Social-ecological resilience for the spatial planning process using a system dynamics model: case study of Northern Bandung area, Indonesia

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Abstract: The spatial planning in Indonesia has been based on the concept of sustainable development, however, the process is considered insufficient to deal with the current dynamic changes and future uncertainty due to global economic pressure. In order to cope with such complex challenges there is an urgent need to prepare resilient spatial plans in responding to major continuous change. The framework of social-ecological systems was used to identify the dynamic interactions between the ecological and social components of the problem of land-use conversion in the Northern Bandung Area. Using a system dynamics model, this research found that the root of such complex problem is the continuous transfer of land ownership. The study ran simulations by applying economic incentives (EIs) in an effort to control land ownership transfer. The simulations show that implementing high effort EIs can decrease the rate of conversion into built-up areas and the degradation of carrying capacity.

Keywords: economic incentive; land use; Northern Bandung area; NBA; spatial plan; social-ecological system; SES; system dynamics; resilience.

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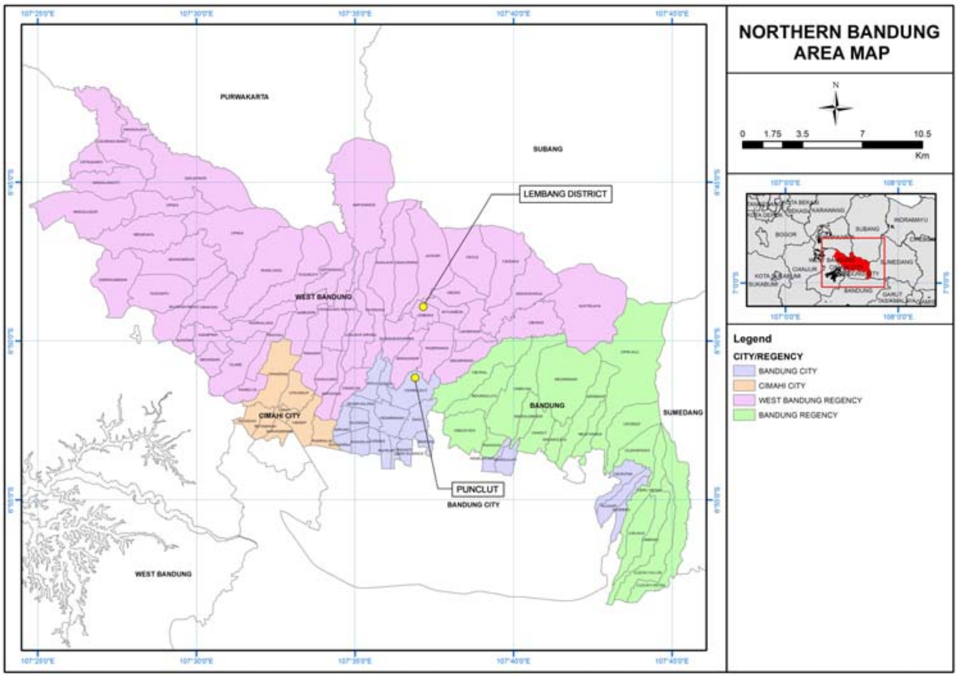
1 Introduction

Nowadays, resilience is widely applied in many interdisciplinary fields including planning. The concept of resilience emerged from the field of ecology in the 1960s and early 1970s through research on the interrelation between people and ecosystems (Folke, 2006). Resilience is defined as the capability of a system to respond to ongoing change while still maintaining the same essential function, structure, identity and feedbacks (Walker et al., 2004). According to Davoudi et al. (2012), there are three types of resilience, i.e., engineering, ecological, and evolutionary resilience. Heslinga et al. (2017) summarised that evolutionary resilience is equal to social-ecological resilience (SER) which reveals a paradigm change and according to Davoudi et al. (2012, p.302), the world is viewed as "chaotic, complex, uncertain, and unpredictable and … in nature or in society can suddenly change and becomes something radically new." Wilkinson (2011, p.148) argued that "at a time when planning theorists are calling for more attention to matters of substance alongside matters of process, social-ecological resilience provides a timely contribution with its specific attention to linked social-ecological system." Social-ecological systems (SESs) comprise both biophysical and social factors, where humans develop physical and organisational infrastructure in responding to outer threats and inside trouble, which forms interdependent systems (Janssen and Ostrom, 2006). In this perspective, "social and ecological systems are in fact linked, and that the delineation between social and natural systems is artificial and arbitrary" [Berkes et al., (2003), p.3]. From this perspective, cities are "arguably the most closely coupled human-nature system" [Du Plessis, (2008), p.3].

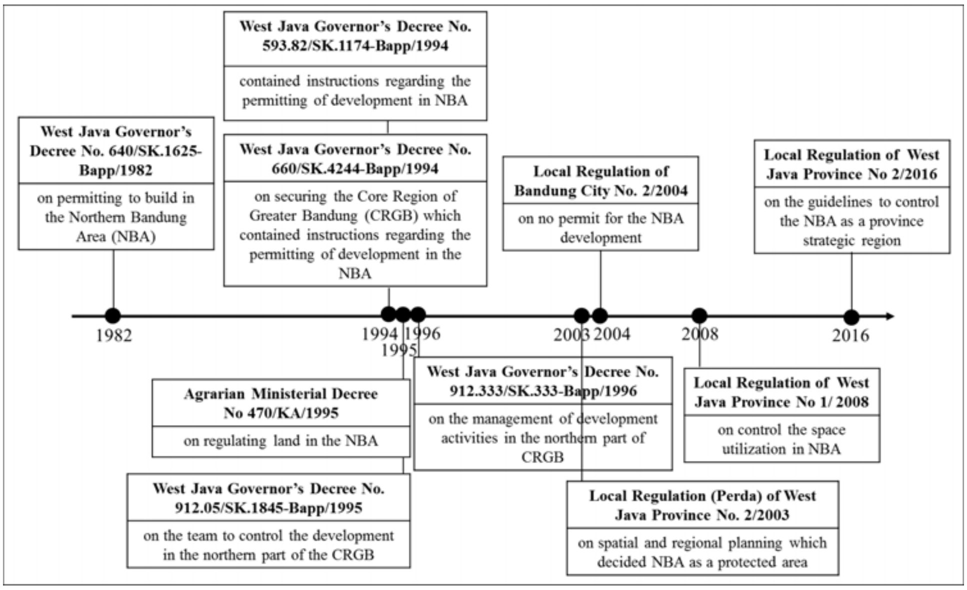
The Northern Bandung area (NBA) was elected as the case study for SER for spatial planning. The land use management of this area was enacted in 1982 and has undergone several revisions; resulting in the current regulation of West Java Province No. 2/2016 (see Figure 2). However, the problem of uncontrolled land use is believed to cause environmental degradation which, in turn, has significantly contributed to recent disasters of flooding and landslides. Similarly, in the case of the protected area of Lake Kerkini in Greece, Manou (2014) concluded that decision to conserve an area through formal regulation does not ensure the effective protection of the ecosystem function. This paper explores the root causes of the inconsistency between implementation on the ground and the formal plan of the NBA. SER can significantly contribute to provide a framework for setting and solving the problem of planning (Wilkinson, 2011). SER applies nonlinear dynamics of change in complex linked SESs (Wilkinson, 2011) so that an approach to understand these nonlinear behaviours of complex systems is needed. System-dynamics has the potential to study the patterns of dynamic relationship. As argued by Stave and Kopainsky (2017, p.31) "system dynamics is well suited for formalising SESs analyses, because it provides a method for operationalising the SES framework, and includes well developed techniques for addressing the challenges of system integration and stakeholder engagement." Therefore, the main question addressed by this paper is what dynamic patterns of social and ecological systems determine land use change in the NBA. Then, using system dynamics, the result of the causal loop diagram (CLD) is used for a simulation with two scenarios of economic instruments to determine the main determinant of land use change.

Figure 1 Map of NBA (see online version for colours)



Source: Authors (2018)

Figure 2 Historical review of spatial plan for the NBA



The use of system dynamics in the study of SES would provide empirical evidence to what Binder et al. (2013) qualify as the human-environment system (HES) framework. The HES framework can be applied to "any research area in which human-environmental interactions play a role" and in "a complex system in which different social and ecological hierarchical levels are involved" [Binder et al., (2013), p.7]. Therefore, identifying the root causes of the ineffectiveness of spatial planning in controlling the highly dynamics land use change in the case study area of NBA contributes to a more adaptive spatial planning process.

2 Literature review

2.1 Concept of SES

The SES concept was first introduced by Berkes and Folke (1994). Based on the Oxford dictionary, a system is "a set of things working together as parts of a mechanism or an interconnecting network; a complex whole." Kerner and Thomas (2014, p.674) argued that "complex interconnectedness of humans and their environment is embodied in what is called social-ecological systems, or SESs". Similarly, Anderies et al. (2004) defined SES as a system consisting of a unit of bio-geo-physics with social actors and related institutions. Therefore, in a simple way, SES may be defined as a system which is built by humans and nature.

Meanwhile, Scholz and Binder (2004, p.2) introduced an approach to the same concept, the HES which was conceptualised as "… mutualism between human and environmental systems. The human and the environmental system are conceived as two different systems that exist in essential dependencies and reciprocal endorsement." Berkes et al. (2003) argued that a resilient SES that can defend itself from stressors is equal to ecological, social, and economic sustainability, meaning that a SES "with low resilience has limited sustainability" [Berkes et al., (2003), p.15]. Furthermore, Miller et al. (2010) differentiated between 'specified' resilience, which concerns certain aspects, and 'general' resilience, which deals with multiple aspects.

2.2 SES and system dynamics

As the study of SES involves a complex interconnection between the social system and the ecological system, a SES requires an approach that is holistic in nature and is able to capture the relationships among the main parts of the system which could contribute to the dynamics of the entire system. According to Sterman (2000, p.42), "system dynamics can be applied to any dynamic system, with any time and spatial scale." Duggan (2015) argued that system dynamics is able to contribute to model development of the long-term behaviour of complex social systems. The aim of an analysis of system dynamics can be:

1 to describe historical trends

2 to forecast the possible behaviour of the concerned system in reaction to a stressor

3 to obtain recommendations based on projected behaviour (Stave, 2015 in Stave and Kopainsky, 2017).

Similarly, Schluter et al. (2014, p.1) emphasise that "through simulating interactions between the social and ecological systems, dynamic models facilitate the exploration of the consequences of salient social-ecological feedbacks for management and sustainability." Thus, system dynamics modelling can help improve our understanding of SES behaviour related to spatial planning in the NBA; not only for the past and the present but also the future behaviour of the system.

Based on Stave and Kopainsky (2017, p.32), the steps in the modelling process of system dynamics are summarised as follows:

1 defining the behaviour of interest

2 developing a conceptual model of the structure underlying

3 validating the proposed structure

4 using the model for analysis.

2.3 SER and spatial planning

Folke (2006) described a series of resilience concepts from a narrow to a wider interpretation, i.e., engineering resilience, ecological/ecosystem resilience and SER. SER is understood as:

1 the amount of disturbance a system can absorb and still remain within the same state

2 the degree to which the system is capable of self-organisation

3 the degree to which the system can build and increase the capacity for learning and adaptation [Folke, (2006), p.260].

Davoudi et al. (2012, p.304) argued that "evolutionary (or socio-ecological) resilience promotes the understanding of places not as units of analysis or neutral containers, but as complex, interconnected socio-spatial systems with extensive and unpredictable feedback processes which operate at multiple scales and timeframes." Therefore, in the context of achieving sustainability in cities, there is a need to reorient planning process to be "guided by an understanding of systemic interactions; take into account issues of behaviour, relationship, resource flows and resilience across the social-ecological system; and acknowledge that uncertainty and unpredictability is a characteristic of cities that requires adaptive management and flexibility in implementation" [Du Plessis, (2008), p.9].

The spatial planning system in Indonesia is regulated by Act 26/2007 on spatial management. Spatial management comprises spatial planning, spatial utilisation and spatial utilisation control. Spatial planning means the process to determine the spatial structure and spatial pattern. Hierarchically, spatial plans are categorised into national, provincial and district/city. The plan differentiates regions, based on their main function into protected areas and non-protected areas.

The spatial use management of the NBA is regulated through Provincial Regulation of West Java No.2/2016. This regulation strengthens the previous legal protection, which still had some weaknesses. This regulation is enacted to increase the control of land use in NBA as a provincial strategic region, because of the environmental degradation caused by the uncontrolled use of land.

Provincial Regulation of West Java No.2/2016 mentions various major functions of NBA, such as:

a providing protection to the lower regions, including protected forests, protected function outside the protected forests, and water catchment areas

b local protected areas that include riparian zones and springs area

c nature conservation area

d the area of cultural heritage and knowledge

e an area prone to geological disaster of volcanoes, landslides, and earthquakes.

In contrast, some areas in and surrounding NBA have become urban centres. For example, Lembang District which is part of the NBA, was defined as Local Activity Centre based on Local Regulation No. 2/2012 on Spatial Plan of West Bandung Regency and has become one of the nodes of transportation that connects the city of Bandung with some other districts in West Bandung Regency. Lembang is also designated as a centre of agro-industry.

2.4 Synthesis of literature review

Since the publication of Berkes and Folke (1994) with the title 'Linking Social and Ecological System for Resilience and Sustainability', the SES has been promoted as a promising approach for achieving sustainable development. Indeed, "research for sustainable development is frontier research by its very nature" and "in order to meet this challenge…we need a conceptual framework within which social-ecological systems can be analyzed appropriately…" [Jahn, (2009), p.1]. Furthermore, Jahn (2009, p.2) emphasised that "the concept of SES has been developed in order to provide two things: scientific progress and an impact on problem solvings with respect to the specific structure of sustainability problems". Similarly, as described above, Wilkinson (2011) argued that SER is able to offer a framework for identifying the core problem within any planning process. As a result, SER can also contribute to solving the identified problem.

However, so far, there has been limited empirical evidence to support those claims. Therefore, this paper contributes to offering an empirical analysis using the framework of system dynamics towards SER of spatial planning. This paper empirically focuses on SER for the spatial planning process. It is applied to a highly dynamic land use changes caused by economic pressure that, in turn, could deteriorate the ecological function of the region and increase the potential hazards threatening the sustainability of the case study area. By using a hybrid framework of system dynamics and SES, the root causes of the problem of the spatial planning of the NBA are identified and the solution to the problem can be formulated.

3 Methods

As explained above, the study of SES concerns the complex interrelation between social and ecological aspect, therefore, there is a need to integrate "knowledge, theories, and approaches from different disciplines, specifically through the use of hybrid frameworks where multiple qualitative and quantitative methodologies are applied, making use of a combination of existing quantitative sources, case studies and stakeholder input" [Duggan, (2015), p.433]. Systems dynamics fits the needs of SES, as it can withdraw "feedback relationships that underlie patterns of change in the system" [Stave and Kopainsky, (2017), p.27].

The framework of system dynamics used in this research consists of the following steps:

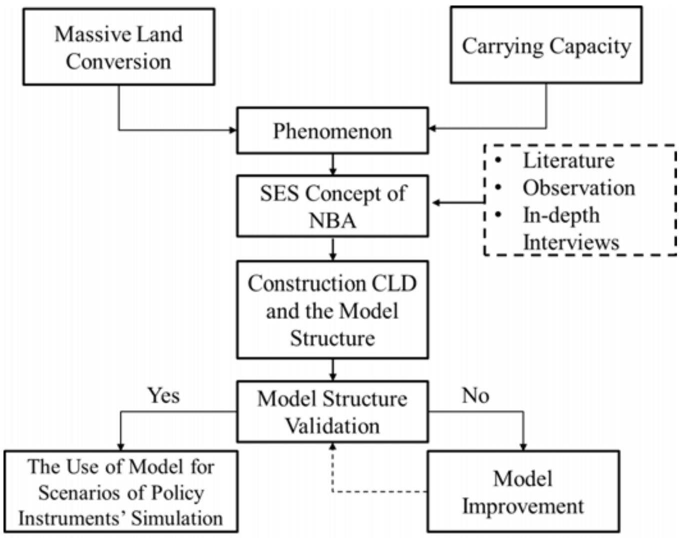
1 constructing a CLD for the model structure

2 validating the model structure

3 using the model for projecting the future of NBA by applying two scenarios of economic incentive (EI) instruments.

The applied methodology is summarised in Figure 3 below.

Figure 3 Research framework



3.1 Construction of CLD and the model structure

The complexity of the problem of SES is related to the dynamics of change occurring over time (Binder et al., 2013). The study of SESs also concerns the extent to which the role of human activities can impact on occurring environmental problems (Scholz and Binder, 2004). Therefore, due to the complexity of spatial planning in the NBA, with its interlinked ecosystem and social system, the system dynamics model is used to identify the past behaviour of the NBA system. This behaviour is then used to predict the future behaviour of the NBA. By understanding the relationship between causes and effects through a causal CLD, the root of the problems of the land use conversion in the NBA can be identified.

The causal relationship between two variables in a model, when connected to another causal relationship, may form a closed chain or loop, called causal-loop or feedback-loop (Kirkwood, 1998). A CLD is made up of several steps. Firstly, based on observations around the NBA and the study of Hernawan (2010), a hypothetical CLD was created. Secondly, in-depth interviews with four informants were conducted to revise the hypothetical CLD. The key respondents were elected to cover the whole spectrum of relevant actors and consist of:

1 Mr. A. Sutari, a prominent traditional figure, interviewed in

2 Mr. N. Siswanto, a representative of the property developers in NBA, interviewed in

3 Dr. E. Nurmardiansyah, a legal expert who was involved in the drafting of Provincial Regulation No. 2/2016, interviewed in

4 Mr. E. Priastono, a respondent from provincial government of West Java.

Interview with Mr. Priastono was conducted by Hapsari in 2014 as part of research for this paper. Subsequently, a SES model structure in the NBA was developed from the constructed CLD and validated, to ensure that the behaviour of the model structure can be used for simulating the future of NBA.

3.2 Validating the model structure

Tasrif (2006) contends that a model is an abstraction of a real world because human beings naturally use models to illustrate problems. A model should be able to represent the dynamics and structures of the relationship between stock and flow (Sterman, 2000). The model structure of the research that has been created can help improve our understanding of the behaviour of existing SESs related to spatial planning in NBA. In the end, system-dynamics modelling is expected to not only provide an understanding of the historical or physical behaviour but also the future behaviour of the system. The validation of the model consists of the following two iterative procedures (Stave and Kopainsky, 2017):

1 to investigate the causal relationship model through data validation and confirmation with theory

2 to stimulate the model with observational data as well as anticipated future conditions.

3.3 Using the model for projecting the future of NBA by applying two scenarios of economics incentive instruments

The validated model can be used for simulating types of policy interventions. The simulation applies two scenarios of EIs in order to compare the responses of the model so that the effect of economic instruments on controlling land use conversion can be assessed.

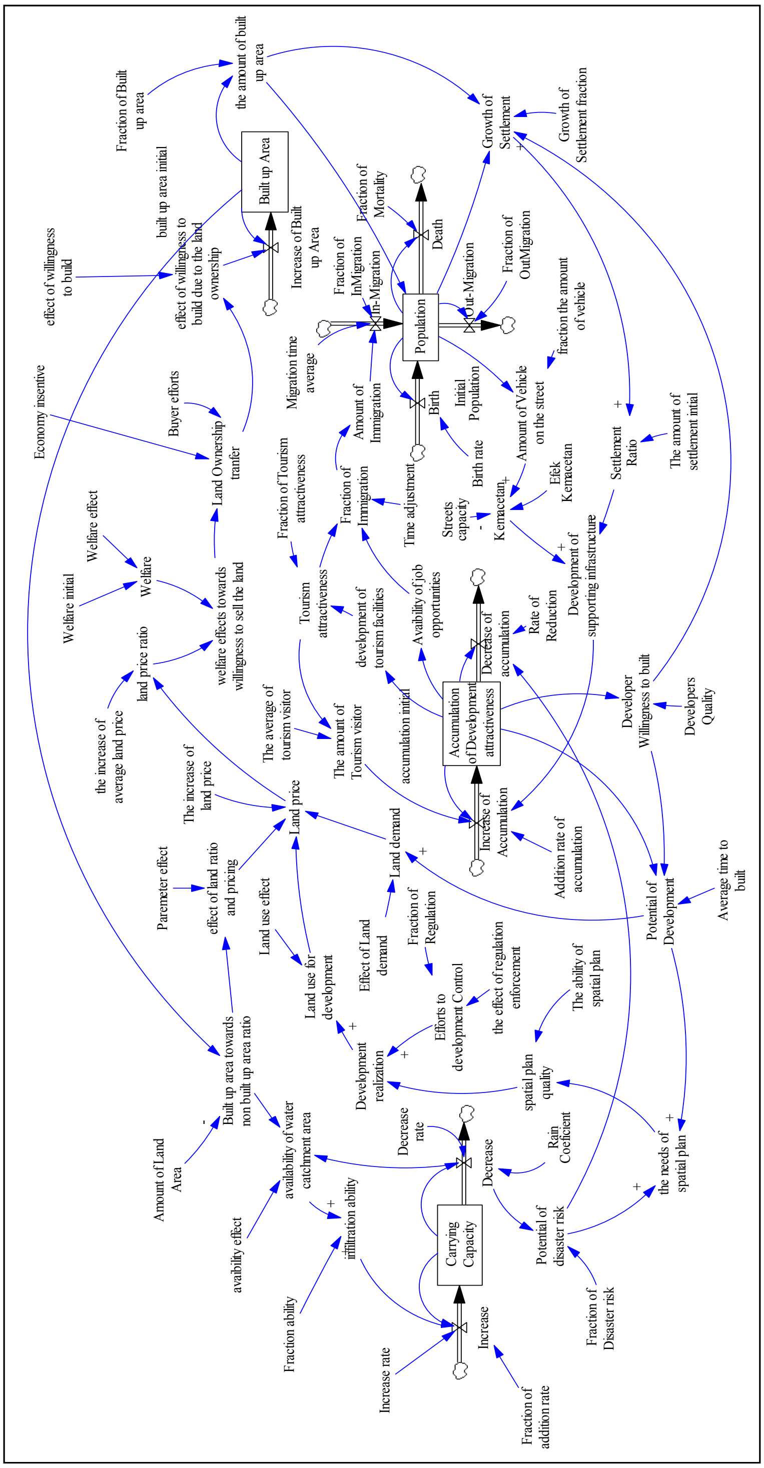
4 Results and discussion

4.1 Dynamic pattern of SES of the NBA

As Figure 4 shows, the number of tourists has increased considerably due to the tourism development around the NBA, especially in Lembang District which is assigned as an urban centre. In addition, a population increase in the City of Bandung has put further pressure on the non-built up areas of the NBA for urban settlements. Based on remote sensing data analysis, Sobirin (2005) reported that from 1984 to 1996, the NBA experienced a 21% decrease of forest areas and a 44% decrease in agriculture areas as well as an increase of built-up areas up to 149%. In addition, Wazni (2017) concluded that from the year 2001 to the year 2015 primary and secondary forests in the upstream Cikapundung watershed – the upper part of the NBA – have reduced significantly. Meanwhile, the settlement areas increased in size.

According to Sobirin (2005), based on the US Army map published in 1933, Punclut was a tea plantation. The plantation stopped in the late 1930s when the colonial government decided to reforest this area to be a green belt (Moeliono, 2011). However, the tea plantation workers still occupied the area and informally claimed their right to open and cultivate the land (Moeliono, 2011). The interview with Sutari (2017), one of the grandsons of a worker at this tea plantation, confirmed that the Punclut area was a tea plantation. The area, now locates the Citra Green Residential Complex and many restaurants and houses. Sutari further stated that the high price of land significantly contributed to the willingness of the native owners to sell their land, thus, the transfer of land ownership occurred extensively. The respondent from the Regional Development Planning Agency, Priastono (2014), also confirmed that one of the primary driving forces for the fast rate of land use change in NBA is the construction of toll road between Bandung and Jakarta, which was formally opened in 2004. In addition, new access from Bandung to Lembang via Ciumbuleuit street was also constructed. Therefore, it can be concluded that on the one hand, the spatial plans concerning the NBA designate the area as predominantly as a protected area, however, on the other hand, they also assign Bandung City as a National Activity Centre and Lembang District as a Local Activity Centre. This policy has sparked further infrastructure developments that, in turn, also contribute to the high price of land. As a result, there has been an acceleration of land conversion towards built-up areas (see Figure 4).

Figure 4 CLD of the dynamics of land-use change in NBA (see online version for colours)



Source: Authors (2017)

Based on the interview with Nurmardiansyah (2017), a legal expert involved in the drafting of the latest regulation no 2/2016 as a revision of the previous regulation of 2011, six issues of the weaknesses of the former regulation were identified, namely:

1 the scale of map for NBA was too small, so that delineation of protected area was unclear
2 recommendations and permits
3 supervision
4 incentives and disincentives
5 zoning regulation
6 legal enforcement.

The new regulation already addresses issues 1, 2, 3 and 5. Number 4, the EIs is not sufficiently addressed and only refers to another provincial regulation on EIs. Although the weakness on the issue of incentives or disincentives still needs further elaboration into a new regulation, Nurmardiansyah (2017) believes that with the revision of provincial regulations, the rate of land use conversion in the NBA can be significantly reduced.

In contrast, Siswanto (2017), a developer who is currently developing a property project in the NBA, has a different opinion of the effectiveness of the new regulation and the use of EIs to control the future land use in the NBA. He is convinced that property developers will always find ways to deal with the implementation of the regulation. He emphasises that there were many examples in Indonesia where 'regulations are made to be disobeyed'. He is also unsure whether the EIs would be as attractive as the high price of land offered by the developers. Moreover, he questions the availability of funding for EIs. Alam (2016) observed a similar phenomenon in the periphery of Greater Dhaka, Bangladesh, i.e., that the role of private developers on land ownership transfer for housing development is difficult to control.

The dynamic pattern of the NBA as outlined in Figure 4 shows that the acceleration of land use changes of initially dominantly agriculture and protected areas into built-up areas was caused by the acceleration of land ownership transfers triggered by the high price of land. This high price was caused by infrastructure developments, which was made possible due to the direction of spatial plans such as the appointment of the Bandung City as a National Activity Centre and Lembang District as a Local Activity Centre. Therefore, the transfer of land ownership from the native owners into the property developers and individual buyers is considered as one of the key problems of land use management in the NBA, which cannot be addressed by conventional spatial planning, i.e., allocation of protected areas. Hernawan (2010) argued that such land ownership transfer can be controlled by applying economics incentive in the form of purchasing development rights (PDR) and payments for environmental services (PES). The next section consists of a discussion of two scenarios of EIs based on the CLD as presented in Figure 4.

4.2 System dynamics of the NBA

4.2.1 Model structure

From the complex land conversion problem in the NBA, the constructed loop diagram as presented in Figure 4 is simplified into a model structure. This proposed model structure contains four sub-models:

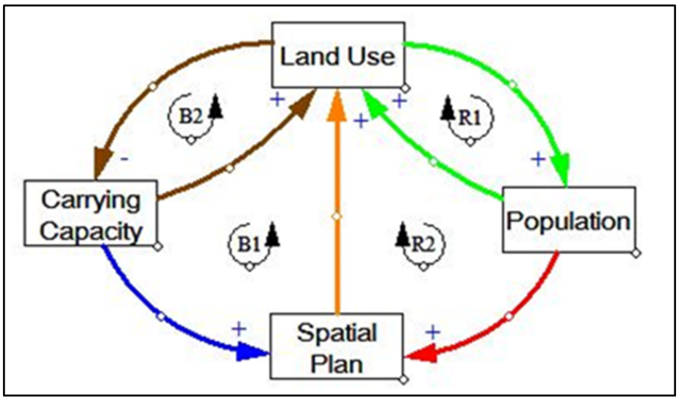
1 carrying capacity

2 land use

3 population

4 spatial plan.

Figure 5 Global model structure (see online version for colours)



Source: Authors (2017)

The interaction between the sub-models forms the main loops as shown in Figure 5. Land use conversion causes a decrease in carrying capacity. Based on Ministerial Decree of Environment No. 17 Year 2009, the inconsistency between the existing land use and land capability is considered to decrease carrying capacity. The NBA, based on land capability, is allocated as a protected area, however, in reality, it is used for housing development. The decline in carrying capacity will increase the need for more effective land use management especially in terms of land-use control (B1). The increased need for better spatial planning will affect land use conversion through zoning directives and license processes (B2). Similarly, the increasing population will drive the community's need for land for settlements as well as support infrastructures (R1). This clearly requires a policy that can regulate the spatial and regional plans for the NBA (R2). Thus, the loop is called reinforcing.

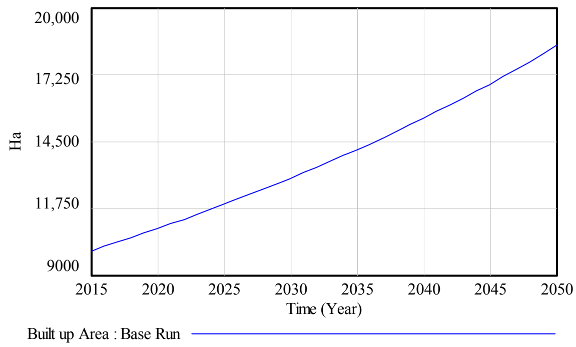
4.2.2 Simulation results

The constructed CLD and the model structure presented above is simulated to validate the model and the expected future behaviour of the NBA is projected for the period from 2015 to 2050 as follows.

4.2.2.1 Built-up area

According to Kuswandana as a head of Division for Spatial Planning of the Regional Road (Bina Marga) and Spatial Planning Agency of West Java Province in Faktabandungraya.com (2017), the NBA has an area of 39,354.31 Ha and covers four administrative regions, i.e., Bandung city (3,366 Ha), Cimahi city (1,524 Ha), Bandung regency (9,235 Ha), and West Bandung regency (25,277 Ha). The total built-up area in the NBA is estimated at about 9,388 Ha which is distributed 3,247.40 Ha in Bandung city, 1,305.60 Ha in Cimahi city, 1,270.10 Ha in Bandung regency, and 3,576.63 Ha in West Bandung regency. Using this data, the simulation obtained the following results.

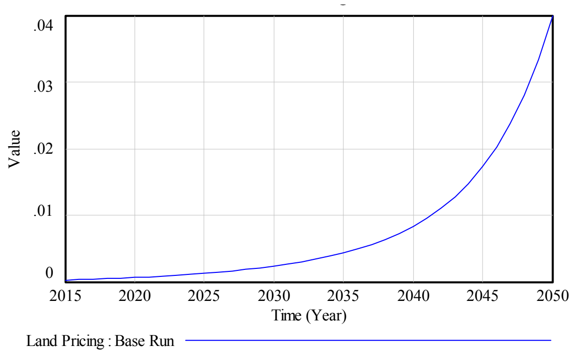
Figure 6 Built-up area (see online version for colours)



Source: Authors (2017)

As described above, the trend of historical land use changes consistently increased and it is expected to continue up to 18,000 Ha by 2050 as shown in Figure 5. Similarly, Figure 7 shows the expected future land price. The model shows a similar trend when comparing with the historical pattern of land prices from 1980 to 2015 in the northern part of the Bandung-Cimahi peri-urban region as reported by Vitriana (2017). According to Vitriana (2017), there was a significant increase of land price in the early 1990s due to the construction of the toll road from Padalarang to Cileunyi, afterward the land price exponentially increased up to 2015.

Figure 7 Land pricing (see online version for colours)

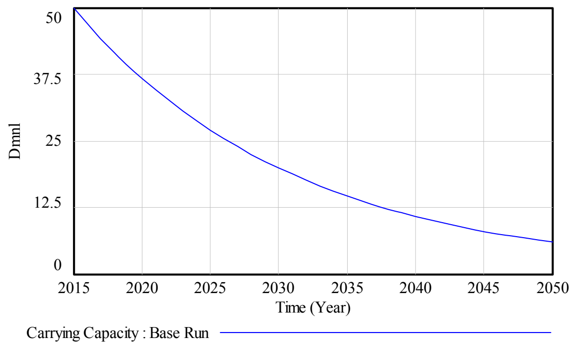


Source: Authors (2017)

4.2.2.2 Carrying capacity

Based on regulation of West Java Province No. 2/2016, the NBA is designated as a provincial strategic area with a water infiltration function. The location of NBA above the elevation of 750 m is also important as a buffer zone to protect the lower regions such as Bandung City and Cimahi City. The rapid developments in the NBA cause a decrease of water infiltration, which, in turn, degrades the region's carrying capacity. This is supported by Putri and Purwadio (2013) who concluded that land use changes from green space into settlements in Lembang District from the period of 2002 to 2013 reduced potential water infiltrations to around 27,501.45 m^3, which may increase potential flood in the lower region. Using the STREAM model, Fajri (2016) proved that land use changes from non-built-up land use to settlements in Southern Bandung increased the flood debit.

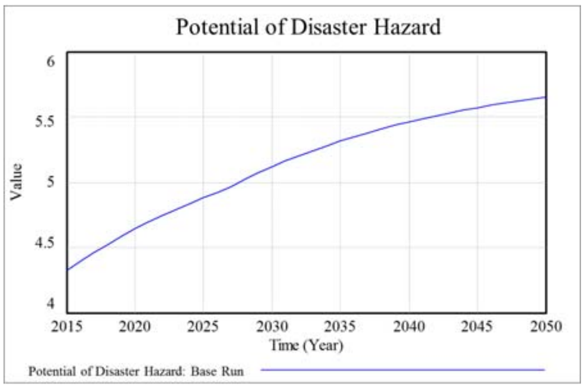
Figure 8 Carrying capacity (see online version for colours)



Source: Authors (2017)

Figures 8 and 9 show the results of the expected future carrying capacity and potential disaster hazards using the behaviour model which was validated by historical data. The diagrams indicate that the future carrying capacity will constantly degrade and the hazard potential would continue to escalate.

Figure 9 Potential for disaster hazard (see online version for colours)

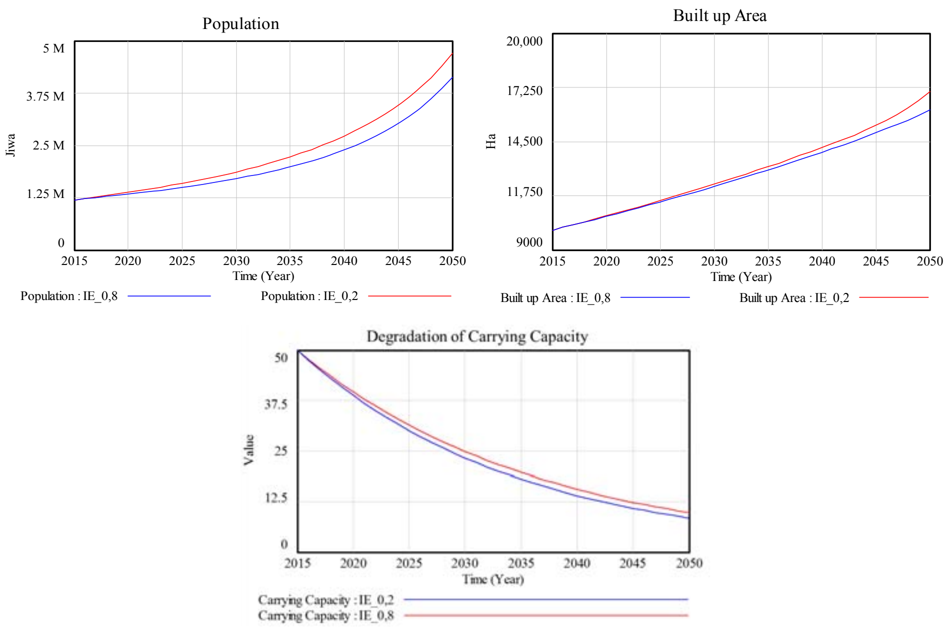


Source: Authors (2017)

4.3 The use of validated model of the behaviour of the NBA for simulating policy interventions

As previously presented, the most important driver of land use change in the NBA has been the pressure from economic development. Therefore, further simulations use EIs to intervene the validated behaviour, especially in reducing the current continuous 'land ownership transfer'. There are two scenarios of EIs, i.e., 'high effort' and 'low effort'. A high effort represents a very serious implementation of economic instruments consisting of the issuance of provincial regulations, the establishment of required institutions, and the provision of necessary funding. The low effort represents a business as usual action meaning no further additional effort asides implementing the newest amended Provincial Regulation No. 2 of 2016 on controlling the NBA. As discussed in Section 4.1 above, Nurmardiansyah (2017) argued that the EI is not sufficiently addressed within Regulation No. 2 of 2016. The low effort simulation represents this existing regulation. The computer simulation used the values 0.8 (high effort) and 0.2 (low effort).

Figure 10 The result of simulations using two scenarios of EI (see online version for colours)



Source: Authors (2017)

The three graphs shown in Figure 10 below are the result of the simulation with two scenarios of 'high effort' and 'low effort' of EIs. The results can be summarised as follows:

1 *Population growth*. The response of the model to the high incentive economics scenario indicates that the number of population in 2050 would be lower than in the low incentive scenario.

2 *Increase of built-up area*. The model also reacts positively to the high effort scenario. It means that the built-up area in 2050 would be smaller than in the scenario of low EIs.

3 *Degradation of carrying capacity*. In response to the higher incentive, the model shows that the degradation of carrying capacity would be slower than with the low effort intervention.

4.3 Discussion

Wilkinson (2011) argued that SER could contribute to planning in two ways. First, in the problem identification and problem-solving of planning. Second, SER could strengthen the ecological substance of planning. Using a hybrid framework of SES and system dynamics, this paper investigates the underlying planning problem of the case study area, the NBA which has consistently undergone land conversion. This conversion has occurred regardless the enactment since 1982 of provincial regulations aimed to conserve the area, which have frequently been amended including the newest Provincial Regulation No. 2/2016. Six issues were identified in the process of formulating the draft of this regulation, i.e., insufficient detail on the scale of maps of the spatial plans, mechanisms of permit issuance, lack of supervision, lack of incentive instruments for controlling land use, zoning regulations, and the weak enforcement of regulations. The most recent regulation of 2016 has already addressed almost all the identified issues, except for the issue of incentives which lacks detail. Using the SES framework and the CLD tool, the paper finds that the root cause of the problem is the accelerated transfer of land ownership due to the high price of land offered by the market, which is triggered by economic development as a result of infrastructure construction. Thus, the key planning problem in the NBA is related to EIs, which are not properly addressed by Regulation No. 02/2016. This means that the latest regulation has not addressed the root of the problem. Further simulations of the system dynamics model confirmed that high effort EIs are expected to reduce the rate of land conversion and degradation of carrying capacity. SES research has been carried out intensively worldwide, Rissman and Gillon (2017) analysed 120 papers on the topic of SES. Of the paper assessed by Rissman and Gillon (2017), 18% used the CLDs method. Although the use of CLD for SES research is not new, the contribution of this paper is to offer an approach for a step in the planning process, i.e., problem identification which in turn supports the solution of the problem. By finding the more fundamental problem in the NBA followed up with a better solution, this paper also could enhance the ecological substance of land use management in the NBA.

Stave et al. (2017) applied a hybrid framework of SES and system dynamics similar to the framework used by this paper, focusing on the sustainability of the Lake Tana Basin, Ethiopia. Stave et al. (2017) focused on the sustainability of the agriculture sector by addressing the issues of agricultural intensification, job creation, and rural to urban migration, whereas this paper focused on the sustainability of an ecologically sensitive area threatened by urban expansion. Although the case study for this paper and the case of Lake Tana Basin, Ethiopia addressed different issues, using a similar approach of combining SES and system dynamics, both studies were able to identify the root of the respective problems.

On the other hand, although addressing the same issues of the NBA, using a different approach, Hernawan (2010) found that the main problem of the NBA was due to contradictory policies in the spatial plan; on the one hand, the plan designated the NBA as protected area, but areas close to the NBA such as Bandung City and even within the NBA such as Lembang City are planned as urban activity centres. The designation of activity centres leads to an increase in urban and economic development, which is related to the findings of this paper that the main problem of the NBA is land ownership transfer due to economic reasons. By using a hybrid framework of SES and system dynamics, this paper could identify the core of the problem of uncontrolled land conversion. This paper is also in line with Palomo et al. (2014) who argued that the static approach in protected area management is out of date. Therefore, an adaptive approach has to be applied in the management of protected areas by taking into account natural and social changes. Further, Heslinga et al. (2017) concluded that traditional protection only views the issue from the perspective of protection and risk avoidance. Meanwhile, from the perspective of social-ecological dynamic, synergies should be found between protection and emerging opportunities as well as between development and risk avoidance. Furthermore, Burnett (2014) argued that applying an island approach in the management of protected areas will not be effective; a better approach is to establish preservation areas as part of 'welfare-maximising management programme'. Similarly, Robinson et al. (2014) contended that economic welfare must be attained in parallel with ecological sustainability.

5 Conclusions and limitations of study

Based on SES analysis using a CLD tool and the simulations of the system dynamics model, it can be concluded that the implementation of a policy of EIs could reduce the rate of land use change and contribute to slow down the degradation of carrying capacity in the NBA. This policy could reduce the rate of land-ownership transfers, which is the root cause of the problem of land use conversion in the NBA.

The simulations show that the implementation of a high level of EIs could reduce the increase in built-up areas compared to a scenario with low incentives. Consequently, a policy of high-level EIs also leads to less environmental degradation than applying a policy of low EIs. The smaller increase of built-up area is also supported by the simulation of population growth, which shows lower growth compared to the low incentive scenario. The model simulation in responding to the high incentive scenario shows that the effective control of the NBA requires a set of economic instruments and the establishment of required institutions to support the implementation of such incentive level for land use management. The simulation implies that the new Provincial Regulation of West Java No 2/2016 is still insufficient in controlling land use conversion in the NBA.

Nevertheless, Siswanto (2017), a respondent representing property developers in NBA, is unsure if the EIs would as attractive as the high price of land offered by the housing developers. In addition, he believes that developers will usually find ways to deal with the regulation and make the land-ownership transfer occur anyway. Therefore, as stated by Wilkinson (2011), the role of socio-ecological resilience for planning is to contribute in formulating more accurate planning problems that result in better solutions.

This paper was able to identify the root causes of land conversion in NBA, i.e., progressive land ownership transfer. However, this paper is not fully satisfactory in terms of providing proper solutions to the problem of a continuous change in land ownership, therefore, further research is needed. In particular, model simulations that could provide more comprehensive solutions to the given problems include more detailed scenarios of economic instruments and the involvement of key stakeholders in a more collaborative model of system dynamics is necessary.

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