The Integration of a System Science for Social Knowledge Co-creation in Enhancing the Local Sustainable Agriculture Development: A Case Study in Phraek Nam Daeng Sub-District, Amphawa District, Samut Songkhram Province

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Abstract

An essential of expanding knowledge of co-creation for social change to encompass the relevance of integrating multiple sustainable value dimensions, as well as the recognition of different types of ecological service under social-ecological systems and social dynamics, is an urgent need in both types of sustainability studies, allowing useful in policy-makers, and community arenas. In this paper, we present a methodological framework on the integration of two system science disciplines, system theory and foresight study for scenario planning design. Three study approaches were designed and detailed application in Phraek Nam Daeng Sub-district (PND), with particular emphasis on the local agriculture system, as a case study. Through the field study and empirical analysis, we also involved 22 local farmers, as well as 41 participants stakeholders in multiple collaborative workshop exercises to construct causal-linked variables and causal loop diagrams, and expose structural critical uncertainty and draft scenario storylines. On-the-ground of sustainability outcomes from our study, we provided the four sets of cross-cutting themes, discussing visions and prospect engagement issues underlying plausible trajectories to ensure they are suitable for the local agricultural. We also discussed four postulated trajectories that likely substantiate the co-evolving of SES and social dynamics, that may include as socials ideally evolve and collective learning for transforming into local sustainable agriculture and bringing forward livelihoods and ES quality to society. Our analytical approaches reflected that devising long-lasting solutions will require deep 'social's knowledge co-creation of change, responding to the sustainable society. In the future, the causal-linked variables would be translated into dynamic models to foster the process of the feedbacks characterizing ecological functions (supply-demand) associated with endorsement of specific and alternative scenario storylines of agriculture development and social livelihoods' trajectory.

Keywords: Causal Loop Diagrams; Local Agriculture; Phraek Nam Daeng Sub-District; Knowledge Co-creation; Scenario planning; System Science

Introduction

The crucial changes and the interacting of the socioeconomic, social-ecological systems (SES), and landscape transformations are characterized and have been suggested as particularly useful for studying the risk and opportunities of the ecological components (Liu et al. 2007; Carpenter et al., 2012) and ecological services (ES) at global, regional and local scales (Schröter et al. 2005; Metzger et al., 2010; Rockström et al., 2009; Huq et al., 2020). With regard to system science (SS), this science emerged on recognizing the integration of scientific and social systems, advocating the process of 'knowledge co-creation' for social change (Carpenter, 2020; Costanza et al., 2014; Mauser et al., 2013) and responding to the sustainability challenges that communities and societies are challenged with (Shahadu, 2016; Jerneck et al., 2011).

Since last two decades, many local agricultural landscapes located at the Upper Gulf of Thailand face two major interlinked challenges of improving the agriculture security, while also halting ES, natural resources and biodiversity decline (WHO, 2015). Moreover, key pressure from the expansion and intensification of agriculture has contributed to local's subsistence-based approaches (Shivakoti et al., 2019). While, the poor coordination of the country governance system and pattern of the local horizontal institutional are fragmentation in responding to the local sustainable agriculture system and of growing social's sustainable livelihoods (OECD, 2018).

In this paper, we present a methodological framework that incorporated three holistic study approaches. To illustrate our approaches, we present a detailed application to the Phraek Nam Daeng Sub-district (PND), Amphawa District, Samut Songkhram Province, one of the most significant natural areas with protected lowland coastal ecosystems in the Upper Gulf of Thailand, with particular emphasis on the smallholder farmers, as a case study, and it was treated as over a two-year period (2018-2020). Notably, our approaches are intended to understand the ES quality in the context of socioeconomic conditions and the co-evolution of SES in order to facilitate different development trajectories, which is a local's sustainable agricultural system and society livelihoods. Our analytical approaches show an understanding is used in combination of cause-and-effect chains analysis and the causal loop diagram (CLD) on the interlinkage variables, underpinning the ES quality and the key dynamics of the SES, with scenario planning to map how current development trends might be amplified or dampened in the future. Our study provided a set of specific challenges and opportunities for local agriculture development, societal livelihoods, and ES quality, and we used these to substantiate four postulates about the trajectories and dynamics of SES and social systems. We found special reflections on the benefit of incorporate SS, as the essential features of our study approaches and analytical processes. The key lesson learned from the analytical approaches are discussed, as well as directions for future research needed are drawn out.

Research Objectives

1. To investigate ES conditions and their linkage to the socioeconomic and ecological importance for the local agriculture system.

2. To conceptualize the Causal Loop Diagram (CLD) underpinning dynamics variables of importance for the local agriculture system and their livelihoods.

3. To explore the plausible scenarios describing social collective learning for transforming into a sustainable agriculture and bringing forward livelihoods and ES quality to society.

Literature Review

Social-ecological systems (SES) are interrelated and co-evolving across spatial and temporal scales, characterized by dynamic complexity and closely linked with social, economic, ecological, cultural, political, technical, and other components (Carpenter et al., 2012; Liu et al., 2007). SES are also involved in the ecosystem services (ES), which provide a range of essential benefits to human livelihoods, and bring forward the benefits of nature to our society (Bordt & Saner, 2019; Carpenter, 2020; TEEB Synthesis, 2010; MEA, 2005). Several studies have been employed and coordinated with efforts at emerging of social dynamics at regional and local levels toward better understanding and management in the context of ES assessment process (Burkhard et al., 2013; Bagstad et al., 2013; Braat & De Groot, 2012; Fischer et al., 2008).

System Science (SS) emerged as a scientific and social systems' integration for researching and responding to the numerous sustainability challenges that communities and societies are challenged with (Shahadu, 2016; Jerneck et al., 2011) advocating the process of knowledge co-creation for social change (Carpenter et al., 2012; Martinez-Alier, 2002). SS is the process of synchronizing a meta-system and its layered, complex, and evolving subsystems with the dynamics of nature, society, and the economy dynamics (Bossel, 1998). This process emphasizes the importance of research with the role of integrating system theory (Burkhard, 2013; Boumans et al., 2015) in assisting decision-makers in the protection of ES quality (Stenseke & Larigauderie, 2017;

Bruckmeier, 2016; Guimarães et al., 2013). SS study process also entails recognizing the desirable futures through transition e of a particular system (Van der Leeuw et al., 2012), such as entry points for effecting transformations in systems, revealing alarming signals for the future towards exploring alternative, more desirable futures through transition (Swart, et al., 2004; Raskin et al., 2002; Kates & Parris, 2003) and transformation (Segers, 2020; Bai et al., 2016; Westley et al., 2011; Haberl et al., 2011; Folke, 2006; Folke et al., 2002; Berkhout et al., 2004; O'Brien, 2012; Friis et al., 2016) the distant interferences of Anthropocene and nature-society interactions across spatial and temporal scales (Preiser et al., 2018; Rockström et al., 2009; Singh et al., 2010), and implement the fundamental changes that society needs to go through to achieve sustainability goals.

The different integrated methodologies were developed using participatory systems mapping (PSM) approaches to support the natural resources management (Lipej & Male, 2015; Lopes & pes, 2016; Burdon et al., 2019; Antunes et al., 2015; Videira et al., 2014), with varying degrees of stakeholder engagement that combined information into a causal mapping technique, allowing the creation of a unified knowledge base (Jeong, 2013). In this context, the role of system thinking has been utilized to the distinct problems and goals (van den Belt et al., 2010; Stave, 2002), as well as how participatory approaches might achieve them (Hare et al., 2003). SS for sustainability research also employed the foresight study to explore and describe the social's ideas of the future states (Raskin et al. 2002, 2008), as well as offering opportunities for participatory processes of knowledge generation, in responding to the uncertainties and risks that threaten the pursuit of sustainability across the social conditions and future trends of SES (Oberlack et al., 2019; Bina & Ricci, 2016). In summary, these two sciences aim to provide society with both knowledge of what the world is like and the choices for sustainability planners and policy-makers have to grapple with uncertainties and for achieving long-term sustainability (Kates et al.,2001; Biggs, & Zurek, 2007).

However, the process of identifying and exploring the interactions between ES key variables often reduces the intractable complexity of the systems studied (Costanza & Kubiszewski, 2012), which is still notorious in other sciences in both types of research and allows useful in policy-making and community arenas (Braat & de Groot, 2012; MEA, 2005; IPBES, 2016). These limitations have led scholars to an intensification of the debate around the methodological framework development, and practical implications of approaches to capture the importance of ES (Costanza et al., 2020; Martínez-Alier,2014; Spash, 2008), under the co-evolving of social dynamics and the SES for learning and transforming into a sustainable society (Suroso & Kombaitan, 2018; Guimarães et al., 2013; Pascual et al., 2016).

In this paper, we present a methodological framework on the integration of two system science disciplines, system theory (Bertalanffy, 1968; Forrester, 2009; Waldrop, 1992; Kauffman, 1995) and foresight study for scenario planning design (Stratigea & Giaoutzi, 2012; Derbyshire, 2018; Palomo et al., 2011). Three holistic approaches were designed and carried out the detailed applications with particular emphasis on the smallholder farmers in Phraek Nam Daeng Sub-district (PND), Amphawa District, Samut Songkhram Province, located at the Upper Gulf of Thailand, as a case study[1]. For our study, this area is an interesting system, since it shares many challenge features on the natural resources degradation driven by the crucial changes of the SES properties, an uncertainty of socioeconomic and environmental changes and the country's governing policy (FAO 2018; Calicioglu, et al., 2019). Our goal was to capture the importance of the co-evolving of social dynamics and the SES, encouraging the development of societal ideal evolves (Chan et al., 2016; Lopes and Videira, 2013, 2016) to foster knowledge exchange and capable of transforming into a sustainable society (Guimarães et al., 2013), that is, utilizing the local sustainable agricultural system, social livelihoods, and ES quality (Giaoutzi et al., 2012).

Case study

Phraek Nam Daeng Sub-district (PND), Amphawa District, Samut Songkhram Province, is located in the Upper Gulf of Thailand (Fig. 2), covering an area of about 36.23 km^2 and divided into the administrative boundaries of six (6) village clusters[2]. PND is a natural area with protected lowland coastal ecosystems. The three naturally dominated by different water zones, freshwater, seawater, and brackish water from these natural sources, create a balanced nature in the area. Since last two decades, this area is rich in natural resources, which have played an important role in sustaining agriculture and local livelihoods as well as driving economic growth (ICEM 2015). Agriculture system in PND is used principally for small-scale farming or traditional farming practices. There are many kinds of agriculture diversity in area, such as aquaculture, coconut plantation, rice farming, shrimp, fish, crab, and vegetation. However, many local agricultural landscapes located at the Upper Gulf of Thailand face two major interlinked challenges of improving the agriculture security while also halting natural resources and biodiversity decline (World Health Organization 2015). Moreover, key pressure from the expansion and intensification of agriculture has contributed to local's subsistence-based approaches.

[1] This study was carried out as a part of the 2 research programs as follows: 1 "Scenario Blueprint Development and Systemic Strategy Formulation for a Security of Agricultural Sector under the Risk of Climate Change and Globalization Era Order Upper Gulf of Thailand." Ethical consideration was certified by MU-CIRB, Certificate of Approval (CoA) No. MU-CIRB 2017/204.0911. 2 "An Application of Participatory Systemic Thinking for Sustainable Smallholder Farmer Agriculture:A Case Study in Phraek Nam Daeng Sub district, Amphawa District, Samut Songkhram Province." Ethical consideration was certified by MU-CIRB, Certificate of Approval (CoA) No. MU-CIRB 2019/070.0103

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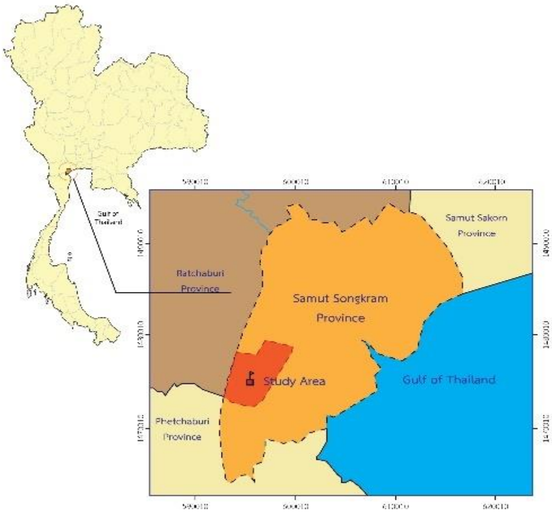

Figure 1 The boundary of Phraek Nam Daeng Sub district (PND)

Methodological Framework and study approaches

Our methodological framework (Fig. 2) was designed as an analytical framework that incorporates three holistic study approaches. Through the field study, descriptive and analytic statistical investigation, and the multiple collaborative workshop exercises in local communities and social stakeholders' analysis, with regard to the study objectives three analytical stages were designed, as detailed follows:

1) *The first stage:* The study approach is concerned with envisaging on the local's history and current conditions of the ES quality and their linkage to the local socioeconomic and ecological importance for the agriculture system (Lopes & Videira, 2015, 2016), so-*called the stage of 'behind the scene of the local conditions.'*

2) *The second stage:* The study approach emerged to foster knowledge exchange and sharing with insights on dynamic issues (Sedlacko et al., 2014). Based on the application of system theory, we conducted the multiple collaborative PSM workshop exercise to construct causal-linked variables (cause-and-effect chains analysis) and causal loop diagrams (CLD) visualizing the interlinkage variables underpinning the ES quality and the key dynamics of the SES conditions for local agriculture system (Guimarães et al, 2013; Pascual et al., 2016; Daconto & Sherpa 2010), *so-called the stage of 'setting the causal system mapping.'*

3) *The third stage:* The study approach is designed to provide a structured approach to identify the four future different scenario storylines (Haeffner et al., 2012; Keough & Shanahan, 2008; Peterson et al., 2003; Rhydderch, 2017; Schoemaker, 1995). Typically, it is employed to encompass the significances significant of the integrating forces of change within in the study areas (PND), as well as in the region (the Upper Gulf of Thailand), describing the various development

trajectories of local sustainable agricultural system, *so-called the stage of 'setting the social's collective learning trajectories.'*

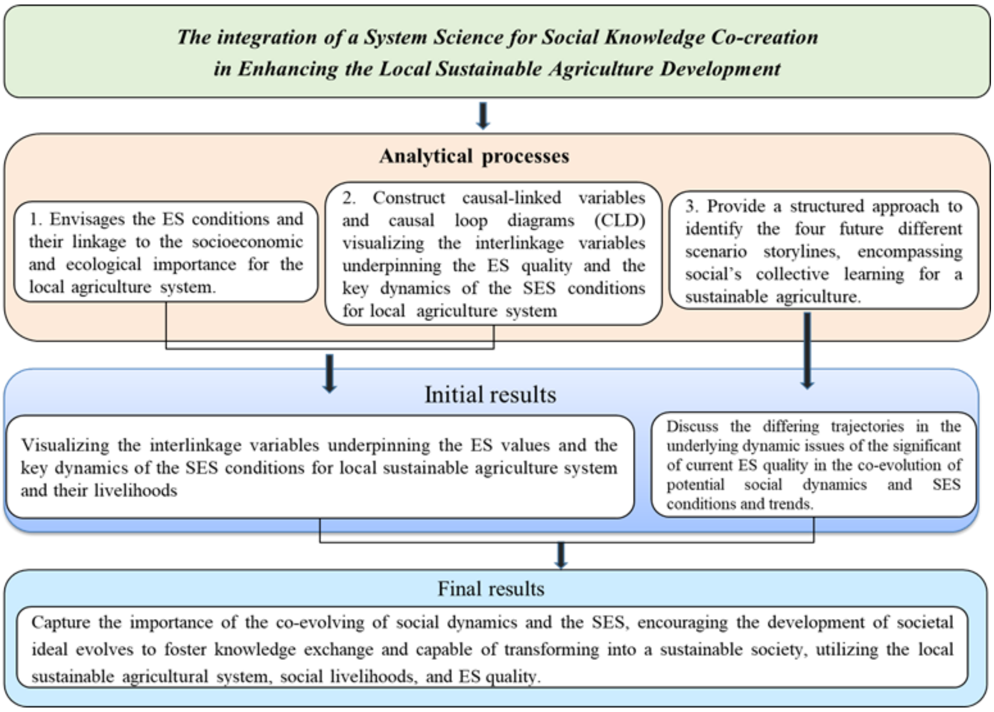

Figure 2 Methodological framework with three integrated study approaches

Data methodology and workshop participants

Data methodology: Questionnaires surveys, semi-structured interviews, and focus group discussions were the three basic components of the field study. For quantitative data analysis, the sample size and valuation methods are designed to gather the necessary information and to gain a more in-depth understanding of local conditions under the effect of socio-ecological and environmental change in the villages. With which restricted to data from 22 local farmers that target villages belonged to (6 villages), all of data for the in-depth analysis were collected using simple random sampling from 85 local farming households (from 548 households), with a 90% confidence level based on Taro Yamane (1973).

We used the proportions of all communities (22 local farmers) to summarize the socioeconomic conditions of different villages. Socio-demographic variables of analysis derived from community-level statistics included total population size and trend, unemployment rate, net migration levels, and the number and proportions of active farmers and youths relative to the total population in a given commune. We assessed and characterized the ES condition/quality in term of the local agriculture system. Variables describing the ES, we used: i) the proportion of available land and natural capital characteristic, ii) farmland biodiversity, and iii) local knowledge and perception on the agriculture conservation status of different communities. Furthermore, we also gathered these data that had previously been conducted and analyzed by Sub-district Agricultural Technology Transfer and Service Center (2018) and Office of Natural Resources and Environmental Policy and Planning (Ministry of Natural Resources and the Environment. "Master Plan for Integrated Biodiversity Management (2015-2021).

Workshop participants: Throughout the study, we invited 41 participants from local communities and socially diverse stakeholders for group discussions and collaborative workshop activities. Their participation was based on prior knowledge of the study's landscape and agricultural system, which included representatives from local farmers (22), community leaders (5), local public staff in local government administration (4), civil society (2), local business (2), central government agency that related to the agricultural development sector (3), local agency organizations concerned with nature conservation and researchers from Higher Education Institutions (3), including an expert on the development of causal mapping technique from Faculty of Environment and Resource Studies, Mahidol University, Thailand. It's worth noting that each collaborative workshop was organized on the basis of a two-day activities at PND Municipality Townhall, Amphawa District.

Research Results

1. Results from the first stage (objective 1): Behind the scene of local conditions.

Results obtained from our filed study and statistically analysis, we classified the local's agriculture system into two diverse grouped: market-based agricultural intensification versus small-scale farming approaches. Based on this grouping, we concluded that village conditions could be summarized by the amounts of the available land for agriculture and crop production. In terms of ES conditions, villages with a high proportion of available land tended to have a high proportion of farmland biodiversity. Villages with a lot of arable land had limited natural capital to generate local goods. Villages with a large share of natural resources, on the other hand, had a high level of farming biodiversity as well as a rich scenic beauty and local tourism. In regard to topography, local farmers in PND have a variety of occupational choices based on ES conditions that are closely linked to the local lifestyle system. In terms of socio-demographic factors, agriculture is one of the most local traditional practices, with local good identity[3] and off-farm profitability. Furthermore, local agro-tourism tourism, nature-based tourism or farm-based tourism contribute significantly to their income and livelihood.

[3] The research has defined local identity as the identity that could provide distinctive features to. small-scaled places, including both positive and negative preferences of people. The local identity contains four aspects: physical, social, sensory and memory aspects.

Since the reform of the National Strategy Act B.E. 2560 (Srisil, 2019) and achievements in the context of the agriculture sector in Thailand (Kasem & Thapa, 2012), the country's sustainable policies and institutions are being reformed and implemented, as well as ecologically beneficial for sustainable agriculture. However, the national policies have emphasized economic growth, particularly in rural regions. In a market-based economy, agricultural and crop goods are in great demand, and local natural resources are utilized where they are profitable. Results highlighted from the group discussion stated that, over the past two decades, a local farmer in this landscape has been one of the vulnerable and dynamic to socioeconomic, which bring several challenges to be sustainable agriculture and nature protection. Rapid economic development has often occurred through the unsustainable exploitation of the natural resources. Moreover, key pressures from the expansion and intensification and market-oriented of agriculture have significant effects on the small-scale farming and traditional agricultural practices of the locals. At the same time, the poor coordination of the country's governance system and pattern of the local horizontal institutional fragmentation makes it difficult to adapt to the local sustainable agriculture system and growing social livelihoods (Nara et al., 2014).

2. Results from the second stage (objective 2). Setting the causal system mapping.

First, the information produced from the first stage, *behind the scene of local conditions*, was retrieved allowing the participant stakeholders to discuss which important variables for enhancing the local’s agriculture development. Then, we conducted three separate participatory systems mapping (PSM) workshops to construct three distinct causal-linked variables, or causal systems). These causal-linked variables were built aiming at a specific information exchange of insights on each causal dynamic variable(s) that participants were concerned: i) prior knowledge and perceptions of the local agriculture/crop system; ii) ES benefit that emphasize necessary and/or sufficient conditions requirements, as leverage points of their agriculture/crop products and livelihoods; and iii) variables related social conditions and SES trends, as well as other important drivers like the country's governing policy or local's institutional arrangement, that local farmers can prosper move-up their sustainable agriculture strategy.

To start drawing the initial CLD, participants were asked to present their mental model upon the variables discussed. They agreed that the central variable in the causal systems should be based on local agriculture (including market-based agricultural intensification and small-scale farming), and crop productions as well as the interaction of socioeconomic factors. Subsequently, we prompted participants to reflect on important variables on the question: *'What causes of increasing the local agriculture/crop productions and enhancing livelihoods?'* Here, the list of probable conditions or pressures identified with the first step (*setting the scene of local conditions*) was utilized to inform and added to the developing causal systems. Following that, based on the three distinct causal systems, we had a second-round workshop to finalize the CLD. During the development process, the common question that guided the participants' activities in each small group was posted as: *'In the next twenty years, how can local farmers and social key agencies would guarantee a sustainable flow of the ES that would enhance agriculture system and their livelihoods, under the social dynamics and SES conditions?*

After the workshop, participants were urged to disclose a broad agreement and increase the quality of the CLD created after the session. Based on the findings of causal system mapping from each PSM small group activity, we did this by combining cause-and-effect chains consistently into a single draft diagram. Here, a few participants recommended adding new variables and identifying certain key leverage points, both of which were included in the final version of CLD. The researchers' team then refined the data, both in terms of format and substance, using a set of guidelines that included presentation clarity, eliminating overlap between variables and closing feedback loops developed in the workshop. At the end of the workshop session, we transcribed all variables and constructed the final CLD with the help of VENSIM® software[4] (Fig. 3). The following discussion is the results obtained from this workshop activity. The results of this workshop activity are discussed in the following sections.

[4] The representation of the feedback mechanisms underlying the unstructured issue by using elements such as variable names and arrows representing causal links between two variables. Causal links can be positive (a "+" sign is used) if the variables change in the same direction, or negative (a "–" sign is used) if the variables change in the opposite direction. The set of links can form feedback loops, which in turn can be designated as reinforcing (a 'R' sign is used) or balancing loops (a 'B' sign is used)

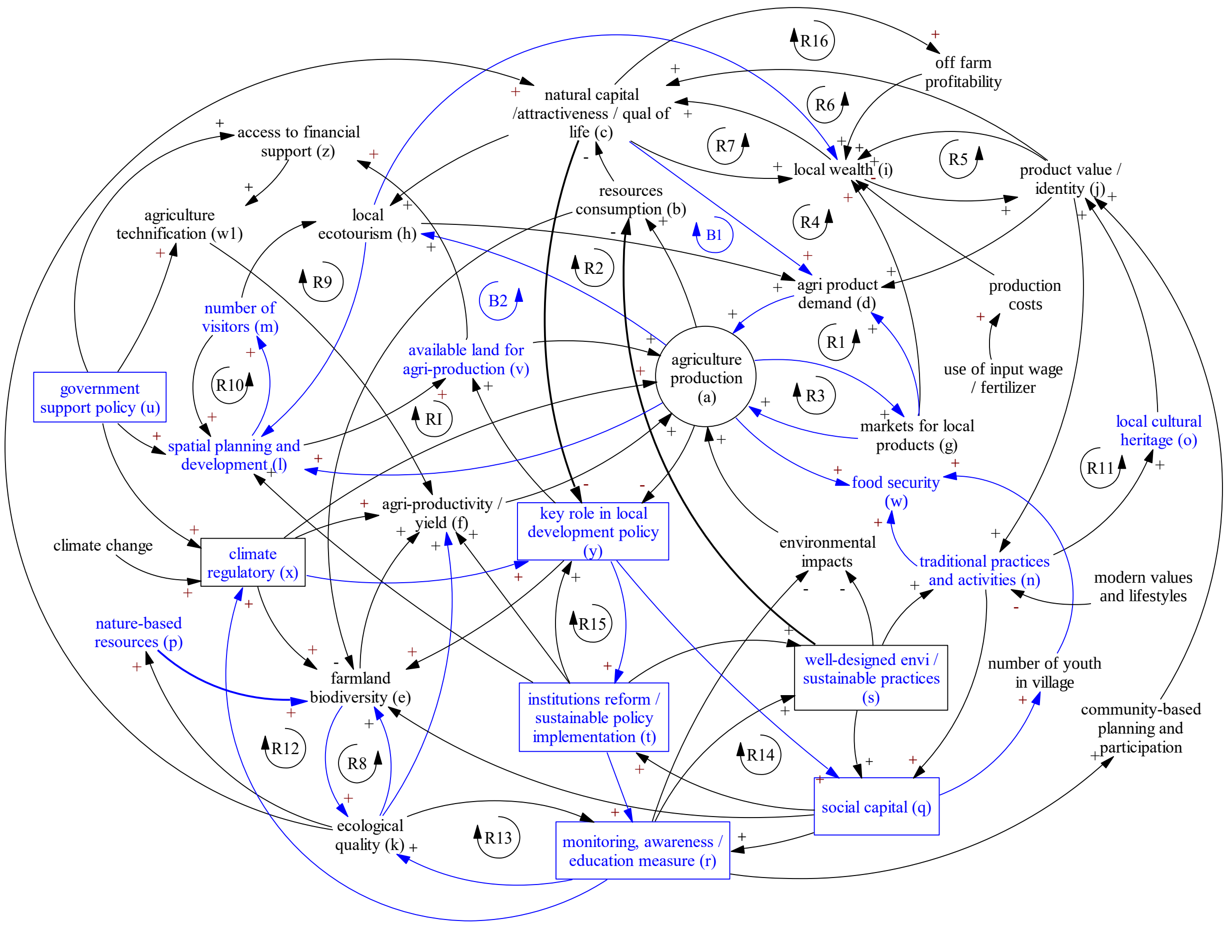

Figure 3 Illustrated the CLD summarizing the cause-and-effect chains of local agriculture system

In PND, agriculture production is one of the most recognizable ES by local people. Participants were interested in its importance of the context of the specific examples of the local agriculture and crop production of the area. Different factors of ES are considered when studying local products, such as the amount of land, the agriculture productivity or yield, crops variety and quality. They are also interested in this service, particularly in terms of its economic values in the context of local agro/eco-tourism. As CLD illustrated in Fig. 3, the loop B1 is a balancing loop that shows how an increase in agriculture production (a) leads to an increase in resources consumption (b), which in turn decreases the area's natural capital/attractiveness and the quality of life (c), and increasing agriculture product demand (d), resulting in an increase agriculture production (a). While an increase in resources consumption (b) cause a decrease in farmland biodiversity (e), which has an impact on yield (f) and agriculture production (a), which subsequently closes the balancing loop B2 by reducing resources consumption (b).

Regarding the expanding markets for local products (g), this variable was one of the emphasized measures that would enhance agriculture product demand (d), which will lead to an increase in agriculture output (a), as shown in the causal diagram as reinforcing loop R1. The reinforcing loop R2 depicts the relation between agriculture production (a) and other services and values such as local ecotourism (h). To put it another way, increased agricultural output may result in an increase in recreation and ecotourism service levels, resulting in a rise in local agriculture demand (d) and, as a result, more agriculture production (a). This reinforcing loop (R2) focused on food and beverage-related, as well as ecotourism (h). Furthermore, participants thought that such local products may help to boost other types of tourism, e.g., coffee farm vintage. The reinforcing loop R3 translates this effect: increasing agriculture production (a) promotes the growth of the markets for local products (g), and vice versa. As a result, participants concluded that increasing the markets for local products (g) leads to an increase in local wealth (i) in other words as increase in local profitability of prosperity and farmer livelihoods, as well as driving up the attractiveness of an area (c), which increases demand for local product demand (d), with the enhancement of agriculture production (a) reinforcing loop R4.

Another discussion on the local sustainable farming approach was the marketing of local products' value, as follows details. Increasing local agricultural product value and identity (j) efforts will lead to a rise in local wealth (i) and the contrary is also true, as depicted in reinforcing loop R5, which indirectly causes an increase in local agriculture demands (d). More marketing plans for local product value and identity (j) will boost the area's attractiveness and quality of life (c), hence increasing local wealth (i), as shown in reinforcing loop R6. Where the reinforcing loop R7 demonstrates that local wealth (i) would lead in driving up the area's attractiveness and quality of life (c). All of these feedback loops demonstrate how agriculture production (a) may be potentiated in the area by acting on the demand side (d).

Following, participants in the second group were then asked to describe how ES variables, such as, local farmland biodiversity, recreation and ecotourism, the current and future stage of the biodiversity conservation plan, and local spatial planning will improve their agriculture sustainability and livelihoods. The variables are then combined and described as follows. Farmland biodiversity (e) and ecological quality (k) are responsible for securing ES from the natural supply side, as shown in the reinforcing loop R8. These variables also encourage natural protection initiatives in the villages, which serve as a foundation for delivering the ES and how it should be preserved. Furthermore, participants began by highlighting the necessary and sufficient conditions that would be recognized as leverage points for local sustainable agriculture, livelihoods, and wealth enhancement. These variables are then merged into the CLD and discusses as follows: the importance of spatial planning and development (l) for increasing the number of visitors (m), which leads to an increase in local recreation and ecotourism (h), and this, in turn, will necessitate an increase in support infrastructures after a given period of time (as shown in the reinforcing loop R9), with a focus on spatial planning and development (l) and also an increase in the number of visitors (m) and vice versa (as shown in the reinforcing loop R10). While investing in the local product value / identity (j) is selected as variables affecting the local's traditional practices and activities (n), which by its turn will drive the protection of local cultural heritage (o) and lead to further reinforcing marketing activities, thus closing the reinforcing loop R11. Further, the social pressures on sustainable nature-based (p) are heightened as variables that may increase the need for farmland biodiversity (e), which in time will increase in ecological quality (k), as shown in reinforcing loop R12.

Further, participants also have a chance to debated and visualize four key variables and projected as important leverage points that will be used to regulate local product demand-side consequences of the ecological quality, as details follows. The spatial planning and development (l) and sustainable of nature-based resources (p), variables would directly affect farmland biodiversity (e), and as essential factors to foster the equilibrium of the local smallholder farmers at local ecological quality (k), thus, indirectly affecting the communities' agriculture productivity (a). They were also expected to combine local knowledge with social and environmental dynamics in order to provide maintenance and support services (ES) and ensure the viability of their agriculture system. These important drivers and their influencing factors are then added to the CLD that have been constructed (as depicted in boxes). Participants first recognized social capital (q), or the role of local sustainable activities, as a leverage point to the variable monitoring, awareness, and educational measures (r), which affect several feedback loops. Increasing the variable of monitoring, awareness, and educational measures (r) may directly enhance ecological quality (k), as illustrated in the reinforcing loop R13. It will also improve the status of local institution reform and policy implementation (t), improving locally well-designed environmental and sustainable practices (s), as indicated in reinforcing loop R14, as well as indirectly enhancing farmland biodiversity (e).

Following that, participants of another small working group were had the chance to add drivers that they believed would have an influence on or improve the local agricultural system, and they agreed to investigate the country's climate regulation service (x). This climate driver (x) is considered as a leverage point of agriculture productivity or yield (f), total agricultural output (a), and farmland biodiversity (e). All of these drivers will lead to the need for government support policy (u), in the form of local regulatory activities in the protected area, which will result in two types of measures: monitoring, awareness, and educational measures (r), or through institutional reform with long-term sustainable policy implementation (t). Furthermore, controlling factors such as government support policy (u) and local farmers' opportunity to access to financial assistance (z), these two factors would lead to increased agricultural technification (w1), which would lead to increased agriculture productivity / yield (f), as well as serve as a key leverage point, decreasing from social pressures while supporting nature-based resources (p). Another controlling variable chosen by participants was government support policy (u) as a leverage point, which, when combined with local farmers' ability to access financial support (z), these two variables would lead to increased agriculture technification (w1) and increased agriculture productivity or yield (f), as well as reduce social pressures on local nature-based resources (q). It's worth noting that in this causal structure, 'farmland biodiversity conservation' is the variable that in influent by the most of the others. Monitoring, awareness, and education measures are active variables in the sense that they influence many other points in the system, and thus play a critical role in the preservation of the ES quality, according to participants.

Finally, at the end of the workshop session, participants were given the chance to debate and reflect on the drivers or variables that would be used as entry points to enhance the community's sustainable agriculture growth. The suggested CLD reflects the premise that there are several entry points in promoting biodiversity conservation in the PND protected area, which are converted into a set of self-reinforcing feedback loops. Especially, a balancing feedback loop B1 demonstrates how an increase in agriculture production output (a) can negatively impact ecological quality (k), leading to an increase in resource consumption and exploitation (b) and consequently the decrease in farmland biodiversity conservation (e). Further, as demonstrated shown in reinforcing loop R8, it is necessary to ensure the conservation of agricultural biodiversity (e) of the local ecological quality (k), and vice versa. Participants also suggested the following relationship between a village's economic variable and its residents' social capital: Traditional farming's low profitability was widely argued for the country's poor economic conditions, which led to emigration, particularly among the young, and land abandonment. Conversion to larger agricultural scales, more intensive farms operated by either affluent locals or from industrial agriculture investors were alternatives to small-scale farming. On the other hand, the larger-scale and capital-intensive farms, might adopt sustainable farming or traditional agriculture practices. Whereas the dual processes of farmland intensification in some areas and abandonment in others were thought to lead to a decrease in traditional small-scale farming, as a result, farmland biodiversity, cultural, regulating, and supporting ecological quality, were seen to be adversely affected. It was proposed that tourism growth may have a good impact on the local economy. Economic prosperity may lead to short-term profiteering, resulting in unsustainable exploitation of some nature-based resources. In the distant future, the SES was seen to have been profoundly affected by changes in the country's economy development ideology, political system, and people's values and lifestyles. These changes, in combination with a trend toward more contemporary ideals, appear to have lowered social capital in the area.

3. Results from the third stage (objective 3). Setting the social's collective learning trajectories.

First, we combined the results from the two previous stages, allowing participants to compose a series of potential forces of change, that has occurred in the past, are occurring now, and are expected to occur in the next 20 years. They also were asked to consider which plausible forces were under and beyond their control, as well as how unpredictable they might involve in future causes of change affecting the local agricultural system and their livelihoods (Daconto & Sherpa, 2010). As a result, we refined our CLD developed in the second stage and considered these as final products representing causal systems consensus.

Next, we created a set of scenario maps to gather participants' perceptions of changes in other key uncertainty drivers or forces of change of the national, regional and local levels. After that, we created internally consistent 'scenario logics' by distinguishing between two axes of four-space characteristics (2 X 2 matrix) from the interaction of higher level (exogenous drivers) and local-level (endogenous drivers). The horizontal axis exposes external uncertainty, such as whether national policies prioritize pro-economic development over promoting pro-sustainability through societal values. The vertical axis represents uncertainties, specifically where local communities and social stakeholders' ability (high and low) to capitalize on socioeconomic opportunities that may arise and scale up the local agricultural system in the future (Fig. 4).

Following that, we employed these data to structure a pattern of changes taking place in the four different scenario storylines, of a 20-year time horizon, beginning in the year 2020, to describe the possible amplification or dampening of existing tendencies toward the future. Each of these scenarios was created to ascertain the significant of current ES or natural resource quality in the co-evolution of potential social dynamics and SES conditions and trends within the study region (the Upper Gulf of Thailand), as well as the local existing trends (PND). Then, we generated four possible storylines (the four plausible trajectories discussed), of the alternative future developments describing how local communities and social stakeholders would take as their ideally evolve and choices of practical guidelines what it would take to achieve the end goal, which is a local's sustainable agricultural system and society livelihoods, as well as maintaining ES quality.

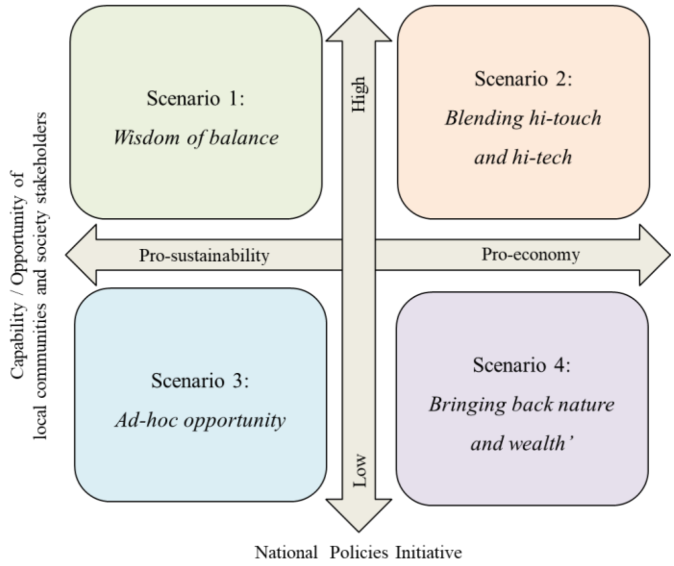

Figure 4 Illustrated scenario logics with four-space characteristics of possible storylines

Scenario 1 'Wisdom of balance': This storyline describes a future in which country growth policy and local institutions are reformed to be able to capitalize on high national and international demand for sustainable farming products. Under the ever-changing social and environmental dynamics, the government and local institutions are committed to regularly reviewing the existing policy implications in the adoption of sustainable agriculture to ensure that it remains relevant and supportive of natural resources and the long-term sustainability of farming communities. With expanded land usage via current local's agricultural practices, sustainable resource utilization coexists with ES quality. Social capital is respected and actively contributes to the country's self-sufficiency growth, therefore improving the quality and identity of local farms and goods, as well as people's incomes from the local tourism business.

Scenario 2 'Blending hi-touch and hi-tech': This storyline describes that under the country's market-based economy, some small-scale agricultural is replaced by intensified farming. In a broader scope, Thailand's incentives and global marketplaces have produced an advantageous business climate. Many local entrepreneurs are utilizing this institutional environment setting to take advantage of agriculture business prospects by leveraging the natural capital available. Cultural and local history are at the core of tourism, and social capital, as well as local value and practice, have improved. Neither the natural environment nor local traditional practices have a substantial impact on nature-based conservation, food security, or the tourist industry. Local agricultural products are restricted to the major business sector, which drives local economic growth, and as a result, individuals are wealthier than they were 15-20 years previously. These changes result in a loss of regional landscape and local ES quality, diminishing farmland biodiversity. The local landscape, natural capital, and quality of life are all suffering, as a result of the abundance of local wealth moving from market local products to demand.

Scenario 3 'Ad-hoc opportunity': This storyline describes local farmers' limited opportunity and capacity to capitalize on possibilities afforded by a country's pro-environment policy framework, such as the self-sufficiency economy. In the communities, local farming continues as it has for decades, however, natural resources are utilized for modern trade and, in some cases, cash crops. Most communities are vulnerable to climate change and natural resources security, putting them disadvantaged in financial wealth and livelihoods. Land use change and Farmland biodiversity are declining somewhat as a result of intensification in some certain areas and some farmers abandonment or leaving in others.

Scenario 4: 'Bringing back nature and wealth': This storyline describes land usage as being oriented, as well as a highly disturbed environment, on a country's market-based economy, resulting in a loss of ES quality. Though the country's growth strategy and program are less likely to encourage sustainable agriculture than in Scenario 1, only small number of local farmers benefits from it. Due to challenging socioeconomic circumstances, most local farmlands are unprofitable from intensive agricultural or industrial agriculture investors, consequently people leave their villages for towns or cities. The decline in traditional small-scale farming was seen to have a negative impact on agricultural biodiversity. The socioeconomic condition differs from the larger-scale situation in a broader sense and at the community level. For decades, local farmers have been trapped in modern values and lifestyles, resulting in social and communal fragmentation.

Four set of cross-cutting themes for local sustainable agriculture and ES quality.

Based on the findings gathered throughout our study approaches, we allowed the participants to discuss the set of cross-cutting themes underlying plausible trajectories, which local communities and social stakeholders may need to be considered as their visions and prospect engagement issues to ensure they are suitable for the PND's agricultural system and ES quality, as are detailed follows.

First: in PND, the local sustainable agriculture system cannot be built upon a social's unstable foundation. Hence, it is critical for the local communities need to address their adaptive capacity with a strongly committed to their key stakeholders. With regard to ES quality issues, the establishment of the local's landscape-scale vision of sustainable resource usage, as well as government policies and subsidies, should be prioritized (Conti et al., 2021). Congenial of local farms need to sustain and continue to be modest agricultural systems while transitioning to contemporary and environmentally friendly techniques. Further, local government capacity must be learned and built into both the local landscape with nature-based aspects of the system (e.g., preservation of ES quality and maintenance of farmland biodiversity), together with the socioeconomic system.

Second: In general, severe and irreversible impacts on complex ecological and cultural systems, and the depletion of ES and non-renewable natural resources caused by the sustainable agriculture system, should be addressed at the highest urgency. Furthermore, this challenge requires at least the following measures, including reducing the impact of existing agricultural practices (e.g., investing in the lower-impact agriculture techniques), and placing limits on system expansion and intensification, particularly when addressing the local goods yield gap (e.g., reducing arable land expansion). In addition, the agriculture system should structurally support the livelihoods and well-being of people working within it. It should be possible to fully nourish and support oneself and earn a reasonable living condition within the agriculture system. It is more than an end in itself to ensure that the local agricultural system supports livelihoods and well-being (Kofinas & Chapin, 2009). Without secure livelihoods, smallholder farmers will continue to struggle in building the necessary capacity and resource base to transition to sustainable models of production.

Third, sustainable and practical choices for local agriculture system is a daily and long-term necessity, a carrier of social cultural values, family traditions, and even personal ideologies. Discussions about sustainable agriculture is almost never merely about technological efficiency; they touch on several polarizing debates around people's identities and views of the world. Thus, local governance and social stakeholders need a multitude of strategies at different levels of the agriculture systems that go beyond individual principles or opinions/convictions in order to address the urgent challenges at hand (Koopmans et al., 2018). As described in our scenario storylines, the discussion of the challenges to transition for the sustainable agriculture system is often framed between social capital, safety net and values versus the needs of the national policy and political environment (Brondizio et al., 2009). In building upon current situations and the constrains to achieving sustainability agriculture, there are some particular attentions before initiating management plans.

Fourth, the central government and relevant agencies should promote communities' capabilities and set up contemporary sustainable farms on a regional and local scale. To achieve a sustainable agriculture policy, local institutions must collaborate. Local farmers should begin to employ contemporary technology and market opportunities, while maintaining skilled labour and traditional agricultural methods. Both national and local governments reform must encourage the development of markets and the essential circumstances for smallholder farmers to thrive. Value and identity of local commodities should be promoted through sustainable economic niches in traditional small-scale farming (Koopmans et al., 2018). As part of a sustainable regrowth strategy and crucial role in local development plans, external stakeholders should enhance the off-farm business and engine. A country's sustainable policies, which have dominated most past strategies, may become complemented by local actors, and the latter may come to take a lead in further iterations of the national strategy. National planning procedures may begin to accommodate multi-actor and process approaches, and may share learning and sharing platforms with recognized local authorities.

Discussions

From the significant outcomes of our investigation, *first* this section offers some discussions on the benefit of incorporate SS as the essential features of our study approaches. Second, we postulated four trajectories of the co-evolving of SES and social dynamics, and how local communities and social stakeholders may include these trajectories as their ideal evolution (i.e., over a 20-year time horizon), utilizing the local sustainable agriculture system, societal livelihoods, and ecological service quality. *Third,* we found three special considerations that authors seem to be most commonly inspired by, referred to here as the lessons learned, the original and robustness, and future research needed, as details follow.

First, under an essential of system science (SS) in sustainability research, this study calls for the study approaches that combines the application of system theory and foresight scenario planning design for studying the evolution of a complex system in research and development. These two integrated sciences created a new platform capable of integrating multiple values dimensions and the recognition of different types of ES under the SES trends and social dynamics (Haslett et al., 2010; Leach et al., 2018). Ultimately, each of these sciences has its own strengthen feathers on manageable support to envision a long-term horizon (Clark & Dickson, 2003) without losing the complexity and diversity of the analyzed object of the interlinkage systems being studies (Cardona et al., 2021). In the process of PSM to construct the CLD developed and, participants stakeholders were gained and improved on how social interlinkage human-environment dynamics (Aspinall & Staiano, 2017; Fischer et al., 2015) would be evolved as all in-one a systemic guidance in rural landscapes is via conceptualizing them as social-ecological systems (SES). Further, the choice of methodology in scenario planning design is quite typical of cooperating with results obtained from the CLD, as there are benefits in the field of study (Bradfield et al., 2005; Bishop et al., 2007). Our storylines have a wealth of narrative inspiration, including literature on existing scenario planning design (De Vries & Petersen, 2009; Metzger et al. 2010) and local stakeholder perspectives (Kok et al., 2011). This analysis examines and evaluates the process of connecting change themes from scenarios literature and stakeholder perspectives to local and regional scenario development (Arnott et al., 2020; Nikolakis, 2020; Quist, 2007; Schwartz, 2012; Rowland & Spaniol, 2022).

Second, the four trajectories of ES quality and the co-evolution of SES and social system dynamics are detailed as follows:

i) Local conditions and development trajectories: The history and current conditions of the interlinkage variables underpinning the ES quality were fundamentally shaped by the development trajectory of the SES (Dearing et al., 2010). Locals' capacity to shift to a sustainable agriculture system appears to be limited by social capital and safety net issues resulting from a violent history, as well as in previous studies. Following the country's agricultural policy effort, poor economic conditions prevented the widespread intensification of farming, and many locals continue to practice low-intensity or semi-subsistence agriculture, though often not by choice. As noticeable in the CLD (Fig. 3), a unique opportunity for sustainable agriculture in PND lies in the combination of the ongoing existence of local land use options that provide a comprehensive set of the fundamental components of ES quality, enhancing local agricultural and crop productions and livelihoods (Pretty et al., 2020). While it may appear obvious that the nature of SES trends and conditions constrained future development trajectories, such as the changing local landscapes and land-use options, as discussed in all scenario storylines.

ii) Adapted by external drivers to the board direction of local trajectories: Based on the insights the cause-and-effect chains (CLD in Fig. 3), reflects on the external key drivers that would be utilized as entry points to improve the local agriculture development. These drivers reflected some key entry points to promote ES quality and biodiversity conservation in the remote area, as shown as feedback influencing forces (as shown in two major balancing loops B1 and B2, Fig.3) how the local's ES would be positive/negative affected in the local agriculture system. However, the external drivers fundamentally influence future developments in SES through their interactions with local agriculture development conditions (Young et al., 2006). In our study, external government supports policy and market settings were identified by local stakeholders as essential drivers of a series of local changes, including the degree of local and regional spatial planning, land use options, and creating synergies among the local farmers to add on the final local products (value and identity). In a broader system, through the combination of explicit government support policy with the level of the crucial role of local institutions, these two policy settings would be used as important strategies and managerial approaches for up-scaling local agriculture system and livelihoods.

In addition, local communities and social stakeholders' ability to capitalize on opportunities, can enhance or counteract the effects of external drivers, and also the adaptive capacity to transform a system configuration into the desired agriculture system development pathways (Meuwissen et al., 2019). This is because local systems can either move up or move out to facilitate or counteract the effects of external drivers. Despite the importance of external drivers, the overall levels of the recognition and a key role in local institution reform and sustainable implementation choices (as noticeable from the reinforcing loop R13, R14 and R 15 in CLD Fig. 3), agriculture sustainability and livelihoods outcomes are strongly influenced by creating of the learning processes and effective bridging organizations (Dentoni et al., 2020).

iii) Utilized by bonding the social capitals and local's institutions dynamic: Our findings highlight that the external uncertainties drivers (e.g., national policy setting, the co-evolving of potential social dynamics and SES conditions and trends) can lead to fundamentally different development outcomes, depending on the local conditions. The social capital and local institutions reform (local system properties and setting) were the key variables in our case study that was mentioned repeatedly in workshop exercises as having a particularly large influence on local system dynamics (as detailed in cause-and-effect chains and possible scenario storylines). By bonding social capital and the collective of local choices of sustainable practical to succeed on a community level at larger scales was described as leverage points of an increasing the accountability and bridging of local institutions reform and agriculture policy implementation (Agnitsch et al., 2006; Cinner et al., 2018). These two internal drivers mediate how external drivers act on SES and seen as a critical component of adaptive capacity (Engle et al., 2011; Adger, 2003; Armitage, 2005), and more likely to mobilize local common resources (ES quality and farmland diversity) and act collectively towards a preferred goal, that is, local sustainable agriculture system.

iv) Challenges from within and without of the future development options: Since, the local actors and the central government are usually reluctant to support any agricultural strategies (national support policy), this might lead to a decrease in production, even if they result in better environmental conditions and higher farmer income (Rodriguez et al., 2009). Other issues include rural labor shortages, a lack of environmental awareness about ES values, and the fact that farmers have not always benefited from adopting sustainable practices (Katsanevakis et al., 2011). As discussed in this paper, local smallholder farmers in the study's remote areas (PND), as well as in the region (the Upper Gulf of Thailand) face many challenges due to the uncertainty of socioeconomic and environmental changes, thus, a fair, quick, and efficient delivery system, e.g., government policymaking and local stakeholders for such assistance, perhaps by keeping local institutions bureaucracy at a distance, should be in place ahead of time. To encourage sustainable farming, governments must provide significant financial support. Substantial subsidies granted by the central government or key-related agencies are not available to sustainable farmers, since they are focused on conventional agriculture. Given the low risk-bearing capacity of local farmers, the necessity for the sustainable farming is likely prospect of loss of productivity for some time, and the non-existence of marketing channels for sustainable produces the financial support must be adequate.

Third, the lessons learned, the original, and the future research needed.

Lessons learned: As wildly discussed in our study, the term *'entry points'* in this study can be both ideas, past experiences or foresight and prospect strategy and action plans. Sometimes these will be subtle and multiple and will develop over several encounters to maintain or up-scale a sustainable local farming system. It is hard to exaggerate the role that agriculture transformative change plays a fundamental part of almost all society and economies. Yet, agricultural systems must adapt, even transform, to meet a growing number of challenges and constraints. A 'leverage points perspective', in turn, seeks to understand a system by analyzing it across the suite of structural depths (Fischer & Riechers, 2019). This perspective can help to think about interventions (i.e., actual leverage points), but it can also help to think about how different levels of how social institutions and sustainability (Mitra & Moldavanova, 2018) interact or reinforce or constrain one another.

In this paper we reflected the term of *'learning mechanism'* as a broad spectrum of key actors (e.g., local communities and institutions, social stakeholders and governments agencies) challenges that are linked their relationship to a transition of sustainable agricultural policy and its outcomes (Rodriguez et al., 2009). These challenges for all actors striving to improve society livelihoods and ES quality coordination may be summarized by two simple principles: i) necessity of an evolving 'outward and foresight looking', and ii) capacity to use information and experience to transform practice and procedure through their present critique and future challenge pathways.

Recognizing the importance of our study goals, in the narratives, however, of our collaborative workshop exercises, there are some changes in local communities from exploring plausible future scenarios with different outcomes for different parts of stakeholders to attempting to identify common societal livelihoods and ES quality. Since, in the future perspectives, these will be as likely driven by emergence as by 'governed' transformation. This implies both taking concrete steps to meet sustainable development goals, and strengthening coping and adaptation mechanisms (Patterson et al., 2017).

The Original, and the robustness of future research needed

Societal knowledge co-creation: By developing the different knowledge for different target groups, as in this research paper has striven for alignment with diverse stakeholders' worldviews. In this paper, our methodological framework provided a clearer picture of the expected outcomes upon the study approaches applied. Our approaches have endeavored through the foundation of system science (SS) with the integration of systemics for sustainability research to make the knowledge of co-creation for social change (Regeer & Bunders, 2009). The study approaches also promote skills like critical thinking, understanding complex systems, imagining future scenarios, and making decisions in a participatory and collaborative way.

In agricultural system, our results reflected that societal knowledge co-creation must leverage agriculture system to local's prosperity security and livelihoods. Devising long-lasting solutions will require deep 'social co-learning, local institution and social structure transformations' in the agriculture sector. Our analytical processes also work well with the answers of: i) proving the need of end-users to create a set of possible visions to take preventive and prosper move-up strategy and adaptive actions plans in becoming a sustainable agriculture system and livelihoods, which will enable ES quality, ii) revealing alarming signals (e.g., 'entry points', 'leverage points perspective') for the future towards exploring alternative, more desirable futures through transition (Raskin et al., 2002, Kates & Parris, 2003) and transformation (Folke et al., 2002; Berkhout et al., 2004; Haberl et al., 2011; Westley et al., 2011, O'Brien, 2012) to implement the fundamental changes that society needs to go through to achieve local agriculture sustainability goals.

For the robustness of future research need, as we assessed and characterized the ES values and participants' prior knowledge of the study's landscape and agricultural system, in order to compare the results obtained by different methods (Structural Equation Modeling: SEM), with the process of causal model, it would be interesting to test the consistency of the results on other available subjective data. Further, by incorporating our results, specially form the causal loop diagram (cause-and-effect chains variable) through system modeling and logical scenario analysis (simulation storylines), and co-design produces the knowledge and methods required for all stages of the sustainability transition (Adam et al., 2012; Martin et al., 2012). These findings would lead to the quantification of the ES supply-demand relationship, while storylines would round out the picture with more contextual future changes such as the agricultural system, social human values shift (Van den Belt & Blake, 2011, 2014; De Groot et al., 2011; Fischer & Eastwood, 2016; Lempert 2013), and institutional components.

Conclusion

In this paper, we present a methodological framework with three holistic approaches on recognizing the integration of system science (SS) for the sustainability research study and sustainable society. Notably, our approaches have endeavored to identify important social-ecological dynamics and critical uncertainties, advocating the processes of knowledge exchange and sharing insights on dynamic issues, with different sustainable outcomes for the local agricultural system in the Phraek Nam Daeng Sub-district (PND). Each approach provides systems with different knowledge entry points to achieve a deeper understanding of the inter-linkage systems being studied, hence enhancing the process of foresight social knowledge co-creation in responding to sustainable ecological services in the face of social-ecological systems changes. Our findings highlight the current conditions of the interlinkage variables underpinning the ecological services were fundamentally shaped by the development trajectory of the social-ecological systems in areas of study. Whereas, the key external uncertainties forces of change would be utilized as entry points for up-scaling local agriculture system and social livelihoods. By bonding social capital and the local institutions reform, these two drivers may act as a critical component of leverage points, mobilizing local common resources, and act collectively towards local agriculture system. Critical changes in local institutions and central governance structure reform are required to provide a prosperous move-up strategy, revealing alarming signals with amplification of action plans in becoming a sustainable agriculture system.

The potential of our methodological framework and analytical approaches described in this study could be thought of as a local's planners and social's key agencies as a mental model blueprint in a holistic manner. The added values of our approaches reflected that devising long-lasting solutions will require deep social's knowledge co-creation of change, and as a learning mechanism of change, responding the sustainable society (Dufva & Ahlqvist, 2015). In future research need, results from the combination of causal-linked variables and causal loop diagram (CLD) should be incorporated in the structural system modelling, that would lead to contribute to further refinement in quantifying ES quality, e.g., supply-demand relationship, visualizing more robustness in scenario logics and storylines development, hence, robustness the co-design produces the knowledge and methods required for the sustainability transition.

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