II. LITERATURE REVIEW

2.1. Sustainable Development Conceptual Framework

According to Webster’s New World Dictionary (1988), the etymological root of sustainability is derived from the Latin verb *sustenere* (= to hold). This etymology is also reflected in the debate among Spanish-speaking scientists about whether *sostenibilidad* (from *sostener*) or *sustentabilidad* (from *sustentar*) is the more accurate translation. The first term is closer to “being upheld” while the latter term is closer to “to uphold” (Becker 1997). The latter terminology indicates a strong normative component in the concept of sustainable development.

Sustainable development has an essentially normative character, which makes it difficult to put into practice. It implies a close relationship between environmental considerations and economic growth. Within sustainable development, economic and social objectives must be balanced against natural constraints. A spirit of solidarity with future generations is included in the concept. Sustainable development is based on the common principles of self-reliance, fulfillment of basic needs and quality of life (Schtivelman and Russel 1989). Bruntland’s Commission defined sustainable development as a process in which the exploitation of resources, direction of investments, orientation of technology development and institutional changes are all in harmony, enhancing both current and future abilities to meet human needs and aspirations (WCED 1987 in Haeruman 1995). Sustainable development must involve an interdisciplinary approach. To present the interdisciplinary nature of sustainability assessment, a conceptual framework or basic structure for sustainability assessment (Figure 2.1) was proposed (Becker 1997).
The framework shows very clearly that an assessment of sustainable development must involve consideration of society’s ethical or cultural values. Thus, any discussion about sustainable development in Indonesia should involve an understanding of local values.

In addition, the policy environment has an impact on sustainability assessment. Neglecting policy considerations in an assessment is likely to lead to an incorrect assessment result. Figure 2.1 shows that development is sustainable if it is economically viable, environmentally sound, socially accepted, culturally appropriate and based on a holistic scientific approach.

As previously mentioned, sustainable development has normative and scientific aspects - these are depicted in Figure 2.2. The normative approach sees sustainable development as leading to the wise use of natural resources and environmentally sound activities. It deals with nature and environmental values, intergenerational and intra-generational equity. To be scientifically
sound, a new paradigm should be implemented that takes into account all relevant factors.

Webster’s New World Dictionary (1988) defines *paradigm* as an overall concept accepted by intellectuals as a science, because of its effectiveness in explaining a complex process, idea, or set of data. The vision of sustainable development must be placed into a new development paradigm which allows for the actual implementation of sustainable development. In the implementation, environmental, economic and social disciplines should be taken into account when assessing sustainability.
2.2. Local Knowledge and Perspectives

Wavey (1993) stated that recently, academics, scientists and researchers have “discovered” that the knowledge which indigenous people hold about the earth, its ecosystems, wildlife, fisheries, forests and other integrated living systems is both extensive and extremely accurate. On the eve of the 500th anniversary of Christopher Columbus having stumbled upon North America, it is appropriate to provide comments from an indigenous North American person on how they perceive the concept of “discovery”.

Johannes (1993) suggested that research on indigenous people, their traditional ecological knowledge and management systems should focus on four essential perspectives and frames of reference: involving taxonomic, spatial, temporal and social factors. Kearney et al. (1999) studied stakeholders’ perspectives on appropriate forest management in the Pacific Northwest of North America by using a conceptual content cognitive map (3CM) and semi-structured interviews. The study found how stakeholders conceptualised “good forest management”, as shown in Figure 2.3. Three stakeholders were identified in the study - environmentalist, industrialist and government (United State Forest Service) stakeholders. Each explained their perspective on “good forest management” which was then categorized. It was found that different stakeholders might have different perspectives on “good forest management”.

**Figure 2.3.** The stakeholders conceptualized components (in box) and their perceived categories (in italic) of “good forest management” (Kearney et al. 1999)

### Stakeholder I: Environmentalist’s representation

**Understanding ways to sustain the ecosystem**
- decide on habitat that must stay
- understand ecosystem
- manage recreation

**Timber activities**
- minimize damage
- avoid roads
- resources are public (philosophy)

**Looking at all Resources**
- effects on all resources
- non-timber resources
- economics

### Stakeholder II: An industry participant’s representation

**Business**
- economics
- reforestation
- regulation

**Water**
- road construction
- riparian areas
- water quality

**Public affairs/acceptance**
- public
- recreation issues
- views

**Habitat**
- wildlife
- landscape management
- habitat after harvest
- habitat prior to harvest

### Stakeholder III: A US Forest service participant’s representation

**Humble approach to management**
- look at whole, not pieces
- leave some areas to nature
- spiritual values

**Bringing stakeholders together**
- collaborate with various interests
- educate public

**Active management**
- manage for goods & services
- multiple uses
- affect forest positively
2.3. Knowledge Base System Development

A knowledge base system (KBS) is a combination of a knowledge base (an articulated and defined set of knowledge) and an inference engine. Inference engine is a logic-based algorithm that draws inferences and conclusions from the broad knowledge base. A knowledge base system is ‘domain specific’, meaning it is developed for a particular knowledge. The knowledge has to be clearly declared, to ensure the inference engine can accurately ‘reason’ with that knowledge. Figure 2.4. describes the general architecture of a knowledge base system. The knowledge base is comprised of any type of relevant knowledge including local and scientific knowledge.

![Figure 2.4. The general architecture of a knowledge base system](image)

The body of knowledge is obtained from experts in a particular domain of knowledge. The outcome of this process can be expressed in languages such as English and Bahasa Indonesia instead of computer languages. It is important to make the outcomes understandable to all stakeholders who are involved in the knowledge base system development. These stakeholders should be able to testify to the outcomes drawing on their own knowledge or by reviewing relevant literature. The domain experts consist of scientists and traditional experts. In forest sustainability assessment, the local people, who have extensive
experience in managing forests, can act as local experts. Structuring and incorporating these two types of knowledge is challenging, because the methodology used to form indigenous or traditional knowledge is often different to the methodology used in scientific knowledge. These differences are shown in Table 2.1.

Table 2.1. The differences between scientific and indigenous or traditional knowledge (Walker 1994)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Scientific Knowledge</th>
<th>Indigenous Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>Universal</td>
<td>Local</td>
</tr>
<tr>
<td>Supernatural</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Transmission</td>
<td>Formal</td>
<td>Informal</td>
</tr>
<tr>
<td>Leaders</td>
<td>Professional</td>
<td>Informal leaders</td>
</tr>
<tr>
<td>Methodology</td>
<td>Hypothesis and experiment</td>
<td>Live experiences</td>
</tr>
<tr>
<td>Original Lifestyle</td>
<td>Western world</td>
<td>Eastern world</td>
</tr>
<tr>
<td>Viewing natural</td>
<td>Exploiting natural resources</td>
<td>Harmony with nature</td>
</tr>
</tbody>
</table>

Forests, from a scientific knowledge perspective, are regarded as sources of biodiversity. Traditional knowledge practitioners use the forest as a source of traditional medicine. Many of these traditional practitioners live a subsistent lifestyle. To assess whether forest management practices maintain forest biodiversity, scientific knowledge needs to use certain assessment parameters - for instance, a Simpson Index or Shannon-Wiener Index, during the forest utilization period. Sometimes, this is impractical, because it is difficult to show changes in biodiversity during the utilization period. Traditional experts may assess forest biodiversity based on the forest’s provision of medicinal sources.
This is not always the case, but generally it offers a possible way to complement modern knowledge in measuring biodiversity.

Knowledge synthesizing between different sources is critical to sustainable forest management. One rule of thumb is using scientific knowledge for universal ideas or concepts and traditional or indigenous knowledge for local applications. It complies with a well-known environmental principle: “think globally act locally”. Scientific knowledge is not adequate to understand the complexity of all forest eco- and social systems. Indigenous knowledge is not optional, but a necessary condition to gain a greater understanding of forests. Furthermore, the term ‘sustainability’ is influenced, if not dominated, by cultural values.

Sukadri (1997), at the XI World Forestry Congress in Antalya, Turkey, revealed there are many different ways to analyze and assess policy reform for sustaining forests, one of them, through ‘expert system’ application. Guangxing Wang (1998) developed an expert system to improve forest inventory and monitoring. This involves incorporating multi-source knowledge into the knowledge base, with three paradigms of rule-based, object-oriented, and procedural programming.

Panigrahi (1998) urged the utilisation of fuzzy logic in biology and agriculture KBS decision-making techniques in response to its lack of quantitative knowledge in some parts. The fuzzy system model is depicted in Figure 2.5. Guerin (1991) used qualitative reasoning for ecological process modelling in hydro-ecology. The architecture of his model is shown in Figure 2.6. Both the fuzzy system and qualitative reasoning help us tackle uncertainties when we are determining the values and parameters of sustainability.
2.4. Multi-agent Systems

Using a simulation model is an appropriate approach when the system is large, complex and requiring a study of different potential impacts of various options. Simulation means making a simplified representation of a reality. Just as a model aircraft captures many important physical features of a real aircraft, a simulation model captures important operational features of a real system (CACI n.d.).

One well-known computer-based simulation dealing with this matter is a systems dynamics approach. This provides an understanding of how things have changed through time (Forrester 1999). System dynamics software such as STELLA, POWERSIM, SIMILE and VENSIM helps to formulate a model using stock and flow components according to difference equations. Systems
dynamics has its roots in the systems of difference and differential equations (Forrester 1980). The difference equation is usually used on biophysical problems where the future state depends on the current state and other factors. Another system is the multi-agent system (MAS), which focuses more on stakeholders' interactions.

MAS is an emerging sub-field of artificial intelligence that aims to provide both principles for the construction of complex systems involving multiple agents, and mechanisms for the coordination of independent agents' behaviors. While there is no generally accepted definition of “agent” in artificial intelligence, an agent is generally considered as an entity with goals, actions, and domain knowledge, situated in an environment. The way an agent acts is called its
“behavior” (Stone and Veloso 1997). The use of modelling based on MAS for tackling natural resources and environment management issues is growing steadily (Bousquet 1999). The study of MAS focuses on systems in which many intelligent agents interact with each other. The agents are considered to be autonomous entities, such as software programs or robots. Their interactions can be either cooperative or egocentric – in other words, the agents can share a common goal or they can pursue their own interests. (Sycara 2000).

Flores-Mendez (1999) said that agents are entities within an environment, and that they can sense and act. This means that agents are not isolated, and that they can communicate and collaborate with other entities. Once agents are ready for collaboration, they need to find other appropriate agents with whom to collaborate.

In this case, a MAS technique was chosen instead of a stock and flow systems dynamic because the focus of this modeling is on forest stakeholders or agents. The research was aimed at answering questions related to a future scenario, aimed at improving the well-being of stakeholders and improving forest sustainability. The hypothesis of the research was formulated to result in better outcomes in forest co-management by all relevant stakeholders.

Figure 2.7. Perception and action subsystems (Weiss 1999)
In order to simulate stakeholders’ activities and interactions, we need a tool that can represent stakeholders’ individual knowledge, beliefs and behaviours. This modelling assumes that each stakeholder or agent acts autonomously, depending on their own perceptions of the environment, as shown in Figure 2.7.

If the agent wants to take into account previous perceptions, then the agent needs to integrate what they perceive and what is already in their mind, as illustrated in Figure 2.8. Figure 2.9 shows a more comprehensive architecture namely Belief-Desire-Intention (BDI). These architectures have their roots in the philosophical tradition of understanding practical reasoning – the process of deciding, moment-by-moment, which action to perform in order to achieve a goal.

Figure 2.8. Agents that maintain state (Weiss, 1999)
The process of practical reasoning in a BDI agent was illustrated by Weiss 1999 as involving: a set of current beliefs, representing information the agent possesses about the current environment; a belief revision function (brf) which takes into account a perceptual input and the agent’s current belief - and on the basis of these, determines a new set of beliefs; an option generating function, (options), which determines the options available to the agent (its
desires), on the basis of its current beliefs about its environment and its current intentions; a set of current options, representing possible courses of actions available to the agent; a filter function (filter), which represents the agent’s deliberation process, and which determines the agent’s intentions on the basis of its current beliefs, desires, and intentions; a set of current intentions, representing the agent’s current focus – those states of affairs that it has committed to trying to bring about; and an action selection function (execute), which determines an action to perform based on current intentions.

Agents always operate and exist within an environment. The environment might be open or closed, and it might or might not contain other agents. If it contains other agents, it can be seen as a society of agents or MAS. Ossowski (1999) illustrated the coordination among agents as shown in Figure 2.10.

Figure 2.10. Coordination among agents (Ossowski 1999)

The communication protocols enable agents to exchange and understand messages. A communication protocol might specify that the following messages can be exchanged between two agents (Weiss 1999): Propose a course of
action; Accept a course of action; Reject a course of action; Retract a course of action; Disagree with a proposed course of action; Counter-propose a course of action.

Although a simulation is a useful approach to a complex system, a precise definition of a “complex system” is neither possible nor necessary. However, it is possible to relate types of systems to formal methods of problem solving in a very general way. The most useful method of dealing with a given problem at a particular time depends on our conceptualization of the problem and the current state of knowledge about the problem within a conceptual framework - which places us in one of the regions in Figure 2.11. Definitely, a simulation method is useful to apply when we have little data but a high level of understanding. Otherwise, statistics or physics would be more appropriate.

Figure 2.11. Comparison in methods of problem solving (modified from Holling 1978, and Starfield and Bleloch 1988 in Grant et al., 1997)

Here, it is useful to distinguish models for understanding and models for prediction (Bunnell 1989 in Vanclay 1994). Models for understanding are useful
for comprehending and linking previously isolated bits of knowledge, and may help to identify gaps where more work is needed. The benefits come from insights gained while developing and exploring the model (Vanclay 1994).

2.5. Forest Stand Dynamic

In Indonesia, forest management and harvesting operations are regulated under TPTI (Armitage and Kuswanda 1989). This system allows for all commercial trees to have 50-60 cm dbh (the minimum harvest diameter depends on the type of production forest), removed within a felling cycle of 35 years. However, in previous times, not all trees above these diameter classes were cut because some of them were not harvestable e.g. non-commercial trees, protected trees (such as Dyera Costulata, Koompassia Excelsa, Eusideroxylon Zwagery, and Shorea Pinanga), hollow trees, trees at steep slope, flute trees and trees that are considered as seed bearers.

Diameter class projection methods (DCPM) represent the oldest class of mathematical models developed for growth projection in tropical forests. The basic concept of DCPM is that the forest is represented as stand table of tree numbers classified by diameter classes. The change in the stand table is calculated over an interval of perhaps 5-10 years using periodic increment data. The revised table is then used as a starting point from which to repeat the calculations. In this way, increment, mortality and in-growth observations made from permanent sample plots over relatively short periods may be used to estimate growth over a complete felling cycle or rotation (Alder 1995).

Vanclay (1994) categorized forest stand growth models into three categories: whole stand models; size class models; and single tree models. He stated that size class models provide information on the structure of the stand. This approach is a compromise between whole stand models and single tree
models. Stand growth models, logging and logging damage constitute stand dynamic.

The form and extent of logging damage on forests is varied. The method and intensity of logging will influence the degree and type of damage (Alder and Synnott 1992). Sist et al. (in prep.) noted that logging in Inhutani II was done under such high felling intensity (more than 9 trees per ha or about 80%), it led to high damage to residual stands. Dead trees due for felling within residual stands for dbh class one to five are 50% (20-30 cm), 40% (30-40 cm), 30% (40-50 cm), 20% (50-60 cm) and 10% (above 60 cm).