

Systems thinking methodology in researching the impacts of climate change on livestock industry

Phương pháp tư duy hệ thống trong nghiên cứu ảnh hưởng của biến đổi khí hậu đến ngành chăn nuôi

Policy paper

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The impacts of climate change on livestock production are complex problems, existing in the relationship among this sector and others sectors such as environmental, social, economic and political systems. The complexity and dynamic of these impacts cannot be solved simply in isolation with the linear approach. A system thinking methodology is introduced in this paper to understand the impacts of climate change on livestock production, and identify effective interventions strategies to address this systemic problem. System thinking is a way of thinking about the world and relationships which has been developed far along way in the past. Today, systems thinking has become increasingly popular because it provides a 'new way of thinking' to understand and manage complex problems, whether they rest within a local or global context. While four levels of thinking is a fundamental tool to identify systemic problems, Causal Loop Diagram (CLD) is a visual tool created by a computer program to illustrate the whole picture of climate change impacts. CLD consist of feedbacks for system, which help strategists identify appropriate intervention strategies in solving the systemic problem.

Ảnh hưởng của biến đổi khí hậu đến ngành chăn nuôi là một trong những vấn đề phức tạp, bởi mối quan hệ chặt chẽ có hệ thống của chúng với các lĩnh vực khác như môi trường, xã hội, kinh tế và chính trị. Những tác động phức tạp đa chiều này không thể giải quyết đơn thuần bằng các giải pháp mang tính đơn lẻ. Phương pháp tư duy hệ thống được giới thiệu trong bài này cho phép hiểu đầy đủ, có hệ thống các tác động của biến đổi khí hậu đến ngành chăn nuôi, đồng thời xác định được những giải pháp chiến lược phù hợp để giải quyết vấn đề mang tính hệ thống này. Tư duy hệ thống là cách tư duy và tiếp cận với sự vật, hiện tượng khách quan, và các mối quan hệ của chúng, phương pháp này đã được nghiên cứu và phát triển từ xa xưa. Ngày nay, tư duy hệ thống đang được ứng dụng phổ biến và rộng rãi hơn trong các nghiên cứu phát triển bền vững vì phương pháp này cung cấp một "tư duy mới" để hiểu và quản lý được các vấn đề phức tạp, dù chúng ở qui mô địa phương hay trên phạm vi toàn cầu. Trong đó, bốn cấp bậc của tư duy là công cụ cơ bản để nhận biết các vấn đề phức tạp, và sơ đồ các vòng tròn tác động (CLD) là công cụ trực quan được xây dựng bằng phần mềm máy tính để chỉ ra bức tranh toàn cảnh các tác động của biến đổi khí hậu. Các vòng tròn tác động này phản ánh các diễn biến thực tế và các thông tin giúp cho việc xác định các giải pháp chiến lược.

Keywords: systems thinking, climate change, livestock production, CLD modelling

1. Introduction

The impact of climate change on the agricultural sector has been evident in recent decades. This has caused significantly higher input costs and lower benefit outcomes for the sector. Many researches have been carried out to

investigate the adaptation and mitigation strategies to deal with further significant changes in climate and their direct and/or indirect effects on livestock production (Curtis, 1983; Shearer et al., 1991; Hahn, 1995; Mader et al., 1997; Mathison et al., 1998; Hegarty, 1999; West, 1999; Mader et al., 2002; Davis et al., 2003; Holt et al., 2004;

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Mader et al., 2007; Thornton et al., 2009; Hunt and Watkiss, 2011; Hall and Wreford, 2012). However, the study of this topic by considering the systemic impacts of climate change on livestock production is rather inadequate. In other words, the impacts of climate change cannot be solved simply in isolation with the linear, narrowly defined approaches of the past due to the complex relationships among livestock systems and other systems such as the environmental, social, economic and political systems. Therefore, given the complex, multi-dimensional and dynamic nature of sustainable development in livestock production, there is a clear and urgent need for using systems thinking approach in addressing this complexity.

Sterman (2000) postulated that the development of systems thinking can replace a reductionist, narrow, short-term, static view of the world with a holistic, broad, long-term, dynamic view and then redesign appropriate policies accordingly. Thus, it is likely that a systems thinking approach is the best tool to analyse and identify the real systemic problems in the whole picture of climate change impacts on livestock production. Using this approach, the common patterns of the impacts of climate change can be recognized, the whole picture of impact factors will be illustrated, and the systemic problems can be identified and addressed. Therefore, the aim of this paper is to introduce the systems thinking approach and some of its associated tools. The paper also discusses how these 'tools' should be applied in researching related climate change impacts on the sustainable development of agriculture, particularly in livestock production.

2. Systems thinking

Systems thinking is the combination of an approach to problem solving and a set of tools, techniques, and methods. Dennis (2002) stated that systems thinking is an appropriate toolkit and a framework for understanding complex systems and their associated properties. While Sterman (2000) noted that systems thinking is a way of thinking holistically about the real problems and modelling complex systems as providing a framework for systems practices. The problem-solving approach of systems thinking is the recognition that systems are complex because of the connectedness between their individual component parts, and that to understand the system it must be examined as a whole. The tools, techniques, and methods of a systems thinking approach are all designed to help this examination, to understand and document how the component parts are connected together, and to interpret and explore their collective dynamic behaviours (Dennis 2002). Furthermore, Bosch et al. (2007) defined that 'Systems thinking is a way of thinking about the world and relationship' which has developed far along way in the past since Checkland (1985) compared the 'hard' and 'soft' traditions of systems thinking.

2.1 A brief review on the applications of systems thinking

Today, systems thinking has become increasingly popular because it provides a 'new way of thinking' to understand

and manage complex problems, whether they rest within a local or global context (Bosch et al., 2007). The application of systems thinking has grown extensively and encompasses work in many diverse fields and disciplines such as, to mention but a few, management (Jackson, 2003), business (Sterman, 2000; Walker et al., 2009), decision making and consensus building (Maani and Maharraj 2004), human resource management (Quatro et al., 2007), organisational learning (Galanakis, 2006), health (Newell, 2003; Lee, 2009), commodity systems (Sawin et al., 2003), agricultural production systems (Wilson, 2004), natural resource management (Allison and Hobbs, 2006), environmental conflict management (Elias, 2008), education (Hung, 2008), social theory and management (Mingers, 2006), food security and population policy (Keegan and Nguyen, 2011), and complexity management (Bosch et al., 2013). However, the application of systems thinking by policy makers, managers and practitioners has been limited (Nguyen et al., 2011).

It is widely recognized that climate change is uncertain and its consequences are complex. The systemic problems of these impacts on livestock production cannot be solved simply by using technical solutions. Recently, many researches have been looking at using systems approaches to examine the impacts of climate change, and identify the better mitigation strategies and adaptation options to climate change (Lovett et al., 2006; Herrero et al., 2008; Randrianasolo et al., 2010; Crosson et al., 2011; Li et al., 2012). A series of systems approaches and models have been considering the impacts of combination between climate variables on production (Zavaleta et al., 2003; Wang and Davidson, 2006; Alvarez et al., 2010), ecology and social-economic (Kokic et al., 2007; Nelson et al., 2007; Guarino and Di Iacovo, 2010) suggesting policies and management methods to mitigation greenhouse gas and adaptation to climate changes impacts.

In addition, Cobon et al. (2009) developed a risk management matrix approach for rangelands Australia in which the biophysical resource, rural communities and public policy had concerned to identify where adaptation responses should be developed. Wixon and Balser (2009) used soft systems modelling (SSM) to develop a web of problematic factors through analysing the 'soft aspects' associated with social-policy and feedback response of soil systems with increased temperatures due to climate change, concluding that varied perspectives on the systems dynamic and the web of controlling factors may lead to seemingly conflicting results. Furthermore, Dennis (2002) evaluated that soft systems methodology is likely the most beneficial approach as it enriches all the participants' knowledge and understanding of the situation, rather than a "scientific" search for the "best" answers. Bosch et al. (2007) suggested that systems thinking should be 'absorbed' into scientific research and this is a useful method for scientists, policy makers and other stakeholders to manage nature resources toward sustainable land management.

However, it seems that the applications of systems thinking in researching the impacts of climate change on livestock production have been limited. There have been only some studies used systems thinking and system dynamics

to investigate the impacts of climate change on agriculture sectors, crop production and grazing management. For example, Richards et al. (2012) presented an approach that combined systems thinking and Bayesian Belief Networks (BBNs) to identify interrelationships in the complex systems of social-economic and environmental determinants in South East Queensland; and examined this method in seeking recommendation to inform decision-makers at different levels in responding to climate change impacts and research adaptation strategies over various sectors. However, the study mainly focused on using BBNs, and also the research area was not particularly related to livestock production. Moreover, up to date, systems thinking approach has not yet been used to research the overall impacts of climate change on livestock production.

2.2 The key concept of systems thinking

2.2.1 Four levels of thinking model

The four levels of thinking model (Figure 1) is illustrated as an iceberg with the tip of the iceberg representing 'events' level where most decisions and interventions take place due to the immediate attentions and actions required to deal with the visible events of day to day reality (Maani and Cavana, 2007). The next level of thinking is 'patterns' which represent the trend of changes in events overtime; or a large set of data points linked together to create the history. The third level is 'systemic structures' which reveal the interrelationships between patterns in complex systems. The last level of thinking is 'mental models'. This deeper level reflects the beliefs, values and assumptions of individuals, organizations or governments in related issues (Maani and Cavana, 2007). The four levels of thinking model moves the stakeholders and decision-makers from the events to the deeper levels of thinking that then can provide a systemic framework to deal with complex problems. Moreover, key leverage points will also be identified where systemic interventions will be most effective in achieving purposes (Nguyen and Bosch, 2013).

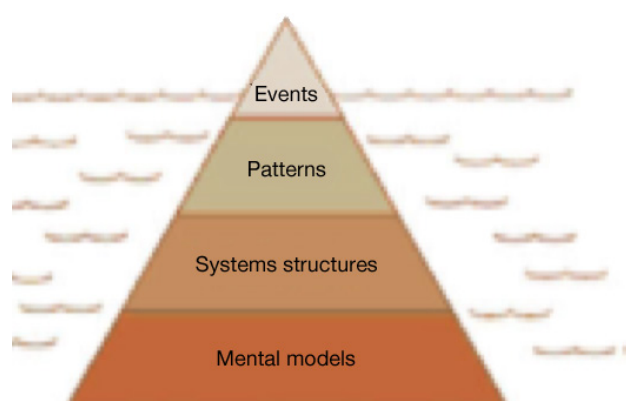


Figure 1. Four levels of thinking model (Maani and Cavana, 2007)

The impacts of climate change on livestock production can be seen as events such as animal productivities lost (low growth rate of cattle), and decline in revenue. These may due to direct impacts of changes in climatic (e.g. increase in temperature; changes in rainfall pattern and

increase extreme weather events), or indirect effects of others sectors (e.g. economic, social and policies). Then both direct and indirect impacts are considered as the patterns of impacts that changing overtime and cause the visible problems. Systematic structure represents the interrelationships among climatic variables, production, social-economic and policies. In addition, the mental models of farmers, producers, traders, scientists and politicians toward climate changes policies and livestock production will illustrate the overall impacts of climate change on this sector in the short-term and in the long-term.

2.2.2 Systems thinking and modelling tools

Systems thinking and modelling methodologies can be employed as the underlying approach to understand the impacts of climate change on livestock production associated with resource management problems (e.g. rangeland and grazing management). It could be regarded as a 'new way of thinking' to manage the complex problems existing in livestock production.

According to Maani and Cavana (2007), a system thinking and modelling intervention consists of five phases: (1) Problem structuring; (2) Causal loop modelling; (3) Dynamic modelling; (4) Scenario planning and modelling; (5) Implementation and organisational learning. Each phase includes several steps that help to generate systems interventions. However, not all of these phases and steps need to be used in solving different problems and the issues (Maani and Cavana, 2007). In this paper, the first two phases are introduced.

3. Identification of systems

3.1 Problem structuring

3.1.1 Scope and identification of problems and main stakeholders

Problems identification is the first and the most important step to create a causal loop modelling of the whole impacts of climate change on livestock production. Indeed, the relationship between climate change and livestock industry is not only the effects of changing climate on animal production (e.g. lost live weight, heat stress or compromise reproduction ability), or how livestock sector contributes to climate change in terms of greenhouse gases emission. It is also related to other sectors such as export, domestic market, and policies. It is therefore clear that the problems under consideration should be looked through a systemic structure of impact factors.

The direct factors can be considered are changes in climate overtime. For example, changes in rainfall pattern, temperature or extreme weather events such as drought and flood that affect directly on animals, animal production or pasture production. Whereas the indirect factors come from implementation of agriculture related policies, perspective of producers and their interest towards feed price, meat market, import and export livestock products,

and their social-economic status as well as practice methods in the production.

In addition, it is important to note that the levels of climate change impacts on livestock production likely depend on the mental models of the key stakeholders. Their beliefs, attitudes and perceptions on climate change will impact the industry both in short term and long term. There are four main stakeholders in this research including cattle producers, traders, scientists and policy makers. Consumers and communities can also be considered as other stakeholders, their choices and attitudes have influence on the mental models of the main stakeholders groups.

3.1.2 Information and data collection

Systems thinking and systems dynamic modelling are required to characterize the problem dynamically base on patterns of behaviour overtime, which shows how the problem arose and how it might evolve in the future (Sterman, 2000). Thus, adequate information and data collection are important to understand the whole impacts of climate change on livestock production and its development over time. The information and data collected and analysed should be included those related to climate conditions, animal productions, economic contribution of livestock production, policies and regulation in agriculture and environment management, and publications or research trends on climate change impacts. These qualitative and quantitative data are collected from historical and statistical records, media reports, policy documents, previous studies and publications.

Moreover, it is important to note that the choice of time horizon have a big influence on our perception of the problem. Indeed, a principal deficiency in human mental model is the tendency to think of cause and effect as local and immediate, but in dynamically complex systems such as climate change and livestock production systems, the causes and effects are distant in time and space (Sterman, 2000). Hence, a long time horizon records of climatic change and animal productions in research is needed to identify patterns of behaviour and the feedback structures generating them.

3.2 Casual loop diagrams

Causal loop diagram (CLD) is also referred to as 'the language of systems thinking' (Maani and Cavana, 2007). It is an important tool for representing the feedback structure of systems (Sterman, 2000). CLD modelling is used in this research to create and construct a preliminary systems model of the dynamics impacts of climate change on livestock systems in general. The model is a framework for seeing interrelationships between components in livestock systems and climate change rather than isolated features, for seeing patterns of change rather than static snapshots of climate change impacts on the livestock sector.

3.2.1 Causal loop variables (words)

The word 'causal' refers to causes-and-effects relationships, and 'loop' associates with closed chain of causality that link back to themselves (Dennis, 2002). Ford (1999) defined causal loop diagram as simple diagram of 'words and arrows'. The words represent variables (factors) in the systems; the arrows show causal connections between the variables. A variable is understood as a factor that can be a condition, a situation, an action or a decision which will influence and also can be influenced by others variable (factors) (Bosch et al., 2007). Variables can be quantitative or qualitative. Quantitative variables are the factors can be measured such as the value of average air temperature, levels of rainfall, cost of feed sources and animal population; while qualitative variables refer to soft factors, for example, traditional culture, belief, moral and reputation. Figure 2 shows an example of causal link in which cattle population and CH₄ emission are words and represent for quantitative variables in the systems.

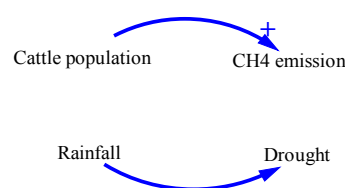


Figure 2. Examples of casual link

3.2.2 Causal loop links (arrows)

The arrows in a CLD are labelled depending on whether the causal influence is positive or negative. The arrow will be labelled by "+" or "s", if the cause-and-effect relationship in which two variables change in the same direction. In contrast, when two variables interact with each other in the opposite direction, the arrow will be marked with "-" or "o". For example, in Figure 3, the arrows marked with "-" could mean that an increase in rainfall causes a decrease in drought or that a decrease in rainfall lead to an increase in drought. However, an increase or decrease of air temperature could result in faster or slower growth rate of grass and plants than normal rate due to the higher or lower of green plants photosynthesis, thus the arrow (interlink) is marked with "+" (Figure 4). Moreover, the positive marked arrow "+" or the negative marked arrow "-" can also stand for the causal links between a flow and the stock that accumulates the inflow or those are drained by the flow (Ford 1999).

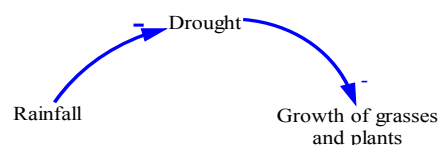


Figure 3. Example of links for effect of rainfall on growth of grasses and plants

3.2.3 Feedback processes

A causal loop consists of a group set of related variables which have been linked together in a connected path. A 'loop' is formed as a closed path circle from the starting variable and back to itself. In the loops everything is ulti-

mately connected to everything else, loops known as feedback loops (Dennis, 2002). Every causal loop tells a story that shows how the effects lead to causes and how the end meets the means (Maani and Cavana, 2007). In general, there are two types of causal loops: *Reinforcing loops* (R) reflecting positive feedback systems, and *Balancing loops* (B), which are known as counteracting loops or a self-correcting process, represent for negative feedback systems. However, in systems thinking, positive feedback or negative feedback does not mean "good" or "bad" and "praise" or "criticism". Reinforcing loops can represent growing or declining actions in systems, whereas balancing loops seek stability or return to control, or aims for a specified target (Maani and Cavana, 2007).

There are three ways that can be used to identify if a causal loop is Reinforcing or Balancing. The fastest way is to count the number of negative links or the number of arrows marked with "-" or "o" in the loop (Sterman, 2000). Accordingly, a causal loop is identified as a Reinforcing loop and denoted by (R) when the number of arrows marked with "-" or "o" is zero or an even number. Conversely, if the number of this negative link is an odd number, the causal loop is balancing and marked by (B). Often, an overall CLD of the systems includes several causal loops. Thus, all the causal loops in CLD are numbered by R1, R2 and Rn for the Reinforcing loops, and B1, B2 and Bn for the Balancing loops.

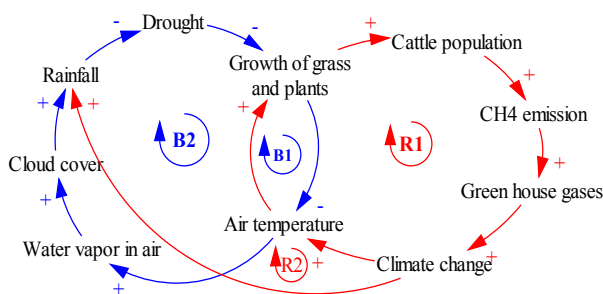


Figure 4. Example of causal loop diagrams for the interrelationships between cattle population and air temperature

In addition, feedback processes often contain delays. A delay is considered as a process and represents for the time to measure and report the information, or the time for managers make decisions to affect the state of a system (Sterman, 2000). There are many types of delays, some of which represent the gradual adjustment of perceptions or beliefs of stakeholders. For example, there is a delay between climate change and scientific evidences reports as the researches would take time to determine whether climate is changing, and occurring in which levels, and identify the impacts of these changes; or a delay between the evidences of climate change impacts and the perceptions of farmers of climate changes impacts which toward their applications of mitigation and adaptation strategies in production.

In general, any belief or perceptions involve an information delay because we cannot instantaneously update our mental models as new information is received. The lengths of delays in the feedback processes are also important factors that affect the rate of systems change. In

short, it can be noted that type of delays and delays time of interrelationships need to be considered in systems to understand how the systems change.

3.2.4 Create causal loop diagram

Maani and Cavana (2007) summarized seven main steps to create a CLD. In this study, the overall CLD representing the impacts of climate change on livestock sector will be structured following the seven steps below:

Step 1: Identify main (key) variables related to livestock production systems and climate change;

In this step, key variables will be identified as the main causes or main effects which have significant influences in the systems or be influenced by others factors over time. Often, these key variables can be represented by data. For example, average monthly atmosphere temperature and annual rainfall amount are the key variables related to climate conditions. The values of these indexes are varied year to year or seasons to seasons. The changes of these factors likely affect significantly not only the productivities of livestock production, but also pasture production. Live weight gain in cattle, reproduction proportion, and growth rate of grasses are the key variable for livestock productivities and pasture production.

Step 2: Draw behaviour over time charts for key variables;

The recorded data of key variables in appropriate period of time will be collected from previous studies, published reports, articles, and documents to identify the trend of changes over time. These data are diagrammatized to determine the patterns of change. The increases, or decreases, or mixed between increases and decreases are the common trends which reflect the feedback of processes are positive, or negative and both negative and positive feedback. Accordingly, the causal loops can be defined as Reinforcing loops (R) or Balancing loops (B).

Step 3: Develop causal loop diagrams to illustrate the relationships among variables;

The relationships among all variables are identified base on the review of literature from previous studies, published articles and reports and documents within the scope of the present research. Also it is important to determine the potential effects (links) among variables for the current situation that may influence the systems. In this step, all the links (arrows) are created with appropriate directions and marked by "+" or "s", and "-" or "o". The causal loops feedback diagram are named and marked by Reinforcing loops (R) or Balancing loop (B).

Step 4: Discuss behaviour over time of the dynamic implied by the causal loop diagrams;

The causal loops diagrams represent the behaviour changes over time of variables are described in detail and discuss the systems dynamic impacts of climate changes on livestock sector.

Step 5: Identify systems archetypes that describe high-level causal patterns;

Systems archetypes that drive the dynamic of systems are demonstrated and discussed in order to identify fundamental factors and patterns of changes within the systems. Identification of systems archetypes also can allow determining possible leverage points and proposing appropriate interventions to minimize climate change impacts on livestock production systems.

Step 6 & 7: Identify key leverage points and develop intervention strategies;

Key leverage points in the systems and intervention strategies to livestock production systems are identified and developed base on the causal loops diagrams and analysis of interrelationships among variables in the systems. These two steps allow the systems thinkers learn the dynamic of systems and provide the possible options to deal with the systemic problems. In these steps, the most important factors are identified to deal with climate changes impacts on livestock sectors, and demonstrated how we can intervene into the systems and by which ways to achieve better outcomes.

3.2.5 Computer program

Vensim is the visual software designed to analyse and create conceptual models or causal loop diagrams, stimulate and optimize models of dynamic complex systems (Ventana Systems, 2006). In this study, Vensim version 5.6b was used to build up the causal loop diagrams of climate change impacts on livestock production systems.

4. Conclusions

Systems thinking methodology has been applied in many disciplines to deal with complex problems. In agriculture, the impacts of climate change on livestock production are the complex and systemic problems that cannot be solved simply in isolation with the linear and narrow approaches of the past. The use of a systems thinking approach is likely the best way to identify the whole picture of climate change impacts. Through the Causal Loop Diagrams (CLDs), the scientists, managers and policy makers are able to provide better adaptation and mitigations strategies toward the sustainable development of livestock production and agriculture in general. This paper aims to introduce systems thinking as a unique and scientific approach in researching the impacts of climate change on livestock production.

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