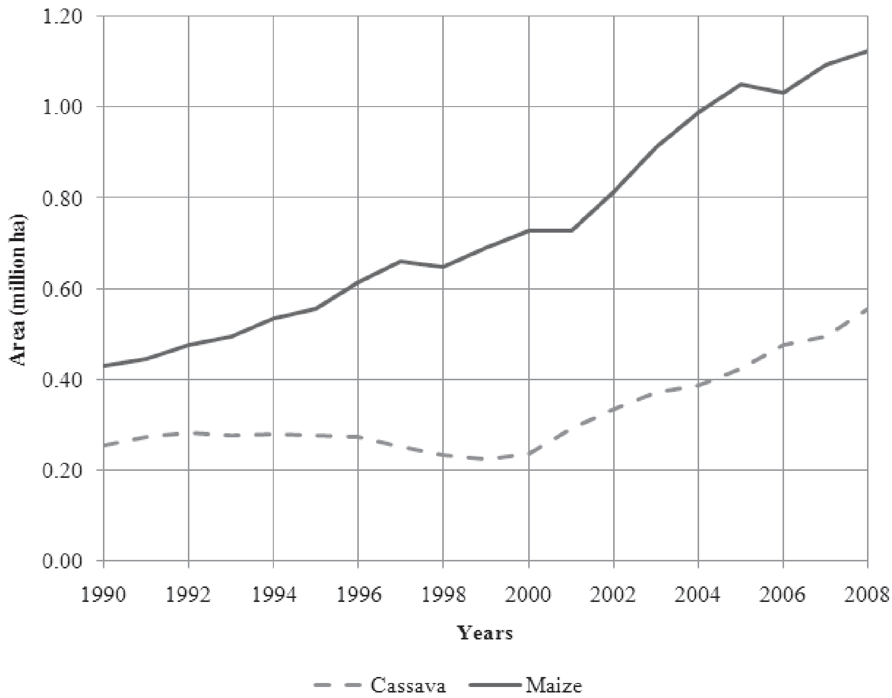
1 Introduction

1.1 Problem statement

Since the mid-1980s, agriculture in Vietnam has moved towards a market economy model, with farmers becoming increasingly responsive to economic incentives, intensively growing annual crops on their land to increase their short-term income levels. In upland areas, agriculture on sloping and fallow land has intensified, with farmers growing maize and cassava year on year. According to FAO statistics, the area of land under maize cultivation in Vietnam has increased considerably since 1990, rising from 0.43 million ha in that year to more than 1 million ha in 2008. The area of land under cassava cultivation has also expanded, rising from 0.238 million ha in 2000 to 0.556 million ha in 2008 (Figure 1).

Figure 1: Area of land under maize and cassava cultivation in Vietnam: 1990-2008



Source: FAO statistics[2]

While growing annual crops in the upland areas has improved the immediate incomes of farmers, it may not be sustainable in the long run, because it degrades soil fertility and can cause soil erosion as well as landslides. Figure 2 and 3 show that those areas with high soil erosion levels are mainly located in upland areas. In the northern parts of

[2] FAO statistics are available from the website: http://faostat.fao.org/site/567/default.aspx

Vietnam this problem mainly occurs in the mountainous areas of the northwest and northeast regions, where land under crops has been cultivated intensively and where fallow periods have shortened, leading to a reduction in top soil fertility (Tien, 2003).

Erosion can lead to floods, siltation, desertification, drought and low crop yields (Ananda and Herath, 2003). People living in mountainous areas primarily face the consequences of these events because they tend to rely on agriculture and have few alternative income sources. The northern mountainous region of Vietnam, which accounts for 30% of Vietnam's land area, is one such vulnerable area, and its ten provinces have the highest poverty rates in Vietnam, ranging from 55 to 78% (Figure 3 - right), in spite of the significant economic development that has taken place across the whole country in recent times (Minot and Baulch, 2002).

In an effort to reduce poverty, the government of Vietnam with the support of international organizations, has introduced various agricultural innovations since the 1990s, the aim being to enhance the livelihoods of the ethnic minorities. Innovations promoted by the government have been extended to farmers through the state extension system, while international organizations have tended to promote innovations through agricultural specialists and consultants, using farm-level training and demonstrations. Ethnic minority households have gradually adopted innovations and discontinued their swidden agriculture practices.

In 2003, an evaluation report by the Social Forestry and Development Project (SDFP) based in Yen Chau, Son La Province, showed that 97.9% of the households at that time were growing improved varieties of maize, 71.1% were growing improved varieties of paddy rice and 88.1% were using mineral fertilizers on their upland fields. The households in Yen Chau have become better-off because they have applied agricultural innovations, invested more in agricultural production techniques and sold more products (Phuong and Foerster, 2003). Nevertheless, intensive land use has created environmental problems, as growing crops such as maize and cassava on sloping land causes soil degradation due to erosion and the shortening of fallow periods (Young, 1990).

Soil conservation practices should be applied to reduce land degradation. Wezel et al. (2002) studied the effect of slope steepness on soil fertility and crop productivity in the uplands of northwestern Vietnam and recommended promoting the adoption of soil conservation practices as erosion declined the soil fertility in the mid and lower mid slope. Valentin et al. (2008) studied various land management options in 27 upland catchments in Indonesia, Laos, Philippines, Thailand, and Vietnam. By assessing the impact of different practices on run-off and soil erosion, he concluded that conservation practices could sufficiently reduce run-off and sedimentation processes.

Figure 2: Topography (left), regions (middle) and slope gradients (right) in Vietnam

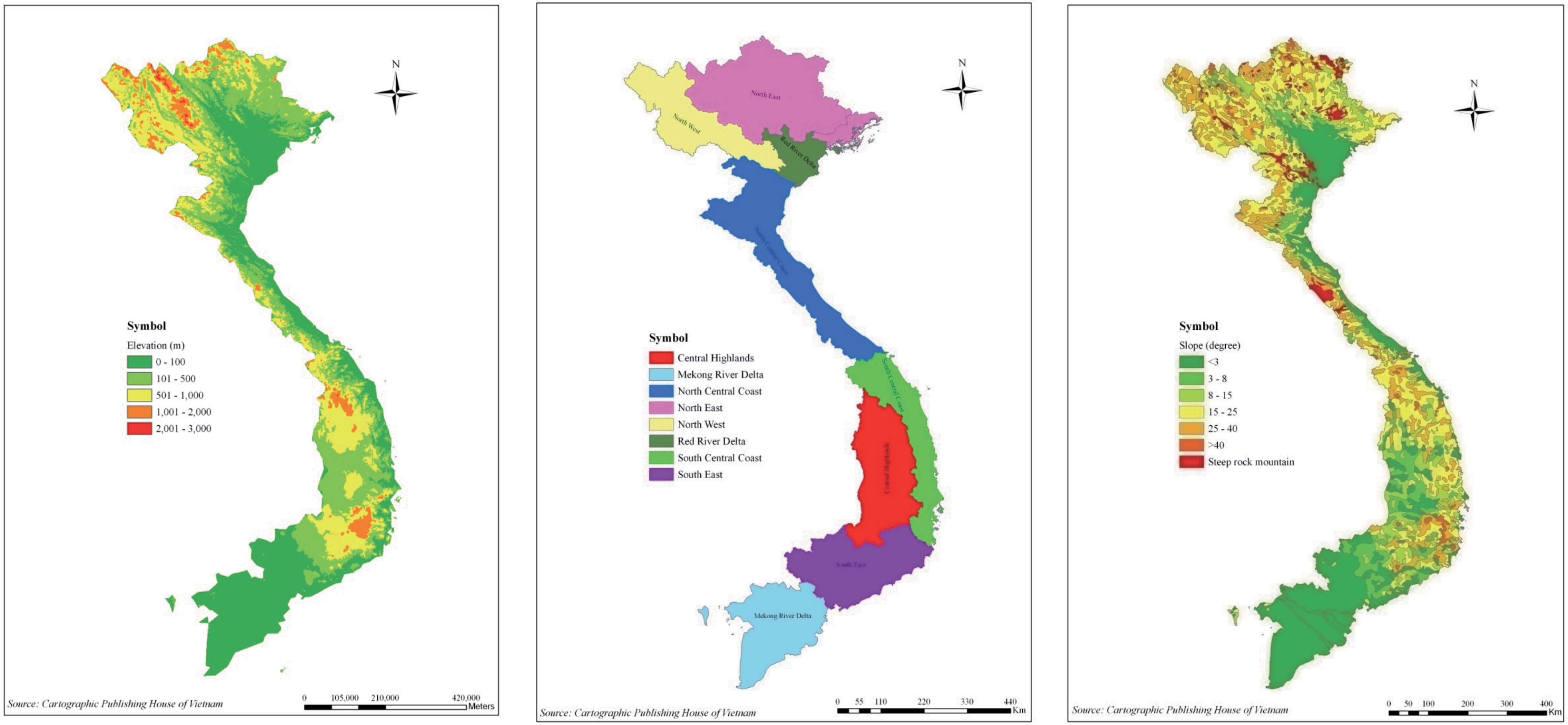
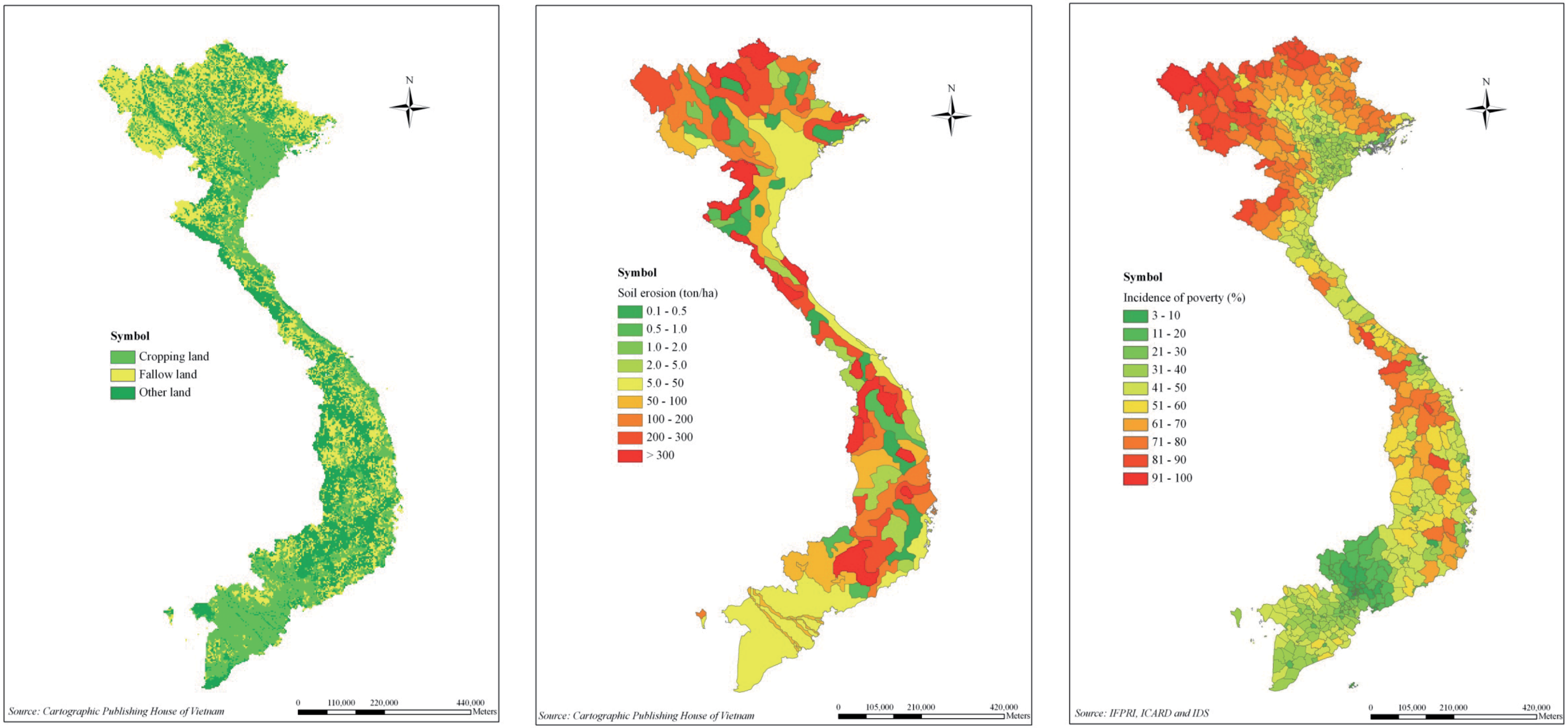


Figure 3: Land use in 1993 (left), soil erosion in the 1990s (middle) and poverty levels in 1999 (right)



A variety of soil conservation practices could be introduced to the northwest mountainous region. Maize intercropped with Leucaena hedgerows could enrich nitrogen in the soils, thereby increasing crop yields. Additionally, it could provide fuel wood to farm-households (Torres, 1983). This soil conservation practice was tried in the northeast of Thailand by Pansak et al. (2008) and was shown to considerably reduce the quantity of soil loss while giving higher yields as compared to two other soil conservation practices of maize with grass strips and maize with grass barriers.

Although field trials of soil conservation methods showed success in reducing erosion, their adoption rates in the northwestern region of Vietnam remain low. Soil conservation practices often require more labor and other inputs, which could be constraints for farmers to adopt them (Affholder et al., 2010). Previous research has shown that farmers in Vietnam know about soil erosion and soil conservation, but still do not apply preventative methods (Saint-Macary et al., 2010), and without soil conservation measures in place, large amounts of soil are eroded from sloping land (Schmitter et al., 2010; Valentin et al., 2008; Wezel et al., 2002). In response to declining soil fertility and high output prices, highland farmers have turned to mineral fertilizers and high yielding varieties, the rapid adoption of which has masked the ongoing process of resource degradation. Current practices would therefore seem to be unsustainable.

The above issues have raised a large number of questions for policy makers in Vietnam, in terms of maintaining the equilibrium between the livelihoods of local people and the conservation of natural resources, such as: how much forest area should be retained; how large an area of upland crops is needed to reduce soil erosion and avoid flooding during the rainy season; how much fertilizer should farmers apply to compensate for lower soil fertility; and, which activities should be introduced to generate a decent income for farmers while lessening pressure on the forests? The equilibrium between livelihoods and ecological conservation is determined by many factors, such as markets, agricultural innovations, soil processes, hydrology and social networks. Any approach used to analyze these interrelated questions should ideally integrate knowledge from different scientific disciplines and apply integrated modeling techniques, which combine the decision-making of local people with the dynamics of their natural resources. A useful approach of this integration is agent-based modeling or Multi-Agent System (MAS) which originally came from the area of artificial intelligence. It has become a commonly used approach over the last 20 years. It can be used to combine the heterogeneous characteristics of various agents and the spatial distribution of environmental features (Bousquet and Le Page, 2004). Owing to this advantage, it can capture the complex relationships between communities and environmental processes. It was thereby intensively applied to understand the interactions between farm-decision making and environmental issues through land use/cover changes (LUCC) (Huigen, 2004; Deadman et al., 2004; Berger and Schreinemachers, 2006; Parker et al., 2003).

Agent-based modeling is a bottom-up approach and more process-based than the conventional models (Boulanger and Bréchet, 2005; Robinson at al., 2007). It spatially integrates socio-economic and biophysical processes (Matthews, 2006; Schreinemachers et al., 2007) and is able to capture both social and landscape heterogeneity (Evans and Kelly, 2004). Such integrated models have been applied to test policy responses, to explore resource degradation, to ex-ante assess alternative technologies, or to understand changes in farm structures, and to verify the decision-making of land managers (Berger et al., 2006; Robinson at al., 2007). MAS models can improve our understanding of the triangular relationships between household well-being, natural resources and crop productivity (Berger and Schreinemachers, 2006). As compared to other models, MAS are a suitable modeling approach for testing hypotheses regarding the sustainability of land use change (Boulanger and Bréchet, 2005) and to study interactions between subsystems in ecosystem management (Bousquet and Le Page, 2004). Generally, MAS have become a useful approach for scientists, policy makers and other stakeholders to test hypotheses, to examine alternative policy options, to improve learning processes and to explore appropriate strategies in sustainable development (Parker et al., 2003).

1.2 Research gaps

The research gaps that I seeks to fill relate to the *ex-ante* assessment of the relationships between socio-economic development and ecological conservation under the concept of agricultural sustainability. Socio-economics in this sense relates to farm decision-making, income, land use and technology adoption, while ecological conservation is related to a reduction of soil erosion and nutrient outflows from the system. Separate to this work, numerous studies in these three areas have been carried out before.

Linear Programming (LP) is a well-established method used for studying farm-decision making and farm management. Bogahawatte (1984) used LP to integrate the crops and livestock used in farming systems, while Sharifi and van Keulen (1994) utilized it to integrate knowledge from different disciplines in order to explore feasible land use alternatives. LP has also been used to compare various farming systems (Lowenberg-De Boer and Abdoulaye, 2000), to examine the effects of new technologies (Norton and Walters, 1988) and to analyze the impacts of policy changes on the sustainability of agricultural practices (Pacini et al., 2004). However, most studies have not taken into account the conservation of natural resources and have not focused on the two-way relationship between farm decisions and the natural environment.

In the area of soil conservation, various conservation practices have been experimented with in Southeast Asia. For instance, Valentin et al. (2008) conducted trials of seven soil conservation practices across 27 catchment areas in Indonesia, Laos, Philippines, Thailand and Vietnam, and found that soil conservation practices can efficiently reduce run-off and total sediment loss at the catchment level. Pansak et al. (2008) experimented with grass barriers and hedgerow conservation practices and concluded that these are potentially effective soil conservation strategies to use on moderate slopes. Nevertheless, these biophysical studies were not able to show how these conservation practices can be adopted. Socio-economic studies, on the other hand, use regression models to identify determinants of adoption (e.g. Sidibe, 2005).

Regarding agricultural sustainability, Schaller (1993) summarized the reasons for scientists to study sustainable agriculture, these being pollution, loss of biodiversity, decreasing soil fertility and productivity, soil erosion, chemical contamination and worsening human health, and studies of agricultural sustainability can present environmental benefits in combination with socio-economic issues. Various approaches and concepts have been developed to assess and to quantify sustainability; for example, Farshad and Zinck (1993) reviewed sustainability concepts across a variety of disciplines and concluded that sustainable agriculture is dynamic in terms of sustainably using natural resources while still maintaining a balance between human consumption and food production resources; however, it requires a stable economy and farming resources to be managed properly. Yunlong and Smit (1994) reviewed sustainable agriculture across social, economic and ecological areas, asserting that various interactions exist among these components at various spatial scales and that agricultural sustainability should be examined relative to these three perspectives.

When applying a long-term analysis, it is essential to use an approach that represents all the farmers' decisions as well as the location of their farmland – as this may relate to several social, economic and bio-physical elements (Ikerd, 1993). My studies thus used an interdisciplinary simulation model to *ex-ante* examine the relationships between farm decision-making and biophysical indicators, within the context of agricultural sustainability.

1.3 Research objective

1.3.1 General objective

The overall objective of my studies was to provide insights into the complex relationship between economic incentives and ecological changes, within the context of policy change, technology adoption and agricultural sustainability, and using an interdisciplinary simulation model.

1.3.2 Specific objectives

- To explore the relationship between the decision-making of farm households and biophysical dynamics such as soil erosion and soil fertility change.
- To assess how the farm households adopt the soil conservation practices in the study area.
- To identify possible constraints on the adoption of soil conservation practices.
- To quantify trade-offs between sustainability (as represented by soil nutrient balances and erosion) and the incomes of farm households.

- To appraise possible policy options to promote the adoption of soil conservation practices.

1.4 Structure of the dissertation

The dissertation is organized as follows. This introduction is followed by a literature review which is mainly focused on the previous literature regarding agent-based modeling. The materials and methods used are covered in chapter three, which describes the study site, the household survey and the agent based model developed for this studies. Chapter four contains a validation of the constructed model, while the results of the experimental simulation are described in chapter five, which is followed by a discussion of the results and the conclusion in chapter six.