safety/risk information.

MLIT requires potential municipalities first to devise and implement the legal river development project and storm-water drainage project and then to incorporate the following three aspects into their safety plan:

1) The target rainfall intensity must be greater, more local and shorter-lasting than the intensities set in both their legal river development project and storm-water drainage project.
2) River and drainage-system administrators, residents and private firms must work collaboratively and mitigate flood disasters by reducing surface runoff and sharing safety/risk information.
3) Measures focused on flood-damage reduction must be emphasized.

The first requirement implies a Safety Plan for 100mm/h-Rainfall is to cover what both the river development project and storm-water drainage project by the municipalities do not. That is why collaboration involving citizens/private firms and "flood-damage reduction" are emphasized in the second and third requirement, respectively. The registered municipality can get a grant from the central government and provide tax breaks/subsidies for those who install rainwater retention/infiltration facilities on their premises.

2.2 Questionnaire survey

A questionnaire survey was carried out to ask the registered local governments how they have planned and managed their rivers and watersheds. The questions included: 1) basic information such as urbanization rate, targeted rainfall intensity, etc., 2) watershed management measures, 3) damage mitigation measures, 4) relevant regulations, 5) public awareness, etc. (see *Table 1*, below). In this study, whether registering a plan is effective or not is judged by the disaster-mitigation measures newly implemented in association with the registration.

The questionnaires were sent by mail firstly on October 29, 2014 and secondly on May 7, 2015, and the responses were returned by November 19, 2014 and by May 27, 2015, respectively. The municipalities registered include the city of Nagoya and Kitakyushu, major cities/metropolises of Japan (population: 2.28 mil. and 0.96 mil., respectively), and 13 mid- to small-sized cities registered as of the end of October, 2015.

The outlines of the plans are open to the public (MLIT, 2014) and are referred to in the analysis of the survey results. The sewer/rainwater drainage system and relevant recent floods are also listed for reference (see *Table 2*).

Table 1. Outline of the questionnaire survey

Period	Oct.15-Nov.19, 2014 and May 7-27, 2015
Items	· Basic information (Urbanization rate, targeted rainfall, etc.) · Watershed management · Damage mitigation · Public awareness · Others
Format	Structured & open-ended

Table 2. Overview of the registered plans

No.	Registration date	City	Urbanization rate in registered watershed*	Coverage of sewer/ rainwater drainage systems	Inundation referred to in the plan: Mo.-Yr.	Inundation referred to in the plan: Above 1st floor level	Inundation referred to in the plan: Below 1st floor level	Period (yrs.)	Targeted rainfall intensity
1	Sep.4, 2013	Takaoka	(17.3%)	89.6%	Jul-12	179 (cases)	348 (cases)	10	67mm/h
2		Kanazawa	18.4%	97.5%	Jul-08**	507	1,476	10	55mm/h
3		Numazu	24.0%	56.5%	Jul-07	16	23	5	49mm/h
4		Yaizu	34.5%	22.5%	Jun-04	57	58	5	88mm/h
5		Hamamatsu	(6.3%)	79.5%	Sep-98	21	107	river:10/ drain: 7	73mm/h
6	Feb.4, 2014	Kanuma	29.5%	60.1%	Jul-13	45	62	10	94mm/h

7		Tajimi	(34.0%)	92.1% (storm drain: 59.7%)	Sep-11	439	183	5	74mm/h
8		Fuji	43.4%	72.5%	Jul-03	2	31	5	62mm/h
9		Nagoya	97.0%	99.2%	Sep-00	218	2,244	5	535.5m m/day
10		Nagoya	97.0%	99.2%	Sep-00	56	890	5	535.5m m/day
11	Sep.9, 2014	Koriyama	(9.1%)	71.7%	Jul-10 Sep-11	62 1,510	141 157	9	74mm/h
12	Feb.3, 2015	Mobara	19.4%	100%	Oct-15	320	183	10	51mm/h
13		Okaya	(17.8%)	99.5%	Aug-13	11	33	10	72mm/h
14		Fukuroi	77.0%	42.1%	Nov-04	4	75	4	76mm/h
15		Kitakyushu	100%	99.8%	Jul-13	1	54	10	73mm/h
16		Saga	100%	100%	Jun-08 Jul-09 Jul-12	24 11 9	484 591 489	6	64mm/h

* [Urbanization designated area/cite area] for Takaoka, Hamamatsu & Koriyama. [Use district/city area] for Tajimi & Okaya.

** Inundations that are not mentioned in the plan but occurred recently.

3. RESULTS

3.1 Overview

The urbanization rate and the coverage of sewer/rainwater drainage systems differ among the municipalities (*Table 2*). The major cities such as Nagoya and Kitakyushu have urbanization rates of 97.0% and 100%, respectively, within the registered watersheds (*Table 2*). The registered watershed of Saga also has an urbanization rate of 100% and the rate of Fukuroi is relatively high (77%). The rates are 20-40% in the other 12 municipalities/plans. The coverage of sewer/rainwater drainage systems is lowest in Yaizu (22.5%). The rates are over 90% in Nagoya (99.2%), Kitakyushu (99.8%), Saga (100%), Okaya (99.5%) and Tajimi (92.1%).

Most of the targeted periods are either five or ten years and the targeted rainfall intensities are less than 100mm/h (see *Table 3*, below). The scheme does not require municipalities to set the goal exactly at 100mm/h as its name indicates. The goals have been set based on recent heavy rainfalls which caused flood disasters in the river basins, however it may sound confusing for a wide variety of stakeholders who would like to get involved in implementing the plans.

A committee has been set up to draw up and carry out a plan for comprehensive flood control. It is to enhance cross-sectional collaborations among the administrators of river and storm-water drainage systems. Needless to say, public involvement is important especially when flood-disaster mitigation is pursued in urban areas. In this regard, Takaoka, Numazu, Yaizu, Fuji, Nagoya, Fukuroi and Saga stand out as they have no residents involved in the committees (*Table 3*).

Table 3. Committee for comprehensive flood-disaster management

No.	City	Month of foundation (Mo.-Yr.)	Participants						
			Central gov.	Pref. gov.	City gov.	Resident	Academic	Business/co-op	Local assembly member
1	Takaoka	Nov-12		○	○				
2	Kanazawa	Oct-09		○	○*	○	○	○	
3	Numazu	Feb-07		○	○				
4	Yaizu	Sep-05		○	○				
5	Hamamatsu	Dec-05		○	○	○		○	○
6	Kanuma	Dec-13		○	○	○			
7	Tajimi	Dec-11	○	○	○	○	○		
8	Fuji	Mar-07		○	○				
9	Nagoya	Mar-87			○				
10	Nagoya	Mar-87			○				
11	Koriyama	Aug-14	○	○	○	○	○	○	
12	Mobara	Dec-14		○	○	○			
13	Okaya	Mar-12		○	○	○			
14	Fukuroi	Mar-07		○	○				
15	Kitakyushu	Aug-03		○	○	○			
16	Saga	Jul-10	○	○	○				

* Secretariat

3.2 Changes in measures in association with registration

Tables 4-7 below illuminate changes in: 1) watershed management measures, 2) damage mitigation measures, 3) relevant regulations, and 4) public awareness, in association with the registration of a Safety Plan for 100mm/h-Rainfall, respectively.

Watershed management measures have changed in seven plans/cities (*Table 4*). Numazu, Kanuma and Koriyama started to install various sizes of rainwater retention/infiltration facilities such as storm-water reservoirs, infiltration trenches and inlets. Takaoka has installed major storm sewers and Fuji has emphasized the importance of a storm sewer network. Tajimi has strengthened collaboration with the central government. Mobara claims that the measures have enhanced the safety of the middle reaches of the watershed.

These cities, excluding Mobara, also report changes in damage mitigation measures (see *Table 5*). Takaoka, Numazu and Koriyama have revised the procedures of making and distributing flood hazard maps and disaster-risk information. Kanuma and Tajimi have strengthened collaboration with relevant administrators. Fuji has emphasized the importance of storm sewer networks as a damage mitigation measure as well.

Table 4. Changes in watershed management measures

No.	City	Measures
1	Takaoka	Collaboration between river and storm-water drainage system administrators. Installation of major storm-water drains.
3	Numazu	Flood-control reservoirs development
6	Kanuma	Flood-control reservoirs development. Reduction in river-development project period.
7	Tajimi	Collaboration with the central government.
8	Fuji	No change in measures that had been already implemented; Increasing importance of storm-water drainage systems.
11	Koriyama	Installation of private rainwater retention tanks and infiltration trenches. Conversion of old septic tanks into rainwater retention tanks.
12	Mobara	Enhanced measures taken in middle reaches of the watershed.

Table 5. Changes in damage mitigation measures

No.	City	Measures
1	Takaoka	Creating/distributing flood hazard maps. Providing residents with risk/safety information via e-mail, etc.
3	Numazu	Creating/distributing flood hazard maps. Providing risk information via the internet.
6	Kanuma	Collaboration between private and public sectors for effective evacuation. Information sharing for self-help. Cooperation between prefectural and city governments. Creating flood hazard maps.
7	Tajimi	Subsidies from the central and prefectural governments.
8	Fuji	No change in measures that had been already implemented; Increasing importance of storm-water drainage systems.
11	Koriyama	Providing residents with risk/safety information. Creating flood hazard maps and using them for education. Flood drills and seminars. Installing water bars.

Table 6. Changes in relevant regulations

No.	City	Measures
1	Takaoka	Implementing a subsidy program for installing private rainwater retention tanks (since Apr.1, 2013).
3	Numazu	Subsidizing river cleanups by residents.
11	Koriyama	Subsidizing two thirds of the cost of a private rainwater retention

tank (continued project).*

*"Continued project" but described as a change in measures in association with the registration.

Table 7. Changes in public awareness for risk management

No.	City	Measures
1	Takaoka	Strengthening public awareness about risk management by drills of sandbagging and by civic education for damage mitigation.
3	Numazu	Public awareness has been improved by providing residents with information on river stages and rainfall intensities in real time.
6	Kanuma	Inundation prevention measures have been promoting public awareness of risk management.
7	Tajimi	The importance of evacuation activities has become better understood.
12	Mobara	Public interest has been enhanced because of media attention.
8	Fuji	Residents' awareness of risk management remains low.
11	Koriyama	Awareness of the importance of self-help remains low; it should be strengthened by all means.

As for relevant regulations, three plans/cities report that there was a change (*Table 6*). Takaoka has provided a subsidy program for those who want to install private rainwater retention tanks and infiltration trenches/inlets. Numazu has subsidized citizens' environmental activities, and Koriyama has renewed its subsidy program for citizens to install private rainwater retention/infiltration facilities.

Five plans/cities report changes in public awareness (*Table 7*). Takaoka, Numazu, Kanuma and Tajimi claim that the public awareness for flood-disaster risks and management has been increased. Mobara points out that public interest has been enhanced because of media attention. On the other hand, Fuji and Koriyama report the awareness remains low. The former group provides no objective evidence for increasing awareness in their response. It may be that the public awareness of risk management in general needs to be improved.

In addition, Fukuroi reports the registration system has enabled them to dredge rivers intensively to prevent inundation along them in a short time.

In contrast, Kanazawa, Yaizu, Hamamatsu, Nagoya, Okaya, Kitakyushu and Saga show no changes in relation to the registration of their Safety Plan for 100mm/h-Rainfall (*Tables 4-7*). Kanazawa, Yaizu, Hamamatsu and Nagoya have the same reason: because they had taken measures of comprehensive flood control long before their registrations, much earlier than the other cities. For instance, the city of Yaizu says: "Our Safety Plan for 100mm/h-Rainfall is no different than before because it was drawn up and registered base on the measures that the Committee of Comprehensive Watershed Management for the Ishiwaki/Takakusa Rivers (of Yaizu) had already been implementing". Kanazawa explains: "We had already enforced an ordinance (concerning comprehensive flood control), so it (our Safety Plan for 100mm/h-Rainfall) does not necessarily include different measures (from those stipulated by the ordinance)".

On the other hand, Kitakyushu and Saga imply, from the viewpoint of effectiveness, that change would occur in the future; Okaya says, "we just continue what we have implemented for flood control since before the registration".

Moreover, the city of Fuji, which suggests changes in their storm-water drainage system, shows: "The measures (of our Safety Plan for 100mm/h-Rainfall) are not so different than before".

Kanazawa, Yaizu, Hamamatsu, Nagoya, Kitakyushu and Fuji had launched their committee for comprehensive flood control before the other cities, who clearly report the changes in the measures. Kanazawa, Yaizu, Hamamatsu, Nagoya, Kitakyushu and Fuji established their committees in 2009, 2005, 2005, 1987, 2003 and 2009, respectively (*Table 3*). They have tackled urban flood disasters from relatively early on.

3.3 Facilitating watershed management measures

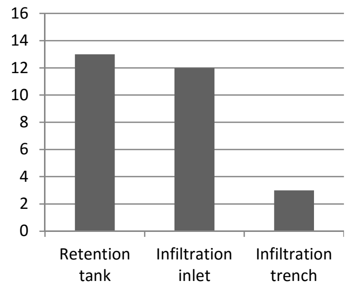

Figure 1. Promotions for private rainwater retention/infiltration facilities

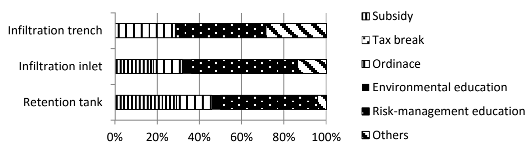

Figure 2. Programs for private rainwater retention/infiltration facilities

Figure 1 shows whether the plans/cities have promotion programs for the installation of private rainwater retention tanks, storm-water infiltration trenches and inlets. Private tanks (13 plans/cities) and infiltration inlets (12 plans/cities) tend to be promoted more than infiltration trenches (three plans/cities). *Figure 2* illustrates how the municipalities are trying to stimulate installation of these facilities. Risk-management education accounts for 40-50% of all the stimuli, including subsidies, tax benefits, ordinances, environmental education, risk-management education, etc.. Subsidy programs account for 20-30% in terms of both private retention tanks and infiltration inlets; and it is not considered, in this survey's responses, as a stimulus for installing private infiltration trenches.

Table 8. Private rainwater retention tanks

No.	City	# of installation	Total capacity (m^3)
1	Takaoka	7	1.2
2	Kanazawa	231	52
3	Numazu	0	0
4	Yaizu	0	0
5	Hamamatsu	0	0
6	Kanuma	1	-
7	Tajimi	281	50
8	Fuji	240	48
9	Nagoya	0	0
10	Nagoya	0	0
11	Koriyama	1,721	3,400
12	Mobara	9	1.43
13	Okaya	136	-
14	Fukuroi	219	58.8
15	Kitakyushu	0	0
16	Saga	0	0

Note: Black represents cities emphasizing both private and public rainwater retentions.

Table 9. Public rainwater retention tanks

No.	City	# of installation	Total capacity (m^3)
1	Takaoka	15	-
2	Kanazawa	4	3,410
3	Numazu	5	5,300
4	Yaizu	1	1,400
5	Hamamatsu	1	0.18
6	Kanuma	2	-
7	Tajimi	86	60*
8	Fuji	5	163,000
9	Nagoya	5	837,00
10	Nagoya	13	149,800
11	Koriyama	2	25,073
12	Mobara	-	-
13	Okaya	3	1,188
14	Fukuroi	5	18,600
15	Kitakyushu	2	18,170
16	Saga	-	934,000

Note: Gray represents cities emphasizing public retention; black: private and public.
* Approximate capacity shown as an example.

Tables 8 and *9* are to examine how private and public rainwater retention facilities are subsidized, installed or built in the registered plans/cities. Nagoya, who has been tackling urban flooding from early on, has no subsidy program for private rainwater retention tanks, but the total capacity of its public rainwater retention facilities are overwhelming (*Table 9*). In a similar fashion, Numazu, Yaizu and Kitakyushu have no subsidy for private rainwater retention tanks, but they have installed or built relatively large, public rainwater retention facilities. Saga also has no subsidy for private rainwater retention/infiltration, but has the largest capacity of public retention function. Saga has developed irrigation-pond networks since ancient times because it was not able to irrigate water from major rivers that did not have enough longitudinal gradients. Those ponds can function not only for irrigation but also for runoff reduction (Kato, H., 1994).

As mentioned earlier (see Section 3.1), in the plans of Numazu, Yaizu, Nagoya (with 2 plans) and Saga, there are no descriptions of public involvement in the framework of their watershed management committees. In Nagoya's response, they point out limitation of private retention/infiltration facilities in flood control. The emphasis/dependency on public works may imply a trend in addressing comprehensive flood control by those who have been tackling it from relatively early on.

In contrast, Kanazawa, Tajimi, Fuji, Koriyama, Okaya and Fukuroi have both many private tanks subsidized by the local governments and public rainwater retention facilities that are overwhelming either in the number or in the total volume. They are well-balanced from the perspective of comprehensive, all-out effort that is indispensable for urban flood-disaster prevention/mitigation.

Furthermore, Koriyama stands out from all the other cities with the number and total capacity of the installed rainwater retention tanks the city subsidized. According to an additional interview with the city, the reasons include: 1) relatively long period of time for the subsidy program (since 1996), 2) reusing old septic tanks, and 3) high public awareness of flood risk management because of frequent occurrence of flooding.

3.4 Facilitating/strengthening self-, mutual and public help as mitigation measures

Figures 3-5 show how the registered plans/cities facilitate/strengthen self, mutual and public help as mitigation measures.

As a measure for facilitating self-help, flood hazard maps are employed in 14 plans and social events and workshops are used in four plans (*Figure 3*). Mutual help is facilitated with comprehensive disaster-preparedness drills and workshops in 13 plans and risk education is employed for mutual help in eight plans (*Figure 4*). Public help is strengthened by utilizing hazard maps in all the 15 plans; other measures such as risk/evacuation information collection/distribution, etc., are used in less than seven plans (*Figure 5*).

In summary, for flood-disaster mitigation, the municipalities who registered their Safety Plan for 100mm/h-Rainfall tend to utilize hazard maps to facilitate/strengthen self- and public help and educational activities to drive mutual help.

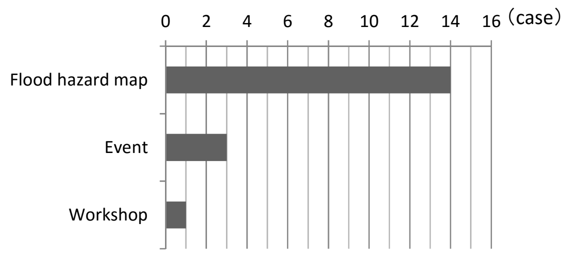

Figure 3. Promotions for self-help

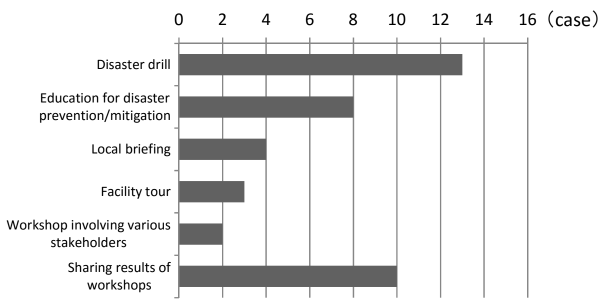

Figure 4. Promotions for mutual help

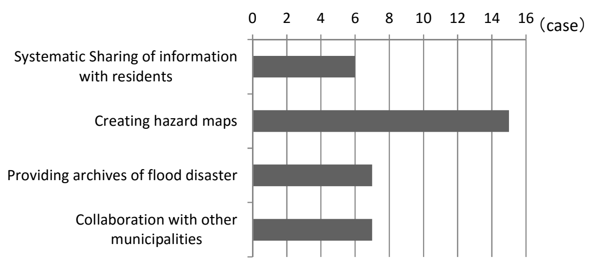

Figure 5. Promotions for public help

3.5 Other responses

Other, important free responses to the questionnaire survey includes: “the name of the plan (Safety Plan for 100mm/h-Rainfall) is difficult to explain to the public, as the target rainfall can be different from (less than) 100mm/h”; “the plan is beneficial only to the municipalities who have a full-coverage of storm-water sewer systems to be improved by newly installing arterial storm drains”; “the scheme in itself is not a subsidy program but a registration system, so it is necessary for the municipalities to provide their own subsidy programs to promote watershed management. The process may negatively affect comprehensive, systematic flood control in the watershed”, etc.

In addition, the importance of: 1) clear description of how to prevent inundation, 2) administrative leadership, 3) enhancement of civic collaboration, and 4) collaboration between river and storm-water drainage systems’ administrators, is also pointed out in their responses as an issue to be addressed.

These responses may be meaningful for future registrations as these are from the municipalities who registered their plans earlier and are quite active in promoting urban flood-disaster prevention/mitigation.

4. DISCUSSION AND CONCLUSION

4.1 Findings

This study carried out a questionnaire survey to examine how municipalities effectively utilize the registration scheme of “Safety Plan for 100mm/h-Rainfall” for their watershed management. The findings obtained are as follows:

1) All the targeted rainfall intensities are below 100mm/h, so the name of the scheme does not fit well with the plans.
2) In association with the registration, watershed management measures including main storm-water drains and small- to mid-sized rainwater retention/infiltration facilities and damage mitigation measures such as hazard maps and risk/safety information distribution are progressing.
3) There are municipalities who have started/revised subsidizing installation of private rainwater retention/infiltration facilities in association with the registration; however, as it now stands, municipalities in general are not so active in promoting runoff reduction by subsidizing private facilities.
4) The registration does not necessarily strengthen public awareness for risk management.
5) There are three patterns in disseminating rainwater retention systems: public-oriented, private-oriented and both.
6) In the plans emphasizing public works for runoff reduction, public involvement is not so active, whereas in the plans devised with relatively new committees of watershed management, public involvement as well as private retention activities tend to be active.
7) For flood-disaster mitigation, the municipalities who registered their Safety Plan for 100mm/h-Rainfall tend to utilize hazard maps to facilitate/strengthen self- and public help and educational activities to drive mutual help.

4.2 Prospect

In summary, there are municipalities who have started/revised subsidizing installation of private rainwater retention/infiltration facilities in association with the registration; however, municipalities in general are not so active in promoting runoff reduction by subsidizing private facilities. In addition, in the plans emphasizing public works for runoff reduction, public involvement is not so active, whereas in the plans devised with relatively new committees of watershed management, public involvement as well as private retention activities tend to be active.

Based on the results obtained, what can be said about watershed management in a city who is considering utilizing the scheme of a Safety Plan for 100mm/h-Rainfall in the near future?

The Hii River Watershed (population: 190 thousand) needs to draw up a plan for comprehensive flood-disaster prevention/mitigation, as it has experienced major flood disasters three times over the past 50 years (Yamashita, S., Watanabe, R. et al., 2015; Yamashita, S., Shimatani, Y. et al., 2013). The latest took place in July 24, 2009, which led citizens to get involved in discussing and implementing comprehensive flood control within the watershed. In association with the disaster and the subsequent move, the prefectural government of Fukuoka, who administers the Hii River System, enforced the Hii River System Development Project in 2014 (Fukuoka Prefecture, 2014). This legal project clearly mentions the future incorporation of a Safety Plan for 100mm/h-Rainfall. The watershed is included entirely within the city area of Fukuoka (population: 1.53 million), one of the metropolises of Japan.

In Fukuoka, 116mm/h was recorded on July 24, 2009. At that time, the spatially-averaged rainfall that caused inundation in the Hii River Watershed was 80.1mm/h. It is greater than the targeted rainfall intensities of both the river development project and the storm-water sewer development project: 72.0mm/h (return period: 40 years) and 59.0mm/h (10 years), respectively. It may be reasonable to set the target for the Safety Plan for 100mm/h-Rainfall of the Hii River Watershed between 80mm/h and 116mm/h and avoid confusion as pointed out in other plans.

The coverage of a storm-water sewer system for the Hii River Watershed is 99.6%. The city of Fukuoka has a subsidized private rainwater retention/infiltration program and had subsidized 692 rainwater retention/infiltration facilities by 2010 (City of Fukuoka, 2010). It is important not only to improve storm-water drainage networks but also to strengthen private rainwater retention/infiltration. The city of Koriyama has 1,721 subsidized rainwater retention tanks installed as of Dec. 2014. The population of the city is a fifth of that of Fukuoka.

As we see in Nagoya and Kitakyushu, public works for runoff reduction should be indispensable also in Fukuoka, as a metropolis of Japan. However, too much dependence on public works may weaken public awareness for disaster-risk management and self-help/mutual help needed in a depopulating society like Japan. Moreover, the installation of a private rainwater retention tank and the domestic use of the retained rainwater can enhance daily preparedness for heavy rainfall (Yamashita, S., Watanabe, R. et al., 2015; Yamashita, S., Shimatani, Y. et al., 2013). Private and communal activities for runoff reduction can and should be rigorously pursued in Fukuoka in order to prevent watershed management from performing poorly (Johnson, N., Ravnborg, H.M. et.al.. 2001), this approach should be beneficial in other urban areas as well.

REFERENCES

City of Fukuoka (2010). *Syakai-shihon Sogo-seibi-keikaku (Comprehensive Plans for Social Capital Improvement (in Japanese)*, City of Fukuoka, Fukuoka.

Fukuoka Prefecture (2014). *Hiigawa-suikei Kasen-seibi-keikaku (River Development Project for the Hii River System (in Japanese)*, Fukuoka Prefecture, Fukuoka.

Furumai, H. (2015). "Oversea trends of storm-water management and future perspectives (in Japanese)", *Journal of Hydrological System*, *97*, 5-10.

Johnson, N., Ravnborg, .H.M. et al. (2001). "User participation in watershed management and research", *Water Policy*, *3*, 507-520.

Kato, H. (1994). *Mizu no Zokei: Mizu-chitsujo no Keisei to Mizu-kankyou Kanri-hozen (Formative Design with Water: Socio-physical system formation and environmental management with water (in Japanese))*, Kyushu University Press, Fukuoka.

MLIT (Ministry of Land, Infrastructure, Transport and Tourism) (2014). *100mm/h Anshin Plan (Safety Plan for 100mm/h-Rainfall (in Japanese))*, http://www.mlit.go.jp/river/kasen/main/100mm/, MLIT, Tokyo.

MLIT (2013). *Implementation Guidance of 100mm/h Anshin Plan (Safety Plan for 100mm/h-Rainfall (in Japanese))*, MLIT, Tokyo.

MLIT (2010). *Sogoteki na Suigai-taisaku: Tokutei-toshi-kasen Shinsui-higai Taisaku-ho no Shikko-jokyo no Kensho (Comprehensive Flood Control: Effectiveness of the Act of Flood-Disaster Measures for Designated Urban Rivers (in Japanese))*, MLIT, Tokyo.

NYC Environmental Protection (2014). *NYC Green Infrastructure 2013 Annual Report*, NYC Environmental Protection, New York.

Shimatani, Y., Yamashita, S. et.al. (2010). "How do we advance the integrated watershed management for flood control and living environment using on-site storm water storage system (in Japanese with English abstract)", *Advances in River Engineering*, *16*, 17-22.

Yamashita, S., Watanabe, R. et al. (2015). "Smart adaptation to flooding in urban areas", *Proceedings of International Conference on Sustainable Design, Engineering and Construction 2015, Chicago, USA, Procedia Engineering*, *118*, 1096-1103.

Yamashita, S., Shimatani, Y. et al. (2013). "Comprehensive flood control involving citizens in a Japanese watershed", *Water Science & Technology*, *68(4)*, 791-798.

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 30-45
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_30

Empowering the Local Community via Biomass Utilization: A Case Study in Thailand

Thanapan Tantiwatthanaphanich[1] and Xiaolong Zou[1*]
1 Graduate School of Asia Pacific Studies, Ritsumeikan Asia Pacific University
** Corresponding Author, Email: zoufuchen@gmail.com*

Received 21 June, 2015; Accepted 5 November, 2015

Keywords: Biomass, Biogas, Thailand, Renewable energy, Policies.

Abstract: As an agricultural country, Thailand produces a large amount of agricultural products and the stench of decomposing biomass is a common problem in many local communities. To dispose of biomass, some communities have utilized it to produce renewable energy or other products for household purposes. Currently, some villages have successfully implemented biomass utilization technology at the household level. Villagers have adopted skills and technical knowledge on biomass waste management from institutions dedicated to research on the development of renewable energy technology at the community level and are now able to mitigate and control waste problems systematically. Presently, biomass utilization technologies in Thailand are able to produce biogas, biodiesel, livestock feeds and organic fertilizers. In addition to the aforementioned environmental and economic benefits, villages that have adopted biomass utilization technology were also able to reduce greenhouse gas emissions, prevent deforestation and reduce household spending for energy and farming products. This paper investigates the current status of the general renewable energy policy in Thailand with specific focus on biomass utilization as a renewable energy source. Case studies further illustrate how these energy policies are being implemented at the community level. We apply the strength, weakness, opportunity and threat (SWOT) analysis to further analyze the case studies, identify potential issues and propose counter measures to solve them.

1. INTRODUCTION

Energy consumption has continuously increased over the years due to the expansion of industry across the globe and to the continuously increasing world population. Fossil fuels remain the world's main energy source; these fuels and other natural resources for energy are diminishing in the face of increasing demand. Oil prices are rising, as are environmental problems that result from burning fossil fuels. Hence, renewable energy alternatives receive attention from many developing countries. Several policies and tools are implemented in order to promote and support the research sector to find suitable sources for alternative energy such as biomass, solar energy, wind energy and hydropower.

Thailand is actively promoting and supporting the utilization of alternative energy and improving energy efficiency while reducing the usage of fossil fuels. The Thai Ministry of Energy aims to increase alternative energy consumption from 9,025 ktoe to 39,388.67 ktoe of the total energy consumption in ten years. The Alternative Energy Development Plan (AEDP

2015-2036) has strategies to promote usage of energy at the community level under the green community concept, as well as to support domestic manufacturers for technology, research and development. The Thai government uses several methods such as incentives for private investment, public education campaigns, as well as activities to raise public awareness. The expected economic and environmental benefits include saving money from oil imports and reducing emissions, respectively.

Since Thailand is abundant in agricultural products, biomass has been the traditional energy source in Thai rural areas, by using agricultural crops and livestock manure as major sources. Several households and small-scale industries in rural areas utilize biomass for generating renewable energy for cooking purposes and for process heating in residential and manufacturing sectors. The obtained benefits are increasing household incomes, reducing greenhouse gas emissions and improving quality of life for local people.

The rural village of Na Duang in north-eastern Thailand is a community that was chosen for the implementation of a biomass utilization plan based on this concept, with help from several Thai government ministries and the Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF). The goal of the plan is to implement biomass utilization technologies, also known as conversion technologies, in the village so that the villagers can use these products in their households, farmlands, and livestock farms.

Biomass crops that Na Duang village produces are oil palm, corn, cassava and rice, which can be processed into fuel (biodiesel, biogas), cooking oil (palm oil), animal feedstock and fertilizer (organic fertilizer and liquid fertilizer). Since production and consumption of biodiesel has become a trend in recent years, there are more than 437 hectares of oil palm plantation in the area and this is increasing annually. If this project becomes successful, it would be a model to other villages that produce similar crops. In order for it to succeed, the project must overcome the problems or threats it might face in the future.

This study aims to provide an analysis on the strengths, weaknesses, opportunities and threats (SWOT) of biomass utilization in Na Duang village of Thailand in order to identify the benefits, opportunities and challenges that exist. The agricultural community empowerment aspect that is observed will be mentioned in the work as well. This research will be useful to governments, organizations, local communities and those who aim to study or implement community-based projects in the agricultural sector. Moreover, the findings of this work can help villagers in Na Duang and other stakeholders to acknowledge the possibilities of development in biomass utilization.

2. METHODOLOGY

This research takes a mainly qualitative approach by investigating and examining the current status of alternative energy, particularly biomass and biogas utilization in Thailand. Moreover, a case study of the community level biomass utilization project is employed for a more in-depth analysis on which to base further conclusions and recommendations.

2.1 Data collection

Gathering of data regarding national policies and general statistics have been accomplished through desktop research. However, due to the country-specificity of this study, some Thai-language literature has been cited where the corresponding literature in English is not available. Other sources of data include academic publications, reports from relevant governmental entities and trust-worthy news reports.

2.2 Case Study Selection and Analysis

Na Duang village's biomass utilization project was chosen as a case study because it receives support from MAFF of Japan, and the focus is not only on technical support but also on human capacity development (Hayashi, 2013). This village is a fitting model because many villages in Thailand do similar crop cultivation and livestock domestication for their livelihoods (Choenkwan, et al., 2014).

Na Duang resembles a number of villages in Thailand in the way of agriculture, the types of crops grown and the livestock raised. The Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is applied for the qualitative analysis of the Na Duang village project. A similar method has been used to analyze case studies of China's biogas development in the renewable energy sector (Zou, 2014), where SWOT analysis and stakeholder analysis was applied to obtain the potentials and challenges on the implementation of each biogas project site in China. Conclusions are made based on the most influential factors or obstacles in those projects for better recommendations to the policy makers as well as the stakeholders.

However, it is not yet possible to conduct stakeholder interviews due to geographical constraints. As a result, conclusions, recommendations and discussion are conducted based on only the data collected and reviewed literature for this pilot study.

3. CURRENT STATUS OF BIOMASS UTILIZATION IN THAILAND

3.1 The Energy Situation in Thailand

Thailand's economy has mainly relied on imported energy. According to energy statistics from the Energy Policy and Planning Office, 57% total commercial energy consumption in Thailand in 2014 came from imports, of which crude oil accounted for 70% of the total energy import (Energy Policy and Planning Office, 2015). Thailand also relies on domestically produced natural gas as a primary fuel to produce electricity. As of 2014, 59% of total electricity production came from natural gas (Energy Policy and Planning Office, 2015). These high ratios contribute to vulnerabilities to the country's supply. Moreover, Thailand's energy demand is forecasted to increase from 75,804 ktoe in 2014 to 131,000 ktoe by 2036 (Department of Alternative Energy Development and Efficiency, 2015).

At present, the Thai government has a strategy that aims to increase the use of renewable energy in an attempt to reduce and replace the usage of fossil fuels. The Thai Ministry of Energy has an Alternative Energy Development Plan (AEDP 2012-2021), which aims to create a framework and direction for increasing alternative energy consumption from 9,025 ktoe in 2014 to 39,388.67 ktoe by 2036 within 10 years (Department of Alternative Energy Development and Efficiency, 2015; Sutabutr, 2013).

Table 1. Target for Alternative Energy Development Plan in 2036

Type		Unit	Amount
Electricity	Community Waste	MW	500.00
	Industrial Waste	MW	50.00
	Biomass	MW	5,570.00
	Biogas (Waste Water/ Waste)	MW	600.0
	Small Hydro	MW	376.00
	Biogas (Crops)	MW	680.00
	Wind	MW	3002.00
	Solar	MW	6000.00
	Hydro	MW	2,906.40
Heat	Waste	ktoe	495.00
	Biomass	ktoe	22,100.00
	Biogas	ktoe	1,283.00
	Solar	ktoe	1,200.00
	Alternatives	ktoe	10.00
Bio-fuel	Bio-diesel	ML/day	14.00
	Ethanol	ML/day	11.30
	Pyrolysis Oil	ML/day	0.53
	CBG	T/day	4,800.00
	Alternatives Fuel	ktoe	10.00
Total Alternative Energy Usage (ktoe)			**39,388.67**

(Source: Department of Alternative Energy Development and Efficiency, 2015)

The available alternative energy sources in Thailand include electricity generation from solar energy sources, wind and hydro power, bio-fuel, bio-energy from waste, biomass and biogas, and new energy types such as tidal power, geothermal energy and hydrogen. The strategies are set by following the following key components (Sutabutr, 2012):

1. Promoting community participation in alternative energy development and consumption across the country
2. Improving incentive measures to foster private investment
3. Amending laws and regulations unfavourable to alternative energy development
4. Improving essential infrastructure such as transmission and distribution system as well as smart grid
5. Promoting public relations and knowledge enhancement
6. Promoting research activities as an entire development tool for the alternative energy industry

3.2 Potential for Biomass and Biogas Utilization in Thailand

According to the AEDP 2015, the plan's target is to increase biomass for renewable energy to 5,570 MW for the year 2036, while the generating capacity of 2014 was 2,451.82 MW (Department of Alternative Energy Development and Efficiency, 2015). This is because biogas sources can be found from biomass especially in agricultural and agro-industrial wastes. The target for biogas production is to increase from 379 ktoe to 1,000 ktoe by 2021 (Sutabutr, 2012). Thailand is an agricultural country that can produce a large volume of agricultural products. According to World Bank Statistics, the agricultural sector contributed 10.5% to Thailand's GDP in 2014 (World Bank, 2015). Approximately 34% of all the households in Thailand work in the agriculture sector, and most of them are located in rural areas. These agriculture activities include crop cultivation and integrated crop-livestock farming, of which the major forms of Thai livestock are pigs, various types of poultry and cattle (Charoensook, et al., 2013). The major sources of biomass from agriculture-based industries are sugar cane, rice and oil palm sectors (Papong, 2015). Therefore, Thailand has the potential to produce biogas from the decomposition of organic matter from biomass and waste water, as well as livestock manure up around 7,800 and 13,000 TJ/year, respectively (Tippayawong & Thanompongchart, 2010). Currently, the stench of decomposing biomass is a common problem in many communities in Thailand. In order to dispose of biomass, some communities have utilized it to produce biogas for household purposes (Mikled, 2009).

In addition, trends on the international tourism market are changing as the principles of sustainable development become more widely accepted in daily life. Modern tourists are becoming aware of the necessity to preserve and protect natural resources and environment from destruction. Therefore, implementation of green technologies and ecological approaches to business development represent a reasonable solution for the protection of the human environment and helps in increasing awareness of the general public on the necessity to implement these approaches in business. Based on this trend, cities or regions that successfully adopt the principles of sustainable development are likely to gain more attention from concerned tourists. With more tourism, these communities would gain positive economic benefits (Cerović, 2014).

3.3 Promoting Biomass Utilization at the Household Level

The government is attempting to promote biomass in all areas of Thailand and develop biomass networks in communities, as well as to improve incentive measures for attracting private investment by allowing the establishment of bio-fuel factories, increasing the number of bio-fuel service stations, and engaging in public relations to create public acceptance of bio-fuel (Department of Alternative Energy Development and Efficiency, 2015). Several laws and regulations on the system security standards have been studied and publicized through various types of media (Sarochawikasit, 2007; Sutabutr, 2013).

At present, several rural areas in Thailand such as Pong Sang Thong district in Lampang province, Takham subdistrict in Trang province, Krathum Lom district in Nakhon Pathom province, and more, have successfully implemented renewable energy from biomass as pilot projects in their respective communities. From the collaboration between The National Innovation Agency and Energy Policy and Planning Office, community-level pilot projects for gasification can be implemented. Gasification is the process of converting solid biomass consisting of carbon and hydrogen elements into fuel gas. The private sector acts as a sponsor for development of gasification technology for each village. The villages that utilize this technology successfully can decrease the amount of biomass in their communities (Ministry of Energy & Energy Research Center, 2011).

In the northern region of Thailand, Rong Wua village in Chiang Mai province has succeeded in utilizing biomass. Having adopted skills and technical knowledge on biomass waste management from Nakornping Energy Research and Development Institute, which is dedicated to research on the development of renewable energy technology at the community level, the villagers are now able to mitigate and control stench problems systematically.

Biogas from these processes is stored and used to generate electricity as well as to produce Compressed Bio-methane Gas (CBG), which is equivalent in quality to Natural Gas for Vehicles (NGV). CBG can then be used to fuel vehicles and it can also replace (Liquid Petroleum Gas (LPG) for cooking purposes. In addition to the aforementioned environmental and economic benefits, villages that adopted biogas technology were also able to reduce the emission of greenhouse gases, prevent forest trees from being used as firewood and cut their household spending for energy (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2014; Nakornping Energy Research and Development Institute, 2013).

3.4 Government intervention

The popularity of energy crops has recently grown due to higher prices resulting from government policies (Mangmeechai & Pavasant, 2013). Government intervention in agricultural products aims to support both providers and buyers. In the case of raising the price of biomass, the government can provide financial support between the biomass farmers and bio-product producers. In 2012, the Thai government provided a total of US$5.8 million to ethanol producers to compensate for the rise in cassava prices (Thailand Ministry of Energy, 2012). This intervention created a favourable situation for everyone: end-users who are exempted from paying the oil tax, producers who are compensated for cost and farmers who profit from selling crops (Thailand Ministry of Energy, 2012).

The government intervenes in the energy market situation in their own country by issuing policies that favour the use of renewable energy, discouraging the use of conventional energy, or both (France International Energy Agency, 2011). For bio-fuel in Thailand, the government subsidized its use by reducing the excise tax on both gasohol and biodiesel, creating a price distortion between the renewable energy and fossil energy markets (Isvilanonda & Bunyasiri, 2009).

In theory, these policies mainly aim to help renewable energy firms compete in the energy market and encourage the adoption of renewable technology by potential investors (Jacobsson & Lauber, 2006; Organization for Economic Co-operation and Development, 2012). However, these policies may also create an unfavourable shift in crop production in Thailand since the net returns from energy crops are more lucrative than those of rice (Mangmeechai & Pavasant, 2013).

4. CASE STUDY OF NA DUANG VILLAGE, LOEI PROVINCE

4.1 Background of Na Duang District

Na Duang village is one of the four villages in Na Duang district, located in Loei province in the north-eastern region of Thailand. The total population is around 3,519 people with a total area of 9,747 Rai (1,560 ha). There are 784 total households, most of which are engaged in agriculture. Therefore, agriculture and livestock farming are the main industry of this village. Maize, rice, cassava, rubber and soybeans are major crops. Others are fruits such as tamarind, longan (lamyai) and mango (Niamsrichand, 2011).

Since 2003, oil palm cultivation has been practiced by local farmers. There is approximately 7,000 rai (1,100 ha) of oil palm planted in Loei province. The oil palm industry has become a new industry in this village since 2003, and the planting area been expanding year by year (Department of Agriculture, 2010).

Table 2. Oil Palm Plantation in Na Duang District

B.E. (A.D.)	Cultivation area (Rai)		Harvest (est.) (MT)	
	Community	Other	Community	Other
2548 (2006)	182.6	458	0	0
2549 (2007)	50.3	116	0	0
2550 (2008)	50.0	633	0	0
2551 (2009)	-	-	273	687
2552 (2010)	98.0	1,275	358	861
Total	380.9	2,482	631	1,548

(Source: Department of Agriculture, 2010)

For livestock farming, there are 63 livestock farms in this area, which include buffalo, beef cattle and pig livestock. Tilapias are raised in small fishing ponds by utilizing rice bran as fish meal (Department of Agriculture, 2010).

Table 3. Animal Husbandry in Na Duang Village

No	Livestock	No. of farmholds	No. of heads
1	Buffalo	8	108
2	Beef cattle	43	303
3	Pig	12	114

(Source: Department of Agriculture, 2010)

Table 4. Tilapia Culture in Na Duang Village

No. of farmholds	Scale (Rai)	Average yield (per Rai)	Selling price (per kg)	Average profit (per Rai)
898	675	120 kg	THB 40	THB 1,620

(Source: Department of Agriculture, 2010)

Na Duang village has begun partially utilizing biomass from these activities to make compost or to reuse it as livestock feed. Household waste, empty palm fruit bunches and palm fibre are totally converted into compost. On the other hand, cassava scraps, rice bran and crushed rice are converted into livestock feed (Hayashi, 2013).

Table 5. The Amount of Major Available Biomass and State of Utilization in Na Duang Village

Category of biomass	Type	Available biomass (tonnes/ year)	Conversion/ treatment methods	Recycled/ treated products	Utilization ratio (%)
Food waste	Household waste	ND	Fermentation	Compost	100%
Agricultural residue	Corn cobs	13,900	Incineration, carbonization, fermentation, natural decomposition	Fuel, compost	Low
	Corn stalks, leaves	1,738		-	0%
	Cassava scrap	2,400		-	0%
	Rice straw	ND	Sun drying	Livestock feed	100%
	Rice straw	4,533	Sun drying, fermentation, incineration	Livestock feed, compost	Low
	Rice husks	54	Fermentation, Incineration	Compost, cooking fuel	Low
	Rice bran	473	Reuse	Livestock feed	100%
	Crushed rice	19	Reuse	Livestock feed	100%
	Empty palm fruit bunches	ND	Fermentation	Compost	100%
	Palm fiber	ND	Fermentation	Compost, livestock feed	100%
	Palm husks	ND	Reuse	Fuel	ND
Livestock	Cattle	ND	Fermentation	Compost	Low
	Pig	ND	Fermentation	Compost	Low
	Poultry	ND	Fermentation	Compost	Low

(Source: Hayashi, 2013)

However, according to the utilization ratios in Table 6, there are some biomass sources that are available in great volume and have not yet been utilized, such as stalks and leaves of corn and cassava; some such as corn cobs, rice straw, rice husks and manure of cattle and pigs are in use, but less commonly so (Hayashi, 2013).

Since the government has been promoting its support for biomass utilization nationwide, Na Duang village has an opportunity to seek more support in order to exploit more potential. Recently, the demand for organic fertilizer from biomass has been increasing as well. The reasons for this are an awareness of health and organic agriculture that has been increasing in recent years, and that the price of chemical fertilizer has increased since 2007.

“Biomass Town Plan” began in Na Duang village with the aim of full realization of potential in every aspect, including biogas production. The utilization of local biomass for organic fertilizer is able to increase farmers' income by reducing the need to buy chemical fertilizer, and substituting it with an organic fertilizer, thereby also creating employment. This opportunity could help prevent the phenomenon of depopulating and aging rural communities by discouraging able-bodied locals from migrating to local areas. Moreover, utilizing local biomass could help the village improve its image, which could then have a positive effect on tourism in the area (Department of Agriculture, 2010).

There are two committees involved in this project, central and local. They were organized to promote the formulation of the Biomass Town Plan and act together in a feedback loop manner: the central committee provides cooperation (support) toward the local committee, while the latter reports on the result.

The project is implemented with support from the Ministry of Agriculture and Cooperative (MOAC) of Thailand and Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, which play an important role in the central committee. Moreover, the Department of Agriculture (DOA) acts as the mediator, takes orders, provides technical support to locals and reports back to the central committee (Hayashi, 2013). This organization of planning bodies is possible because all related parties are aware of the need to raise farmer income and to improve their quality of life.

Table 6. Organization of Local and Central Committees

Central Committee	
Ministry of Agriculture and Cooperatives	Ministry of Energy
Ministry of Science and Technology	Ministry of Natural Resources and Environment

Local Committee	
Local Government	Na Duang Village
Central Government	Ministry of Agriculture and Cooperatives
University/Research Institutions	Khon Kaen University
Involved parties in the community	Farmers

(Source: Hayashi, 2013)

4.2 Operational status of the Na Duang Project

In Na Duang village, several biomass utilization projects were launched under the Biomass Town Plan: bio-digester installation, livestock feed production, mushroom cultivation, composting of bio-waste and introduction of oil palm cultivation. For the bio-digester aspect of the plan, pig manure is collected and sent through an anaerobic fermentation process in tanks in order to be converted into methane gas or biogas. Local people use this biogas as cooking fuel and the liquid residues are digested for liquid fertilizer. Effective management systems and centralized manure collection are able to reduce odours. The operation succeeded with help from the Ministry of Agriculture and Cooperatives that provided financial support for the research and development of optimal fertilizer application, as well as Khon Kaen University that helped in design and construction of the digester as well as technical support (Niamsrichand, 2011; Hayashi, 2013).

There are other projects as well. Feed production for livestock targets unused biomass agricultural waste such as corn cobs, rice straw and rice husks. Private sector relationships also provide support to the mushroom cultivation project. Residue from oil palm and digestive liquid from bio-digesters are being used to make mushroom beds for cultivating mushrooms. With support from the department of Land Development, compost facilities were built for the local community for composting household food waste, agricultural residue and livestock waste (Niamsrichand, 2011; Hayashi, 2013).

Since oil palm became a new industry in this village, a small scale crude palm oil mill was introduced to the community by the members themselves with a low interest loan from the Ministry of Energy. In the future, a biodiesel refinery is planned to be built for processing extracted oil into biodiesel for vehicle fuel and converting the residue (fibre, shells, etc.) into livestock feed and compost.

However, most projects have been only partially completed (Hayashi, 2013). So far, the achievements include the capacity development of the core members in the local and central committees, completion of the Biomass Town Concept at Na Duang Village, implementation of some projects in Biomass Town and the setup of a program for research, and the formation of the "Central Committee" for Biomass Town Concept promotion.

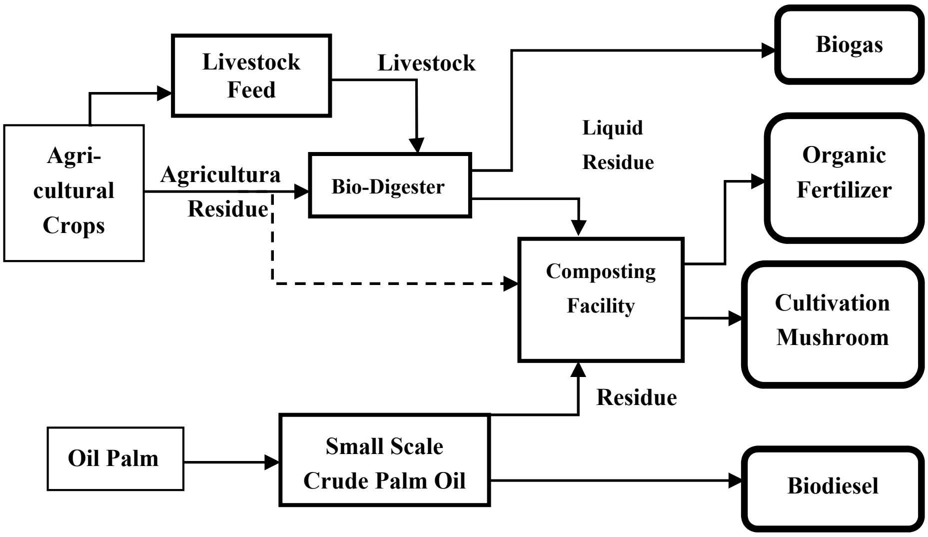

Figure 1. Future Plan in the Area (Develop to "Integrated Biomass Town")
(Source: Niamsrichand, 2011)

4.3 SWOT Analysis of Na Duang Project

The SWOT analysis is used as a tool for identifying challenges and obstacles of the project for sustainable development in Na Duang village.

Table 7. SWOT Analysis of Na Duang Village Project

Strengths	**Weaknesses**
• Strong collaboration between involved parties • Renewable energy sources • Create value to biomass products • Environmental friendliness • Health improvement • Reduce odours • Raise farmer incomes • Reduce use of chemical fertilizer	• Unable to standardize the project • Limitation in cultivating area due to cluster of mountainous and lowland area • Limitation in variety of biomass crops due to water shortage

Opportunities	Threats
• Create new industry • Create new employment • Improve local image toward tourism • Increase potential of similar projects to succeed in the future • Expanding research area • Potential for Low-Carbon emitting Renewable Energy Production for vehicular use	• Risk of being neglected if not successfully standardized • Risk from the rising price of agricultural products • Risk of fluctuation in amount of biomass produced annually

4.3.1 Strengths

Strong collaboration of community members made it possible to form the central committees and capacity development. Active participation of the members in attending seminars and workshops show how much they are willing to participate in the project. Also, the committees are open for members to voice their opinion and propose new projects (Niamsrichand, 2011).

The project was able to provide renewable energy sources in the form of biogas for cooking in households. Also, value is added to biomass by converting it into environmentally friendly organic fertilizers and livestock feeds. From there, the problem of odours from manure is mitigated, thereby reducing stress on the villagers' health.

In addition, by using organic fertilizers from biomass, farmers can reduce use of chemical fertilizers. Without having to buy the chemical fertilizers, farmers' costs decrease, increasing their profits.

4.3.2 Weaknesses

Even though the Na Duang project seemed to be successful in producing biogas and other products, the standard of this project is still questionable. The final outcome of the whole project is still uncertain, meaning that its overall success or lack thereof remains to be seen. At present, there is no known monitoring or evaluation report that compares Na Duang with other villages applying a similar approach. Without clear evidence, this project currently is not sufficient as a role model to other villages.

In terms of the landscape, Na Duang village is located in a mountainous region of Loei province which limits cultivating and farming. The potential for increasing crops and livestock production is therefore limited.

Water shortage, which is common in the north-eastern part of Thailand, might affect the variety of biomass as well. As water is crucial for consumption as well as for crop plantation and for livestock farming, there is a concern that some crops with a high demand for water might be unsuitable for cultivation in Na Duang. In the year 2021, two watersheds in the north-eastern region are going to face serious water stress if no measures are taken (Gheewala, et al., 2013).

4.3.3 Opportunities

The achievement of project implementation will create new opportunities for manufacturers who are interested in investing in facilities such as a biogas power plant or refinery plant in Na Duang. If new business is being created, more jobs will be available in the area. In terms of tourism, the number of agro-tourists increased greatly in 2014 to 494,582 compared to previous years (Office of Agrotourism Promotion, 2014). According to a study of agriculture in the mountains of north-eastern Thailand, specialty crops (for example, mushroom) generate high income and serve as a magnet for tourism; if Na Duang village can promote mushroom cultivation, they might gain more visitors (Choenkwan, et al., 2014). Moreover, as eco-tourism in nearby villages becomes more popular, the likelihood that they will visit Na Duang village could also increase (Naduang Sub-district Municipal Office, 2014)

Na Duang would be a model village for developing and applying technology in order to spread it to other areas. The potential for successful adoption can increase by using Na Duang village as a case study.

Expanding the research area might help in improvement of existing technology or creation of new technology. Also, research opportunities can be expanded by conducting joint research, researcher exchanges, and technical transfers.

Lastly, there is also the potential of having a locally produced renewable energy that will be specifically used in vehicles. Biodiesel and Compressed Bio-methane Gas (CBG) are common fuels that come from biomass. Compared to typical fossil fuels, they produce less carbon dioxide and are more cost-effective.

4.3.4 Threats

In the long term, the project faces a risk of being neglected since there was no active reporting about the project. It is possible that this village either achieved the project's goals already, or failed to do so. If the government does not continue to keep in touch with the local committees, the locals might not be able to seek proper support from the government for maintenance or fixing problems that might occur.

Renewable fuels are affected by economic factors just as fossil fuels are. Biodiesel is no exception; when the price of oil palm rises above a certain level due to increase in demand of renewable energy, farmers would instead sell it for other purposes if the profit from selling to make biodiesel is not the most lucrative. However, their actions may depend on government policy regarding the issue. For example, if the government subsidizes farmers, they might agree to sell oil palm at a lower price than that of the market.

Fluctuation in biomass production is another threat to this project. In the event of an agriculturally unproductive year, only a small amount of biomass would be available for bio products. To ensure adequate supplies of biomass throughout the year; farmers should plan ahead of time and stock some biomass to prevent shortages.

5. DISCUSSION & RECOMMENDATIONS

In order to ensure the success of the biomass utilization plan and to handle the risks from opportunities and threats, support and protection need to be addressed.

Since there is a potential for renewable energy production, the problem of emission of greenhouse gases that might follow should be considered. The Pollution Control Department (PCD) of the Ministry of Natural Resources and Environment (MNRE) provides standards and regulation that includes an approach to measure the emission from the energy production process (Pollution Control Department & Ministry of Natural Resources and Environment, 2012). To regulate compliance from energy producers, MNRE should act as a regulator by providing pollution measuring personnel to monitor the emissions.

In addition, villagers could benefit if the energy can be commercialized, which would require government support, for example, to adopt technology for compressing biogas in to compressed bio-methane gas (CBG) and packaging into containers for selling it (Sutabutr, 2013). Currently, the Ministry of Energy of Thailand supports renewable energies, including biogas by allowing the establishment of bio-fuel factories, increasing the number of bio-fuel service stations, and engaging in public relations to create public acceptance of bio-fuel (Department of Alternative Energy Development and Efficiency, 2015). At the economic level, the government has three strategies to support biogas commercialization: 1) To encourage investment and development for economic benefits; 2) To improve biogas innovation and technology to decrease imports from other countries; and 3) to improve latent energy crop cultivation for stability in long-term procurement (Energy Research Institute of Chulalongkorn University, 2014). In regard to the issue of agricultural price fluctuations, the government should help to provide an incentive for the buying and selling parties, to ensure that farmers will sell their crops while producers can afford them. To handle the risk of fluctuation in the amount of biomass produced annually, the local government should work with researchers to come up with farming techniques to produce more crops annually.

In terms of new industry opportunities, the government can provide financial incentives to attract private investors to invest in businesses such as biomass power plants. These businesses will create job opportunities; however, in order to protect the interests of people in the community, businesses should focus on hiring as locally as possible. Furthermore, even though the introduction of new industries can affect the community positively, the resources of the community should be protected from being excessively utilized by the businesses.

6. CONCLUSION

This analysis of the Na Duang village biomass utilization project has been conducted based on a sustainable development approach. The project itself is hosted by MAFF of Japan and several Thai government ministries that intend to have this project follow the objectives of AEDP. The objective of this project is to improve farmer incomes in Na Duang village and their quality of life. The village is located in the north-eastern part of Thailand and its major industries are agriculture and livestock farming which make it suitable for the biomass utilization project.

It has been found that the key influential factors for empowering people in the community is strength in collaboration. Strong collaboration was made successful through the support from various government agencies both domestically and overseas; it seems to have authority that is sufficient to support the local people, and the small size of the Na Duang village farming community makes it easier to create a local network. The villagers welcome supporters from outside because they are willing to help the community by sharing knowledge about how to utilize the biomass in farms. Also, because the villagers do wish to improve their financial status, they are willing to accept outside support.

There are several benefits and opportunities obtained from the biomass utilization project in Na Duang village that are related to social, economic and environmental aspects:

The project succeeded in providing renewable energy sources in the form of biogas. The village also succeeded in producing organic fertilizers and livestock feeds. In the social aspect, the community has become more liveable because more jobs have been created within the agricultural sector and through the creation of the bio-product sector. By creating local village jobs, the social problem of depopulation of the village can be mitigated.

This project has important economic contributions as well. Farmers directly benefit from the money they save by utilizing biomass. For the community, the future production of other kinds of renewable energy is made possible with this project; this will create new business opportunities and new jobs for people in the village. Additionally, the number of visitors to Na Duang village can be expected to increase, which would bring additional income to the village.

In terms of the environment, utilizing pig manure to produce biogas successfully removes the stench from the air; thus, the health of villagers also improves. There is also a chance that, by expanding research in the area, technological improvements or the creation of new environmentally-friendly technologies is being made possible, especially regarding techniques of reducing of carbon-emissions. Other researchers that were not participating in the project could take an interest, so it is possible that in the future there could be more joint research, research exchanges, and technical transfers.

Several challenges this project might face in the future that could lower the benefits of the project, or even make it unsuccessful will require local and national government support to solve. Landscape and water problems are physical problems that require provincial level resource management. On the other hand, the agricultural product price fluctuations depend on the current policy of the national government. The attention that local and national government pay to these issues will determine this project’s odds of success. Without proper management, some farms might go out of business, and the village might face depopulation because people would try to look for better opportunities in other areas. Resources in the community could be unsustainably consumed, which would eventually lead to shortages. Additionally, the environment can be strained by pollution resulting from the lack of technical knowledge. Eventually, they might fail to develop the village socially, environmentally and economically.

ACKNOWLEDGEMENTS

The authors are grateful to the referees who gave constructive comments and suggestions in improving the manuscript. And also would like to show our appreciation towards Ms. Christine Meister and Mr. Wanas Panasahatham for their valuable input during the revisions of the manuscript.

This work was partially funded by the MEXT scholarship and JASSO scholarship entrusted from Ritsumeikan Asia Pacific University.

REFERENCES

Charoensook, R., Knorr, C., Brenig, B., & Gatphayak, K. (2013). "Thai pigs and cattle production, genetic diversity of livestock and strategies for preserving animal genetic resources". *Maejo International Journal of Science and Technology, 7*(1), 20.

Choenkwan, S., Fox, J.M., & Rambo, A.T. (2014). "Agriculture in the Mountains of Northeastern Thailand: Current Situation and Prospects for Development". *Mountain Research and Development, 34*(2), 95-106.

Mikled, C. Faculty of Agriculture, Chiang Mai University. (2009). *Development of biogas technology for livestock farms in Thailand [Powerpoint Slide]*. Retrieved from http://www.mekarn.org/workshops/environ/PDF/Choke Mike.pdf

Department of Agriculture, Ministry of Agriculture and Cooperatives. (2010). "Biomass Town Concept in Na Duang village, Loei Province". *International Symposium on East Asia Biomass Town Concept Promotion*.

Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand (2015). *Alternative Energy Development Plan - AEDP2015 [In Thai]* (pp. 1-22). Retrieved from http://www.dede.go.th/download/files/AEDP2015_Final_version.pdf

Deutsche Gesellschaft Für Internationale Zusammenarbeit (Giz). (2014, Feb 20). Thailand: New support for community-based biogas “Distributed Green Generation for Community Enterprises” programme published. Retrieved from http://www.giz.de/fachexpertise/downloads/giz2014-en-community-based-biogas-thailand-factsheet.pdf

Energy Policy and Planning Office, Ministry of Energy, Thailand,. (2015). *Energy Statistics of Thailand 2015 [In Thai and English]*. Retrieved from http://www.eppo.go.th/info/cd-2015/Energy Statistics of Thailand 2015.pdf.

Energy Research Institute of Chulalongkorn University. (2014). *Draft for Bio-methane Promotion Strategies 2015-2035*. Retrieved from http://www.eri.chula.ac.th/eri-main/wp-content/uploads/2014/08/Final-CBG-Roadmap-Presentation-PART-2.pdf

France International Energy Agency. (2011). *Deploying Renewables 2011: Renewable Energy Markets & Policies*. Retrieved from http://www.iea.org/publications/freepublications/publication/Deploying_Renewables2011.pdf

Gheewala, S.H., Silalertruksa, T., Nilsalab, P., Mungkung, R., Perret, S.R., & Chaiyawannakarn, N. (2013). "Implications of the biofuels policy mandate in Thailand on water: the case of bioethanol". *Bioresour Technol, 150*, 457-465.

Jacobsson, S. & Lauber, V. (2006). "The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology". *Energy Policy, 34*(3), 256-276.

Cerović, L. Drpić, D.,Milojica, V. (2014). "Renewable Energy Sources in the Function of Sustainable Business in Tourism and Hospitality Industry". *TURIZAM, 18*(3), 130-139.

Naduang Sub-district Municipal Office. (2014). *3-Year Develop Plan of Na Duang District [In Thai]*.

Mangmeechai, A., & Pavasant, P. (2013). "Water Footprints of Cassava- and Molasses-Based Ethanol Production in Thailand". *Natural Resources Research, 22*(4), 273-282.

Ministry of Energy, & Energy Research Center, M.U. (2011). *Biogas from Pig Farm Developing program. [In Thai]*.

Nakornping Energy Research and Development Institute, C.U. (2013). Energy Research and Development Institute - Nakornping of Chiangmai University successfully developed tank CBG to replace LPG, led Rongwua village to be the first LPG-free village in Thailand [In Thai]. Retrieved from http://www.prcmu.cmu.ac.th/perin_detail.php?perin_id=574

Office of Agrotourism Promotion, Department of Agricultural Extension. (2014). *Thailand's Agrotourism Statistics - Summary of Tourist and Income from Agrotourism of Fiscal Year 2014.* Rectrieved from http://agrotourism.doae.go.th/agro-stat.html

Organization for Economic Co-Operation and Development. (2012). *Linking Renewable Energy to Rural Development* Retrieved from http://www.oecd.org/regional/regional-policy/Renewable-rural-energy-summary.pdf

Niamsrichand, P. Department of Agriculture, Ministry of Agriculture & Cooperatives,. (2011). *Biomass Town Concept Promotion Project in Thailand [Powerpoint Slide]*. Retrieved from http://www.apip-apec.com/ja/policies/upload/Biomass_Town_Concept_Promotion_Project_Thailand.PPT.pdf

Pollution Control Department, & Ministry of Natural Resources and Environment. (2012). *Road Map to Pollution Control [In Thai]* (pp. 1-92). Retrieved from http://oic.go.th/FILEWEB/CABINFOCENTER3/DRAWER056/GENERAL/DATA0000/00000304.PDF

Sarochawikasit, R. (2007). *Renewable Energy Development and Environment in Thailand* Retrieved from http://www.jst.go.jp/astf/document2/en_22doc.pdf

Papong, S. C.Y., Lohsomboon, P. and Malakul,P. (2015). "Overview of Biomass Utilization in Thailand". *Clearner Technology Advancement Program, National Metal & Materials Technology Center.*

Isvilanonda, S. & Bunyasiri, I. (2009, August 24-28). *Food Security in Thailand: Status, Rural Poor Vulnerability, and Some Policy Options.* Paper presented at the Agricultural and Food Policy Reforms: Food Security from the Perspectives of Asian Small-scale Farmers ,International Seminar in Seoul.

Hayashi, T. (2013). *Biomass Town Plan: Japan's experience in ASEAN countries [Powerpoint Slide] Department of Agriculture, Ministry of Agriculture & Cooperatives.* Retrieved from http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2015_events/3rd_Bioenergy_Week_25-29_May_Indonesia/25_5_5_HAYASHI.pdf, http://www.maff.go.jp/e/pdf/part3-2.pdf

Thailand Ministry of Energy. (2012). National Energy Policy Council Resolution [In Thai]. Retrived from http://www.eppo.go.th/nepc/kbg/kbg-104.htm - 3

Tippayawong, N., & Thanompongchart, P. (2010). "Biogas quality upgrade by simultaneous removal of CO2 and H2S in a packed column reactor". *Energy, 35*(12), 4531-4535.

Sutabutr, T. (2012). "Alternative Energy Development Plan: AEDP 2012-2021". *International Journal of Renewable Energy, 7*(1), 10.

Sutabutr, T. (2013). *Thailand's Renewable Energy Development-Plans and Implementation at the community level [Powerpoint slides]*. Retrieved from http://www.thai-german-cooperation.info/download/20130902_04_pdp_twarath_thailand__re_development_plan.pdf

World Bank. (2015). *Agriculture, value added (% of GDP).* Retrieved from: http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/countries

Zou, X. (2014). "Analysis of the Chinese Biogas Project Development in the Renewable Energy Sector – Strengths, Weakness,Opportunities and Threats". University of Applied Sciences Trier.

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 46-59
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_46

Review on Urban GHG Inventory in China

Fan Yang[1*], Yan Li[2] and Jiangang Xu[3]
1 School of Geographic and Oceanographic Sciences, Nanjing University
2 College of Asia Pacific Studies, Ritsumeikan Asia Pacific University
3 School of Architecture and Urban Planning, Nanjing University
* Corresponding author, Email: mg1427036@smail.nju.edu.cn

Received 9 June, 2015; Accepted 28 October, 2015

Key words: GHG inventory, GHG emissions, China, Research progress

Abstract: With the rapid urbanization progress of China, a study on an urban GHG inventory is of great significance. However, related studies in China are still in the exploratory stage. This paper firstly introduces three major urban GHG inventory accounting methods and related issues with regard to Chinese cities, and then reviews the published studies of urban GHG inventories in China in the past few years. Methodology frameworks, gas types, emission scopes, geographical boundaries are examined and compared. With great distinctions in the accounting methods and contents, there is no direct comparability between the research results. However, the following characteristics can still be found: the GHG emissions per capita and GHG emissions per unit of GDP are higher than the world average level, and the total GHG emissions maintains an increasing trend, although the GHG emissions per unit of GDP keeps declining. Currently, researches on the urban GHG inventory in China are mainly based on the non-urban-level IPCC Guidelines and Provincial-level guidelines. The release of urban-level GHG inventory estimation guidelines in China is expected to provide unified standards for related studies in the future.

1. INTRODUCTION

Greenhouse gas (GHG) emissions, also called carbon emissions, mainly consist of CO_2 and as a result, the word carbon is usually applied for representing GHGs (Hu and Yang, 2011). The Intergovernmental Panel on Climate Change (IPCC) (2014) stated explicitly in their Fifth Assessment Report (AR5) released in 2014 that the average surface temperature of the earth increased by 0.85°C from 1880 to 2012, and it might be mainly caused by human activities. To realize the temperature control target for alleviating climate changes, GHG emissions need to be reduced profoundly. Urban areas are concentrated areas of energy consumption and certainly become the hotspots of emissions (Cai, 2014b). Urban areas only cover about 2.4% of the land area of the earth, but contribute nearly 67% - 80% of all GHG emissions (Chen, et al., 2010). The world's urbanization rate had already increased to 53.6% in 2014 from less than 30% in 1950 and it is predicted to reach 66% in 2050. Meanwhile, since its reform and opening-up, under the context of rapid social and economic development, China has undergone a rapid urbanization process and the urbanization rate of China reached 54.77% in 2014 (United Nations, 2015). With rapid urbanization process, urban carbon emissions studies attract more and more attention. The estimated urban-level GHG inventory will feature the status of urban GHG emissions and provides scientific support to the formulation of plans by local government, which will be of great significance for the construction of a low-carbon city. At present, a few cities in the world have carried out calculation of a GHG inventory and substantial scholars launched related studies aiming at the calculation of an urban GHG inventory (Dodman, 2009; Croci, et al., 2011; Hoornweg, et al., 2011; Chavez and Ramaswami, 2013). However, related studies started later in China and the estimation of GHG emissions is still in the preliminary exploration stage. In this study, recent studies on GHG inventory are reviewed and compared by referring to related pre-stage comprehensive research achievements based on the introduction of the main methods and key issues of the urban GHG inventory (Chen, et al., 2010; Gu, et al., 2014; Li, et al., 2013; Cong, et al., 2012; Bai, et al., 2013).

2. URBAN GHG INVENTORY METHODS AND KEY ISSUES

2.1 Main methods of GHG inventory

Currently, there are two mainstream methods of accounting for a GHG inventory. The first calculates the inventory within a geographical boundary. Guidelines such as the *IPCC Guidelines for National GHG Inventories*, *China's Guidelines for provincial-level GHG Protocol* and the *Provincial-level Guidelines for GHG Inventory Estimation* belong to this type. The second method concerns the organizational boundary of an economic unit, which includes the *Guidelines for Enterprise GHG Inventory*, *ISO 14064 Series of Standards* and so on (Gu, et al., 2014; Bai, et al., 2013). The former is more popular as the mainstream method of inventory estimation for Chinese cities. Three methods using the geographical boundary will be introduced in this paper:

2.1.1 IPCC Guidelines for National GHG Inventories

The Parties under the UNFCCC (United Nations Framework Convention on Climate Change) are required to submit their National Communication on Climate Change. For guiding and standardizing the accounting of GHG inventories, IPCC has issued two editions of *IPCC Guidelines for National GHG Inventories* (shortened as IPCC Guidelines): one published in 1996 and the other in 2006. Currently, all countries apply the IPCC Guidelines (Edition 2006) for the estimation of a GHG inventory. The basic principle of the guideline is: to combine the information (activity data) of human activities and coefficient (emission factor) of quantizing the emission or elimination by unit activities, and the product of the two shall be the estimated value of the GHG emissions (IPCC, 2006):

$$E = AD \times EF$$

In which, E is the total GHG emissions estimated value, AD is the activity data, and EF is the emission factor of the activity. IPCC Guidelines mainly start with basic methods and carry out the GHG emissions' accounting in two ways, the top-down and bottom-up methods (Bai, et al., 2013). The top-down method means that the data of GHG inventories are aggregated and analyzed with the upper-level government statistics, while the bottom-up method describes data collected and processed at the local level (U.S. Department of Agriculture, 2015). Although the IPCC Guidelines aim at the GHG emissions accounting at the national level rather than the urban level, the general methods, computational equation and emission factors are generally referred to by studies on urban GHG inventory estimation, and it is of strong guiding significance.

2.1.2 China's Guidelines for Provincial-level GHG Protocol

The NDRC (National Development and Reform Commission) released the *China's Guidelines for provincial-level GHG Protocol (Trial)* (Provincial-level Guidelines for short) in 2011, for the launch of GHG inventory estimation in regions selected for low-carbon pilots. The Provincial-level Guidelines are mainly based on the IPCC Guidelines and its GHG emissions accounting is similar to the IPCC Guidelines in basic principle, with the top-down method as the main accounting method. However, it adjusts the emission factors and computational formulas according to practical conditions in China (NDRC, 2011). Although the Provincial-level Guidelines are originally for the provincial-level administrative regions rather than the urban-level, it is much more practicable at urban level because of the low accessibility of higher level data, and therefore has been widely applied to studies on urban GHG inventories in China.

2.1.3 Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

WRI (World Resource Institute), C40 and ICLEI (2014) released the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GHG Protocol for short), and it was the first globally tested accounting standard of an urban GHG inventory. In addition, the *International Local Government GHG Emissions Analysis Protocol* released by ICLEI (2009) (ICLEI Protocol for short) can be deemed as the predecessor to the GHG Protocol. Although the inventory estimation method targets the urban level, it can also be applied to other administrative regions below the national level. The ICLEI Protocol has been applied to the estimation of GHG inventories around the world and meanwhile, the GHG Protocol draft has been implemented in several cities throughout the world since its promotion. Similar to the calculation methods of IPCC Guidelines, the basic method of equating GHG emissions with the product of activity data and the emission factor is still employed in the GHG Protocol and ICLEI Protocol. The main accounting method is from the bottom to the top, which may have a higher level of precision and can get closer to the actual GHG emission status of the city. To make it convenient for the estimation of an urban GHG inventory, WRI customized an urban GHG accounting tool for China based on the GHG Protocol in 2015.

2.2 Key issues of urban GHG inventory

Direct comparisons of GHG emission inventories of different cities and researchers may not have any significant meaning due to different inventory accounting methods, greenhouse gas types and inconsistent emission scope.

Emission scope division is always based on an urban geographical boundary, and urban boundary definitions of different countries or regions are also diverse. Difference of gas types, emission scope and urban boundaries make it difficult to compare inventories.

2.2.1 Types of greenhouse gas

Six types of greenhouse gases that were originally stipulated to be reported in the *Kyoto Protocol* . They are natural gases: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and artificial gases: Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulfur Hexafluoride (SF_6). Though a new type of GHG, Nitrogen trifluoride (NF3), was included in the commencement of the second commitment period of the Kyoto Protocol from 2013, the three guidelines introduced above are all about the six types of greenhouse gases. CO_2 and CH_4 are the two most common greenhouse gases (Cai, 2014b). With CO_2 as the benchmark, the remaining different greenhouse gases have different global warming potentials (GWP) at different time-horizons. Centenary GWPs are generally adopted by each guideline (IPCC, 2007). GHG emission multiplied by its GWP of a specific time-horizon equals its carbon emission equivalent.

2.2.2 Scopes of GHG Emission

GHG emissions are further classified into three scopes by the WRI and WBCSD (2004). Scope 1 refers to all direct emissions inside the city, including GHG emissions produced by energy activities, industrial processes, agroforestry and land use change and waste within the city. Scope 2 includes all indirect energy-related emissions that have occurred outside the geographical boundaries of the city, including emissions produced by secondary energy such as purchased electricity and heating. Scope 3 includes other indirect emissions that have occurred outside the city which are caused by activities within the city, but that are not included in Scope 2, including the carbon emissions during intermediate links brought by items purchased outside the city (Cong, et al., 2014). The classification methods and ideas of WRI have been generally recognized by urban GHG emissions inventory researchers (Cai, 2014b). The current IPCC Guidelines only concentrate on direct emissions, while Provincial-level Guidelines and GPC Protocol cover indirect emissions.

2.2.3 Urban geographical boundaries

There are great differences in the geographical boundaries between cities in China and those of developed countries in terms of administrative division. Besides municipal districts in the city, prefecture-level cities have both jurisdictions over counties that are mainly rural areas, and representative jurisdiction over county-level cities that include both urban areas and rural areas. As for land use, cities in China include urban built-up areas as well as massive rural land. At present, geographical boundaries of urban GHG inventories in China are primarily based on urban administrative regions. According to Cai (2013), the urban built-up area is a reasonable geographical boundary for urban GHG inventories. In consideration of statistical data accessibility, he defined four types of urban geospatial boundaries: city administrative boundary (UB1), city district boundary

(UB2), city built-up area (UB3) and urban proper (UB4). He thought that urban proper (UB4), as determined by method of the Organization for Economic Co-operation and Development (OECD), is the most appropriate urban boundary of China to that of developed countries. The method developed by the OECD is a widely accepted way to classify local units into two types: urban area and rural area, based on the population density. For that reason, Cai developed a reasonable population density threshold for the identification of urban boundaries based on the urban definition method by China's Fifth National Population Census.

3. STUDY ON THE URBAN GHG INVENTORY IN CHINA

3.1 GHG emissions in China

Ever since its reform and opening-up, China has undergone over 30 years of high-speed development with the rapid process of urbanization. In accordance with the *China Statistical Yearbook* and statistical statement of the national economy and social development, China's domestic gross product (GDP) increased from 521.2 billion dollars to 10,240.9 billion dollars, while the total energy consumption converted to standard coal units increased from 1.18 billion tons to 4.26 billion tons in two short decades from 1994 to 2014. Meanwhile, the urbanization rate also increased to 54.77% from 28.62%, reaching the point at which the urban population surpassed the rural population. However, China is still in an extensive development stage. Its rapid economic growth and urbanization progress rely on the substantial consumption of energy and resources, which may result in the drastic growth of GHG emissions. Liu (2014) estimated the GHG emissions from 1997 to 2011 and found that China's total GHG emissions had reached 10.664 billion tons in 2011, which increased by 216.83% compared to 1997, where the coastal area accounts for 43.62% of the country. The report released by PBL (2015) displayed that China's GHG emission in 2013 was about 10.3 billion tons, which had grown by 4.2% when compared with 2012. Moreover, Friedlingstein et al. (2014) argued that GHG emissions had already broken through 10 billion tons in 2013 in China, higher than any other country in the world. Meanwhile, they estimated that it would reach 12.7 billion tons in 2019, accounting for 29.4% of the world's total GHG emissions (43.2 billion tons).

As the contracting states of UNFCCC, China shall provide a national emissions inventory compiled according to IPCC Guidelines regularly. The first notification to the United Nations according to the convention was submitted in 2004, including the national GHG inventory of 1994. The second notification was released in 2013, covering the GHG inventories of Mainland China, Macau and Hong Kong in 2005, whose total GHG emissions in that year were 7.47 billion tons, 1.83 million tons and 41.56 million tons respectively (NDRC, 2014). At the provincial level, NDRC released Provincial-level Guidelines with seven provinces as the low-carbon pilot regions, including Liaoning, Yunnan, Zhejiang, etc. for guiding the estimation of provincial-level inventories. Until 2014, the GHG inventories of the above pilots had been basically completed, however, the results of these provincial-level GHG inventories have not been published. Compared with well-documented national-level and provincial-level GHG guidelines, China has not released any urban-level inventory guidelines. Therefore, four direct-controlled municipalities, including Beijing, Tianjin, Shanghai and Chongqing, being the provincial-level administrations, can launch their inventory estimation directly under the guidance of Provincial-level Guidelines, but other cities lack official guidance in the compilation of their GHG inventories. Consequently, studies on urban GHG inventories in China mainly refer to IPCC Guidelines and Provincial-level Guidelines. However, the *Guidelines of Town GHG Inventories in China,* which is formulated by the Institute of Urban Environment, Chinese Academy of Social Sciences (2015), has already been completed preliminarily and submitted to NDRC for reference. The *Guidelines of Town GHG Inventories in China* classify the cities and towns in China into three types: prefecture-level city, central urban area and county-level city or town, then mainly focus on fields such as industry, construction and transport, and propose to combine the top-down and bottom-up methods. China is expecting standardized guidelines for the compilation of urban GHG inventories in the future.

3.2 Research of urban GHG inventory in China

Studies on urban GHG inventories in China started relatively late, but with the constant increase of GHG emissions and rising of the concept of low-carbon cities, studies on the GHG inventories in China have started to attract more and more attention. The GHG emissions produced by energy activities took a dominant position in the urban GHG emissions in China. Zhu (2009) discovered through statistical analysis that energy activities contributed more than 90% of the GHG emissions from 1970 to 2007 in Beijing. Therefore, early urban GHG emissions' studies in China mainly focused on the estimation of emissions in energy activities. Xing et al. (2007) estimated the terminal energy GHG emissions in Beijing according to the IPCC method and made the inventories of different sectors, energy varieties and industries. Zhang and Yang (2010) also estimated the GHG emissions of Shanghai in 2008 by referring to the IPCC Guidelines, and discovered that GHG emissions of coal took up nearly 54% of the total energy emissions. In addition, related scholars also estimated the GHG emissions in different cities, including Xiamen (Cao, et al., 2010), Guangzhou (Wang, et al., 2014) and Nanjing (Liu and Qiu, 2012). Liu et al. (2011) summarized three methods of estimating the GHG emissions and compared the results of different GHG inventories with Beijing as the specific research case.

Although the GHG emissions based on energy activities are the subject of urban emissions, the GHG emissions brought by the industrial process, agricultural and land utilization changes, as well as the waste, cannot be neglected. Therefore, Wang et al. (2011) supplemented the non-energy GHG emissions of the industrial process and solid waste based on the energy unit of GHG emissions and analyzed the GHG emissions in Wuxi. Zhao (2011) started from several sectors, such as that of energy activity, industrial production, etc., and estimated the GHG emissions of Shanghai comprehensively, finding that CO_2 was the main greenhouse gas accounting for more than 95% of the total emissions in Shanghai. Yuan and Gu (2011) sorted the GHG inventories and data sources in Beijing according to the ICLEI 2009 Protocol and concluded that the statistics in China are not sufficient for urban GHG inventories.

In recent years, there are more studies on urban GHG inventories in China than ever before. Yang et al. (2012) synthesized the greenhouse gas produced in five processes, including fuel burning and fugitive emission, industrial processes, husbandry processes, waste disposal and wetland processes, and found out that GHG emissions presented an increasing trend from 1997 to 2008 in Chongqing. During this period, the primary energy GHG emissions increased most substantially, but the GHG emissions per unit of GDP kept declining. Wang (2013) selected Nantong as a representative for the inventory construction following IPCC Guidelines, and calculated that the GHG emissions of Nantong was 43.8451 million tons in 2009. In addition, its GHG emissions per capita was higher than the national average, but the GHG emissions per unit of GDP was a little lower. Meanwhile, energy activity was the main GHG emission source, and the GHG emissions of raw coal was far higher than that of other fossil fuels. Qin et al. (2012) developed a GHG inventory of Shenzhen by referring to the IPCC Guidelines, settled the activity data, emission factor, GHG emissions of all sectors in detail, and found that the energy sector and industrial process sector contributed 97.3% of the total emissions. Moreover, its reliance on coal was lower than that in Beijing, Tianjin and Shanghai, and the GHG emissions per capita and GHG emissions per unit of GDP were relatively lower than those cities. Zhou and Deng (2013) made the GHG inventory of Guangzhou in 2010 based on the Provincial-level Guidelines, and found out that CO_2 took a dominant position, while the energy activity was the largest emission source. As a result, they compared the GHG emissions per capita in Guangzhou with that of other cities. Zhao et al. (2015) analyzed the GHG emissions in Xi'an by combining IPCC Guidelines and Provincial-level Guidelines and found out that GHG emissions presented an evidently increasing trend from 1995 to 2011, and sectors with the highest increase were the cement production, waste and energy consumption sectors. Moreover, they also found that the GHG emissions per unit of GDP in Xi'an kept declining, while the GHG emissions per capita and GHG emissions per area grew rapidly. Zhang (2014) made the GHG inventory of Qingdao from 2001 to 2011 based on such sectors as the energy activity, industrial production, environment, urban population, agricultural and forestry carbon storage sectors, finding that changes in the ratio of industry composition was the main influencing factor of the gradual annual growth of GHG emissions. In addition, he also discovered that GHG emissions per capita were far higher than the national average. In addition, Wang et al. (2013) calculated the GHG emissions of Shanghai from 2000 to 2008, and found that it increased by nearly 48% during the research period. Moreover, only the GHG emissions of the agricultural sector decreased, and the GHG emissions per capita in Shanghai was higher than the national and world averages, but the GHG emissions per unit of GDP was higher than the world average, though lower than the national average. Lin et al. (2013) estimated the direct and indirect GHG emissions of Xiamen in 2009 with a mixed method, and found out that the GHG emissions of Scope 3 that was overlooked by many researchers may reach 33.84%. It was concluded through a comparison that GHG emissions per capita was only 1/3 of that in Denver, America.

The GHG inventory studies above mainly conducted the business accounting according to related statistical data of urban administrative divisions following a top-down method. However, due to the particularity of the urban geographical boundary in China, the top-down accounting method may not be able to support a direct comparison of cities. Cai tried the bottom-up method early in China and realized the construction of GHG inventories using the point data of industrial enterprises. He and Wang constructed a 1km of GHG emissions' grid in Tianjin in 2007 by settling the GHG emissions data of all industrial enterprises of the city, separating them into the grid of the city, and sharing the GHG emissions of primary and tertiary industries according to the corresponding population ratio. Meanwhile, they also conducted a comparative analysis of the GHG emissions in four urban geospatial boundaries of Tianjin (Cai and Wang, 2013). Cai also conducted studies on Chongqing (Cai, 2014a), Shanghai (Cai and Zhao, 2014) and cities in the Yangtze River Delta (Cai and Wang, 2015), following the same methodology, and further refined the grid method of GHG emissions accounting. The main method is to equalize urban residential emissions, rural residential emissions and agricultural activity emissions to the urban construction land, rural residential area and cropland, respectively, obtained through remote sensing imaging and population data, in order to improve the spatial precision of GHG emissions.

By integrating the GHG emissions studies above, we selected significant research papers that cover not only the energy sectors, but also the non-energy sectors, and listed the accounting results in Table 1. It shall be noticed that different scholars differ greatly in their accounting method, gas type, emission scope, geographical boundary and inventory content and therefore, the accounting results are of no direct comparability. However, the inventory accounting result of different studies may reflect the following features: seen from the horizontal comparison, the total GHG emissions is basically related to the urban-level, and the GHG emissions per capita of eastern cities, such as Shanghai, Shenzhen and Xiamen, are relatively higher than that in mid-west cities, such as Xi'an and Chongqing. But, the GHG emissions per unit of GDP of the mid-west cities are relatively high, with relevance in the differences of urban industrial structure. In addition, the GHG emissions per capita and per unit of GDP are generally higher than the world average level. Seen from the longitudinal comparison, research results covering more than one year are selected, and it basically reflects the constant increase of total GHG emissions and GHG emissions per capita. However, the GHG emissions per unit of GDP presents a decreasing trend, showing that with the technical promotion, GHG emissions per unit of GDP keep decreasing. However, due to the rapid increase of economic mass, the GHG emissions still grows rapidly and a reduction of emissions is an urgent need. It is worth noting that the total urban GHG emissions currently increases more rapidly. For instance, the research conducted by Zhao et al. (2015) indicated that ever since 2000, the growth speed of GHG emissions of Xi'an increased substantially when compared with the previous stage, while the research conducted by Yang et al. (2012) also found that the growth speed of GHG emissions of Chongqing after 2002 kept accelerating rapidly.

According to the analysis of accounting methods, gas types covered and emission scopes in all research literature, it was found that (Table 2): seen from the accounting method, nearly all researches are based on IPCC Guidelines, and some refer to the Provincial-level Guidelines, but few refer to other methods. Quite a few literatures would select the Provincial-level Guidelines or other corresponding studies as the source of the emission factors, since these factors are closer to the practical conditions in China. Seen from the gas types covered, most studies are limited to three basic

Table 1. Studies on urban GHG inventories in China

No.	Authors	Cities	Research Period	Total (10^4 t CO_2)	per capita (t CO_2 / person)	per unit of GDP (t CO_2 / 10^4 dollars)
1	Zhao et al. (2011)	Shanghai	1996 - 2008	11713.5 - 18364.2	8.97 - 13.20	-
2	Wang et al. (2011)	Wuxi	2004 - 2008	6778.6 - 11536.2	15.16 - 24.98	24.93 - 17.32
3	Xu (2011)	Nanjing	2008	4229.15	-	-
4	Yang et al. (2012)	Chongqing	1997 - 2008	6636.4 - 15338.4	-	36.47 - 24.31
5	Sugar et al. (2012)	Shanghai, Beijing, Tianjin	2006	23252, 16964, 12806	12.8, 10.7, 11.9	-
6	Wang et al. (2012)	Shanghai	2000 - 2008	13554 - 20002	9.81 - 14.03	22.49 - 9.90
7	Wang (2013)	Nantong	2009	5196.37	4.69	8.47
8	Qin et al. (2013)	Shenzhen	2008	6569.4	7.49	5.83
9	Zhou et al. (2013)	Guangzhou	2010	16239.64	-	-
10	Cai et al. (2013)	Tianjin	2007	12599	11.3	-
11	Zhang et al. (2014)	Qingdao	2001 - 2011	2802.8 - 9059.8	4.45 - 12.35	24.66 - 8.91
12	Cai et al. (2014)	Chongqing	2007	13804.34	4.9	25.47
13	Gu (2014)	Nanning	2003 - 2012	1469 - 4396	-	-
14	Lin et al. (2013)	Xiamen	2009	2435.52	6.91	-
15	Zhao et al. (2015)	Xi’an	1995 - 2011	1207.16 - 3934.17	1.86 - 4.62	32.99 - 7.23

types of GHG, including CO_2, CH_4 and N_2O,except studies on Shenzhen conducted by Tan et al. and studies on Xiamen conducted by Lin et al. (2013), which cover six types of greenhouse gas. CO_2 takes up a dominant position in the GHG emissions of all cities. Seen from the emission scopes, studies involving Scope 1 and Scope 1 and 2 account for half of the studies, and only Lin (2013) et al. covered Scope 3 in studies on Xiamen. In addition, the geographical boundaries of the previously studied cities are analyzed, and all studies used the boundary of the administrative division, rather than the entity or the functional boundary of the city as the spatial boundary of

Table 2. Methods, gases and scopes of studies on urban GHG inventories in China

Literature No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Methods															
IPCC	√	√	√	√	√	√	√	√		√	√	√	√	√	√
Provincial-level									√	√		√			√
ICLEI		√													
Hybrid-EIO-LCA														√	
Accounting gases															
CO_2	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
CH_4	√	√	√	√	√	√	√	√	√				√	√	√
N_2O	√	√	√	√	√	√		√	√					√	√
HFCs								√						√	
PFCs								√						√	
SF_6								√						√	
Scopes															
Scope 1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Scope 2		√	√	√						√		√	√	√	√
Scope 3														√	

Notes: The Literature No. of this table corresponds to Table 1

the study. Among these, Cai's GHG inventory contains four types of urban boundary defined by the author, while the rest of the studies mainly take the municipal administrative area (including not only the municipal districts, but also counties and county-level cities that contain vast land of rural areas) as the geographic boundary of inventories.

As for the industrial process and product application, the Provincial-level Guidelines covers the GHG emissions in the production process of 12 industries, such as the cement, lime, steel, calcium carbide industries and so on, while the IPCC Guidelines cover at least 33 industrial products. However, due to the low accessibility of the data in industrial field, especially the data of intermediate input, there are few industrial categories included in the GHG emissions in the investigated literature. Most research on urban GHG emissions have included cement and steel into the inventory accounting. Major industrial products such as glass and synthetic ammonia are also regularly included.

In agricultural activities, many researches has calculated the methane emissions from rice, enteric fermentation and waste management methane emissions. Since it is difficult to procure the data of waste and straw, nitrous oxide emission accounting is excluded in the inventory by most researchers. Quite a lot of literature fails to include any agricultural activities in the inventory content. As for the sector of the land use changes and forestry, fewer studies have estimated the emissions from land use change, carbon storage and carbon storage of forestry or plants. Compared with other emission sources, the inventory content of much research literature fails to cover these two sectors.

As for the waste, the guidelines have covered the disposal of solid waste, burning of solid waste and waterwaste treatment. Since burning is not the main method of treating solid wastes in China, some literature neglects it and only calculates the GHG emissions in the disposal of solid waste and waterwaste treatment. For the methane emission from the disposal of solid waste, the first-order attenuation equation recommended by IPCC Guidelines requires long-time time series data, but there is a general problem of lacking the statistical data in China. Consequently, most literature employs the hypothesis that the methane has been discharged completely within a year. This method may overrate the methane emission to a certain extent.

Table 3. Contents of studies on urban GHG inventory in China

Literature No.	1	2	3	4	5	6	7	8	9	11	13	14	15
Energy													
Industries	√	√	√	√	√	√	√	√	√	√	√	√	√
Commercial / Institutional	√	√	√		√	√		√	√	√		√	√
Residential	√	√	√		√	√		√	√	√	√	√	√
Biomass Energy									√				
Transportation	√	√	√		√	√		√	√	√	√	√	√
Fugitive Emission				√									
Industrial Processes													
Cement	√	√	√	√	√	√	√		√	√	√		√
Lime													
Iron and Steel	√	√	√		√	√	√		√	√	√		
Ferroalloys		√											
Aluminium		√											
Glass	√					√	√	√	√	√		√	
Synthetic Ammonia		√	√				√		√	√			
Calcium Carbide									√				
Ceramic								√					
Sodium Carbonate													
Electronics Industry								√				√	
Agriculture													
CH_4 Emissions from Rice	√			√		√	√		√			√	√
N_2O Emissions from Cropland	√					√		√				√	√
Enteric Fermentation	√			√		√	√	√	√			√	√
Manure Management	√					√	√	√	√			√	√
Land Use and Forestry													
Land Use	√			√				√				√	√
Plant Carbon Storage	√					√			√	√		√	√

Soil Carbon Storage										√			
Waste													
Disposal of Solid Waste	√	√	√	√	√	√	√	√	√		√	√	√
Burning of Solid Waste	√				√	√		√	√			√	
Wastewater	√			√	√	√	√	√	√			√	√

Notes: The Literature No. of this table corresponds to Table 1

4. CONCLUSION

Urban areas are the hot spots of GHG emissions. With the rapid growth of urbanization progress around the world, especially in China, study on urban GHG emissions is of great significance. The calculation of urban GHG inventories will contribute to the learning of urban GHG emission and provide support to low-carbon urban planning and construction. However, urban GHG inventories are still in the exploratory stage in China. Based on the introduction of the main methods and key issues in the estimation of the GHG inventory, urban GHG inventory researches and results are reviewed. Currently, China's urban GHG inventory research mainly refers to the IPCC Guidelines and Provincial-level Guidelines. The inventory accounting method, contents and scopes are diversified, and there is a lack of unified guidance. Since the IPCC Guidelines aim at the national-level regions and Provincial-level Guidelines at the provincial-level administration divisions, their applications to the urban-level GHG inventories have inevitable limitations. Firstly, the adoption of inventory frameworks of a non-urban scale may not satisfy the urban GHG emissions' accounting demand, and there is insufficient attention to such fields as the industry, commerce, residence and traffic fields. Secondly, the statistical data is of low accessibility and precision, which may result in the inconsistency of inventory content. Meanwhile, this also brings about the uncertainty of GHG inventories. Thirdly, due to the disunity of method frameworks and inventory contents, as well as the particular urban geographical boundaries in China, it is difficult to compare inventory content between Chinese cities and cities in other countries. Although the inventory research result is of no direct comparability, the following characteristics can be found: both the GHG emissions per capita and GHG emissions per unit of GDP are higher than the world average level; although the GHG emissions per unit of GDP declines with technical promotion, the rapid development of urban economic mass brings the rapid growth of GHG emissions per capita, especially the constantly increasing GHG emissions over the past decade which reflects the severe situation of GHG emissions reduction in China; generally, China's government has made some efforts on the specification guidance on urban GHG inventory compilation; and, some cities have developed inventory compilation at the government level. However many related achievements have not been made public. With the *International Standard of the Urban GHG Accounting* and urban GHG accounting tool designed especially for Chinese cities, and *Guidelines for the Estimation of GHG Inventories for Cities and Towns in China* completed and ready for release, it is expected that standards for urban GHG inventory accounting and related studies will be provided, and the unification and perfection of the urban GHG inventory framework and method in China will be realized.

ACKNOWLEDGEMENT

This paper was supported by grants from the National Natural Science Foundation of China (No. 51278239) and Japan Society for the Promotion of Science (KAKENHI No.26420634).

REFERENCES

Bai W.G., Zhuang G.Y., and Zhu S.X. (2013). "Progresses and Prospects of Municipal Greenhouse Gas Inventory Research in China". *China Population Resources and Environment*, 01, 63-68.

Cai B.F. (2014a). "CO_2 emissions in four urban boundaries of China-Case study of Chongqing". *China Environmental Science*, 09, 2439-2448.

Cai B.F. (2014b). *Study on Key Issues of City Carbon Emission Inventory*. Chemical Industry Press, Beijing.

Cai B.F., and Wang J.N. (2013). "CO_2 emissions of Tianjin based on 1 km grid dataset". *Acta Scientiae Circumstantiae*, 33(6), 1655-1664.

Cai B.F., and Wang J.N. (2015). "Analysis of the CO_2 Emission Performance of Urban Areas in Yangtze River Delta Region". *China Population Resources and Environment*, 10, 45-52.

Cai B.F., and Zhang L.X. (2014). "Study on the Spatial Characteristics of Urban CO_2 Emissions in Shanghai". *Progressus Inquisitiones DE Mutatione Climatis*, 06, 417-426.

Cao B, Lin J.Y., and Cui S.H. (2010). "Scenario analysis of reduction potentials of energy demand and GHG emissions based on LEAP model in Xiamen City". *Acta Ecologica Sinica*, 12, 3358-3367.

Chavez A., Ramaswami A. (2013). "Articulating a trans-boundary infrastructure supply chain greenhouse gas emission footprint for cities: Mathematical relationships and policy relevance". *Energy Policy,* 54, 376-384.

Chen C.C., Liu C.L., and Tian G. (2010). "Progress in Research of Urban Greenhouse Gas Emission Inventory". *Environmental Science*, 11, 2780-2787.

Cong J.H., Liu X.M., and Wang Q. (2012). "Urban greenhouse gas emission inventories: methodology, models and research progress". *Review of Economic Research*, 31, 35-46.

Cong J.H., Liu X.M., and Zhao X.R. (2014). "Demarcation Problems and the Corresponding Measurement Methods of the Urban Carbon Accounting". *China Population Resources and Environment*, 04, 19-26.

Croci E., Melandri S., and Moheni T. (2011). "Determinants of Cities' GHG Emissions: A Comparison of Seven Global Cities". *International Journal of Climate Change Strategies and Management,* 3(3), 275-300.

Dodman D. (2009). "Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories". *Environment & Urbanization,* 21, 185-201.

Friedlingstein P., Andrew R.M., Rogelj J., et al. (2014). "Persistent growth of CO_2 emissions and implications for reaching climate targets". *Nature Geoscience*, 7, 709-715.

Gu C.L., Li Y., and Cook IG. (2014). "China's Urban GHG Inventory and Emissions". *Climatology & Weather Forecasting*, 2, 118.

Gu F.M. (2014). *Anthropogenic Carbon Emission Accounting and Analysis of its Influencing Factors of Nanning City.* Guangxi University.

Hoornweg D., Freire M., Lee M.J., et al. (2011). *Cities and Climate Change Responding to An Urgent Agenda.* The World Bank, Washington DC.

Hu J.Y., and Yang M. (2011). "Research on the Achievement of Carbon-Emission Field at Home and Abroad". *Information Technology & Standardization*, Z1, 60-64.

ICLEI. (2008). *International local government GHG emissions analysis protocol.*

Institute of Urban Environment, Chinese Academy of Sciences. (2015). *Guidelines of town's GHG Inventory in China*. http://iue.cass.cn/keti/show.asp?ID=2458. [Accessed 2015-03-30].

IPCC. (2007). *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, London.

IPCC. (2014). *Climate change 2014: mitigation of climate change*. http://www.ipcc.ch/report/ar5/wg3. [Accessed 2014-09-16].

IPCC/IGES. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Institute for Global Environmental Strategies, Geneva.

Li Q., Tang L.N., and Shi L.Y. (2013). "Research and compilation of urban greenhouse gas emission inventory". *Acta Ecologica Sinica*, 02, 367-373.

Lin J.Y., Liu Y., Meng F.X., et al. (2013). "Using hybrid method to evaluate carbon footprint of Xiamen City, China". *Energy Policy*, 58, 220-227.

Liu H., and Qiu F.D. (2012). "Analysis on Industrial Energy Carbon Emissions and Influencing Factors in Nanjing". *Territory & Natural Resources Study*, 05, 55-57.

Liu Y.W., Zhao L.K., and Hu Z.Y. (2014). "Empirical Research on Provincial Differences and Factors of Carbon Emissions in China". *Journal of Quantitative Economics*, 04, 75-80.

Liu Z., Geng Y., Xue B., et al. (2011). "A Calculation Method of CO_2 Emission from Urban Energy Consumption". *Resources Science*, 07, 1325-1330.

NDRC, National Development and Reform Commission. (2011). *Guideline Editing Team of provincial-level greenhouse gas inventory. Provincial guidelines for the preparation of greenhouse gas inventories (Trial).*

NDRC, National Development and Reform Commission. (2014). *China's second National Information Notification.* http://qhs.ndrc.gov.cn/zcfg/201404/W020140415316896599816.pdf . [Accessed 2015-04-16].

PBL, Netherlands Environmental Assessment Agency. (2015). *Trend in Global CO_2 Emissions 2014 Report.*

Qin X.L., Lu Q., Zheng J.Y., et al. (2012). "Study on greenhouse gases emissions inventory in Shenzhen City". *Research of Environmental Sciences*, 25(12), 1378-1386.

Sugar L., Kennedy C., and Lemen E. (2012). "Greenhouse gas emissions from Chinese cities". *Journal of Industrial Ecology*, 16, 552-563.

United Nations. (2015). *World Urbanization Prospects: The 2014 Revision.*

United States Department of Agriculture. (2015). "Top-Down and Bottom-Up Approaches to Greenhouse Gas Inventory Methods: A Comparison Between National- and Forest-Scale Reporting Methods". http://www.fs.fed.us/pnw/pubs/pnw_gtr906.pdf. [Accessed 2015-05-30].

Wang H.K., Zhang R.R., Bi J. (2011). "Carbon accounting for chinese cities - A case of Wuxi City". *China Environmental Science*, 06, 1029-1038.

Wang P. (2013). "Estimation of Greenhouse Gas Emissions for Nantong". *Environmental Monitoring in China*, 04, 147-151.

Wang W.X., Kuang Y.Q., Huang N.S. (2014). "Spatial Autocorrelation Analysis on Energy-Related Carbon Emission in Guangdong". *Environmental Science & Technology*, 03, 180-187.

Wang Y.S., Ma W.C., Tu W., et al. (2013). "A study on carbon emissions in Shanghai 2000–2008, China". *Environmental Science & Policy*, 27, 151-161.

WRI, ICLEI, C40. (2014). *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.*

WRI, WBCSD. (2004). *The Greenhouse Gas Protocol-A Corporate Accounting and Reporting Standard.*

Xing F.F., OuYang Z.Y., Wang X.K., et al. (2007). "Inventory of Final Energy-Carbon Consumption and Its Structure in Beijing". *Environmental Science*, 09, 1918-1923.

Xu S. (2011). "Carbon Accounting and Space Distribution for the cities in China - A Case of Nanjing City". Nanjing University.

Yang J, Ju L.P., Chen B. (2012). "Greenhouse Gas Inventory and Emission Accounting of Chongqing". *China Population Resources and Environment*, 03, 63-69.

Yuan X.H., and Gu C.L. (2011). "Urban Greenhouse Gas Inventory and Methods in China". *Urban Environment & Urban Ecology*, 24, 1-4.

Zhang M.L. (2014). "The Amount and Characteristics Analysis of Carbon Emissions of Qingdao". Ocean University of China.

Zhang W.C., and Yang Y. (2010). "Urban Energy Consumption and Carbon Dioxide Emissions Inventory". *Urban Management Science & Technology*, 06, 17-21.

Zhao Q. (2011). "Shanghai greenhouse gas inventory". Fudan University.

Zhao X.G., Ma C.H., Xiao L., et al. (2015). "Dynamic analysis of greenhouse gas emission and evaluation of the extent of emissions in Xi'an City, China". *Acta Ecologica Sinica*, 06.

Zhou J., and Deng Y.R. (2013). "Study on greenhouse gases emissions inventory system for cities: A Case of Guangzhou". *Environment*, S1, 30-32+36.

Zhu S.L. (2009). "Present Situation of Greenhouse Gas Emission in Beijing and the Approach to Its Reduction". *China Soft Science*, 09, 93-98.

International review for spatial planning and sustainable development, Vol.4 No.2 (2016), 60-75
ISSN: 2187-3666 (online)
DOI: http://dx.doi.org/10.14246/irspsd.4.2_60

Cellular Automata for Urban Growth Modelling:

A Review on Factors Defining Transition Rules

Agung Wahyudi[1*] and Yan Liu[1]
1 School of Geography, Planning and Environmental Management, The University of Queensland
** Corresponding Author, Email: a.wahyudi1@uq.edu.au*
Received 17 August, 2015; Accepted 26 November, 2015

Key words: Cellular automata, Urban growth models, Driving factors, Review

Abstract: Urban growth modelling has attracted considerable attention over the past two decades. This article reviews the driving factors that have been identified and studied in cellular automata (CA); one of the popular methods in urban growth modelling. Over a hundred articles published between 1993 and 2012 were selected and reviewed. We extracted the driving factors from CA transition rules and arranged them in a list. The list contributes to early spatial research for the selection of factors in CA models. Our analyses show that studies between 1993 and 2000 mainly focused on using earth's physical factors in predicting urban growths, while recent studies combined them with socio-economic factors, resulting with models with a greater number of inputs. Nevertheless, the human-behaviour factors impacting urban growth were generally under-represented. Geographically, more applications of the CA urban growth models have been seen in the developed countries compared with those in the developing countries, suggesting substantial work is needed to address issues in understanding and modelling rapid urban growth processes in developing countries.

1. INTRODUCTION

Studies on the selection of factors affecting urban growth – the transformation of a non-urban into an urban area – have existed for decades. The earliest concepts of urban growth proposed that urban growth is the consequence of two factors, the distance to the city centre and the transport cost (Alonso, 1960; Ullman, 1941). The selection of factors affecting urban growth and the concept of urban systems has evolved since then, largely because urban studies have attracted researchers from various disciplines other than the geographer (Ullman, 1941). Factors affecting urban growth, hereafter called urban driving factors or factors, have been implemented to explain the urban system, and for projecting possible urban growth by implementing these factors in a model to bring insight on the location, distribution, and size of a new urban area. Through urban modelling, urban researchers are able to simulate and visualize portions of an urban system and analyse it in order to improve the understanding of urban growth mechanisms.

The urban modelling approach that counts explicitly the urban driving factors and the influence of the surrounding area is the cellular automata (CA) approach. CA has become a dominant tool among urban modellers in the last three decades (Barredo et al., 2003; Batty, 1997; White and Engelen, 1993). The popularity of CA in urban studies can be attributed to its ability to represent complex urban morphology with simple rules and its intuitive appearance which provides a strong message to its users (Itami, 1994; Jantz et al., 2004).

In its generic form, CA consists of four basic elements (Batty, 1997); the cell, the state of cells, the transition rules, and the neighbourhood. The transition rules are an element that determines the changing state of a cell. For urban studies, the transition rule in CA models plays a key role in determining how the cell changes its land cover attribute, for example from non-urban into urban states (Lau and Kam, 2005; Silva and Clarke, 2005). The transition rules reflect the mechanism and the individual contribution of the driving factors to urban growth. The transition rules require urban driving factors as an input to govern the transition of a cell's state.

In the absence of consensus among urban modellers on how to derive the input for CA transition rules, a vast array of urban driving factors has appeared in the literature. Various approaches have been used in determining the driving factors. The selection of the driving factors in CA models can be derived based on the scale of analysis i.e. city-scale, regional-scale, or global; the geomorphology of the region being modelled i.e. slope, elevation, water body; or on the data availability(Hagoort et al., 2008; Irwin and Geoghegan, 2001; Wu and Webster, 2000). Within the same region, the input in the CA transition rules may exhibit a distinct selection of factors because the background knowledge of the researchers and the approaches they took were different (see Han et al., 2009; Zhang et al., 2011, for example). Faced with this wide array of factors, researchers in their early careers in urban modelling have difficulties in grounding the selection of factors for the CA models. Thus a systematic review on the selection of the driving factors on urban growth models from past studies is needed.

A number of review works on CA based urban studies have been reported in the literature. Haase and Schwarz (2009) reviewed 19 models of different approaches; the economy approach, system dynamic, agent-based, and CA models. Schwarz et al. (2010) provided a general review of 21 urban models where they found no models were specifically designed for urban shrinkage studies (a process that is marked by the decline of urban population and economic growth). The most recent review was by Silva and Wu (2012) who classified 64 CA urban models based on their level of analysis, the spatio-temporal scale, and tasks performed. These aforementioned reviews focus on the selection of CA models and gave less attention to the selection of factors based on the transition rules. Sante et al. (2010) provided a more thorough review of CA urban models including the selection of factors. They found that the transition rules of their 33 reviewed articles implement the repeated 19 factors in the models. While the review by Sante et al. (2010)provides an improved picture of the application of factors in the urban models, they left knowledge gaps on whether the selection of factors has changed over time, and on the location of CA that have been tested. Therefore, follow up work that reviews the two knowledge gaps could bring a more complete picture on the selection of urban driving factors and the spatial spread of CA models.

With the above reasons, this article focuses on the two aspects that were overlooked in previous review works; the time of study and the geographic location of CA urban models. Specifically, we hypothesise that the selection of factors driving urban growth is not independent, has changed over time, and varies in different geographical areas. Thus, in the analysis and discussion sections, urban growth factors were recorded and presented according to time and implementation across different regions. The empirical results from this research serve as an entry point for subsequent studies in urban modelling practice and hopefully foster more young urban researchers to adopt CA in urban modelling in the future.

2. METHODS AND MATERIALS

2.1 The procedure for selecting the articles

The selection of articles consists of three stages (*Figure 1*). On the first stage, the initial search was done using the Web of Knowledge (WoK) database by inserting the keywords ‘cellular automata’ and ‘urban*’. The wildcard ‘*’ aimed to expand the search coverage by including any articles containing the multiple ‘urban’ terms such in *urban*, *urbanization* or *urbanism*. By October 2012, the first stage returned 470 articles. These articles contain a mixture of themes not necessarily related to urban growth models such as traffic flow modelling, ecological sustainability, and disaster management. Clearly, these articles need to be screened further to be in line with the focus of this study on modelling urban growth. In the second stage, articles were filtered-out based on their aim and objectives that are relevant to the CA urban modelling themes. This was done by reading through the title and abstract of each article.

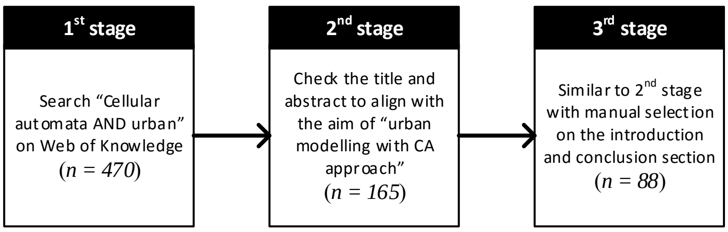

Figure 1. The selection procedure of articles

There were articles that contained the word ‘urban’ both in the title and its abstract but that were reporting non-urban land changes, such as modelling agricultural fields, or modelling the shrinking of forest regions. As the driving factors for modelling non-urban land covers differed from the ones of urban areas (Lambin et al., 2001), the last screening stage aimed to further refine the selected articles based on the following two points. First, by reading through entire articles, it could be decided whether the focus of the selected articles is on the urban growth or shrink modelling, thus in line with the aim of this study. Secondly, it could be checked whether the models were using real case studies. The latter aimed to record the geographical location of the model which is impossible if the study uses simulation data. The complete list of the 88 selected articles that were reviewed in this paper can be obtained from the correspondent author.

2.2 The extraction of the driving factors from transition rules

We extracted three components from the selected articles (*Figure 2*): (i) the driving factors that were implemented as inputs in the urban growth model, (ii) the study area where the model was applied, and (iii) the year of the study, approximately represented by the publication year of an article.

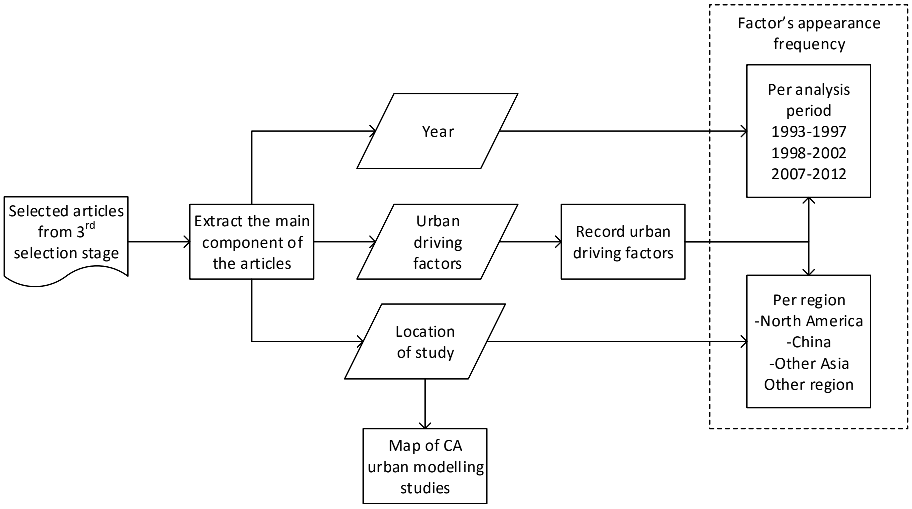

Figure 2. Reviewing procedure of CA urban growth modelling

Table 1 records the driving factors of urban models with the following procedure: each column in *Table 1* represents a single factor referring to a distinct urban driving factor. The terms used in the selected article to refer to the factor in the CA model might vary from one article to another. An example using earth's physical factors is that authors mentioned *aspect, angle,* and *hillshade* to refer to the same physical attribute of the sloping face of land. To avoid redundancy on the naming of factors, factors referring to similar urban factors were grouped together in one column on *Table 1*. The new factors previously unregistered in the current columns will be placed in the new column, thus expanding the column in *Table 1* with the rule that it appears at least in three articles, otherwise, the factor will be merged with the existing factor with the closest meaning. The factors in *Table 1* were named using the terms mostly appearing in CA literature and with less ambiguous meanings.

Despite efforts to reduce redundancies and ambiguous terms of factors in *Table 1*, a few driving factors need to be clarified further to align with the context of urban studies. The following describes the factors that have ambiguous meaning,

- *Thematic* refers to the local characteristic of a city that drives the urban growth in the area. These local characteristics could be the existence of a community centre, the religious facilities, or facilities such as power lines.
- *Greenery* refers to factors that trigger urban growth in an area due to its proximity to vegetated areas such as a city garden, croplands, or agricultural fields.
- *Environment other* factor includes any environmental considerations such as air quality, noise disturbance, or water availability.
- *Institutional factors* include government intervention in urban growth, other than zoning regulations, such as appointed urban development on government allocated lands or area prioritisation for urban development.
- *Land genetic* is defined as the conversion probability of non-urban to urban areas, for example, the Markov transition

probability, urban propensity, the repulsion-attraction due to neighbouring cells, or land change calibration factors (Guan et al., 2011; Zhang et al., 2011).

The broader groups in the driving factors classification help urban modellers when collecting data in the field. There are different classification systems for grouping urban driving factors in the literature. The classification of urban driving factors can be based on the geographical unit of analysis such as macro-meso-micro scale factors, for example the national economic policy that plays a part in a macro level of analysis (Engelen et al., 1995). The macro-meso-micro has an affinity with the local-regional-state scale classification that sees the influence of factors on the spatial-scale context (Stanilov and Batty, 2011; Zhang et al., 2010). A classification based on field of study was proposed by Burgi et al. (2004). They classified the urban driving factors as a groups of socioeconomic, political, technological, natural, and cultural factors which this study adopted. An addition of group factors was necessary to accommodate the urban driving factors which are not covered in Burgi's list.

Despite that the concept of cellular automata has existed since the 1980s (Tobler, 1979), the analysis period was set between 1993 and 2012. The starting period of 1993 was selected as this was the year when the earliest article of CA – based on the selection criteria in this paper – was found. Four periods each with five year ranges 1993-1997, 1998-2002, 2003-2007, and 2008-2012, were set to determine the timeframe for the subsequent analysis. The timeframe allows the chronological observation of urban growth factors in CA models.

Table 1. Key driving factors to urban growth extracted from existing CA models

Group	Driving factor
Earth physical	Elevation
	Slope
	Hill-shade
Connectivity	Highway
	Tollgate/ramp
	Road
	Waterways
	Railways
	Road intersection
Facilities	Station
	Airport
	Major towns
	Shopping centre
	Business centre
	Industrial area
	Existing developed areas
	School
	Health facilities
	Thematic
	Recreational
Environment	Greenery
	Environment-other
Government	Zoning regulation
	Institutional factor
Constraints	Water bodies
	National parks, forest

	Wetlands
	Protected areas
Demography	Population size
	Annual growth rate
	Population density
	Migration
Economy	Gross domestic products (GDP)
	Land value
	Economic trends
Land suitability	Land suitability
	Land availability
	Land genetic

3. RESULTS

3.1 The general trend of CA urban articles from 1993 to 2012

Between the periods of 1993 and 2012, there has been a steady increase in CA urban studies (*Figure 3*). Starting with a modest five articles in the periods of 1993 to 1997, the number raised seven-fold to 35 articles in the 2003-2007 period. On average, there was an increasing trend from five articles annually in 1993 to 1997 to seven articles annually in the 2008 to 2012 period.

The increasing number of publications in CA urban modelling suggests an increasing popularity of CA within spatial research (Liu, 2012). A reason for an increasing number of published CA urban studies could be linked to the ability of CA in capturing the complex shape of urban changes. The possibility of an urban areas ability to grow or shrink (urban changes) relates to a number of urban driving factors acting together, and using a deterministic approach with a linear regression equation, it is impractical to find the optimum solution for such complex urban changes. Instead, with CA, the solution for estimating urban changes comes from observing the area in the surrounding and their previous land statuses. Moreover, the natural solution in CA exhibits an uncertainty which is more intuitive where, for instance, the conversion rate from a non-urban to an urban area increases as the surrounding becomes urban area.

Another reason for CA popularity relates to its spatial shape akin with raster-based layers in GIS. With CA resemblance to the raster data type, the coupling of CA with spatial analysis (i.e. buffering, zonal analysis) within GIS becomes straightforward. The dynamic properties of each cell in CA can be transferred immediately into the attributes in a GIS raster layer. This seamless coupling of CA in GIS is a key advantage in developing urban CA models, which was much preferred by urban modellers (Clarke and Gaydos, 1998; Wu, 1998).

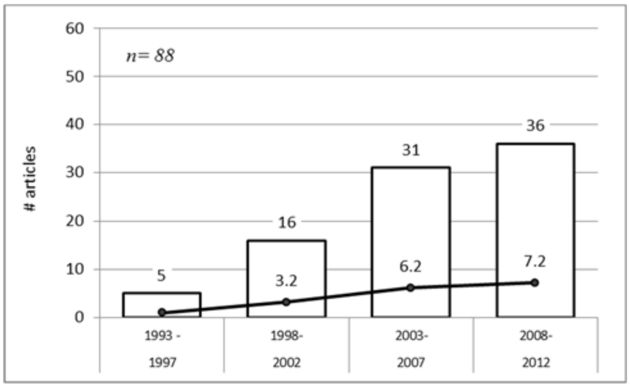

Figure 3. The increasing number of articles in CA urban modelling from 1993 to 2012. The number of articles for each of the five-year periods is shown by the bar graph, and the annual average number of articles is represented by the line graph

3.2 The spatial coverage of CA urban model applications

While CA has been implemented in cities across the globe, the early application of CA was recorded in cities of North America, specifically in the USA, and of China (*Table 2*). The examples of this early application were in Amherst and San Francisco Bay, USA, and in Guangzhou, China (Batty and Xie, 1994; Clarke1997). In the period after 1997, the increasing applications of CA in urban modelling in Europe and other Asian countries, such as in Japan, Korea, Malaysia, and Nepal have been observed (Guan et al., 2011; Naimah et al., 2011; Thapa and Murayama, 2011). In Nepal for instance, the combination of CA with the Bayesian approach has been successfully implemented to predict the future expansion of urban areas in Kathmandu.

Table 2. The number of CA urban model articles based on the regions (in absolute unit and percentage of total article for each period)

Year	North America		China		West Europe		Other Asia--		Others**	
	articles	%	articles	%	articles	%	articles	%	articles	%
1993-1997	5	100	0	0	0	0	0	0	0	0
1998-2002	3	19	13	81	0	0	0	0	0	0
2003-2007	10	32	7	23	5	16	4	13	5	16
2008-2012	6*	17	11	31	9	25	8	22	2	6
total	24	27	31	35	14	16	12	14	7	8

--including Australia

** including South America and Africa

Figure 4 visualizes the content of *Table 2* in the Google Map interface. *Figure 4* visually suggests the imbalanced distribution of CA applications around the world with at least 50 percent of articles having mainly been implemented in cities of USA (North America) and China whilst the other 50 percent was spread across other regions. The high number of CA applications in USA and China was in strike contrast with the implementation of CA in cities of Africa, South America, and the rest of Asia, where it has been scarce. The spatial distribution of CA implementation reflects better with a research cluster in CA rather than the distribution of cities which are facing urban problems such as managing the unprecedented growth of their urban populations, the provision of basic infrastructures, or distributing urban services. With cities in Asia and Africa being the place of nearly 90 percent of the world's urban population in the next two decades (UN-HABITAT, 2010), CA urban modelling in these regions is crucially important, not only to explore the capability of CA in regions known with limited data availability, but also to bring a better understanding of the urban system in these cities with the hope to better anticipate the expansion of urban areas. The fact of spatial imbalance in CA's study area highlights the potential regions to be explored in the future within CA urban models.


(a) (b)


(c) (d)

Figure 4. The implementation of CA urban growth modelling across the globe in different periods; (a) 1993-1997; (b) 1998-2002; (c) 2003-2007; (d) 2008-2012.
Similar images in colour are available online.

3.3 The number of factors in CA models

The average number of factors in CA models shows in general an increasing trend (*Figure 5*). Between 1993 and 1997, there were on average three factors in CA urban models and this doubled into seven factors in the 1998-2002 period. The number decreased slightly in the 2003-2007 period, but bounced back with nearly eight factors in every CA urban model in the years between 2008 and 2012.

While the increasing number of factors in recent CA models could be attributed to a number of reasons, the three concurrent reasons are the greater availability of data from sources previously limiting data sharing to the public, the shifting paradigm in CA modelling, and the advancement of computer power. In the recent application of CA during the 2003 to 2012 period (see Section 3.5), applications of CA have been made possible with increased data availability in categories such as social, economic, and demographic. Data gathering from socio-economic surveys previously missed the spatial information or came in a large spatial unit, for example the national-scale unit, constraining urban researchers to include these data in the CA model. Nowadays, these data have better, disaggregated spatial information which allows them to be linked with other urban driving factors and helps the analysis become more detailed (Irwin and Geoghegan, 2001).

Another reason could be attributed to a shifting paradigm in CA. In the 1993-1998 period, the urban growth models were intended to introduce CA to spatial researchers (Batty and Xie, 1994), thus using a simple model with few factors was considered as a way to gain attention and reach the objective of becoming one of the popular and versatile approaches in urban modelling. In a later period, the focus in using CA has been shifted to achieve a greater accuracy in reconstructing the configuration of the urban areas. It invites modellers from various backgrounds to perceive urban growth from their perspective, where involving non-spatial factors such as the *demography* and *economy* could lead to better accuracy in urban growth modelling (Batty and Xie, 1994; Clarke et al., 1997).

It is inevitable that the advancement of computer technology allows urban modellers to include more factors into the model with various weights representing the degree of influence of the factors on the urban growths. Complex spatial analysis that involves multiple factors to be simultaneously operated in a higher spatial dimension (i.e. the additional spatial dimension representing vertical development) or in a higher spatial resolution has been made possible with a stronger computer power than in the previous period where CA was initially adopted for urban research in the 1990s (Liu et al., 2012; Xian et al., 2005).

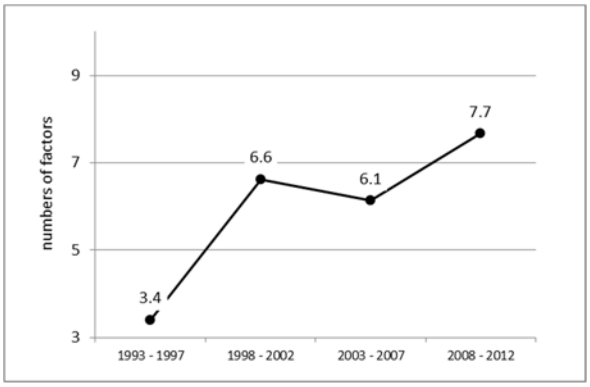

Figure 5. The average number of factors in urban CA models based on years.

The question whether the number of factors in CA urban models will continue to rise in the future remains open. We tend to agree with what Park et al. (2011) have argued, that the number of factors in CA models will reach a 'saturated level', where adding additional factors in CA models will give diminutive contribution in predicting urban growth. Indeed, the non-deterministic nature of urban growth means putting more factors in the model may not necessarily produce better prediction in urban growth (Itami, 1994; Syphard et al., 2005). Moreover, in the developing countries, data availability is still an impeding problem for urban modelling studies to proliferate (Barredo et al., 2004; Thapa and Murayama, 2012).

3.4 The selection of factors in different regions

The selection of factors for CA urban modelling across regions is presented in *Figure 6*. The various peaks in driving factors in *Figure 6* indicate that each region has unique driving factors affecting its urban growths. Among all driving factors, *road* was the most popular factor as indicated with the high peaks (above 75 percent) across all regions.

In North America, most of the CA urban models used factors such as *slope*, *road, water bodies,* and *land genetic.* These are factors similar to the input of the popular CA model in the USA; the SLEUTH, a CA urban model developed by Clarke et al. (1997). The SLEUTH model has been opted for as the preferred model for urban growth and frequently used in urban growth models within and outside the USA (Feng et al., 2012; US-EPA, 2000).

In China, the CA urban models implemented a wider variety of factors than the models in North America, as indicated with more peaks and less flat lines in the dotted line of *Figure 6*. The factors that appear more frequently in the articles in China – apart from *road* – are *major towns, land genetic* and *highway*. *Existing developed area*, *railway*, and *water body* also appear in the CA articles.

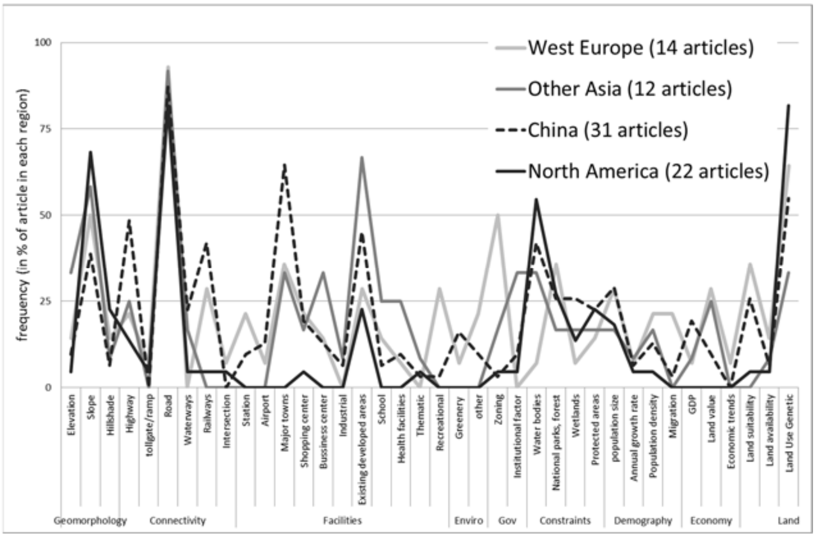

Figure 6. Summary of factors in CA urban growth models based on regions.

In other Asian countries, *existing developed areas* emerged as a key driving factor in CA urban models. In this region, people tend to live near the already developed areas to experience the benefits of the existing infrastructure and proximity to their workplaces (Maithani, 2010; Thapa and Murayama, 2011). In most Asian cities in developing countries, faced with unreliable public transportation and facilities, typical urban development near existing urban areas is common practice (Hudalah and Firman, 2012).

In West Europe, *land suitability* and *zoning* were amongst the most frequently used factors in the CA model. In West Europe, limited land availability could be a constraint for urban development for every country, thus highly competitive land markets is inevitable (Ligtenberg et al., 2004). Zoning, as an instrument to control and regulate land development, was strictly imposed by various local governments in West Europe to ensure the most suitable use of land. Zoning was also an important strategy to maintain the balance in land distribution for supporting non-urban activities, for example securing land parcels for food crops (Hansen, 2010).

3.5 The variety of urban growth factors over time

Figure 7 displays the frequency (number of appearance) of factors in CA urban growth models over the period between 1993 and 2012. *Figure 7* suggests that *road* was constantly used in CA urban models over the entire analysis period (1993 – 2012). The high appearance of *road* as an input in CA urban model corroborates with what Sante et al (2010) found where *road* is indeed the main driving factor in many urban studies. The highly appearing *road* was followed by *land genetics* and *slope* as the most frequently used factors in CA models.

Looking into the details of every period, the period of 1993 to 1997 was notable with few peaks above 25 percent and more flat lines, indicating that in this period the CA employed a limited number of factors in the model, with *road, existing developed areas,* and *land genetic* appearing more in the models. In the later period, between 1998 and 2002, more peaks were observed (above 25 and 50 percent) with the following factors - *major towns*, *water body*, and *protected areas* - as the leading factors in the CA urban models. In the periods of 2003 to2007 and 2008 to 2012, the selection factors include groups of factors relating to the *environment, demography,* and *economy*; these are the factors that appear less frequent in the previous periods.

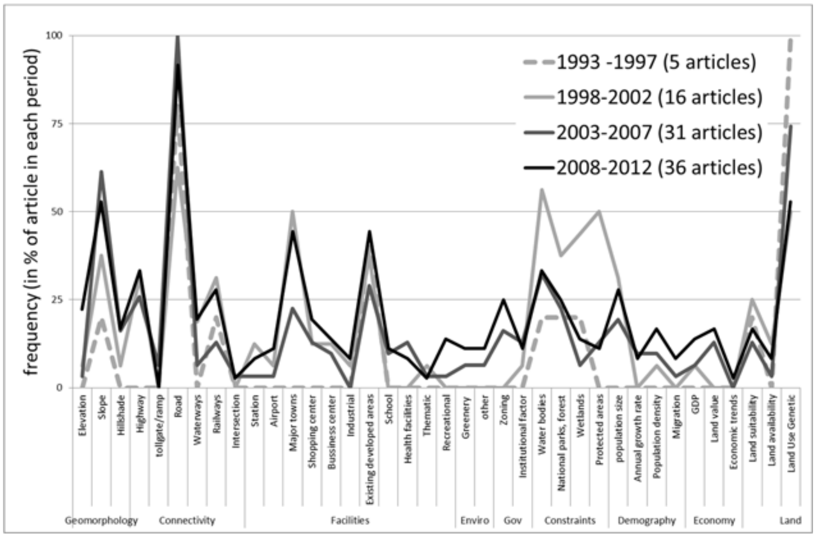

Figure 7. Summary of factors in CA urban growth models based on the periods.

4. DISCUSSION AND CONCLUSION

Unlike previous reviews, which oriented the focus of studies on the different types of CA models, the present study focuses on investigating the spatial location of *driving factors* in CA urban growth models and the temporal variability of these factors during the 1993 to 2012 period.

The results show that the number of factors in CA urban models between 1993 and 2012 has steadily increased. In the early 1990s, CA urban models incorporated less than five factors, such as *road, slope*, and *land genetic.* In the last decade, the number of factors in CA urban models has increased to more than seven factors with the addition of socio-economic factors such as *population size*, *migration* and *GDP*. The increasing factors in CA models stem from the influence of research from, for example, economy, demography, or social disciplines that view urban growth as a result of combined physical and non-physical factors. In the early development of CA urban models, the social, economy, and demography factors were considered to be macro-level, thus were generally considered as external and constant factors in the models. With the inclusion of these factors by urban researchers from various disciplines, the understanding of urban changes and its system has become richer as the newer era of urban modellers perceive the urban changes as more than a result of physical factors (i.e. *slope*, *hillshade*). The inclusion of more factors in CA models has been reported to produce a better variation in the micro-scale of urban changes than if the modellers include the physical factors alone (Lauf et al., 2012).

As CA modelling was born from a complex system developed alongside the rise of computer power (Batty and Xie, 1994), it is unavoidable to perceive that the increasing number of factors in CA urban model is linked to the exponential growth of computer power that enables rich information from various factors to be processed simultaneously in the model. Initially, in the 1980s, the socio-economy and population factors were externally determined outside the CA model using standard regression or predetermined models (Chen et al., 2002) because it was intractable to do processing simultaneously inside the CA model. However, in the recent development of CA urban models, analysis can be done endogenously inside the CA model or seamlessly coupled with spatial analysis within GIS applications. The tight-coupling analysis of CA and GIS allows the spatial analysis, the transition rules, and the influence of neighbouring cells in CA to be performed and visualised in a single computer application. The demand for more powerful computing seems to be inevitable as more complex analysis, such as the following: (i) the repulsion-attraction as an effect from the neighbourhood cells, (ii) the combination of macro-meso-micro scale factors, and (iii) the uncertainties that require the simulation to run multiple times, dictate future research in CA models (Liu et al., 2012; Xian et al., 2005). These analyses and simulations, whilst currently can be done by parallel computing, will be handy and practical if they can be done in a single computer.

Despite reports on the increasing accuracy when using more factors, it remains unclear whether the effort to obtain the data and fine-tuning the relative weights within the factors is worth the accuracy gained from this effort (Clarke, 2004). In the face of complex urban systems, where each urban element interacts with other elements, the intention of urban modelling is not merely to mimick the pattern of urban growth, but to understand the processes underlying the growths. Thus, using fewer factors could be beneficial to help explain the larger process and mechanism in the urban system without losing the generality (or replicability) of the model. Urban researchers should measure their effort to obtain the necessary data for input in CA models with the expected accuracy from the analysis and consider whether their effort is worthwhile in terms of improving their understanding of the urban system being analysed.

In terms of the spatial distribution of the study area, CA urban models have been dominantly applied in cities of North America (largely and historically in USA), China, and West Europe. In the remaining part of the world like Asia and Africa, the applications remain sparse. The numerous applications of CA models in North America, China, and West Europe may reflect more on the leading research clusters than the locations where managing urban growth is the crucial issue. Cities with a population of more than 10 million (megacity) like Delhi, Mumbai, Kolkata (India), Jakarta (Indonesia), or in West Africa, will grow tremendously fast and they are facing a serious threat to their sound and sustainable urban futures (UN-HABITAT, 2010). It is in these regions that it is crucially important for CA urban modelling to be developed and applied. Not only to address, but also to mitigate the unwanted impacts of urban growth by visualizing possible urban growth and designing urban strategies to cope with the projected urban growth. The future study areas of CA should be re-oriented toward addressing the urban problems in these megacities.

Apart from its contribution in improving the knowledge on the *driving factors* commonly used in CA urban models, this study provides a list of factors for urban modelling which contributes to the study of urban growth as a reference point to select and define the urban driving factors for CA modelling. While the list is not exhaustive, factors in *Table 1* could serve as pointers for early urban modellers or practitioners to select which factors should be selected as starters in the model. Knowing that different urban regions in the world exhibit unique characteristics, they can then adapt the selection of factors to the region where the CA model is being implemented (see *Figure 6*).

In the course of reviewing the factors, it was noticed that the *human behaviour factor* was starting to gain attention in the CA models. While considered to be one of the most influential factors impacting urban growth (Thapa and Murayama (2011)), the *human behaviour factor* was generally overlooked on the CA articles or was not well represented (Benenson, 1999). Lauf et al. (2012) mentioned that the *human behaviour factor* improves the variability, adapting to the stochastic nature of predicting urban changes, and improving the dynamic presentation of the spatial changes. However, a sceptical view on the inclusion of *human behaviour factors* in urban modelling exists. The supporters of the sceptical view argue that the requirement to define and develop the human agent including its inter-relationship with the physical factors inevitably cause the data requirement to grow exponentially (Batty et al., 2012). With this data-hungry requirement, the inclusion of the *human behaviour factor* in CA urban models will face a challenge, in particular, in the cities of the developing countries where data availability and accessibility to the public is still limited. A demonstration of the inclusion of human behaviour factors in CA modelling with case studies in the locations where data is lacking should be a target for any urban growth studies in the future.

The other reason for the increasing inclusion of the *human behaviour factor* in CA models could be attributed to the changing paradigm within CA urban modellers. Pattern-based models have dominated the studies of CA urban modelling in the last three decades (70s, 80s and 90s). In this paradigm, the main target of CA urban modelling was to mirror the spatial configuration of cities, whilst in the later period (year 2000 onward), the pattern-process paradigm started to rise. In the later paradigm, the modellers aim to find the relationship between the spatial patterns (size, direction, magnitude of urban growth) that configure the city with the process underlying the urban growth. In this regard, taking into account the *human behaviour factors* supports the main hypothesis of a pattern-process paradigm where humans are considered to be the major cause of urban growth (Irwin and Geoghegan, 2001). A new school of urban modelling based on cellular automata and human (agent) behaviour will emerge in future urban modelling practice.

This review investigated the driving factors of urban growth in CA urban modelling from two aspects, the time and geographic locations of the case studies. The reader might find the two aspects of analysis in this study were too narrow to cover the consideration in CA urban modelling. As the paper orients itself for the early urban researcher, this paper offers simplicity in the CA concept with the hope to attract more young and early urban researchers, with little background and experience in spatial modelling, to involve themselves in developing a better understanding of urban growth changes. It is worth noting that the selection of *factors* varies depending on how the models were derived, the type of CA models being employed, the scope of the study (multi-scale or local scale), and so on. These considerations were not recorded and analysed in the current research, a task to be explored in future studies. The analysis and claims in this paper were drawn from the selection criteria defined in Section 2.1, from which the 88 articles were selected for review. It highly possible that selected works highly relevant within this study were missed in the selection list, thus affecting the conclusions drawn in this study. Readers should regard the findings in this study as complementary to one of a comprehensive review.

ACKNOWLEDGEMENT

This study is supported by the International Postgraduate Research Scholarship (IPRS) and the University of Queensland Centennial Scholarship (UQ Cent), for Agung Wahyudi as part of his PhD completion. The authors wish to thank three anonymous referees for their comments in improving the early version of this manuscript.

REFERENCES

Alonso, W. (1960). "A theory of the urban land market", *Papers in Regional Science*, 6(1):149-157.

Barredo, J. I., Demicheli, L., Lavalle, C., Kasanko, M., McCormick, N. (2004). "Modelling future urban scenarios in developing countries: an application case study in Lagos, Nigeria", *Environment and Planning B: Planning & Design*, 31(1): 65-84.

Barredo, J. I., Kasanko, M., McCormick, N., Lavalle, C. (2003). "Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata", *Landscape and Urban Planning*, 64(3): 145-160.

Batty, M. (1997). "Cellular automata and urban form: A primer", *Journal of the American Planning Association*, 63(2): 266-274.

Batty, M., Crooks, A. T., Linda, M. S., Heppenstall, A. J. (2012). "Perspectives on Agent-Based Models and Geographical Systems", in: Agent based models of geographical systems (M. Batty, A. T. Crooks, M. S. Linda, A. J. Heppenstall, eds.), Springer, pp. 1-15.

Batty, M., Xie, Y. (1994). "From cells to cities", *Environment and Planning B: Planning & Design,* 21(7): S31-S48.

Benenson, I. (1999). "Modeling population dynamics in the city: from a regional to a multi-agent approach", *Discrete Dynamics in Nature and Society*, 3(2-3): 149-170.

Burgi, M., Hersperger, A. M., Schneeberger, N. (2004). "Driving forces of landscape change - current and new directions", *Landscape Ecology*, 19(8):857-868.

Clarke, K. C. (2004). "The Limits of Simplicity", in: GeoDynamics, CRC Press, 215-232.

Clarke, K. C., Gaydos, L. J. (1998). "Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore", *International Journal of Geographical Information Science*, 12(7): 699-714.

Clarke, K. C., Hoppen, S., Gaydos, L. (1997). "A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area", *Environment and Planning B: Planning & Design*, 24(2): 247-261.

Engelen, G., White, R., Uljee, I., Drazan, P. (1995). "Using Cellular Automata for Integrated Modelling of Socio-environmental Systems", *Environmental Monitoring and Assessment*, 34(2): 203-214.

Feng, H.-H., Liu, H.-P., Lu, Y. (2012). "Scenario Prediction and Analysis of Urban Growth Using SLEUTH Model", *Pedosphere*, 22(2): 206-216.

Guan, D., Li, H., Inohae, T., Su, W., Nagaie, T., Hokao, K. (2011). "Modeling urban land use change by the integration of cellular automaton and Markov model", *Ecological Modelling*, 222(20-22): 3761-3772.

Haase, D., Schwarz, N. (2009). "Simulation models on human-nature interactions in urban landscapes: a review including spatial economics, system dynamics, cellular automata and agent-based approaches", *Living Reviews in Landscape Research*, 3(2): 1-45.

Hagoort, M., Geertman, S., Ottens, H. (2008). "Spatial externalities, neighbourhood rules and CA land-use modelling", *Annals of Regional Science*, 42(1): 39-56.

Han, J., Hayashi, Y., Cao, X., Imura, H. (2009). "Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China", *Landscape and Urban Planning*, 91(3): 133-141.

Hansen, H. S. (2010). "Modelling the future coastal zone urban development as implied by the IPCC SRES and assessing the impact from sea level rise", *Landscape and Urban Planning*, 98(3-4): 141-149.

Hudalah, D., Firman, T. (2012). "Beyond property: Industrial estates and post-suburban transformation in Jakarta Metropolitan Region", *Cities*, 29(1):40-48.

Irwin, E. G., Geoghegan, J. (2001). "Theory, data, methods: developing spatially explicit economic models of land use change", *Agriculture Ecosystems & Environment*, 85(1-3): 7-24.

Itami, R. M. (1994). "Simulating spatial dynamics - Cellular-automata theory", *Landscape and Urban Planning*, 30(1-2): 27-47.

Jantz, C. A., Goetz, S. J., Shelley, M. K. (2004). "Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area", *Environment and Planning B: Planning & Design*, 31(2): 251-271.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skånes, H., Steffen, W., Stone, G. D., Svedin, U., Veldkamp, T. A., Vogel, C., Xu, J. (2001). "The causes of land-use and land-cover change: moving beyond the myths", *Global Environmental Change*, 11(4):261-269.

Lau, K. H., Kam, B. H. (2005). "A cellular automata model for urban land-use simulation", *Environment and Planning B: Planning & Design*, 32(2): 247-263.

Lauf, S., Haase, D., Hostert, P., Lakes, T., Kleinschmit, B. (2012). "Uncovering land-use dynamics driven by human decision-making - A combined model approach using cellular automata and system dynamics", *Environmental Modelling & Software*, 27-28: 71-82.

Ligtenberg, A., Wachowicz, M., Bregt, A. K., Beulens, A., Kettenis, D. L. (2004). "A design and application of a multi-agent system for simulation of multi-actor spatial planning", *Journal of Environmental Management,* 72(1): 43-55.

Liu, Y. (2012). "Modelling sustainable urban growth in a rapidly urbanising region using a fuzzy-constrained cellular automata approach", *International Journal of Geographical Information Science*, 26(1): 151-167.

Liu, Y., Yang, S., Chen, J. (2012). "Modeling Environmental Impacts of Urban Expansion: A Systematic Method for Dealing with Uncertainties", *Environmental Science & Technology*, 46(15): 8236-8243.

Maithani, S. (2010). "Cellular Automata Based Model of Urban Spatial Growth", *Journal of the Indian Society of Remote Sensing*, 38(4): 604-610.

Naimah, S., Rosmiyati, H., Yasin Abdalla, E. E. (2011). "Modelling land use changes at the peri-urban areas using Geographic Information Systems and Cellular Automata Model", *Journal of Sustainable Development*, 4(6): 72-84.

Park, S., Jeon, S., Kim, S., Choi, C. (2011). "Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea", *Landscape and Urban Planning*, 99(2): 104-114.

Sante, I., Garcia, A. M., Miranda, D., Crecente, R. (2010). "Cellular automata models for the simulation of real-world urban processes: A review and analysis", Landscape and Urban Planning, 96(2): 108-122.

Schwarz, N., Haase, D., Seppelt, R. (2010). "Omnipresent sprawl? A review of urban simulation models with respect to urban shrinkage", Environment and Planning B: Planning & Design, 37(2): 265-283.

Silva, E., Wu, N. (2012). "Surveying Models in Urban Land Studies", Journal of Planning Literature, 27(2):139-152.

Silva, E. A., Clarke, K. C. (2005). "Complexity, emergence and cellular urban models: Lessons learned from applying sleuth to two Portuguese metropolitan areas", European Planning Studies, 13(1): 93-115.

Stanilov, K., Batty, M. (2011). "Exploring the Historical Determinants of Urban Growth Patterns through Cellular Automata", Transactions in GIS, 15(3): 253-271.

Syphard, A. D., Clarke, K. C., Franklin, J. (2005). "Using a cellular automaton model to forecast the effects of urban growth on habitat pattern in southern California", Ecological Complexity, 2(2): 185-203.

Thapa, R. B., Murayama, Y. (2011). "Urban growth modeling of Kathmandu metropolitan region, Nepal", Computers Environment and Urban Systems, 35(1): 25-34.

Thapa, R. B., Murayama, Y. (2012). "Scenario based urban growth allocation in Kathmandu Valley, Nepal", Landscape and Urban Planning, 105(1): 140-148.

Tobler, W. (1979). "Cellular geography", Philosophy in geography, 20:379-386.

Ullman, E. (1941). "A Theory of Location for Cities", American Journal of Sociology, 46(6):853-864.

UN-HABITAT (2010). The State of Asian Cities 2010/11, UN-HABITAT, Fukuoka, Japan, 279.

US-EPA (2000). "Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns", in: EPA/600/R-00/098. U.S., Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, 260.

White, R., Engelen, G. (1993). "Cellular-automata and fractal urban form - a cellular modeling approach to the evolution of urban land-use patterns", Environment and Planning, A, 25(8): 1175-1199.

Wu, F. L. (1998). "SimLand: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules", International Journal of Geographical Information Science, 12(1): 63-82.

Wu, F. L., Webster, C. J. (2000). "Simulating artificial cities in a GIS environment: urban growth under alternative regulation regimes", International Journal of Geographical Information Science, 14(7): 625-648.

Xian, G., Crane, M., Steinwand, D. (2005). "Dynamic modeling of Tampa Bay urban development using parallel computing", Computers & Geosciences, 31(7): 920-928.

Zhang, H., Zeng, Y., Bian, L., Yu, X. (2010). "Modelling urban expansion using a multi agent-based model in the city of Changsha", Journal of Geographical Sciences, 20(4): 540-556.

Zhang, Q., Ban, Y., Liu, J., Hu, Y. (2011). "Simulation and analysis of urban growth scenarios for the Greater Shanghai Area, China", Computers Environment and Urban Systems, 35(2): 126-139.

IRSPSD International

ISSN 2187-3666 (Online)

For investigation regarding the impact of planning policy on spatial planning implementation, International Community of Spatial Planning and Sustainable Development (SPSD) seeks to learn from researchers in an integrated multidisciplinary platform that reflects a variety of perspectives—such as economic development, social equality, and ecological protection—with a view to achieving a sustainable urban form.

This international journal attempts to provide insights into the achievement of a sustainable urban form, through spatial planning and implementation; here, we focus on planning experiences at the levels of local cities and some metropolitan areas in the wolrd, particularly in Asian countries. Submission are expected from multidisciplinary viewpoints encompassing land-use patterns, housing development, transportation, green design, and agricultural and ecological systems.

2B519, Natural science and technogly hall 2, Kanazawa Univeristy, Kanazawa
Tel&Fax: 0081-76-234-4650
Email: spsdpress@gmail.com

School of Architecture, Tsinghua University, Beijing
Email: lilicareer@hotmail.com

International Review for Spatial Planning and Sustainable Development
https://www.jstage.jst.go.jp/browse/irspsd
http://spsdpress.jimdo.com/volumes
http://dspace.lib.kanazaa-u.ac.jp/dspace/bulletin/irspsd