Land-use change, food security and climate change in Vietnam

A global-to-local modelling approach

LEI WAGENINGEN UR

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Disclaimer

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List of abbreviations

ASEAN	Association of Southeast Asian Nations
BAU	Business As Usual
CET	Constant Elasticity of Transformation
CDKN	Climate & Development Knowledge Network
CO_2e	Carbon dioxide equivalent
CGE	Computable General Equilibrium
CLUE	Conversion of Land Use and its Effects model
DGTM	Dynamic Global Timber Market Model
FIPI	Forest Inventory Planning Institute
GDP	Gross Domestic Product
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
GDLA	General Department of Land Administration
GDOF	General Department of Forestry
HCI	High Climate Impact
HEG	High Economic Growth
IMAGE	Integrated Model to Assess the Global Environment
ILUC	Indirect Land-Use Change
LULUCF	Land Use, Land-Use Change and Forestry
MAGNET	Module Applied GeNeral Equilibrium Tool
MARD	Ministry of Agriculture and Rural Development
NIAPP	National Institute of Agricultural Planning and Projection
MONRE	Ministry of Natural Resources and Environment
PBL	Dutch Environmental Assessment Agency
pp	percentage points
REDD	Reducing Emission from Deforestation and Forest Degradation
SAS	Story And Simulation
SEDS	Socio-Economic Development Strategy
SRI	System of Rice Intensification

Preface

Land use is directly related to development, food security and climate change in Vietnam. The agricultural sector, which is the dominant land-using sector in the country, accounts for 21% of GDP. Seventy-one per cent of the population reside in rural areas, most of whom are small-scale farmers that produce paddy rice, the main staple food in Vietnam and also an important export product. Changes in land use patterns over time also play a crucial role in climate change mitigation and adaptation. Before the year 2000, more than 50% of greenhouse gas emissions in Vietnam were attributable to agriculture and land-use change. At the same time, Vietnam is considered as one of the countries in the world that is most vulnerable to climate change. Flooding and extreme weather events are expected to impose substantial risks to agricultural production, in particular in the two major delta regions (Red River Delta and Mekong River Delta), where most paddy rice areas are located.

To address these issues, decision makers in Vietnam need to be aware about the complex and uncertain relationships between global and local drivers of land-use change and take a forward look when formulating food security and climate change mitigation and adaptation policies. This study presents an innovative modelling approach to visualise future land-use change patterns under different scenarios. The results can be used to evaluate policies such as the Green Growth and REDD strategies that are currently being developed and implemented. The same approach can also be applied to guide food security and climate change policies in other countries.

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Managing Director LEI Wageningen UR

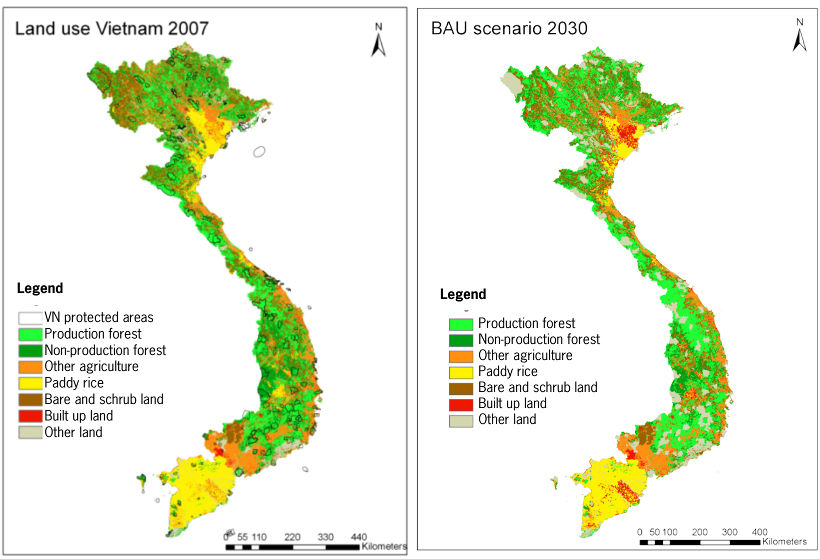
Summary

S.1 Key findings

- *Socio-economic development*
  All three scenarios - Business As Usual, High Economic Growth and High Climate Impact - find that Vietnam will go through a process of profound structural transformation between 2010 and 2030. The economy will become increasingly oriented towards services and manufacturing while the agricultural sector will become less important. Despite the declining relative importance of agriculture in the economy, the sector is still growing and Vietnam remains one of the main global exporters of rice in the world in 2030 (see Chapter 5).
- *Land-Use Change*
  Economic development and structural changes will lead to considerable change in land use under each of the three scenarios. Production forest land and built-up land will expand at the expense of paddy rice area, non-production forest, and shrub land (see Section 6.1). Future land-use maps reveal that the land-use changes are not distributed evenly over the country; most of the urban growth is concentrated in the Red River Delta and Mekong River Delta. The growth of production forest area mainly will take place in the North Central Coast, Central Highlands and South Central Coast regions (see Section 6.2 and Section 6.3).
- *Food Security*
  In Vietnam's major rice producing areas, the Red River Delta and the Mekong River Delta, large areas of paddy rice disappear under each of the three scenarios due to the expansion of built-up land, particularly in the Red River Delta (see Section 6.2). However, the available land for paddy rice in 2030 is still slightly larger than the 3.8 million hectares of rice land that is mandated by the Resolution on National Food Security (No. 63/NQ-CP). The study found serious discrepancies between several official sources of land-use data in Vietnam (see Paragraph 2.2.2 and Box 2.2). It is doubtful if the paddy rice land target will still be met if alternative sources of data are used which generally assume a smaller paddy rice area than has been assumed in this study.

- *Climate Change*
  Climate change has a negative effect on economic growth in Vietnam, in particular in the agricultural sector and the rest of the world. In addition to economic development, flooding induced by climate change poses a serious threat to rice production in Vietnam. In particular, the paddy rice fields in the low-lying Mekong River Delta and, to a lesser extent, the Red River Delta are susceptible to floods. This results in a risk to domestic food production and international rice trade (see Section 7.1). To meet the national food security target, policies are needed that safeguard the paddy areas for the risk of flooding. The foreseen decline in paddy rice area is expected to result in fewer greenhouse gas emissions. More research is needed to provide a detailed picture of total future greenhouse gas emissions in Vietnam (see Section 7.2).

Figure S.1 **Land use in 2007 and 2030, BAU scenario**



S.2 Complementary findings

Scenario analysis and models can be a very powerful tool to assess the trade-offs between policy options, but they remain a simplification of a complex reality, and outcomes rely on the coverage and quality of available data. Key areas for improvement are the Vietnamese land-cover and land-use maps, which exhibit a number of inconsistencies. In particular, there is a need to develop one consistent classification system that harmonises the different sources of spatial data in Vietnam (see Paragraph 2.2.2 and Box 2.2).

S.3 Methodology

The aim of this study is to provide insights into causes and consequences of future land-use change in Vietnam and how this relates to climate change, development and food security in the country. The main research questions this study addresses are:

1. What is the impact of socio-economic development on land use and land-use change for the period 2010-2030 using different scenarios, including climate change?
2. What is the spatial pattern of land-use change in Vietnam?
3. What are the implications for food security and greenhouse gas emissions?

This study uses a novel global-to-local approach that combines an economic (CGE) model with a spatially explicit land-use model to capture change at the global, national and landscape level under alternative futures.

Samenvatting

Veranderingen in landgebruik, voedselveiligheid en klimaatverandering in Vietnam; een aanpak volgens het model 'globaal-naar-lokaal'

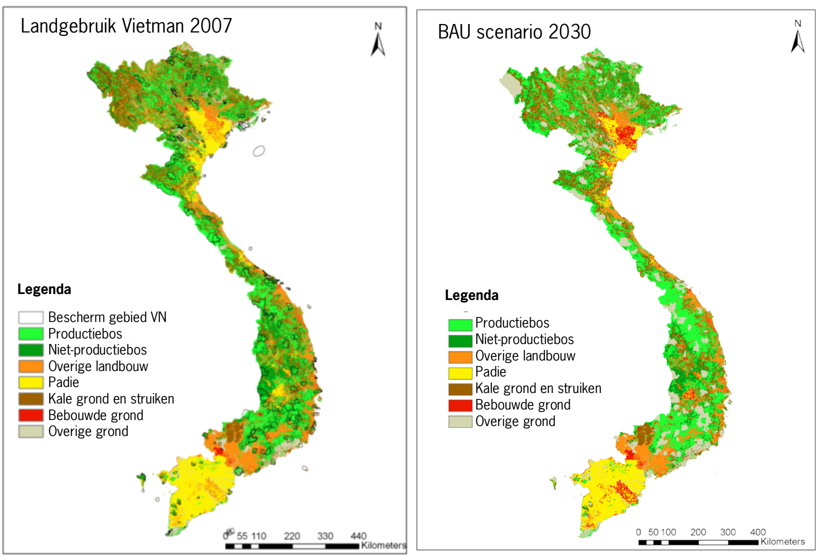
S.1 Belangrijkste uitkomsten

- *Sociaal-economische ontwikkeling*
  Uit alle drie de scenario's - 'Business As Usual', 'High Economic Growth' en 'High Climate Impact' - blijkt dat Vietnam tussen 2010 en 2030 een proces van verregaande structurele transformatie zal ondergaan. De economie zal in toenemende mate gericht zijn op dienstverlening en industrie, terwijl de landbouwsector steeds minder belangrijk zal worden. Ondanks het afnemende relatieve belang van landbouw voor de economie, groeit deze sector nog altijd en blijft Vietnam ook in 2030 wereldwijd een van de belangrijkste exporteurs van rijst.
- *Veranderingen in landgebruik*
  Economische ontwikkelingen en structurele veranderingen zullen leiden tot grote veranderingen in landgebruik volgens alle drie de scenario's. Productiebossen en bebouwde grond nemen in oppervlakte toe ten koste van padievelden, niet-productiebossen en struiken. Kaarten van het toekomstige landgebruik laten zien dat de veranderingen in landgebruik niet gelijkmatig over het land verdeeld zijn; de stedelijke groei concentreert zich in de Rode Rivier-delta en de Mekong-delta. Het aantal productiebossen neemt hoofdzakelijk toe langs de noordelijke centrale kust, in de centrale hooglanden en in de zuidelijke centrale kustregio's.
- *Voedselveiligheid*
  In de grote rijstproducerende gebieden van Vietnam - de Rode Rivier-delta en de Mekong-delta - verdwijnen volgens de drie scenario's grote hoeveelheden padievelden vanwege de toenemende bebouwing, met name in de Rode Rivier-delta. De hoeveelheid land die in 2030 nog beschikbaar zal zijn voor padievelden is echter nog steeds iets meer dan de 3,8 miljoen hectare rijstland die verplicht is krachtens de Resolutie over Nationale Voedselveiligheid (nr. 63/NQ-CP). De studie legde grote discrepanties bloot tussen verschillende officiële gegevensbronnen over het landgebruik in Vietnam. Het is niet

zeker of ook nog wordt voldaan aan de verplichte omvang van padievelden als er alternatieve gegevensbronnen worden gebruikt, die over het algemeen uitgaan van minder padievelden dan waar in deze studie van uit is gegaan.

- *Klimaatverandering*
  Klimaatverandering heeft een negatief effect op de economische groei in Vietnam, met name in de landbouwsector, en de rest van de wereld. Naast de economische ontwikkeling vormen ook overstromingen als gevolg van klimaatverandering een serieuze bedreiging voor de productie van rijst in Vietnam. Met name de padievelden in de laagliggende Mekong-delta en in mindere mate de Rode Rivier-delta zijn kwetsbaar als het gaat om overstromingen. En dat betekent een risico voor de binnenlandse voedselproductie en de internationale rijsthandel. Om te voldoen aan de target voor de nationale voedselveiligheid moeten de padievelden beleidsmatig worden beschermd tegen het risico van overstroming. De voorspelde afname van padievelden zal naar verwachting leiden tot een lagere uitstoot van broeikasgassen. Er is meer onderzoek nodig om een gedetailleerd beeld te schetsen van de toekomstige uitstoot van broeikasgassen in Vietnam.

Figuur S.1 Landgebruik in 2007 en 2030, BAU-scenario



S.2 Overige uitkomsten

Scenarioanalyses en -modellen kunnen een zeer krachtig hulpmiddel zijn om de trade-offs tussen beleidsopties te beoordelen, maar ze blijven een vereenvoudigde weergave van een complexe realiteit en de uitkomsten zijn afhankelijk van de hoeveelheid beschikbare data en de kwaliteit daarvan. De belangrijkste verbeterpunten zijn de kaarten van de landbedekking en het landgebruik in Vietnam, die een aantal inconsistenties vertonen. In het bijzonder is er de noodzaak om één consistent classificatiesysteem te ontwikkelen dat de verschillende bronnen van ruimtelijke gegevens in Vietnam harmoniseert.

S.3 Methode

Het doel van deze studie is inzicht te krijgen in de oorzaken en gevolgen van het toekomstige landgebruik in Vietnam en op welke manier dit verband houdt met klimaatverandering, economische ontwikkeling en voedselveiligheid in het land. De belangrijkste onderzoeksvragen voor deze studie zijn:

1. Wat is de impact van sociaal-economische ontwikkeling op landgebruik en veranderingen in landgebruik voor de periode 2010-2030 volgens verschillende scenario's, inclusief klimaatverandering?
2. Wat is het ruimtelijke patroon van de veranderingen in landgebruik in Vietnam?
3. Wat zijn de implicaties voor de voedselveiligheid en de uitstoot van broeikasgassen?

Deze studie maakt gebruik van een nieuwe aanpak, 'globaal-naar-lokaal', die een economisch model (CGE) combineert met een ruimtelijk expliciet model voor landgebruik dat veranderingen inzichtelijk maakt op wereldwijd, nationaal en landschapsniveau op basis van verschillende toekomsten.

Tóm tắt

Thay đổi sử dụng đất, an ninh lương thực và biến đổi khí hậu tại Việt Nam: Tiếp cận lập mô hình từ toàn cầu tới cục bộ

1 Các kết quả chính

- *Phát triển kinh tế-xã hội.*
  Cả ba kịch bản - Phát triển Bình Thường , Tăng trưởng Kinh tế Cao và Tác động Khí hậu Cao - đều thấy rằng Việt Nam sẽ đi theo một quá trình chuyển đổi cơ cấu sâu rộng từ năm 2010 đến năm 2030.Nền kinh tế ngày càng trở nên hướng tới các dịch vụ và sản xuất trong khi lĩnh vực nông nghiệp trở nên ít quan trọng hơn. Mặc dù suy giảm tầm quan trọng tương đối của nông nghiệp trong nền kinh tế, ngành này vẫn tăng trưởng và Việt Nam vẫn là một trong những nhà xuất khẩu gạo chính trên thế giới tới năm 2030 (xem Chương 5).

- *Thay đổi Sử dụng Đất.*
  Phát triển kinh tế và những thay đổi cơ cấu sẽ dẫn đến sự thay đổi đáng kể trong sử dụng đất theo từng kịch bản. Đất rừng sản xuất và đất xây dựng sẽ mở rộng trên đất lúa, rừng phi sản xuất và đất cây lùm bụi (xem đoạn 6.1). Các bản đồ sử dụng đất trong tương lai cho thấy những thay đổi sử dụng đất không phân bố đồng đều trên toàn quốc; hầu hết sự tăng trưởng đô thị đều tập trung tại Đồng bằng Sông Hồng và Đồng bẳng Sông Cửu Long. Sự gia tăng diện tích rừng sản xuất sẽ chủ yếu diễn ra ở vùng Duyên hải Bắc Trung bộ, Tây Nguyên và Duyên hải Nam Trung bộ (xem đoạn 6.2 và 6.3).

- *An ninh lương thực.*
  Trong các vùng sản xuất lúa chủ yếu của Việt Nam, Đồng bằng Sông Hồng và Đồng bằng Sông Cửu Long, diện tích trồng lúa lớn biến mất theo từng kịch bản trong số ba kịch bản do việc mở rộng đất xây dựng, đặc biệt là ở ĐBSH (xem phần 6.2). Tuy nhiên, diện tích đất có sẵn cho lúa tới năm 2030 vẫn còn lớn hơn một chút so với diện tích 3.8 triệu ha đất đã được quy định theo Nghị quyết về An ninh Lương thực Quốc gia (Số. 63/NQ-CP).

Nghiên cứu này cho thất sự khác biệt nghiêm trọng giữa một số nguồn số liệu chính thức về sử dụng đất tại Việt Nam (xem đoạn 2.2.2 và Hộp 2). Có một sự nghi ngờ là liệu rằng mục tiêu đất lúa vẫn sẽ vẫn được đáp ứng nếu như các nguồn số liệu khác được sử dụng có giả định chung là diện tích lúa nhỏ hơn như đã được giả định trong nghiên cứu này.

- *Biến đổi Khí hậu.*
  Biến đổi khí hậu có những tác động tiêu cực tới tăng trưởng kinh tế tại Việt Nam, đặc biệt tới ngành nông nghiệp và những nơi khác trên thế giới. Ngoài phát triển kinh tế, lũ lụt gây ra do biến đổi khí hậu cũng có đe dọa nghiêm trọng tới sản xuất lúa tại Việt Nam. Đặc biệt các cánh đồng lúa gạo ở vùng đất thấp ở Đồng bằng Sông Cửu Long, và ở quy mô nhỏ hơn, Đồng bằng Sông Hồng, đang dễ bị lũ lụt. Điều này dẫn đến một nguy cơ đối với sản xuất lương thực trong nước và thương mại lúa gạo quốc tế (xem đoạn 7.1). Để đáp ứng mục tiêu an ninh lương thực quốc gia, cần có các chính sách bảo vệ vùng đất lúa có nguy cơ bị lũ lụt. Sự suy giảm dự kiến trong diện tích đất lúa dự kiến sẽ dẫn đến phát thải khí gây hiệu ứng nhà kính ít hơn. Cần có nghiên cứu sâu hơn để đưa ra một bức tranh chi tiết về tổng lượng phát thải khí gây hiệu ứng nhà kính trong tương lai ở Việt Nam (xem đoạn 7.2).

2 Phát hiện bổ sung

Phân tích kịch bản và các mô hình có thể là một công cụ đắc lực để đánh giá sự cân bằng (trade-offs) giữa các lựa chọn chính sách, chúng là quá trình đơn giản hoá một thực thể phức tạp, và các kết quả (outcomes) dựa vào mức độ bao phủ và chất lượng của số liệu sẵn có. Một lĩnh vực cần cải thiện đó là các bản đồ thảm phủ và sử dụng đất của Việt Nam, bởi chúng thể hiện nhiều sự không đồng nhất. Đặc biệt, cần xây dựng một hệ thống phân loại đồng nhất để hài hòa các nguồn khác nhau về số liệu không gian ở Việt Nam (xem đoạn 2.2.2 và Hộp 2).

3 Phương pháp luận

Mục đích của nghiên cứu này là cung cấp những hiểu biết tốt hơn về nguyên nhân và hậu quả của sự thay đổi trong tương lai sử dụng đất tại Việt Nam và điều này liên quan như thế nào đến biến đổi khí hậu, phát triển và an ninh lương thực trong nước. Các vấn đề nghiên cứu chính mà nghiên cứu này nhắm tới:

(1) Tác động của phát triển kinh tế - xã hội tới sử dụng đất và thay đổi sử dụng đất trong giai đoạn 2010-2030 bằng cách sử dụng các kịch bản khác nhau bao gồm cả biến đổi khí hậu là những tác động gì?
(2) Mô hình không gian của thay đổi sử dụng đất tại Việt Nam là mô hình gì?
(3) Tác động đối với an ninh lương thực và phát thải khí gây hiệu ứng nhà kính là những tác động gì?

Nghiên cứu này sử dụng một phương pháp tiếp cận mới lạ từ cấp toàn cầu đến cấp vùng đó là kết hợp một mô hình kinh tế (Mô hình Cân bằng Tổng thể hay CGE) với một mô hình sử dụng đất rõ ràng về mặt không gian để nắm bắt sự thay đổi ở cấp độ toàn cầu, quốc gia và cấp cảnh quan theo các kịch bản khác nhau

1 Introduction

1.1 Context

Land plays a crucial role in the development process of Vietnam. Not only does the agricultural land using sector in Vietnam account for a substantial share of GDP (21% including forestry and fisheries), a large part of the Vietnamese population (71%) resides in rural areas, mostly consisting of poor and small-scale farmers involved in the production of paddy rice, making agriculture a key sector regarding poverty reduction and food security.[1] Although Vietnam is the second largest exporter of rice, food security is a concern since many rural households are net buyers of food. Vietnam experienced one of the fastest increases in food prices in early 2008, and, consequently, has been classified as one of the hunger hot spots in Asia and the Pacific.[2]

Land use by agriculture and forestry sectors and changes in land use patterns over time also play a crucial role in climate change mitigation and adaptation. Climate change concerns have risen recently since Vietnam has enjoyed a very rapid GDP growth, averaging 6 to 8% over the last decade, resulting in an exponential increase in greenhouse gas (GHG) emissions. For 2000, total emissions in Vietnam were reported to equal 151 million tonnes of GHG in carbon dioxide equivalent (CO_2e), of which 53% was attributable to agriculture and land-use change, of which in turn over half was accounted for by rice (MONRE, 2010). Whilst Vietnam's GHG emission is relatively low in the global context, it is expected to continue to grow rapidly and will likely triple by 2030 unless significant mitigation options are undertaken. Vietnam is considered to be a high-risk country in the context of climate change because of its delta structure and the long coastline that is sensitive to flooding and extreme weather events. This makes the rural population increasingly vulnerable in terms of poverty and food security.[3]

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[1] See http://www.fao.org/countries/55528/en/vnm) for more key facts on Vietnam's agricultural sector and food security situation [Accessed July 29, 2012].
[2] See http://www.foodsecurityportal.org/Vietnam for more key facts on food security in Vietnam [Accessed July 29, 2012].
[3] For more information on climate change and food security in Vietnam see http://www.unescap.org/LDCCU/Meetings/HighLevel-RPD-food-fuel-crisis/Paper-Presentations/C2-FoodSecurity/VietNam-FoodSecurity.pdf.

The Vietnam government has demonstrated its commitment to combat climate change by signing Decision 3119/QD-BNN-KHCH in December 2011 which confirms the country's commitment to increase agricultural production by 20% and reduce emissions and poverty by 20% by 2020. The Vietnamese government is currently also in the process of drafting a Green Growth strategy and completed the final approval of the Reducing Emissions from Deforestation and Forest Degradation (REDD) programme document, which is now in the inception and implementation phase.[1]

Land use patterns in Vietnam are expected to change dramatically over time as a consequence of several global and local processes that interact at various scales and domains. Next to climate change, key global drivers that will affect land use in Vietnam are technological change, population growth and international trade. At the national and local level, spatial policies that ensure the safeguarding of areas with rich biodiversity will have important consequences for land use, as well as climate adaptation and mitigation strategies (i.e. REDD), expansion of urban and industrial zones and food security policies such as a mandatory allocation of land for the production of paddy rice.

The interplay between global and local drivers is complex and uncertain, which makes it difficult to predict their impact on the economy, landscapes, rural livelihoods and the environment. To formulate pro-active policies and identify challenges and opportunities, decision-makers need information about potential land use and other, economic, outcomes in different situations as well as insights into the underlying dynamics, potential trade-offs and the potential impact of policies. A popular approach to assess the future of complex systems and identify policy alternatives is to implement scenario analyses using models or a combination of models. A study of global-to-local land use impacts possesses challenges as an integrative assessment is needed at different scales: (1) the global-to-national scale examining the interplay between macro-economic factors, population growth and climate change, and (2) the national-to-local scale which demands a spatial analysis at a higher detail level.

[1] For more information on the UN-REDD programme in Vietnam, see http://www.un-redd.org/UNREDDProgramme/CountryActions/VietNam/tabid/1025/language/en-US/Default.aspx [Accessed July 29, 2012].

1.2 Objective of the study and main research questions

The aim of this study is to provide better insights into the future development of land-use change in Vietnam and analyse how this relates to climate change and food security in Vietnam. Main research questions that will be addressed are:

- What is the impact of socio-economic development on land use and land-use change for the period 2010-2030 under alternative futures, including climate change?
- What is the spatial pattern of land-use change in Vietnam?
- What are the implications for food security and GHG emissions?

1.3 Approach

This study applies an innovative assessment method which integrates a global macro-economic Computable General Equilibrium (CGE) model with a 'local' spatial land use allocation model to analyse future land use patterns in Vietnam under various scenarios. It adds to the existing CGE studies on Vietnam that have generally focused on the economic impacts of trade liberalisation, with a few focusing on the environment and natural resources (World Bank, 2010; Coxhead and Van Chan, 2011). These studies, however, use a single economic modelling approach and are therefore unable to derive impacts on land-scape-level land-use changes and are missing out potentially important feedback effects (e.g. areas that become more vulnerable to climate change are likely to become less food secure). Similarly, the national scope of these studies misses out important global effects (e.g. via the channel of trade). Our study also contributes to existing modelling studies in terms of improving country data for Vietnam, most notably data and projections for land use and improved modelling of the land market. A final contribution lies in the participatory approach through which the scenarios carried out in this study have been formulated. Specifically two workshops were held which informed the model set up, data used and construction of the scenarios to be analysed. The results of this exercise are therefore particularly useful to inform policies concerning economic growth, food security, climate change, REDD, land use, green growth and climate smart agriculture in Vietnam.

The global-to-local model combination is used to implement three scenarios for the period 2010-2030:

1. Baseline scenario, reflecting 'Business As Usual' (BAU), simulates an economic growth path for Vietnam and the rest of the world assuming no implementation of new policies;
2. High Climate Impact (HCI) scenario, which reveals the consequences of climate change on Vietnam's economy and land use (modelled primarily through yields);
3. High Economic Growth (HEG) scenario, which implements the growth target incorporated in the Socio-Economic Development Strategy (SEDS, 2010) of Vietnam and yield targets of Vietnam's Agricultural Development Plan (NIAPP, 2011).

1.4 Structure of the report

This report is organised as follows. Chapter 2 presents the methodological approach of the study, including a description of the models and data used. Chapter 3 summarises the global and local drivers of land use followed by a discussion of the three scenarios that have been formulated in Chapter 4. Chapters 5 and 6 present the results of the scenario analysis for socio-economic and landscape development, respectively. Chapter 7 analyses the impact of climate change, in particularly looking at flooding and emissions. Chapter 8 summarises and discusses the results of the previous chapters along four themes: socio-economic development, land-use change, climate change and food security in the context of Vietnam. Finally, Chapter 9 presents conclusions and policy implications.

2 Methodology and data

2.1 Scenario development and model framework

The methodology used in this study is designed to quantify the impact of both global and national drivers and policies on land use in Vietnam up to 2030 using a number of scenarios. It builds upon the innovative work of Van Meijl et al*.* (2006) and Verburg et al*.* (2006; 2007) to model land-use dynamics in Europe under various scenarios. This study presents the first application to a developing country. Figure 2.1 presents the overall methodology.

To explore future trends and dynamics, the development of scenarios is very useful to address possible uncertainties and enable policy analysis. Scenario analysis is commonly used in environmental impact assessment studies which need to take into account the complex and uncertain interplay between climatic, economic, technological and political factors (Alcamo, 2008a). In such a setting simple projections only based on historical trends are of limited use. Scenarios are not equal to forecasts, which give only the most likely future. Instead, scenarios are storylines with a coherent set of assumptions that together describe potential but plausible futures. They are a tool to help thinking how the future might unfold, given certain assumptions and guide the formulation of policies that are contingent on future expectations. There are several scenario typologies available that can be characterised by different facets (Börjeson et al., 2006; Westhoek et al., 2006): e.g. exploratory versus policy-oriented; participatory versus desktop and qualitative versus quantitative. For this study the choice was made to use a combination of approaches, namely: (1) to put uncertainty central, in the form of climate change impacts; (2) to focus on policy options for the Vietnamese government including most important policy plans; and (3) to have a strong participative approach including most important Vietnamese stakeholders. As part of such a participative approach, two workshops were organised to discuss assumptions, define and refine the scenarios and model set up, and discuss available data for the analysis.[1]

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1 The first 'scoping' workshop was held in Hanoi, 12-13 October 2011, and focused on the formulation of scenarios to be analysed, the modelling assumptions and improving the land-use data. The second 'scenario' workshop was held in Hanoi, 22 March 2012, and focused on discussion of preliminary results and further refinement of the scenarios.

Box 2.1	Global CGE models and the assessment of climate change, food security and land use

MAGNET/GTAP belong to the class of global computable general equilibrium models. The main advantage of CGE models is their ability to simulate the interaction of all sectors (i.e. agriculture, manufacturing and services). Hence they capture the impact of non-agricultural sectors on agriculture, something which is not possible with partial equilibrium models that only cover one or a limited number of markets. In a CGE model it is assumed that all markets are in 'equilibrium', meaning that demand is equal to supply throughout the (global) economy. Markets are cleared by means of a price movement - a price increase in the case of excess demand and a price decrease in case of excess supply. Global CGE models are specifically designed to simulate the interaction and interdependence of multiple economies by combining relationships between actors and markets within the economy with actors and markets in other economies via bilateral trade. This cannot be done with single economy CGE models that reflect the structure of one country.

Global CGE models such as GTAP and MAGNET have been used extensively to model trade liberalisation in in the context of various WTO negotiation rounds. However, recently they are increasingly applied to assess the economic impact of major global issues such as climate change, transition to bio-fuels, food security and land use. The models are often combined with scenario analysis to undertake counterfactual analysis (e.g. 'what if' questions) or deal with long-run uncertainties by using a set of exploratory scenarios. Prominent examples of this approach are the analysis of the European biofuel directive on indirect land-use change (ILUC) and the impact of climate change on food security under the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES).

Source: Hertel (1997), Francois and Reinert (1997), Parry et al. (2004) and Banse et al. (2011), https://www.gtap.agecon.purdue.edu/ [Accessed April 7, 2012].

The second step in the approach is the application of models to quantify the scenarios. No single model is able to capture the impact of global and local drivers of land-use change. For this reason, two models are combined: the global economic model MAGNET and the spatially explicit land use allocation model CLUE.

MAGNET (Modular Applied GeNeral Equilibrium Tool) is a computable general equilibrium (CGE) model based on the Global Trade Analysis Project (GTAP) model that is widely used by national governments and international institutions to simulate the impact of trade policies, climate change and land use issues on global economic development. MAGNET has been expanded relative to the standard GTAP model by adding a more sophisticated specification of the land market. The model has been applied to analyse the medium and long-run effects of global and EU agricultural, trade, land, and biofuels policies (Francois et al., 2005; Van Meijl et al., 2006; Banse et al., 2008). Box 2.1 provides more information on GTAP and MAGNET.

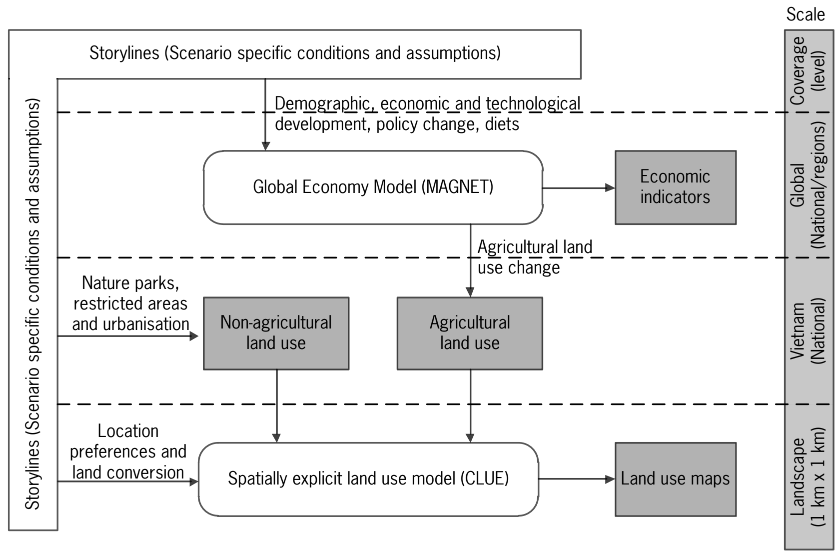
In this study, MAGNET will be used to isolate the effects global socio-economic drivers on the Vietnamese economy and the associated demand for land by agricultural sectors towards 2030. The most important inputs for the model are global demographic, macro-economic and technological developments (including yields) but also assumptions on trade policy and food consumption patterns. The model also takes into account the relations between the manufacturing, services and agricultural sectors that indirectly affect the demand for land in an economy. At the same time it also captures the impact of Vietnamese economic development on other countries, for instance, by means of changes in imports and exports. Appendix 1 provides detailed information on the structure and assumptions of MAGNET. The main output of the model is a set of important economic indicators that describe the development of the Vietnamese economy for the period 2010-2030 and the interaction with other countries. These indicators cover structural change, sectoral growth, employment, prices and trade.

In line with the expectations on economic growth and development, MAGNET also determines the need for land. However, as the lowest level of aggregation is the country or regional level, MAGNET is not able to show spatial dynamics of land-use change such as, the emergence of new urban clusters, the specific conversion of one land class into another (e.g. the conversion of natural forest into agricultural land) and the location of specific types of land, such as protected parks. Precisely this type of information is essential for the assessment of climate change on food security (for instance the vulnerability of paddy rice areas to flooding) and the formulation of rural development and biodiversity policies. Furthermore, CGE models like MAGNET only provide information on economic activities and the resulting demand for agricultural land. They do not directly assess the impact of economic development on non-agricultural land such as natural forest, built-up land, and shrub land, which is the combined result of spatial policies (protected areas, land use targets and infrastructure), natural succession and pressure from the expansion of agricultural and production forest land.

CLUE, or the Conversion of Land Use change and its Effects model (Verburg et al., 2002), is linked to the MAGNET model to downscale the aggregate land-use information at the level of Vietnam (national level) from MAGNET to the landscape (local) level with a resolution of 1 by 1 km. The CLUE model is frequently applied to study land-use dynamics at the regional and national level, and has been implemented in several studies, including in Vietnam (Verburg, Overmars, et al., 2006; Castella et al., 2007). CLUE allocates future land-use change by combining spatial and non-spatial data on the bio-geophysical and human drivers of agricultural land use with current land-use maps and incorporating assumptions on land-use conversion and spatial policies. At the spatially disaggregated level, location characteristics such as the type of soil, slope and proximity of infrastructure and populated areas, are important drivers of land use and land-use change. By statistically linking GIS data on location characteristics with current land use, CLUE is able to identify the most suitable location for different types of land-use classes (see Appendix 1 for detailed information). In this study seven different land-use classes are identified (Table 2.1). Land use scenarios are quantified into land-use change demand tables and used as input to simulate future land use for each scenario. Probability ('suitability') maps can be generated by the model for each land use type showing a suitability distribution that will be used to determine future allocation. Part of the scenario information on aggregated land-use change is derived from MAGNET, such as the expected change of paddy rice and production forest land. The future demand for built-up land is based on additional information sources with projections on population growth and urbanisation. For all land classes assumptions are made about the expansion or contraction over time and the time it takes to convert one land class into another. For some land-use classes land conversion can be achieved within a short time frame (e.g. from natural forest to crop land), while for others this will be more time consuming (e.g. from pasture to commercial forest) and for yet others it might be impossible (e.g. from urban land to forest). The CLUE model provides a future land-use maps per scenario with a resolution of 1 by 1 km for each year within the period 2008-2030.

Finally, the outcome of the combined model simulations are a number of indicators that can be used to assess the possible impacts of each scenario. Indicators include macro-economic figures that reflect changes in socio-economic drivers such as food price changes, trade and sectoral development in Vietnam and the rest of the world, as well as output that reflects physical land change itself, such as land-use maps. In the following chapters, land-use maps are combined with flood maps and GHG emission data to analyse the impact of climate change.

Figure 2.1 **Overall representation of the methodology**



2.2 Data

2.2.1 Economic data

MAGNET has been estimated (calibrated) using the most recent GTAP database version 8, final release. The database contains consistent information on the economic structure of 129 countries and/or regions for the year 2007.[1] For each country that database includes data on 57 sectors, trade, tariffs and protection, taxes, skilled and unskilled labour, capital, natural resources and land use. For the purpose of this study, the GTAP database has been aggregated in more manageable categories, namely fifteen regions and twenty-three sectors (Table 2.1).

Vietnam is specified separately, as are its most important neighbouring and trading partners. The sectoral division distinguishes twelve agricultural

[1] Since the base year of the GTAP database is 2007, the model is first projected towards 2010 using historical information on economic and population growth. In the next step the different scenarios are simulated up to 2030.

(land using) sectors available in GTAP at the highest level of detail, including eight crop sectors, two livestock sectors, two animal produce sectors, a commercial forestry sector[1] and a fishing sector. Furthermore, six processed food categories are distinguished, which have strong links with the aforementioned primary sectors, and aggregate the remaining sectors into lumber industry (which is the destination of most of the commercial forestry sector's output), other manufacturing and services categories. The model retains the standard GTAP specification of five factors of production, including skilled and unskilled labour, capital, land and natural resources.

Table 2.1 MAGNET countries/regions and sectors and CLUE land classes

MAGNET						**CLUE**	
Countries/regions			**Sectors**			**Land-use classes**	
1	eu27	EU27	1	pdr	Paddy rice	1	Paddy rice
2	fsu	Former Soviet Union exclusive Baltics	2	wht	Wheat	2	Other agriculture
3	roe	Rest of Europe	3	gro	Cereal grains nec	3	Production forest
4	nam	North America	4	v_f	Vegetables, fruit, nuts	4	Non-production forest
5	csa	Central and South America	5	osd	Oil seeds	5	Shrub and grassland
6	mena	Middle East and North Africa	6	c_b	Sugar cane, sugar beet	6	Built-up land
7	ssa	Sub-Saharan Africa	7	pfb	Plant-based fibres	7	Other land
8	vnm	Vietnam	8	ocr	Other crops		
9	asean	rest of ASEAN	9	ctl	Cattle: sheep, goats, horses		
10	chn	China (+ Hong Kong, Taiwan and rest of East Asia)	10	oap	Animal products nec		
11	kor	South Korea	11	rmk	Raw milk		

[1] Commercial forestry or productive forestry, as opposed to natural forests, produces an economic output, timber, using scarce resources, most notably land, for which it competes with the agricultural sector.

Table 2.1	MAGNET countries/regions and sectors and CLUE land classes (continued)						
MAGNET						**CLUE**	
Countries/regions			**Sectors**			**Land-use classes**	
12	jpn	Japan	12	wol	Wool, silk-worm cocoons		
13	ind	India	13	frs	Commercial forestry		
14	rsa	Rest of South Asia	14	fsh	Fishing		
15	oce	Oceania	15	pcr	Processed rice		
			16	cmt	Cattle & meat products		
			17	vof	Vegetable oils & fats		
			18	mil	Dairy products		
			19	sgr	Sugar		
			20	fbt	Food, bev & tobac prod nec		
			21	lum	Wood products		
			22	mnf	Other manufacturing		
			23	Svc	Services		

2.2.2 Land-use data

The land-use data in MAGNET are derived from the GTAP database, which contains global land-cover data for 2004, prepared by SAGE (Centre for Sustainability and the Global Environment). This information has been updated to the base year 2007 by using the percentage change of harvested land area between 2004-2007 using FAO data. In a second step the land-cover data, which comprise seven classes, has been distributed over the twelve agricultural sectors in GTAP using information on harvested area from FAO, value added data and additional information from the Dynamic Global Timber market Model (DGTM) database. Lee et al. (2009) provide more information about the land-cover database and the linking procedures that are used by GTAP.

The land-cover data in the GTAP database is compiled from global sources and therefore lacks certain detail at the country level (e.g. paddy rice area). Moreover, it is only available in an aggregate form and therefore cannot directly be used as input for the landscape analysis with CLUE. For this reason, additional and spatially disaggregated data were collected to improve the land-use data for Vietnam. However, a major problem is the inconsistency in the classifications and methods between the two map sources of land use information: the Forest Inventory and Planning Institute (FIPI) under the Ministry of Agriculture and

Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE), which produce on a regular base a land-cover map and a land-use map respectively (see Box 2.2). The most recent finalised and available FIPI land-cover map is for the year 2007 while the available MONRE land-use maps are from 2005 and 2010. A detailed comparison found inconsistencies between the MONRE digital maps on the one hand, and the FIPI map and the land use survey data that accompanies the MONRE land-use map, on the other hand.[1] For this study the FIPI-2007 map is preferred over the MONRE-2005 and 2010 maps because the latter allocate an unrealistically small area to paddy rice, one of the key agricultural sectors in Vietnam. This choice is strengthened by the observation that overall the FIPI map is more in line with the MONRE-survey. Nonetheless, a comparison with population density maps (Appendix 2) also pointed out a potential problem with the FIPI map. The analysis reveals a mismatch between the location of the major cities, in particular Hanoi, and that of built-up land, where one would expect more overlap. All these issues raise questions about the quality of the land-use maps in general and are reason for concern. This must be taken into account when interpreting the results of the land use analysis.

A disadvantage of the FIPI map is the limited detail on the agricultural sector and incomplete information on the use of forest land which might lead to inconsistencies. The Vietnamese Law on Forest Protection and Development (No. 29/2004/QH11), distinguishes between three types of forests: Protection forest, Production forest and Special use forest (i.e. forest in natural parks and protected areas), which are also used in the land-use classification of MONRE (see Table 3.4).[2] The FIPI map only includes information on the types of forests (e.g. bamboo, coniferous and plantation forest) but not how they are used.

To match the spatial land use information with the MAGNET results a two-step procedure is applied. First, additional GIS information on protected areas, collected from a number of external sources, is overlaid with the FIPI map to identify the Special use forest areas (see Section 3.2.2). Next, the 118 lower level land classes in the FIPI map are aggregated to seven broad land classes based on the land class description. There are three agricultural classes, name-

[1] The research team encountered various versions of the MONRE map. It is possible that the maps which were eventually compared with the FIPI 2007 still included errors that have been removed in 'final' versions.

[2] According to the law, Protection forests are mainly used 'to protect water sources and land, prevent erosion and desertification, restrict natural calamities and regulate climate, thus contributing to environmental protection'.

ly Paddy rice, Other agriculture and Production forest, and four other land classes: Non-production forest, Shrub and grassland and Other land (including rivers, canals and streams, swamps, and rock land). Unless otherwise noted, the so-called Special use forest and other protected areas are not affected by land-use change and are therefore merged with the Other land class which remains constant over time. The area for Production forest is derived by summing all forest types that would normally be used for production purposes. Non-production forest is defined as the areas with forest that are not classified as Production forest or Special use forest. Examples of Non production forest are natural and regenerated forest.

An overview of land-cover and land-use data for Vietnam by source is displayed in Table 2.2. To ensure consistency between the global-to-national modelling with MAGNET and the national-to-local modelling with CLUE, the same map is also used as a base map for the spatial analysis. In the second step, similar to the construction of the GTAP database, additional information on harvested area and value added is used to distribute land cover over the agricultural subsectors. Finally, the GTAP land-cover data for Vietnam is replaced by those derived from the FIPI land-cover map.

Box 2.2	**Land-cover and land-use data for Vietnam**

For land management purposes, there are two official land-use classifications in Vietnam. One is mainly used by the General Department of Forestry (GDOF) and Forest Inventory and Planning Institute (FIPI), both under the Ministry of Agriculture and Rural Development (MARD) to manage forest resources. The other belongs to the General Department of Land Administration (GDLA) that is part of the Ministry of Natural Resources (MONRE) and focuses on land use planning and management. FIPI produces a land-cover map which combines information from field surveys and remote sensing. GDLA/MONRE does not use remote sensing information but conducts land-use inventories every five years based on the National Land Registration System, ground surveys and annual land use statistics to prepare a land use-map. In line with their objectives, the GDOF classification provides a lot of detail with respect to types of forestry cover (14 types) while the GDLA classification is more extensive on broader land use purposes, distinguishing for example between production and protected forest and various categories for built-up land. Surprisingly, both classifications include a separate class for paddy rice but do not present information on any other specific crop except for broad categories such as perennial crops in the case of the GDLA classification. Both MONRE and MARD have acknowledged the need to create one integrated national land classification system, but until present progress has been limited.

Box 2.2	Land-cover and land-use data for Vietnam (continued)

Table 2.2 presents a comparison between the various sources of land-cover and land-use data in Vietnam. Roughly, the distribution of major land use groups: agriculture (paddy rice plus other agriculture), forest (production forest, non-production forest and special use forest) and other land (shrub and grassland, built-up land and other land) are similar in the Vietnamese data sources. The GTAP database shows a different pattern as it allocates a relative large area to (production) forest and a zero share to other land. Differences between the Vietnamese data sources are mainly caused by differences and contradictions between the GDOF and GDLA classifications. For this study the FIPI map is selected over the MONRE map as it is provides more realistic information on paddy rice land and overall is more in line with the MONRE-survey.

Table 2.2 Comparison of land-cover and land-use sources (%)

Land-use class	FIPI map (2007)	MONRE map (2010)	MONRE survey (2010)	GTAP (2007)
Paddy rice	16	7	12	- b)
Other agriculture	16	26	18	28
Production forest	22	18	22	35
Non-production forest	13	16	18	21
Special use forest a)	6	5	6	- c)
Shrub and grassland	19	8	9	14
Built-up land	3	12	8	1
Other land	6	8	6	0
Total	100	100	100	100
Total land area (km^2)	332,910	321,231	330,957	332,910

a) Special use forest refers to forest that is located within protected parks and nature reserves; b) Part of other agriculture; c) Part of Non-production forest. GTAP does not provide information on the non-production forest area. This has been estimated using information on the total land area from the GDOF digital map.
Source: Hoang et al. (2010), GIS and survey data from MARD and MONRE, GTAP database.

2.3 Limitations and challenges

The particular scenario methodology that is adopted for this study resembles what Alcamo (2008b) has termed the Story And Simulation (SAS) approach, which combines participatory and analytical methods of scenario building. The core of the approach is: (1) the development of qualitative 'storylines' that describe potential futures during a series of workshops and meetings with the active involvement of stakeholders and experts, and (2) the quantification of the storylines with the use of models to make the various pathways explicit by means of numerical data. The complete procedure also includes several steps with feedback loops and re-iteration to revise the storylines and model quantification and enhance their coupling. For this study, roughly similar steps were taken and two workshops were organised to inform the scenarios and share preliminary results. Nonetheless, due to limited resources, the SAS approach could not be followed in detail.

Alcamo (2008b) highlights the strengths and weaknesses of the SAS approach. One advantage of the approach is that it leads to the formulation of scenarios that are relevant to policy and science as stakeholders are given the opportunity to influence the scenarios and verify the applicability of the models. For example, one outcome of workshops that were organised as part of this study was the need to take into account information from SEDS and the Agricultural Development Plan (NIAPP, 2011). Furthermore, detailed information on the functioning of the land market in Vietnam directly influenced the design of the models used. The active involvement of policymakers, stakeholders and experts in the scenario building process also adds to the legitimacy of the scenario exercise. Finally, the use of state-of-the-art computer models that are often published in scientific literature combined with expert knowledge offers a consistency check on the scenario narratives and enhances the credibility of the analysis.

A serious problem in the SAS approach is the translation of qualitative knowledge into quantitative knowledge and back again. Scenario storylines consist of rich narratives or even diagrams and pictures that describe a complex system of global and local drivers and usually do not contain numerical information. To quantify this information in such a form that it can be fed into the models requires considerable abstraction and sometimes bold assumptions that are not easy to make and, perhaps, are not always transparent. For example, due to the nature of the economic model it is not possible to assess all channels through which climate change affects the economy, such as the impact of extreme weather events (e.g. typhoons and storms) and an increase of livestock deaths as a consequence of heat stress. Also the modelling of the forestry sector and the demand for forest land can be improved by collecting better spatial data on forest land and taking into account the age structure and rotation period of production forest and plantations (Sohngen et al., 2009).

Finally, a limitation of the methodology is the top-down linking of the economic (MAGNET) and spatial land use (CLUE) model. It is likely that the expansion of crop and commercial forestry land will result in lower (average) yields because less fertile (shrub) land is taken into production. Furthermore, land-use change and potential deforestation might contribute to climate change through emissions, in turn affecting yields. With the current model set-up, these feedback loops cannot be taken into account.[1]

[1] Large integrated assessment models, such as the IMAGE model of the Netherlands Environmental Assessment Agency that has been used for the Millennium Ecosystem Assessment (Carpenter et al., 2005), are better able to capture the interaction between climate change and land-use change. However, this type of model operates at a much coarser scale and therefore is less suited for national and local analyses.

3 Global and local drivers of land use in Vietnam

Land-use change is a complex phenomenon that directly and indirectly is influenced by multiple socio-economic and bio-physical driving forces that operate over different scales. There are several ways to classify drivers of land use. First, some drivers, such as demographics and location characteristics (e.g. slope, soil quality and weather) operate largely independently of policy making, while others, such as climate change and technical change, policy has an impact but mainly in the long term (10-20 years horizon). It is common practice to treat these drivers as exogenous and use projections as input to the model analysis. They can be distinguished from policy instruments such as agricultural policy (e.g. price and income support to farmers), trade policy (e.g. tariffs and quotas guided by international trade agreements) and environmental and spatial policy (e.g. establishment of protected park, urban areas and industrial zones), which have an intermediate or medium term effect (5-10 year horizon). Second, one can use scale (e.g. global, national and landscape) to classify drivers of land-use change.

In line with the modelling framework and the objective of this project to analyse land-use change in Vietnam, the second classification is used in the remainder of this report. The list of main global and local drivers of land use is based on similar studies that analysed land-use dynamics in Europe (Nowicki et al., 2006; Van Meijl et al., 2006; Verburg et al., 2007). This chapter briefly reviews historical trends and existing policies of these driving forces with a focus on Vietnam. The next chapter discusses the assumptions for each of these driving forces as part of the various scenarios that are simulated.

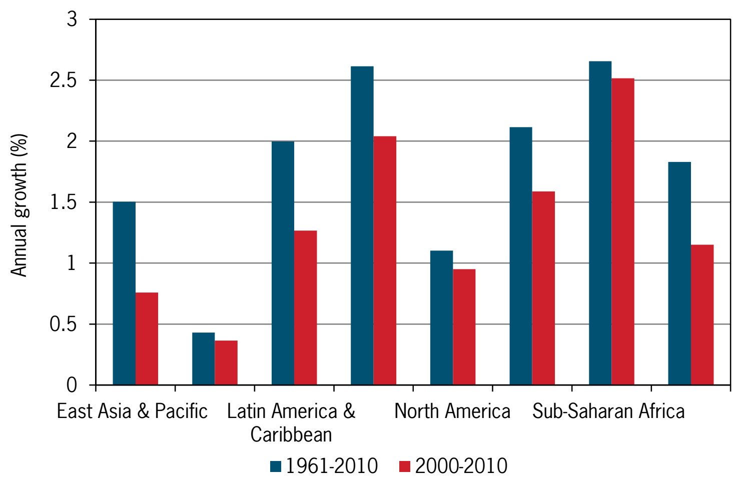
3.1 Global land-use drivers and trends

3.1.1 Population growth

According to the United Nations, the world population is expected to reach 9.3 billion by the middle of the century (United Nations, 2011). To feed all these people, the FAO (Bruinsma, 2011) has estimated that overall food production needs to be increased by at least 70% over the period 2005-2050. Recently, Tilman et al. (2011) looked in detail at the per capita demand for crops measured as caloric or protein content of all crops combined and even revised this figure upwards to 100-110%.

Figure 3.1 depicts historical trends for population growth for selected regions as well as Vietnam for the period 1961-2010 and the most recent decade. With around 2-2.5%, population growth has been the highest in low/middle-income regions (Latin America and the Caribbean, Middle East and North Africa, South Asia and Sub-Saharan Africa) also including Vietnam, while growth has been around 0.5-1.5 in the high income regions (East Asia and Pacific, European Union and North America). In all regions, population growth has been slowing over the last decade. The decrease was particularly pronounced in Vietnam where population growth decreased from an average of 1.8% in 1961-2010 to 1.2% in 2000-2010. Except for Sub-Saharan Africa, the downward trend in population growth is expected to continue between 2010 and 2030 in all regions.

Figure 3.1 **Population growth, 1961-2010**



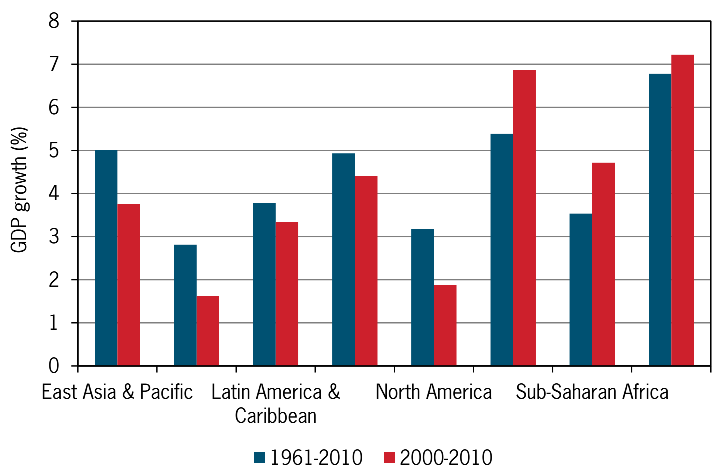
Source: World Bank (2012).

3.1.2 Macro-economic growth

In addition to population growth, macro-economic growth is another key driving force of demand for agricultural production and resulting land-use change. The development process is characterised by a rise in income, changing diets, and a process of structural transformation from agriculture towards manufacturing and services, which together result in a greater demand for food, feed, fuel and fibre. In addition, the recent awareness that the supply of fossil fuels is limited has led to an increasing global demand for feedstock, mainly maize and sugar cane, to produce biofuels.

Figure 3.2 shows figures for historical trends of GDP growth. Global economic growth has been unequally distributed between regions of the last five decades. High- and middle-income regions such as the European Union, North America and Latin America and the Caribbean have experienced relative low rates of growth rate of around 3 to 5%, while developing regions have achieved rates in the region of 5%. Only Sub-Saharan Africa has lagged behind with a growth rate of 3.5%. Vietnam is among the fastest growth countries in the world with a GDP growth of near 7%. The process of catching up has been even more evident in the past ten years, during which rich countries have experienced a slump in economic growth, partly caused by the financial crisis, and in particular South Asia (including Vietnam) and Sub-Saharan Africa have accelerated economic development. The economic growth pattern for the coming 30 years is expected to be similar to in the past decade. Rich economies will grow much slower than emerging economies, in particular India, China and Vietnam, but also Sub-Saharan Africa, which will reach growth rates of 4.5% to 7.5% (see Figure 4.1 below).

Figure 3.2 **GDP growth, 1960-2010**



Source: World Bank (2012).

3.1.3 Consumer food preferences

Urbanisation and rising incomes worldwide are accompanied by changing dietary patterns, also called the nutrition transition. Specifically, diets are observed to change towards increased intake of high energy-dense and low nutrient-dense foods (e.g. fried foods or fast food) that are high in fat and sugars but low in vitamins, minerals, and other micronutrients. This transition is accompanied by a trend towards decreased physical activity due to the increasingly sedentary nature of jobs, changing forms of transportation, and increasing urbanisation. The nutrition transition has given rise to a shift in the disease pattern from infectious to chronic diseases, not only in developed countries but increasingly so in developing countries, entailing high human suffering and high cost to society. Table 3.1 shows trends in the consumption of meat, projected up to 2050.

Table 3.1 Meat consumption (kg/person/year) by region, 2000-2050

Region	2000	2050
Central and West Asia and North Africa	20	33
East and South Asia and the Pacific	29	51
Latin America and the Caribbean	58	77
North America and Europe	83	89
Sub-Saharan Africa	11	22

Source: Rosegrant and Thornton (2008).

3.1.4 Yield growth

An increase in yield, measured in tonnes per hectare, is essential to fulfil the increasing demand for food, feed, fuel and fibre that is spurred by population growth, macro-economic growth and change in consumer preferences. Table 3.2 shows the average annual yield growth of various crops between 1961 and 2010 for selected regions. The selected crops are representative for the eight agricultural crop sectors that are analysed by the CGE model (see Table 2.1). They include the principal cereals that dominate human diets (rice, wheat and maize) and important feedstock for biofuels (maize and sugar cane). For almost all regions and crops, yield has been increasing over time but considerable differences remain across countries. Vietnam has achieved high yield growth rates, in particular for rice, the main staple and export crop, but also for maize, sugar cane and cotton. Agricultural productivity growth only accelerated in the 1980s as a consequence of the market reforms, decollectivisation and liberalisation in the 1980s that were part of the Doi Moi process (Pingali and Xuan, 1992). Overall, developing countries experienced a sharp increase in yield growth during the Green Revolution period of the late 1960s, but exhibit a decline from the mid-1980s to the most recent decade. There is evidence of a gradual slowdown in yield growth for most crops in both developed and developing countries (Fischer et al., 2009), also confirmed by the lower figures for most regions and crops for the period 2000-2010. This trend is expected to continue in the future due to decreasing availability of arable land and constraints in reaching attainable yields in each country and agro-ecological zone. On average, global annual yield growth for major crops in the future is expected to be half the historical rate of 1.7% (2.1% for developing countries) to 0.8% (0.9% for developing countries) for the period 2005/07-2050 (Bruinsma, 2011).

Table 3.2 **Average annual yield growth (%), various crops, 1961-2010**

	Paddy rice		Wheat		Maize		Potatoes	
	1961-2010	2000-2010	1961-2010	2000-2010	1961-2010	2000-2010	1961-2010	2000-2010
Africa	1.09	0.98	3.20	3.56	2.33	1.46	1.06	2.22
Asia	1.83	1.21	2.92	1.09	3.05	2.59	1.20	1.06
European Union	0.93	0.93	2.47	0.98	3.05	3.46	1.62	1.36
Northern America	1.50	0.77	2.05	1.65	2.85	1.42	1.43	0.45
Oceania	3.66	7.58	6.71	9.46	2.99	1.65	2.04	1.67
South America	2.09	2.32	2.90	3.89	2.96	4.79	1.73	1.56
South-Eastern Asia	1.97	1.58	6.25	5.51	3.10	4.08	2.51	1.31
Vietnam	2.31	2.42	-	-	3.26	4.96	0.75	0.34

Note: The crops are representative of the eight agricultural crop in the CGE model: Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibres and Other crops nec (see Table 2.1); Due to limited production yield data are missing for some regions and time-period combinations.
Source: FAO (2012).

Table 3.2	Average annual yield growth (%), various crops, 1961-2010 (continued)							
	Paddy rice		**Wheat**		**Maize**		**Potatoes**	
	1961-2010	**2000-2010**	**1961-2010**	**2000-2010**	**1961-2010**	**2000-2010**	**1961-2010**	**2000-2010**
	Soybeans		**Sugar cane**		**Seed cotton**		**Roots and Tubers, nec**	
	1961-2010	**2000-2010**	**1961-2010**	**2000-2010**	**1961-2010**	**2000-2010**	**1961-2010**	**2000-2010**
Africa	3.17	2.66	-0.16	-1.37	1.33	0.63	2.54	3.67
Asia	1.96	0.77	0.76	0.43	3.24	3.05	0.93	-0.49
European Union	6.14	3.02	1.61	-1.19	2.39	-1.37	2.14	-0.45
Northern America	1.67	1.71	-0.53	-1.80	1.87	2.18	-	-
Oceania	5.36	2.53	0.95	-1.11	10.07	1.99	-0.26	-0.38
South America	2.55	2.98	1.02	1.46	3.18	3.63	0.82	2.70
South-Eastern Asia	1.57	1.43	0.14	1.77	1.86	1.07	0.79	0.78
Vietnam	2.82	2.60	1.47	1.39	6.74	4.37	-	-

Note: The crops are representative for the eight agricultural crop sectors in the CGE model: Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibres and Other crops nec (see Table 2.1); Due to limited production yield data is missing for some regions and time-period combinations. Source: FAO (2012).

3.1.5 Climate change

Climate change will have a substantial impact on future food and crop production (Easterling et al., 2007; Nelson et al., 2010), in turn affecting land use. At the same time, land-use change, in particularly deforestation, will result in the emission of greenhouse gasses and is therefore regarded as one of the major causes of climate change. This study mainly deals with the former effect, albeit that its outcomes might be used to estimate the contribution of land use, land-use change and forestry (LULUCF) to climate change. Changes in temperature and rainfall will impact on agricultural productivity, resulting in a change in the demand and use of land. Sea-level rise will affect land use along the coast and the increase of extreme weather events, pests and diseases might force farmers to reallocate or change crops. There is evidence that Vietnam will also be seriously affected by climate change. According to Vietnam's official scenario for climate change, published by MONRE (2009), the annual average temperature in the country will increase by 2.3 C° by 2100. Over the same period, average rainfall will increase by 5.8% (Table 3.3). The study also points out that extreme weather events, such as typhoons and cold surges, occurred more frequently and with higher intensity in the past and are expected to do so in the future. Finally, Vietnam is very vulnerable to sea-level rise due to its long coastline and delta structure. Dasgupta et al. (2009) find that Vietnam is among the countries most heavily affected by the consequences of sea-level rise. The country ranks first in terms of impact on population, GDP, urban extent, and wetland areas, and ranks second in terms of impact on land area (behind the Bahamas) and agriculture (behind Egypt).

Table 3.3 Impact of climate change in Vietnam, 2020-2100

	2020	2060	2100
Annual average temperature change relative to 1980-99 (C°)	0.4	1.4	2.3
Annual average rainfall change relative to 1980-99 (%)	1.2	3.7	5.8
Sea-level rise (cm)	12	37	75

Note: Unweighted average of seven Vietnamese regions for the medium (B2) scenario.
Source: MONRE (2009).

3.1.6 Trade policy

Trade policy can have major consequences on economic growth, in turn influencing the direct and indirect demand for land (Van Meijl et al., 2006; Laborde, 2011). In this study, the impact of trade policy is not addressed. It is assumed that no new multilateral or bilateral trade agreements will be signed and tariffs and non-trade measures will not change after 2007, the last year for which trade information is available in the GTAP database.

3.2 Local land-use drivers and trends

3.2.1 Historical patterns of land-use change

The economic model endogenously determines the demand for land by each of the agricultural (land using) sectors. However, information on historical land use patterns is required to model the total supply of land that is available for future agricultural production. Data on past land use trends are also useful to place the model results on future land use into perspective. Table 3.4 presents land-use data for Vietnam over the period 2000-2010. The information is taken from land-use inventories that are organised every five years by the General Department of Land Administration (GDLA), part of MONRE (see Box 2.2). The table presents five main land-use categories: Agricultural land, Forest land, Built-up land, Other land and Unused land as well as several subcategories that are used in the GDLA classification. It shows an increase in agricultural land from 96 (29%) to 102 (31%) thousand km^2, which is mainly caused by an increase in perennial crop land. However, at the same time land for paddy rice is decreasing from 45 (13%) to 41 (12%) thousand km^2. Land-use change is particularly pronounced in the Forest land class, where the total land share of production forest increased by 33% from 116 to 154 thousand km^2, which is equal to an increase from 14% to 22% of the total land in Vietnam. Also the other two forest classes exhibit a growing land use pattern. The increase in forest area is a relative recent phenomenon that started around 1995 and has been stimulated by several large-scale national afforestation and reforestation programmes to promote forest protection and development. Despite this improvement, it has been found that the quality of the overall forest is still low. The share of rich and medium forest has been reduced while regenerated and plantation forest increased (MARD, 2007).

In total 46% of the land in Vietnam is covered by Production, Protection or Special use forest. Built-up land also increased substantially from 16 (5%) to 27 (8%) thousand km^2, reflecting the growth of the urban population (see below) and a process of economic transformation in which manufacturing and services are becoming more important.

Growth in agricultural land and, in particular, (Production) forest land has been at the expense of Unused land, which decreased from 82 to 29 thousand km^2, a reduction from 25% to 9% of total land cover. The table shows a sharp decrease in the size of both Unused flat land and Unused hill-upland, although the latter is by far the largest category. The relative small share of Unused land that remains in 2010 implies that there is limited capacity to expand agricultural and built-up land in Vietnam unless other land-use classes, such as Protection and Special use forest, are converted. According to the Agricultural Development Plan to 2020 and Vision to 2030 (NIAPP, 2011) not all Unused land is suitable for expansion due to different soil types and slope. For example the expansion of paddy rice area is only possible on 10% of the Unused flat land. The projections on growth of land for agricultural production in the analysis and the spatial analysis account for the limitation of total available Unused land and location-specific conditions (e.g. slope, rainfall and soil quality).

Table 3.4	Land-use data, 2000-2010						
	Km²			**%**			**%**
	2000	**2005**	**2010**	**2000**	**2005**	**2010**	**2000-2010**
Agricultural land	95,700	94,310	101,522	29	28	31	6
Paddy rice	*44,678*	*41,653*	*41,202*	*13*	*13*	*12*	-8
Other annual crops a)	*22,918*	*22,356*	*23,697*	*7*	*7*	*7*	3
Land for cultivation of perennial crops	*28,104*	*30,455*	*36,885*	*8*	*9*	*11*	31
Forest land	115,754	146,774	153,665	35	44	46	33
Production forest	*47,341*	*54,349*	*74,318*	*14*	*16*	*22*	57
Protection forest	*53,982*	*71,737*	*57,955*	*16*	*22*	*18*	7
Special use forest	*14,432*	*20,689*	*21,392*	*4*	*6*	*6*	48
Built-up land	16,091	20,920	26,551	5	6	8	54
Land with rivers, canals and streams b)	21,493	22,347	20,831	7	7	6	-3
Unused land c)	82,174	46,860	28,744	25	14	9	-65
Unused flat land	*7,397*	*3,717*	*2,377*	*2*	*1*	*1*	-68
Unused hill-upland	*73,796*	*43,111*	*26,327*	*22*	*13*	*8*	-64
Total land	331,212	331,212	330,957	100	100	100	0

a) Includes other land for agriculture; b) Includes land for aquatic farming; c) Includes Rocky mountain without tree.
Source: MARD.

3.2.2 Protected areas

There are different types of protected areas (ICEM, 2003). MARD is responsible for the management of Special use forests, which consists of National Parks, Nature Reserves and Cultural and Historic Sites. In addition, there are also a number of Marine Protected Areas (under responsibility of MARD), Ramsar Sites, Man and Biosphere Reserves (both under responsibility of the MONRE and World Heritage Sites (under responsibility of the Ministry of Culture and Information). Most of the national protected areas in Vietnam are Special-use Forests, which are mainly comprised of terrestrial but also may include a small number of wetland sites and marine areas. Figure 3.3 shows the location of all protected areas in Vietnam. The map is compiled on the basis of data from a number of sources and therefore the classification of the areas differs from that used by the Vietnamese Ministries. In total 167 areas have been identified.

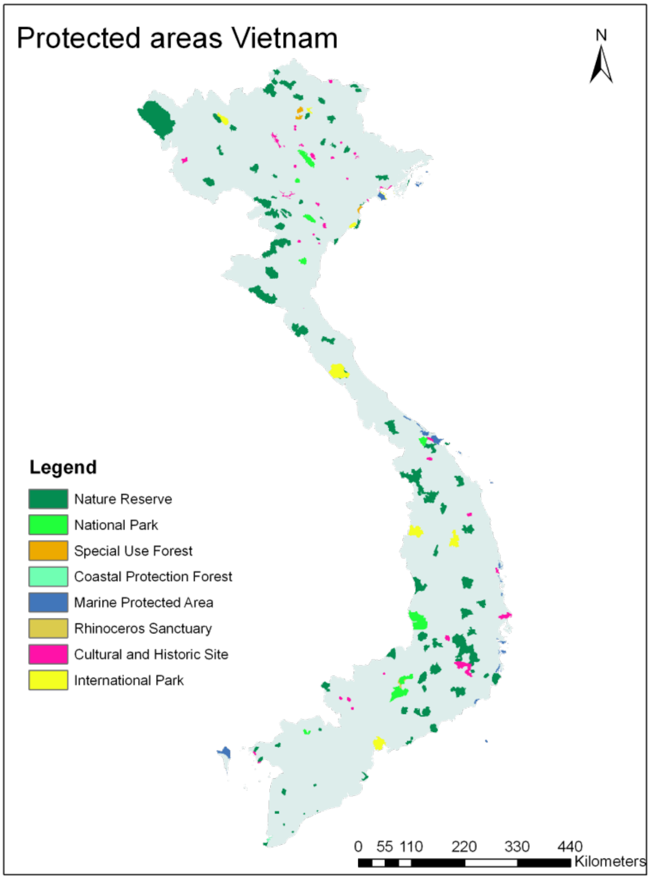
An overlay with the FIPI land-use map 2007 reveals that 32,246 km^2 or almost 10% of the total land area is located in protected areas (Table 3.5), of which 6% are forests and 2% shrub and grassland. Pursuant to the nature of protected areas the share allocated to productive land (paddy and other agriculture) and built-up land is very small. Given the large size with regard to total land area, the allocation and treatment of protected areas are an important element of spatial policy in Vietnam. In two out of the three scenarios, it is assumed that the size and number of protected areas remains constant and that conversion of protected forest and shrub and grassland to land for agricultural production is not possible. In the third scenario it is assumed that the protection of national parks and nature reserves is completely lifted and all land located in protected areas can be converted to other land classes such as paddy rice, agriculture, production forest and built-up land.

Table 3.5 Land-use classes in protected areas, 2007

Land-use class	**km^2**	**share (%)**
Paddy rice	1,166	0.4
Other agriculture	2,240	0.7
Protected/Special use forest	19,740	5.9
Shrub and grassland	5,771	1.7
Built-up land	255	0.1
Other land	3,074	0.9
Total protected areas	32,246	9.7
Total land area	332,980	100.0

Source: FIPI map 2007 and Figure 3.3.

Figure 3.3	Protected areas in Vietnam



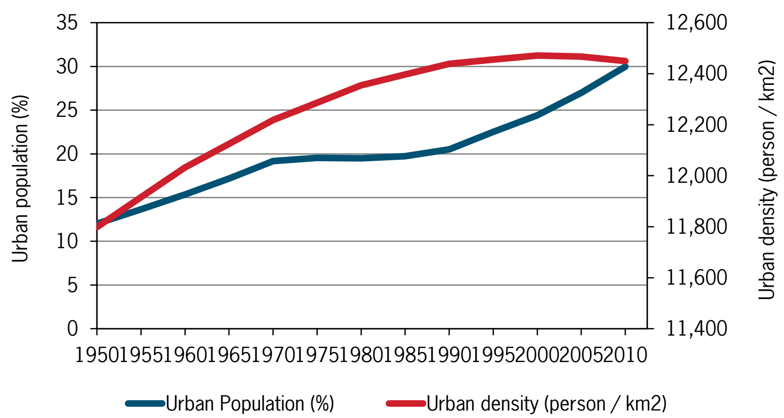
Source: ASEAN Declaration on Heritage Parks and Reserves, ASEAN Heritage Park list, Birdlife International Sourcebook of Existing & Proposed Protected Areas in Vietnam, UNESCO and World Heritage Site List.

3.2.3 Urbanisation

Urbanisation is an important driver of land-use change. As a result of economic development and modernisation, a growing share of the population is migrating from the countryside to urban areas. At the same time the population already living in urban areas is increasing as well. This results in rapidly growing cities and the establishment of industrial zones that that encroach on rural land. Already more than half of the world's population lives in urban areas and this is expected to increase to two-thirds in the future (UNDESA, 2012). Not all regions have reached the 50% level of urbanisation. It is projected that half of the population of Asia will live in urban areas by 2020, while Africa is likely to reach this level of urbanisation only in 2035. In Vietnam the share of people living in urban areas is relatively low in comparison with other Asian countries. In 2010, only 30% of the total population resided in cities and this is projected to reach more than half after 2030 (Figure 3.4 and Figure 4.5). The total demand for urban land is a function of urbanisation and urban density. Studies show that urban density can be approximated by a bell curve (Klein Goldewijk et al., 2010; OECD, 2012a), expanding up to a certain point and afterwards, with increasing incomes and mobility, decreasing again causing urban sprawl. In Vietnam urban density seems to have reached its peak around 2000 and is gradually decreasing again.

In Vietnam, the four biggest cities (Da Nang, Hà Noi, Hai Phòng and Ho Chi Minh City) already make up almost 12 million people, who represent 44% of the whole urban population. Of these cities, Ho Chi Minh City, with more than 6 million people, is by far the biggest, though Hà Noi is growing fastest at a pace of more than 4% per year (UNDESA, 2012). In the coming decades, the smaller urban centres are expected to grow faster than these four cities.

Figure 3.4 **Urban population and urban density in Vietnam, 1950-2010**



Source: Klein Goldewijk et al (2010) and UNDESA (2012).

4 Scenarios

This chapter discusses the three scenarios that were analysed with the MAGNET-CLUE model framework to study their impact on land use in Vietnam. A baseline or Business As Usual (BAU) scenario is used to reflect common expectations on how the (global) economy will develop with no new policies being implemented. This scenario acts as a reference to analyse changes in the economy and resulting land-use described by two alternative scenarios that pose a number of counterfactual 'what if' questions. First, a High Climate Impact (HCI) scenario that reveals the consequences of climate change on Vietnam's economy and land use is modelled. Second, a High Economic Growth (HEG) scenario is carried out, which implements the growth target incorporated in SEDS of Vietnam and yield targets from the Agricultural Development Plan (NIAPP, 2011) that is linked to the SEDS.[1] All scenarios cover the period 2010-2030. For each of the scenarios, the assumptions on global socio-economic drivers, the main input for MAGNET, and local land-use drivers, the input for CLUE, are briefly summarised.

4.1 The Business As Usual (BAU) scenario

Box 4.1	Business As Usual storyline
The BAU scenario reflects a future in which major socio-economic drivers follow current trends. It assumes that there are no major policy changes (e.g. WTO agreement, REDD, biofuels, etc.). Furthermore, yields will keep on increasing at the same pace as in the past. Climate change is assumed not to have any significant impact on agricultural productivity and economic growth, and extreme weather events are not an issue.	

4.1.1 Global Socio-economic drivers

The BAU scenario in MAGNET is generated using information on the expected growth path of the economy (GDP) and endowments (capital, labour, land and natural resources) over time for all countries and/or regions in the world, and the productivity of these endowments, most notably that of land, i.e. yields.

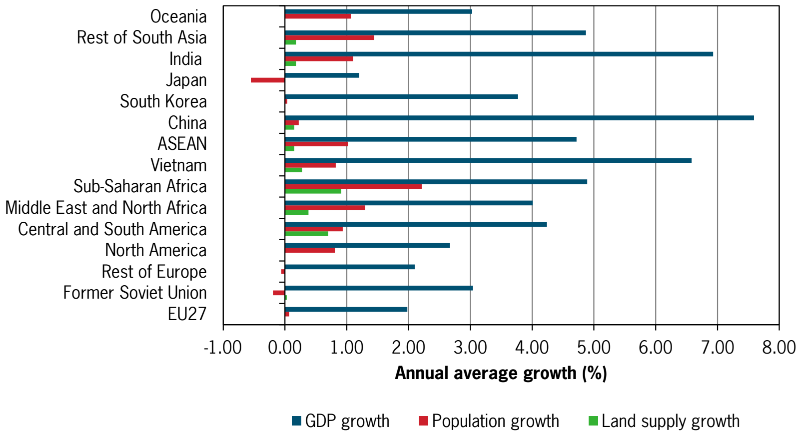
[1] The BAU, HCI and HEG scenarios were informed by a scenario building workshop that was held in Hanoi, October 2011.

This information is then used to derive the implied technological change by region, which is subsequently fixed so as to endogenously generate the targeted GDP. Technological progress is assumed to be labour saving.

For the BAU scenario projections for GDP and population growth are taken from USDA's Economic Research Service.[1] World economic growth reflects a movement back towards long-run steady growth following a slowdown as a consequence of the global recession and financial crisis. Specifically, MAGNET assumes that labour supply (skilled and unskilled) follows the growth path for population and that capital growth equals growth in GDP. The latter assumption is consistent with the stylised fact of economic growth that the capital-output ratio is roughly constant over time. Natural resources grow at a quarter of the rate of capital. Land supply growth rates (agriculture and commercial forestry) for Vietnam are based on historical rates of agricultural land expansion, drawn from GDLA land use survey (2000-2010). For the rest of the world, data are employed from Willenbockel (2011), who surveys the literature on future land-use change. Land productivity (i.e. yield) projections are included from the Dutch Environmental Assessment Agency (PBL), drawn from its IMAGE (Integrated Model to Assess the Global Environment) model and based upon FAO projections up to 2030 (Bruinsma, 2003). The baseline assumptions are displayed in Figure 4.1 and Figure 4.2 for the period 2010-2030.

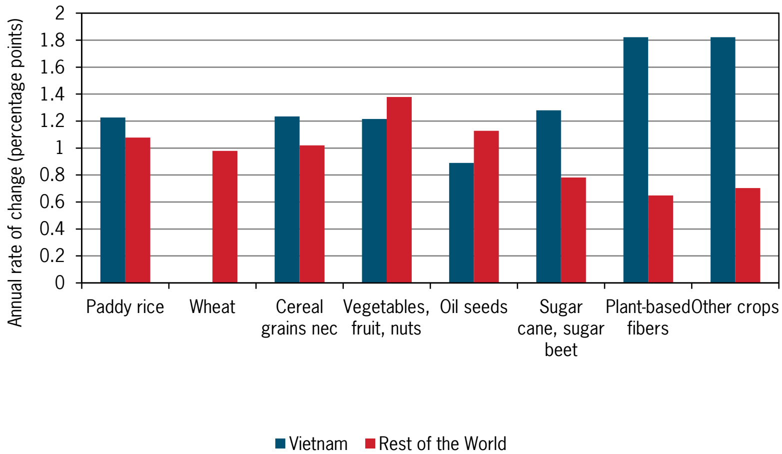
[1] Available from http://www.ers.usda.gov/data/macroeconomics/#BaselineMacroTables [Accessed May 14, 2012]. Data have originally been prepared by the US Census Bureau, which are an alternative to the United Nations World Population Prospects. Both sources provide similar trends but to maintain consistency with the GDP figures, the US Census Bureau projection is preferred here.

Figure 4.1	GDP, population and land supply growth assumptions for BAU scenario, 2010-2030



Source: GDP and population from USDA (ERS) and land supply from MONRE (Vietnam) and Willenbockel (2011).

Figure 4.2	Yield assumptions for BAU scenario, 2010-2030



Source: Bruinsma (2003).

As shown, Vietnam is expected to realise high economic growth, averaging 6.6% per year over the coming two decades, which is the third highest growth rate in the world after China (7.6%) and India (6.9%). Population growth is declining across the world, though Sub-Saharan Africa lags somewhat behind with a population growth of 2.2% per year over the period 2010-2030. Over this period, Vietnam's population is growing at a rate of 0.8% per year, lower than the rest of ASEAN, India and Rest of South Asia, but higher than in China (one child policy), Japan (which experiences negative population growth and an ageing population due to low birth rates) and South Korea. Land supply available for use in agriculture and commercial forestry in Vietnam is growing at a rate of 0.3% per year over the coming two decades. This is higher than the growth rate of land recorded elsewhere in the Southeast Asia region, and only lower than the Africa region (0.4 to 0.9%) and Central and South America (0.7%). The expected growth in agricultural land supply is based on historic trends, which show a considerable expansion of plantation forest over the last two decades as well as an increase in perennial crop area at the expense of unused land. Growth in paddy rice yields, cereal grains, sugar cane, plant based fibres and other crops is projected to be higher than in the rest of the world for the period 2010-2030. This is in line with the analysis of historical yield growth patterns in Section 0, which shows a high (relative) productivity for the same crops over the last decade.

4.1.2 Local land-use drivers

For the spatial analysis with CLUE in the BAU scenario, land use projections for paddy rice, other agriculture and production forest are taken from MAGNET. The growth of built-up land change is dependent on a combination of two factors. Projections for urban population in Vietnam are taken from the World Urbanisation Prospects (UNDESA, 2012) and is based on the proportion of the population living in urban areas. This is combined with projections on urban density (persons per m^2) from the History Database of the Global Environment (HYDE), version 3.1 (Klein Goldewijk et al., 2010). It is assumed that the land required for industrial areas, ports and military purposes growths proportionally to urban land. The increasing demand for agricultural land and built-up land will be at the expense of non-production forest, and shrub and grassland. Other land, which also includes protected areas, is not affected by pressures for more land and therefore remains constant.

4.2 High Climate Impact (HCI) scenario

Box 4.2	**High Climate Impact storyline**
The HCI scenario reflects a global future with rapid temperature change, high sensitivity of crops to global warming, and a CO_2 fertilisation effect at the lower end of published estimates. In Vietnam, extreme weather events will be more frequent resulting in flooding in the coastal areas and the Mekong River Delta. Lower yields and flood risks pose a threat to agricultural production and food security, and are expected to have a negative impact on GDP growth. No policies are implemented to mitigate or adapt to climate change.	

4.2.1 Global socio-economic drivers

In the HCI scenario it is assumed that climate change will have a major and negative effect on global agricultural productivity. The annual growth in crop yields will be lower than in the BAU for Vietnam and the rest of the world. No efforts are undertaken to mitigate the impact of climate change and farmers do not invest in new technologies or production methods (e.g. drought tolerant crop varieties or irrigation) to adapt to climate change. Furthermore it is assumed that the impact of climate change is mainly transmitted through a negative effect on yields because of changes in temperature, precipitation and hydrology. The scenario does not account for the effect of extreme weather events such as pests, diseases and typhoons on agricultural performance.

Following the approach of Hertel et al. (2010), a literature review is conducted to collect information on the impact of climate change on future crop yield in Vietnam that will be used as input for economic modelling. Table 4.1 summarises the results expressed as a yield shock with regard to a no-climate change baseline. Yield figures are estimated by means of crop models or econometric approaches under a wide variety of emission and climate change scenarios. Most studies have analysed the impact of climate change on rice and maize yields, while there are only limited findings for other crops. The table shows a broad range of estimates, ranging from -23% in the most pessimistic scenario to 28% in the most optimistic scenario for rice, while yield figures for maize range between -19% and 4%. The large differences across studies and between pessimistic and optimistic scenarios illustrate the high level of uncertainty that is associated with estimating the impact of climate change on agricultural productivity as well as differences in approach and time period covered.

The table presents a range of possible outcomes of which the extreme values can be regarded as the 5th and 95th percentile values in a distribution of potential yield impacts.[1] For the HCI scenario, the most pessimistic yield shock for each crop from is implemented to simulate the potential (maximum) impact of climate change on economic development and land use in Vietnam.[2] Zhu (2010; also see Yu et al., 2010) presents the most detailed study, covering most crops, and provides the most extreme values. This is probably caused by the methodology which involves a standard crop model and a hydro-crop model to simulate potential yields under baseline and climate change scenarios. Hence, it captures both the effect of climate change on rainfed and irrigated land. The latter is particularly relevant in Vietnam where rice production is largely irrigated.

For the Rest of the world, data are taken from Hertel et al. (2010). Figure 4.3 shows the yield shock for Vietnam and the Rest of the World expressed as percentage points (pp)[3] relative to the BAU scenario. It reveals that Vietnam is particularly negatively affected by climate change; with the exception of wheat (not grown) and other grains, yield growth is at least 0.3pp per year lower in Vietnam compared to the rest of the world. Relative to the baseline, the yield growth assumptions are scaled downwards, generating a new growth path for the Vietnamese economy, with a different land use pattern.

[1] Note that the studies in the table often present the impact of climate change on yield for a number of scenarios. Only the most extreme values are presented here. They do not necessarily relate to the same scenario.

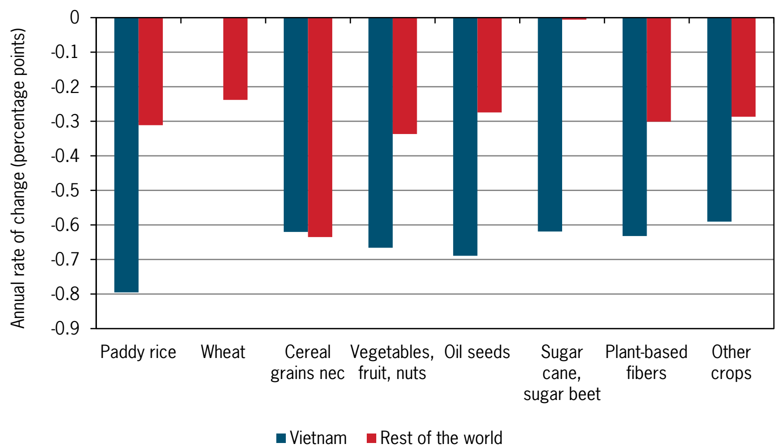
[2] In order to use the yield shock figures from the literature, annual growth rates were calculated and rescaled to match the period that is used in the analysis (2010-2030).

[3] Defined as the arithmetic difference between two percentages.

Table 4.1	Climate change impact on yields in Vietnam			
Commodity	**Yield change (%) relative to baseline**		**Horizon**	**Source**
	pessimistic	**optimistic**		
Rice	-10.27	1.7	2000-2030	Lobell et al. (2008)
	-0.21	2.34	2000-2050	Iglesias and Rosenzweig (2009)
	-12.5	-1.7	1990-2050	ADB (2009)
	-14.2	27.7	2000-2050	Mainuddin et al. (2011) a)
	-23.55	4.19	2000-2030	Zhu et al. (2010)
	0.4	2.3	2000-2050	Masutomi et al. (2009)
Maize	-5.8	-3.77	2000-2050	Iglesias and Rosenzweig (2009)
	-6.4	7.2	1990-2050	ADB (2009)
	-18.89	4.38	2000-2030	Zhu et al. (2010)
Cassava	-19.81	4.34	2000-2030	Zhu et al. (2010)
Sugar cane	-18.93	4.23	2000-2030	Zhu et al. (2010)
Coffee	-18.95	3.61	2000-2030	Zhu et al. (2010)
Vegetables	-20.83	5.33	2000-2030	Zhu et al. (2010)

a) Mekong River Delta estimations.
Source: See table.

Figure 4.3 **HCI scenario - change in yields, difference from BAU scenario, 2010-2030**



Source: Zhu (2010) for Vietnam, Hertel et al. (2010) for the rest of the world.

4.2.2 Local land-use drivers

The assumptions on land-use drivers for the HCI scenario are the same as in the BAU scenario.

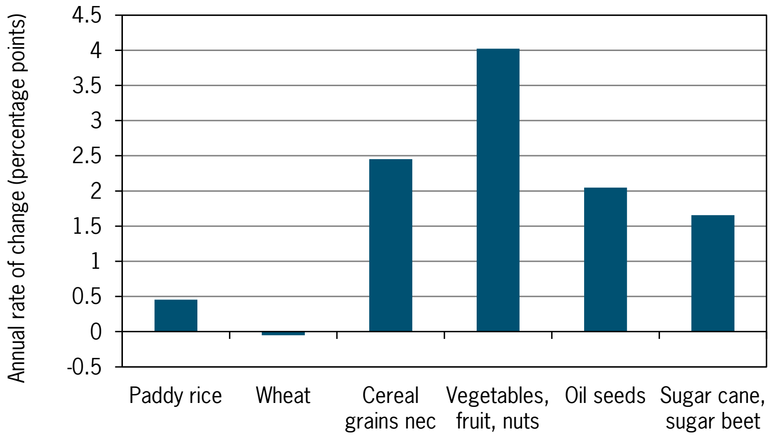
4.3 High Economic Growth (HEG) scenario

Box 4.3	**High Economic Growth storyline**
In the HEG scenario the Vietnamese economy is projected to grow at a higher pace, in line with Vietnamese official growth targets as described by the SEDS (see Box 4.4). A main driver of this growth is assumed to be growth in agricultural yields for which the projections also follow Vietnamese official targets, and technological change in the manufacturing, and to a lesser extent, service sector. Climate change is assumed to be absent. The rest of the world is assumed to grow at the same pace.	

4.3.1 Global socio-economic drivers

Under this scenario the Vietnamese economy is assumed to obtain a higher growth path, of 8% per year over the period 2010 to 2030. This is in line with the high end of the growth target of 7% to 8% formulated in the SEDS 2011-2020 (Van Chinh, 2011). With this high economic growth, the Vietnamese government aims to achieve a GDP per capita of USD3,000 in 2020. Combining GDP figures under this scenario with population estimates from USDA's ERS reveals that this target will not be met in 2020 (GDP per capita is then expected to be around USD1,800) but somewhere around 2028 assuming 8% GDP growth. A main driver of the high economic growth is assumed to be growth in yields (Figure 4.4) but also technological change in the manufacturing sector, and to a lesser extent, the service sector (in line with the distribution of productivity growth over sectors in the baseline). Yield figures are taken from the Agricultural Development Plan (NIAPP, 2011) that presents detailed land use planning for the period 2010-2020 in line with the SEDS. As shown, yields particularly grow faster in vegetables and fruits (4pp) additional growth per year relative to the baseline) and other grains (2.5pp extra growth per year), followed by oil seeds (2pp additional growth per year).

Figure 4.4	HEG scenario - change in yields, difference from BAU scenario, 2010-2030



Note: In comparison with the BAU yields do not change for plant-based fibres and other crops.
Source: NIAPP (2011).

4.3.2 Local land-use drivers

As before, land-use change for paddy rice, other agriculture and production forest is calculated by MAGNET. Similar to the BAU and the HCI scenario, built-up land is a function of the number of people living in urban areas and urban density measured by the number of persons per km^2. In line with the SEDS and related national land use plans (Van Chinh, 2011), it is assumed that 45% of the total population is living in urban areas in 2020 and this reaches 55% in 2030. In addition, as a consequence of a rise in welfare with the demand for larger houses and increased mobility, urban density will be lower in the HEG than in the BAU. Figure 4.5 shows the difference in urbanisation between the BAU and the HEG scenarios. To fulfil the demand for agricultural and built-up land, non-production forest, and shrub and grassland are expected to contract. To capture the higher pressure on land, it is assumed that nature reserves and protected zones are no longer shielded off from land conversion and can be used for productive purposes or settlements.

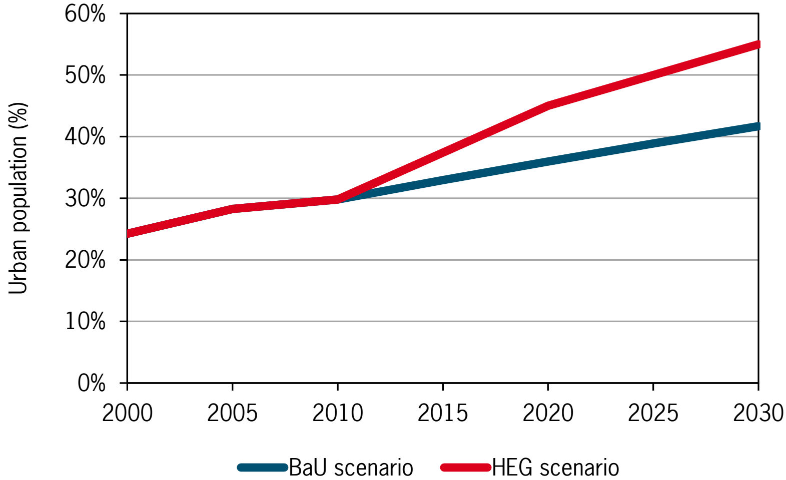
Box 4.4	SEDS (2011-2020) and Agricultural Development Plan to 2020 and Vision to 2030

Every ten years the Vietnamese government develops a Socio-Economic Development Strategy (SEDS), which outlines the long-term development objectives for the country. The most recent SEDS, which covers the period 2011-2020, has recently been released. The document is supplemented with the Agricultural Development Plan to 2020 and Vision to 2030, which describes the detailed plans for the agricultural sector, including land use projections. The overall goal of the SEDS is to turn Vietnam in an industrialised country with in stable social, political setting where living conditions have substantially been enhanced. Key economic, cultural and social, and environmental objectives are:

- GDP growth rate of on average 7-8% per year;
- Income per capita will reach about USD3,000;
- The total share of agriculture will be around 15% and that of industry and services 85%;
- Share of agricultural labour will be 30-35%;
- Urbanisation rate will reach 45% (55% in 2030);
- Human development index (HDI) will reach the average high-income group in the world;
- Population growth of 1%;
- Forest cover reaches 45%;
- Access to clean water for most of the population;
- Protection of the environment and improvement of environmental quality, active response to climate change, control and prevention of natural calamities.

Note: In comparison with the BAU yields do not change for plant-based fibres and other crops.
Source: NIAPP (2011).

Figure 4.5 **Urban population - BAU and HEG scenarios, 2000-2030**



Source: Klein Goldewijk (2010), Van Chinh (2011) and UNDESA (2012).

4.4 Summary of scenarios

For this study three scenarios are analysed using a combination of a global macro-economic simulation model (MAGNET) and a landscape-level spatial allocation model (CLUE). Table 4.2 summarises the assumptions for both models and levels of analysis.

Table 4.2	Global socio-economic and local land-use assumptions per scenario		
Driver	**Business As Usual (BAU)**	**High Climate Impact (HCI)**	**High Economic Growth (HEG)**
Global socio-economic drivers			
Demo-graphics	Population trends as observed in the past.	Same as BAU.	Same as BAU.
Macro-economic growth	Growth in line with past trends but taking into account negative effect of the global slowdown.	Negatively affected due to negative yield shock.	Vietnam: High growth in line with the SEDS. Rest of the world: same as BAU.
Land supply	Vietnam: As observed in the past taking into account available land. Rest of the world: Based on historical trends.	Same as BAU	Vietnam: Same as BAU plus additional land from protected areas. Rest of the world: same as BAU.
Crop yield	Yield increase as observed in the past.	Negatively affected as a consequence of climate change.	High yield growth for several crops in line with the Agricultural Development Plan.
Technological change	Continuous trends in labour saving technological progress.	Same as BAU.	More rapid labour saving technological change.
Local land-use drivers			
Urbanisation	Continuous trend in urbanisation.	Same as BAU.	High rate of urbanisation in line with the SEDS.
Protected areas	No change in size and location of protected areas. Shielded from pressure for productive land.	Same as BAU	No longer protected from land conversion.

5 Socio-Economic Development outcomes

This chapter presents potential socio-economic futures for Vietnam that result from the MAGNET model under the three different scenarios.[1] First the findings for the Business As Usual (BAU) scenario are presented, including the impact on economic structure, land use, employment, food security and trade. In the next chapter, the findings for the High Climate Impact (HCI) and the High Growth Impact (HEG) are discussed in comparison with the BAU scenario for each of these issues.

5.1 Business As Usual

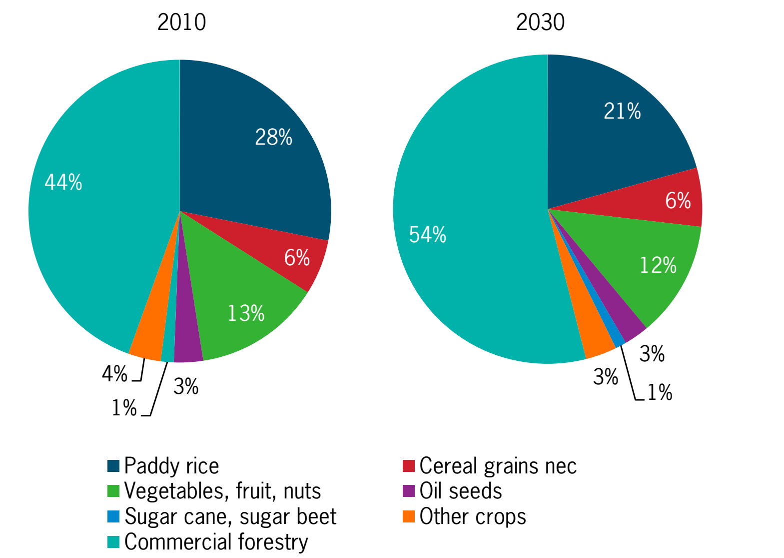
Box 5.1	**Summary of Business As Usual scenario outcomes**
Vietnam increasingly becomes a service and manufacturing-orientated economy, at a cost of agriculture and commercial forestry. Especially the paddy rice sector is slowing down, growing only marginally over the coming two decades. All sectors grow except for the lumber industry that produces wood products mostly for exports. Overall food security in Vietnam improves, both from domestic and imported sources. The Vietnamese consumption pattern changes, however, with a rising importance of fish, vegetable oils and fats and other food, beverage and tobacco products, at a cost of processed rice and vegetables and fruits. Trade in manufacturing and services continues to rise in prominence and display increasing trends over time. Despite the declining importance of the paddy rice sector in Vietnam's economy, Vietnam continues to be one of the main exporters of rice in the world, with exports of processed rice increasing substantially over the coming two decades, thereby contributing to global food security and notably that of Sub-Saharan Africa.	

In the BAU scenario, the structure of the Vietnamese economy changes into one more dominated by services (value added share of over 50% in 2030) and manufacturing, away from agriculture, and most notably crops (Figure 5.1). Within crops (not shown), most of the fall of the value added share can be attributed to the paddy rice sector (falls from 4.3% to 1.6%) and vegetables, fruits and nuts (falls from 3.7% to 1.7%). Commercial forestry sector becomes less

[1] For more detailed information about the model analysis see Rutten et al. (2012).

important (value added share falls from 2.1% to 1.1%) as does its most important client, the lumber industry producing wood products (value added share falls from 1.6% to 0.5%).

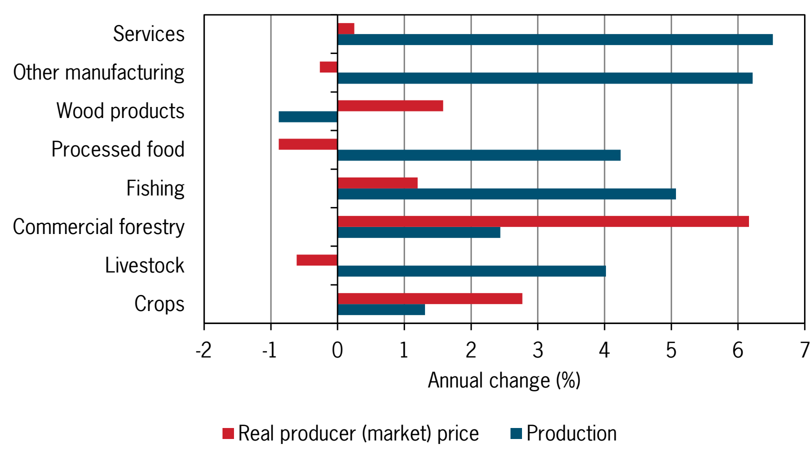
Figure 5.1 **Value added generated in Vietnam by broad economic sectors, BAU**



Source: MAGNET simulations.

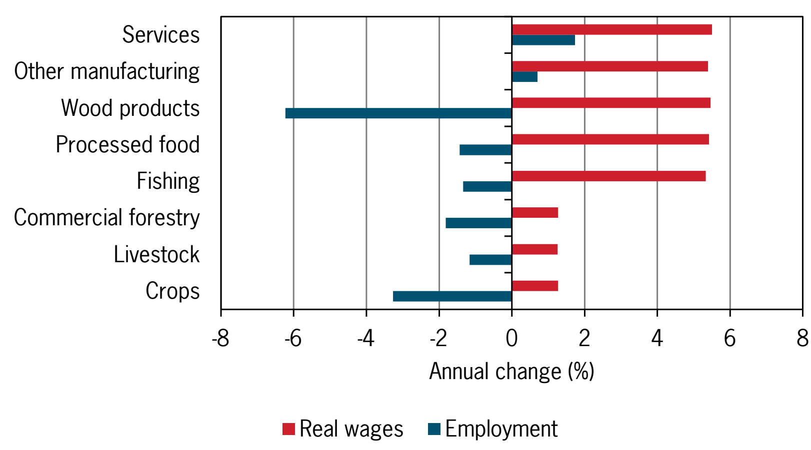
Underlying the changes in the economy are differential growth rates across economic sectors. Notably, the economic growth that Vietnam records over the period 2010-2030 primarily takes place in services and other manufacturing. These sectors show annual growth rates of over 6% (Figure 5.2). Other sectors also expand but with lower growth rates. Considering the land using sectors, crop sectors still grow by 1.3% per year, livestock sectors by 4% per year and commercial forestry by 2.4% per year. Within the crop sector (not shown), especially paddy rice is slowing down, recording a growth of only 0.5% over the period 2010-2030. The only contracting sector is the lumber industry producing wood products, which also experiences a (real) producer price increase of 1.6% per year. The negative growth is caused by a loss in international competiveness (most of the output is destined for the export market) as a consequence of a price increase in the commercial forestry sector (growth rate of around 6% per year over 2010-2030), which supplies the majority of raw materials.

Figure 5.2 **Annual changes in production and prices, BAU, 2010-2030**



Source: MAGNET simulations

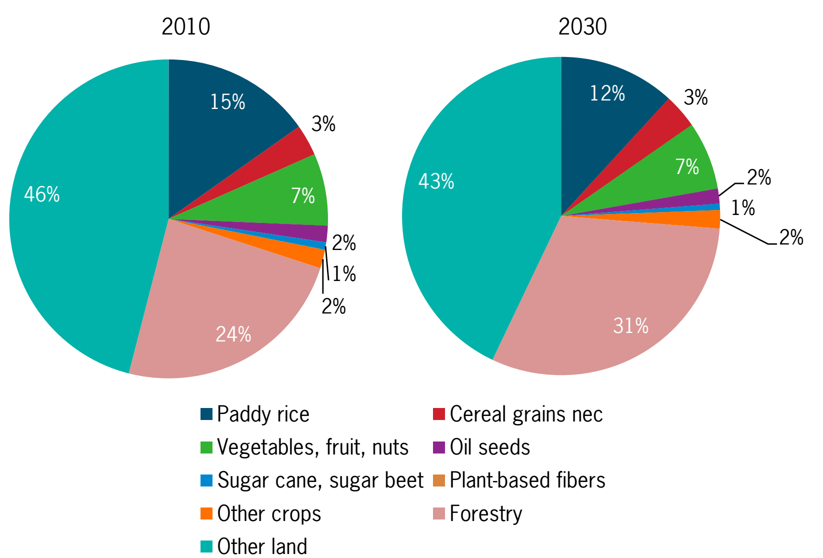
Figure 5.3 **Annual change in employment and wages, BAU, 2010-2030**



Source: MAGNET simulations

The observed changes in Vietnamese producer prices are likely to have their origin in factor markets. Of particular importance for social and economic development are the labour market and expected changes in wages. The increased service and industry orientation of Vietnam generates employment in services and to a lesser extent manufacturing at a cost of other sectors, most notably wood products and crops, with employment falling by 6.2% and 3.3% per year (Figure 5.3). Segmentation between agricultural and non-agricultural labour markets causes (real) wages in the crops, livestock and forestry sectors to lag behind (increase of 1.3% per year, compared to 5.5% per year in non-agriculture). The real wage rises explain part of the rise in the (real) producer prices.

Figure 5.4 **Land use in Vietnam by agricultural and commercial forestry sectors, BAU**



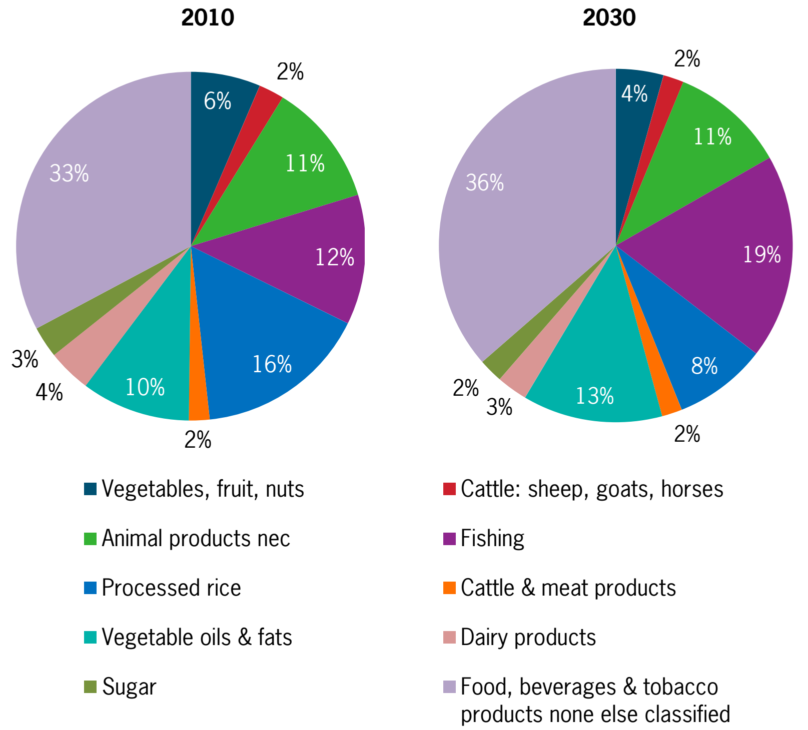
Note: small data points (with a share <1%) have been removed.
Source: MAGNET simulations.

The structural change in the economy, in particular the development in the crop and forestry sectors, lead to changes in the demand for land. Figure 1 shows the share of land use for land using sectors and other land classes (e.g. the sum of non-productive forest, shrub, built-up and other land). Notably, the share of land used by the commercial forestry sector increases from 24 to 31%

of total land used by the agricultural and commercial forestry sector. This is mainly achieved at the expense of the land used by paddy rice which decreases from 15% to 12% but also at the expense of other crop sectors and other (non-productive) land (Figure 5.4). Chapter 6 provides an in-depth spatial analysis of total land-use change in Vietnam.

Overall food security, measured in terms of the change in the Vietnamese consumption of food items (weighted by expenditure shares in the base year), improves by approximately 4% per year, both from domestic and imported sources. The average food price, the composite of the consumer (market) prices of all food items consumed (again weighted by their shares in the base year), in Vietnam falls slightly by 0.8% per year over the period 2010-2030. As shown in Figure 5.5, the Vietnamese consumption pattern does however change, with a rising importance of fish (from 12% of the consumption basket in 2010 to 19% in 2030), vegetable oils and fats (from 10%to 13%) and other food, beverage and tobacco products (from 33% to 36%), at a cost of processed rice (share falls from 16% to 8%).

Figure 5.5	Vietnamese food consumption pattern, BAU

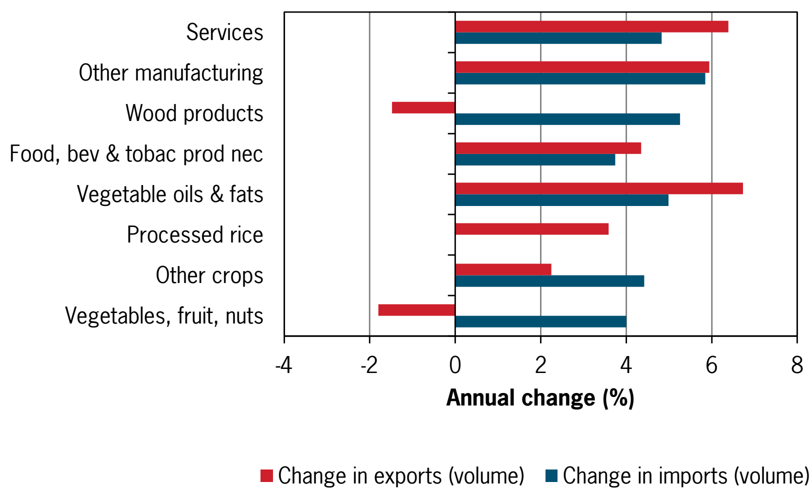


Note: small data points (with a share <1%) have been removed.
Source: MAGNET simulations.

Figure 5.6 displays the changes occurring in Vietnamese trade in terms of exports and imports between 2010 and 2030. As shown, most trade continues to take place in other manufacturing (accounting for 75% to 80% of trade in 2030) and services (7-10% of trade in 2030), with trade in both rising over time. With respect to the other traded commodities, trade is generally improving, with the exception of vegetables, fruits and nuts (decline in exports of close to 2% per year) and wood products from the lumber industry experiencing a fall in exports of 1.5% per year and a rise in imports of around 5% per year due to decreased competitiveness relative to cheaper foreign wood products.

Finally, despite the declining importance of the paddy rice sector in Vietnam's economy, Vietnam continues to be one of the main exporters of rice in the world, with exports of processed rice increasing by close to 4% per year over the coming two decades (Figure 5.6). Vietnam thereby contributes to global food security and notably that of Sub-Saharan Africa, which sees its imports of processed rice from Vietnam increase by around 6% per year over the period 2010-2030. Global food security, or the consumption of food, improves by 1.5% per year over the period 2010-2030, with global food consumption prices slightly falling (by 0.1% per year over the period 2010-2030.

Figure 5.6 **Changes in the Vietnamese trade pattern, BAU, 2010-2030**



Note: categories with trade shares <1% are not shown.
Source: MAGNET simulations.

5.2 Alternative scenarios

Box 5.2	Summary of High Climate Impact scenario outcomes

Climate change slows down the Vietnamese economy. Whereas the structure of the economy roughly remains the same, impacts are felt at the sectoral level, where the fall in crop yields lowers production of crop sectors (notably paddy rice and vegetables and fruits) and increases their unit costs. The latter is primarily due to increased demand for land by crops, at a cost of livestock and forestry. This causes livestock and commercial forestry also to contract and has negative knock-on effects on industries of processed food and wood products. Employment falls in all sectors, apart from services and commercial forestry, which lowers wages. Overall food security falls in Vietnam, but generally with substitution towards imported commodities away from domestic commodities as it is cheaper to consume certain products from abroad. Exceptions are fish and vegetable oils and fats that actually become cheaper in Vietnam, with consumption of fish rising. In terms of trade, the lumber industry becomes less competitive and less is exported of Vietnamese processed rice, including to Sub-Saharan Africa. Across the globe, climate change is worsening food security.

Box 5.3	Summary of High Economic Growth scenario outcomes

Rising crop yields and higher technical progress bring Vietnam onto a higher growth path. As a result, the structure of the economy changes in favour of crops (vegetables and fruits), and the processing food and lumber industry, at a cost of manufacturing and services. All sectors expand in size nevertheless and producer prices fall, except for commercial forestry, fishing and services. The fast expanding lumber and food processing industries and services draw in labour at a cost of employment elsewhere. Market segmentation causes wages to rise faster in industry and services compared to agriculture. Land used by crop sectors (most notably vegetables and fruits) falls due to high yield growth to the benefit of mostly livestock sectors. Overall food security in Vietnam improves as domestic food has become cheaper. Especially more is consumed of cattle meat, fish, vegetable oils and fats, other food products and beverages, and vegetables and fruits. Consumption of processed rice becomes less important, whereas consumption of other food products and beverages becomes relatively more important. Almost all sectors become more competitive and export more and import less, notably vegetables and fruits. Processed rice exports rise to the benefit of Sub-Saharan Africa and global food security, which slightly improves.

5.2.1 Economic growth and structural change

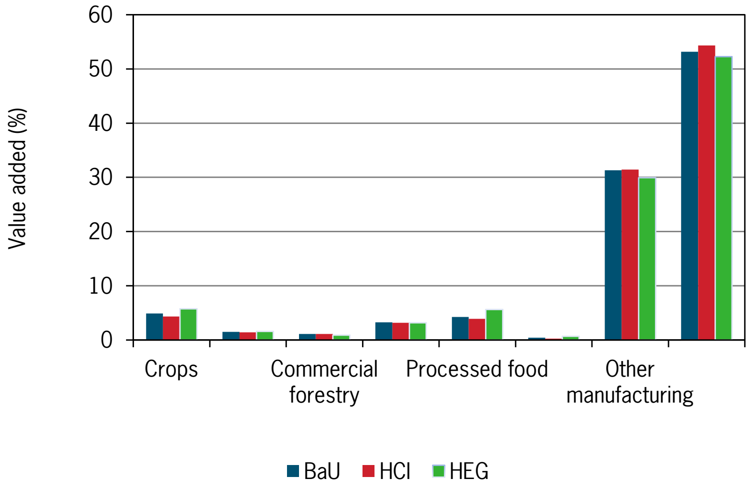
Due to climate change the Vietnamese economy is slowing down by 0.2pp (percentage points) per year over the period 2010-2030, from a growth rate of 6.6% per year in the BAU scenario to a growth rate of 6.4% per year on average in the HCI scenario. This is equivalent to a fall in growth of 11pp in total over the period 2010-2030. In the HEG scenario, economic growth is fixed at of 8% per year over the period 2010 to 2030 in line with the SEDS.

Figure 5.7 depicts the structure of the Vietnamese economy for each of the three scenarios, expressed in the share of value added per sector. Climate change and high growth have limited impact on the structure of the economy. All scenarios show a pattern of structural change in which services (around 53%) and manufacturing, including processed food (around 35%) are the largest sectors in the economy, while the share of agriculture decreases (around 11%).

Changes are however visible at the sub-sectoral level. In the HCI scenario production of all agricultural sectors as well as the food and wood products sectors is falling and their prices mostly rising (see Table 5.1). Within crops, paddy rice and vegetables and fruit sectors contract by 0.7pp. The crops sector also records the biggest (real) price increase of 2.7pp per year in addition to the BAU increase of 2.8pp per year. This is due to the fall in yields caused by climate change.

In the HEG scenario, the production pattern that emerges from this scenario is quite different from the baseline and climate change scenario. All sectors expand in size, most notably wood products (by 3.3pp per year in addition to the BAU), and the processed food industry (by 2.5pp in addition to the BAU), with (real) producer prices falling everywhere compared to the BAU scenario, except for commercial forestry, fishing and services, which experience small producer price increases. The crop sector is becoming visibly larger due to higher crop yields, accounting for a share in the economy of 5.8% in 2030 compared to a share of 4.9% in 2030 in the BAU scenario (Figure 5.7). Within crops, the vegetables and fruits sector is especially growing with a 1.2pp higher share in 2030 compared to the BAU. This benefits processed food industry, which increases its value added share to 5.6% in 2030 (compared to 4.3% in the BAU scenario).

Figure 5.7 **Structure of Vietnam's economy in 2030 under different scenarios**



Source: See text.

Table 5.1 **Production and prices for HCI and HEG scenarios, 2010-2030**

	Production (difference with BAU in pp.)		Real producer price (difference with BAU in pp.)	
	HCI	**HEG**	**HCI**	**HEG**
Crops	-0.59	1.70	2.69	-1.30
Livestock	-0.44	1.31	1.19	-0.32
Commercial forestry	-0.14	0.01	1.33	0.38
Fishing	-0.12	0.94	-0.64	0.20
Processed food	-0.60	2.47	0.98	-1.07
Wood products	-2.60	3.31	0.84	-0.57
Other manufacturing	-0.02	0.89	-0.36	-0.03
Services	0.06	0.97	-0.45	0.41

Source: See text.

5.2.2 Employment and wages

In the HCI scenario, in line with sectoral developments, employment in primary sectors, fishing, processed food and especially wood products falls (by 2.5pp per year in addition to the BAU), whereas employment in services (and commercial forestry) rises slightly (Table 5.2). This leads to downward pressure on (real) wages, in the range of 0.6pp to 0.7pp per year compared to the BAU scenario.

Employment is affected very differently across economic sectors in the HEG scenarios. The expanding lumber industry, processed food and services sectors draw in labour, at a cost of other sectors, most notably commercial forestry and fishing sectors, but also crops, livestock and other manufacturing. Given that the latter sectors increase production there is substitution away from labour into other factors of production, including land for land using sectors but also capital and natural resources. Due to market segmentation the observed labour market developments drives up (real) wages by close to 2pp per year in industry and service sectors, and close to 1pp per year in agricultural sectors, in addition to the BAU scenario.

Table 5.2 Employment and wages for the HCI and HEG scenarios, 2010-2030

	Employment (difference with BAU in pp.)		Real wages (difference with BAU in pp.)	
	HCI	HEG	HCI	HEG
Crops	-0.23	-0.54	-0.75	0.87
Livestock	-0.36	-0.69	-0.74	0.86
Commercial forestry	0.07	-2.05	-0.74	0.87
Fishing	-0.17	-1.97	-0.57	1.85
Processed food	-0.47	0.62	-0.56	1.81
Wood products	-2.49	2.06	-0.54	1.81
Other manufacturing	-0.03	-0.68	-0.57	1.83
Services	0.06	0.27	-0.56	1.83

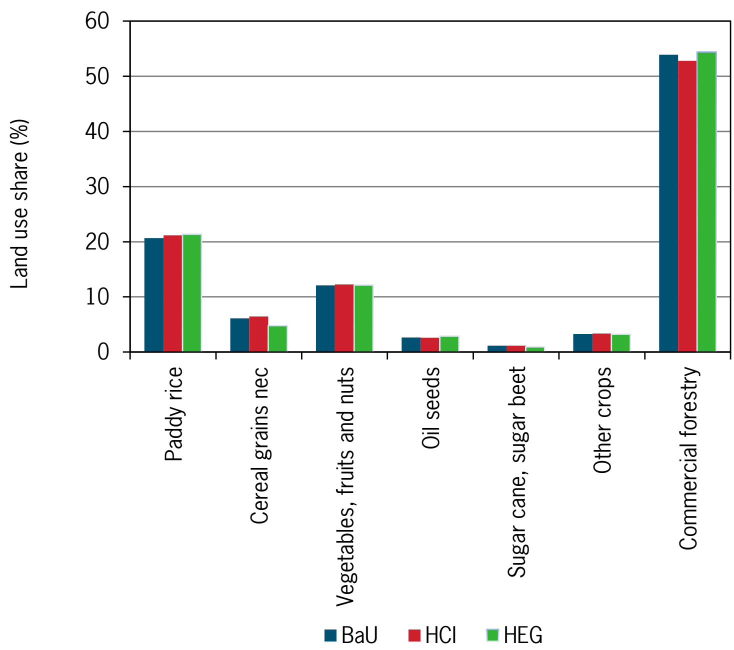
Source: See text.

5.2.3 Land use

Land-use change pattern in the HCI and the HEG is broadly comparable to that for the BAU (Figure 5.8) with minor differences at the detailed sectoral level. In the HCI scenario, only slightly more land is allocated to crops (most notably

0.5pp to paddy rice, 0.3pp to other grains and 0.2pp to vegetables and fruits), at a cost of commercial forestry. In the HEG scenario, the land allocation across sectors remains fairly constant with only the share of other grains falling and that of paddy rice (by 0.7pp relative to the BAU scenario) and commercial forestry (by 0.5pp relative to the BAU scenario) slightly rising.

Figure 5.8 **Land-use pattern in Vietnam in 2030 under different scenarios**



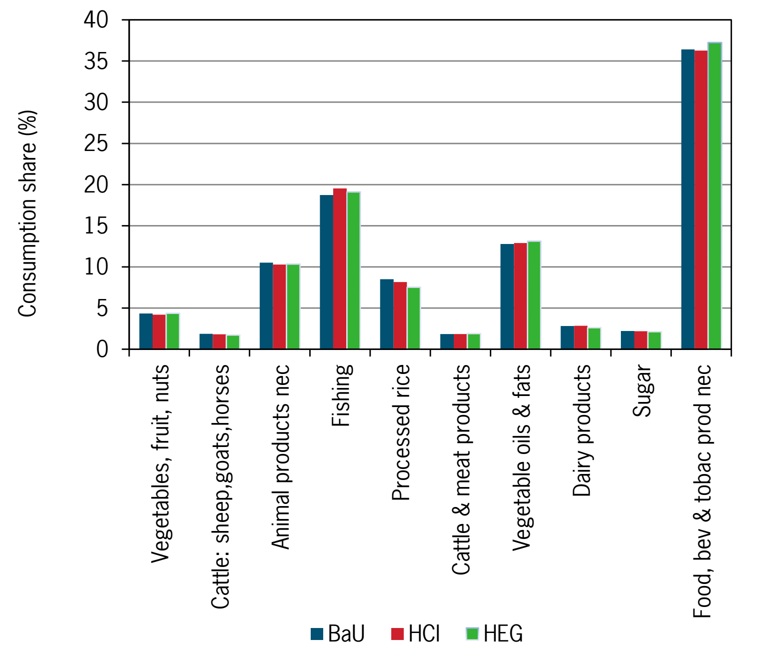
Note: small data points (with a share <1%) have been removed.

5.2.4 Food security

In the HCI, overall food security in Vietnam falls by approximately 0.2pp per year compared to the BAU scenario due to an increasing food (market) price of on average 1pp per year, but with a bigger fall in domestic consumption compared to consumption from imports. Due to domestic price rises it actually becomes cheaper to consume certain food products from abroad. Exceptions are fish and vegetable oils and fats, which actually become cheaper in Vietnam relative to the rest of the world. These changes in the Vietnamese consumption pattern have little impact on the composition of the consumption basket (Figure 5.9). As a share of total food consumption in 2030, only slightly more (1pp) is consumed of the fish sector.

In the HEG scenario overall food security in Vietnam improves by approximately 0.7pp per year compared to the BAU scenario due to a falling food (market) price by approximately the same amount. There is a substitution away from imported goods to domestic goods since domestic food products have become cheaper. This leads to small changes in the Vietnamese consumption pattern. Specifically, as a share of total food consumption in 2030, less is consumed of processed rice (1pp difference with BAU scenario), to the benefit of other food products, beverages and tobacco.

Figure 5.9 **Vietnamese food consumption pattern in 2030 under different scenarios**



Note: small data points (with a share <1%) have been removed.

5.2.5 Trade

Table 5.3 compares the changes in trade for the HCI and the HEG scenarios. In the HCI scenario exports of wood products decline, whereas imports rise due to its decreased competitiveness. The Vietnamese commercial forestry's trade (albeit small) improves despite the fact that this sector is contracting and experiences a price increase, as the price increase on the world market is slightly higher (0.8pp per year over the period 2010-2030) compared to the BAU and so it is becoming more competitive compared with the rest of the world. The processed rice sector, following the yield decrease in the paddy rice sector, experiences higher unit costs and prices, contracts, and so exports become less and imports more. Within imports of processed rice there is substitution away from China and India towards other rice exporting countries. Exports of processed rice to Sub-Saharan Africa fall by almost 2pp per year over the period 2010-2030 compared to the BAU scenario. Generally, climate change is detrimental for global food security, which deteriorates by close to 0.25pp. per year over the period 2010-2030 compared to the BAU, with global food consumption prices rising by 1.4pp.

In the HEG scenario, almost all sectors become more competitive and export more and import less, most notably vegetable and fruits which exports almost 10pp per year more in addition to the BAU scenario over the period 2010-2030 due to its yield rise. Exceptions are the commercial forestry sector and the services sector that import more and export less. Processed rice exports rise by 2.6pp per year in addition to the BAU scenario, also due to higher yields (and lower costs), to the benefit of Sub-Saharan Africa and global food security which slightly improves.

Table 5.3	Imports and exports for the HCI and HEG scenarios, 2010-2030			
	Change in imports (volume), difference with BAU in pp.		Change in exports (volume), difference with BAU in pp.	
	HCI	HEG	HCI	HEG
Vegetables, fruit, nuts	0.22	-2.16	-0.87	9.71
Other crops	0.29	-0.10	-0.34	-0.14
Commercial forestry	-1.41	1.87	0.72	-1.68
Processed rice	1.62	-1.97	-1.11	2.67
Vegetable oils & fats	-0.02	0.10	2.96	3.97
Food, bev & tobac prod nec	-0.26	-0.07	-1.20	3.58
Wood products	0.17	0.46	-2.84	3.46
Other manufacturing	0.01	0.82	0.02	0.67
Services	0.17	1.81	0.10	-1.45

Note: categories with trade shares <1% have been removed.

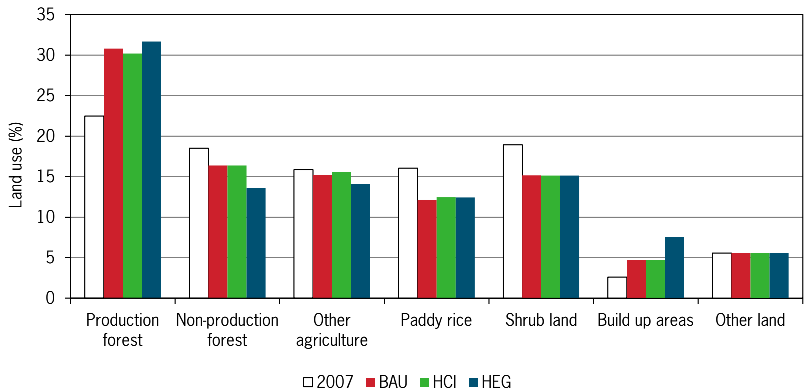
6 Landscape level outcomes

This chapter presents a spatially explicit analysis of land change in Vietnam for the period 2007-2030. It uses the CLUE model to construct land-use maps for Vietnam in 2030 by combining projections for agricultural land-use change presented in the previous chapter with assumptions on land-use change in other land-use classes (e.g. non-production forest, shrub, built-up and other land) outlined in the scenario chapter. Appendix 1 provides detailed information on the CLUE model and the procedures used to create the land-use maps.

6.1 Land-use change dynamics

Figure 6.1 and Table 6.1 summarise the results for land-use change by scenario between 2007 and 2030. The results are very similar for all three scenarios, with the exception that in the HEG scenario built-up land is assumed to increase much faster than in the other two scenarios. The production forest area shows the biggest absolute increase of all land uses, from 22% of the total land area in 2007 to around 31% in 2030 equivalent to a growth of 34-41%, depending on the scenario. This goes mostly at a cost of various other land classes, mainly non-production forest (share falls from 19% to 16% (BAU and HCI) and 10% (HEG)), paddy rice area (share falls from 16% to 12%) and shrub and grassland areas (share falls from 19% to 15%). Built-up land increases substantially in the BAU and the HCI scenarios (share increase from 3% to 5%) but most in the HEG scenario (up to 8%) indicating a high degree of urbanisation. The Other land class remains constant throughout the period of analysis.

Figure 6.1	**Land use (%) by land class and scenario, 2007-2030**



Note: To make the results of the BAU and the HCI scenarios comparable with the HEG scenario, the Non-production forest (Special use forest) as well as small tracts of other land classes that are located in the protected areas are added to the respective categories.
Source: FIPI 2007 map, BAU, HCI and HEG 2030 scenario land-use maps.

Table 6.1 **Land-use change by land class and scenario, 2007-2030**

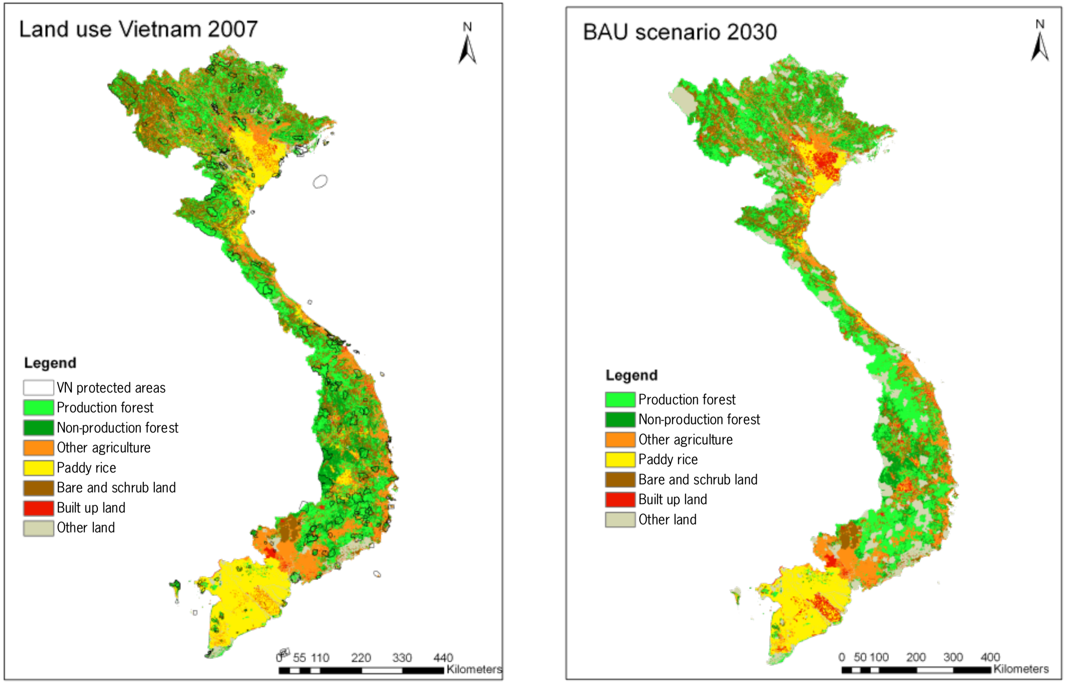
	2007	**2030 - BAU**		**2030 - HCI**		**2030 - HEG**	
	Km²	**Km²**	**Change (%)**	**Km²**	**Change (%)**	**Km²**	**Change (%)**
Paddy rice	53,462	40,463	-24	41,434	-22	41,362	-23
Other agriculture	52,802	50,672	-4	51,775	-2	46,941	-11
Production forest	74,858	102,553	37	100,498	34	105,429	41
Non-production forest	61,640	54,543	-12	54,543	-12	45,246	-27
Shrub and grassland	62,986	50,420	-20	50,401	-20	50,375	-20
Built-up areas	8,645	15,742	82	15,742	82	25,039	190
Other land	18,517	18,517	0	18,517	0	18,517	0
Total	332,910	332,910	0	332,910	0	332,909	0

Note: The Other land class in the BAU and the HCI scenarios also covers protected areas that include, apart from non-production forest, small tracts of Paddy rice land, Other agriculture and Shrub land. To make the scenarios comparable with the HEG scenario, these areas are added to the respective categories.
Source: FIPI 2007 map, BAU, HCI and HEG 2030 scenario land-use maps.

Figure 6.2, left- and right-hand side panel, shows the FIPI land-use map for 2007 and the BAU land-use map for 2030, respectively. Figure 6.3 depicts the land-use maps in 2030 for the HCI and the HEG scenarios. In line with the scenario assumptions of the BAU and HEG, protected areas are excluded from land conversion and remain constant over time. In the HEG scenario, these areas are no longer protected and Special use forest can be cleared for productive use.

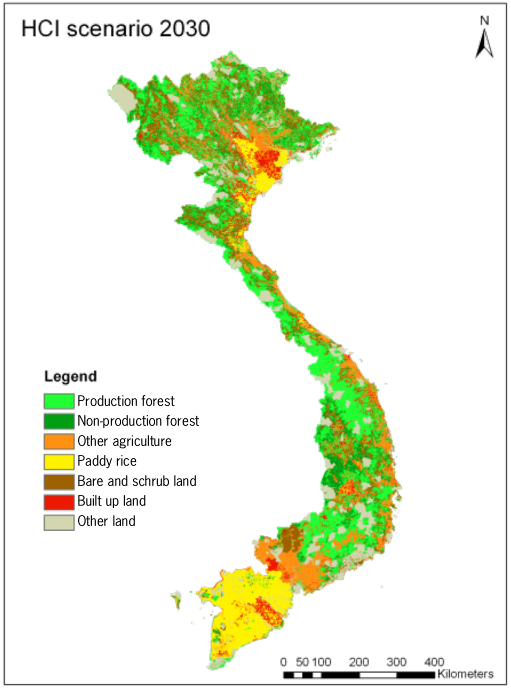
By comparing the four maps, a good impression can be obtained of the spatial distribution change across scenarios and over time. As there are only marginal differences in aggregate land use between the BAU and the HCI scenarios, the respective land-use maps are near identical. The HEG land use shows the impact of rapid urbanisation that characterises this scenario. This is better visible in the regional maps that are discussed in the next section. Differences in land use are more pronounced over time. The growth of production forest area mainly takes place in the centre of Vietnam (North Central Coast, Central Highlands and South Central Coast regions) at the expense of non-production forest but also shrub and grassland. The conversion pattern is explained by the probability maps that show the areas that are most suitable allocate production forest (Appendix 1). Another striking development is the expansion of built-up land in the Red River Delta and, to a lesser extent, the Mekong River Delta.

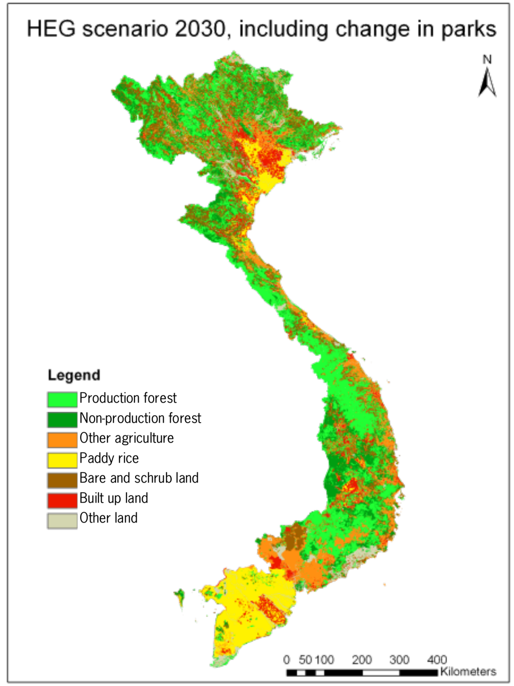
Figure 6.2 **Land use in 2007 and 2030, BAU scenario**



Source: FIPI (2007) and CLUE simulations (2030).

Figure 6.3 **Land use in 2030 High Climate Impact and High Economic Growth scenarios**





Source: CLUE simulations.

6.2 Land-use change in the Red River Delta and the Mekong River Delta

The Red River Delta and the Mekong River Delta are key economic and agricultural regions in Vietnam. The Mekong River Delta, sometimes referred to as the 'rice bowl' of Vietnam is responsible for about half of total paddy rice in Vietnam with the Red River Delta adding another 15% (IAE, 2011a). The regions are therefore of crucial importance for domestic food production and rural employment as well as international rice trade, given that Vietnam is the second largest exporter of rice in the world. The Red River Delta and the Mekong River Delta are also core urban and industrial regions which are clustered around the four largest cities in the country, Hanoi and Hai Phong cities in the North, and Ho Chi Minh and Can Tho cities in the South. Both Delta regions accommodate one third (about 10 million) of the total national urban population (World Bank, 2011). For these reasons it is relevant to zoom in on the land-use maps of the Red River Delta and the Mekong River Delta (Figure 6.4 and Figure 6.5).

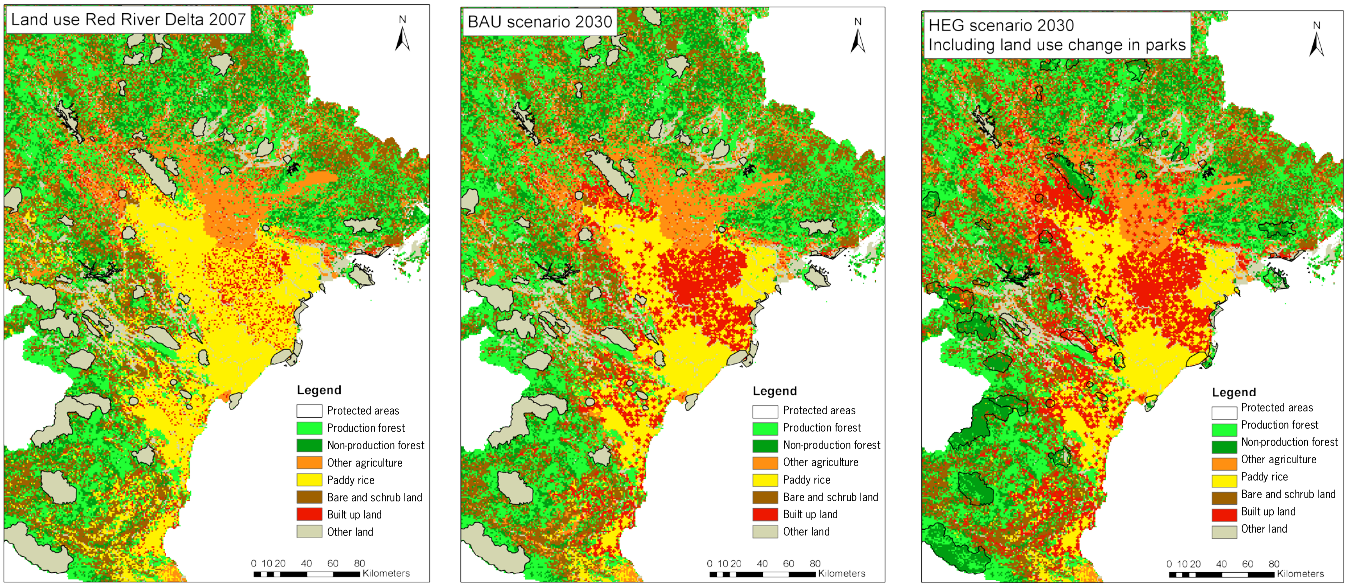
Both regions show a major expansion in built-up land between 2007 and 2030 in line with expected urban population growth in Vietnam and the four abovementioned cities (UNDESA, 2012). The growth of built-up land in these regions is driven by factors such as the presence of infrastructure, closeness to populated areas and flat terrain which in conjunction contribute to a high suitability (Appendix 1). The maps coincide with the different patterns of built-up land growth that characterise the Red River Delta and the Mekong River Delta and are associated with the specific spatial profiles of Hanoi and Ho Chi Minh City (World Bank, 2011).[1] Between 1999 and 2009, the Red River Delta has witnessed a very high pace of industrial activity that led to an expansion of urban land throughout the region, probably caused by its proximity to massive Chinese industrial centres. The new industrial areas are predominantly located in suburban areas at a distance of about 70-140 km from Hanoi, not in the city centre itself. The Mekong River Delta also experienced industrial growth but, in contrast to Hanoi, (heavy) manufacturing is located close to (distance of less than 70 km) the centre of Ho Chi Minh City. This leads to different patterns of built-up land expansion in 2030. In the Red River Delta built-up land growth is dispersed

[1] The maps also illustrate the potential shortcoming of the FIPI land-use map with respect to the location of built-up land and in particular the overlap with the geographic position of major cities (Appendix B). In particular in the case of Hanoi, it seems that all the built-up land is completely spread around the city but not in the centre itself. Although this is in line with recent urban and industrial development in the Red River Delta, it is unclear why there is virtually no overlap between built-up land and the city centre itself.

while in the Mekong River Delta expansion is heavily concentrated around Ho Chi Minh City but also in some areas of the Mekong River Delta. This pattern is even more pronounced in the HEG scenario where the rate of urbanisation is much higher.

In both regions, large areas of paddy rice disappear due to the expansion of built-up land. This effect is particularly strong in the Red River Delta and directly related to the specific development trajectory of Hanoi and surrounding industrial areas. In the HEG scenario, urbanisation also leads to the conversion of other agricultural lands. In the Red River Delta, agricultural land is lost in the Northern region, while in the Mekong River Delta, the expanding borders of Ho Chi Minh City encroach on agricultural areas.

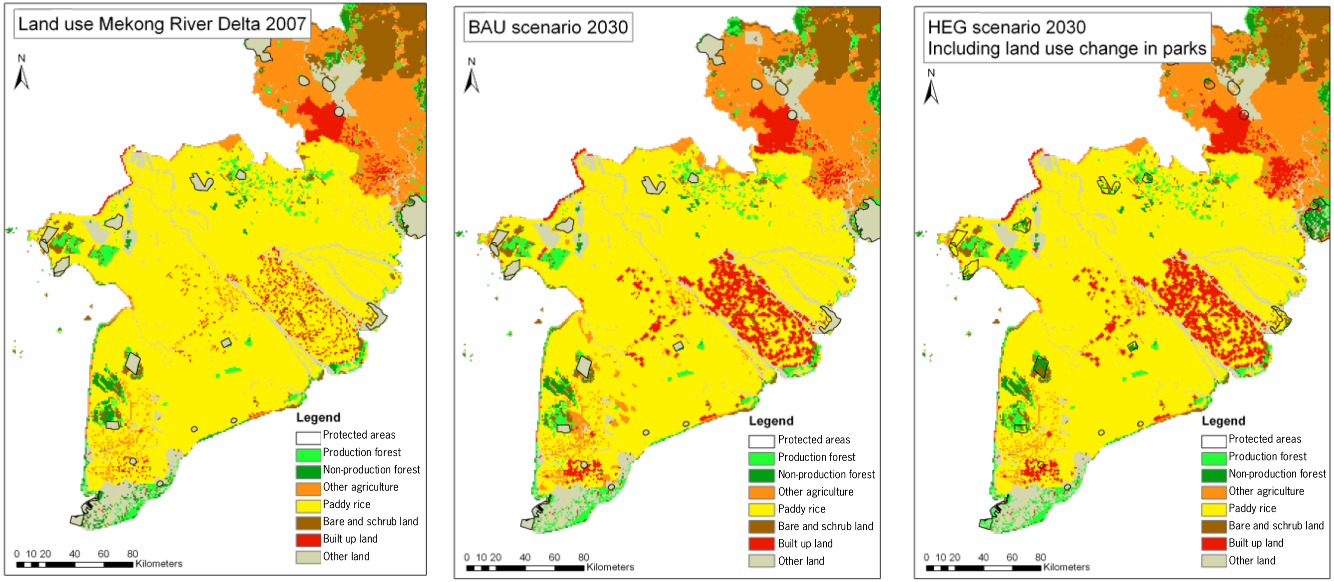
Figure 6.4 **Land use in Red River Delta in 2007 and 2003, BAU and HEG scenarios**



Note: As there is limited difference between the BAU and HCI land-use maps, the latter is not depicted.

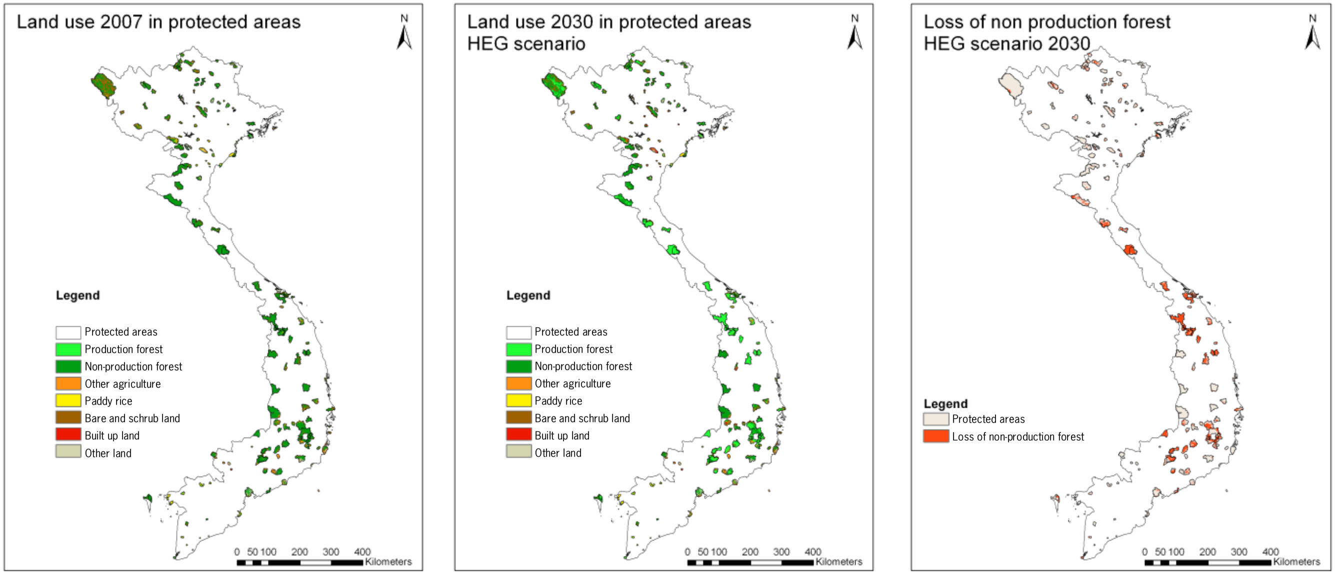
Source: FIPI map 2007, BAU and HEG 2030 land use scenario maps.

Figure 6.5 **Land use in Mekong River Delta in 2007 and 2003, BAU and HEG scenarios**



Note: As there is limited difference between the BAU and HCI land-use maps, the latter is not depicted.
Source: FIPI map 2007, BAU and HEG 2030 land use scenario maps.

Figure 6.6 Deforestation in protected areas



Source: FIPI 2007 map, HEG scenario 2030 land-use map and protected areas map.

6.3 Deforestation in protected areas

A specific feature of the HEG scenario is the opening up of National parks, Nature reserves and Wold Heritage sites for commercial logging and agriculture. This means that so-called Special use forest (i.e. non-production forest in protected park (see Table 3.4 and Figure 3.3) that is located in these areas will be negatively affected. In 2007 the total area of Special use forest is 19,740 km^2, decreasing to 10,529 km^2 in 2030 (Table 6.2). In other words, 47% of Special use forest will be lost in the HEG scenario due to economic pressure. Figure 6.6 illustrates this using a land-use maps. The maps show that deforestation will mainly take place in the protected parks that are located in the North Central Coast, Central Highlands and South Central Coast regions, where expansion of production forest is largest. The loss of rich, mostly natural forest, will threaten biodiversity in Vietnam. In addition, deforestation will also contribute to greenhouse gas emissions unless it is compensated for by growing new forest to sequester carbon or other measures to mitigate climate change.

Table 6.2 Loss of Special use forest in the HEG scenario

Land-use change	Km^2	%
Special use forest area (2007)	19,740	100
Special use forest area (2030)	10,529	53
Loss of Special use forest area (2007-2030)	9,211	47

Source: FIPI 2007 map, HEG scenario 2030 land-use map and protected areas map.

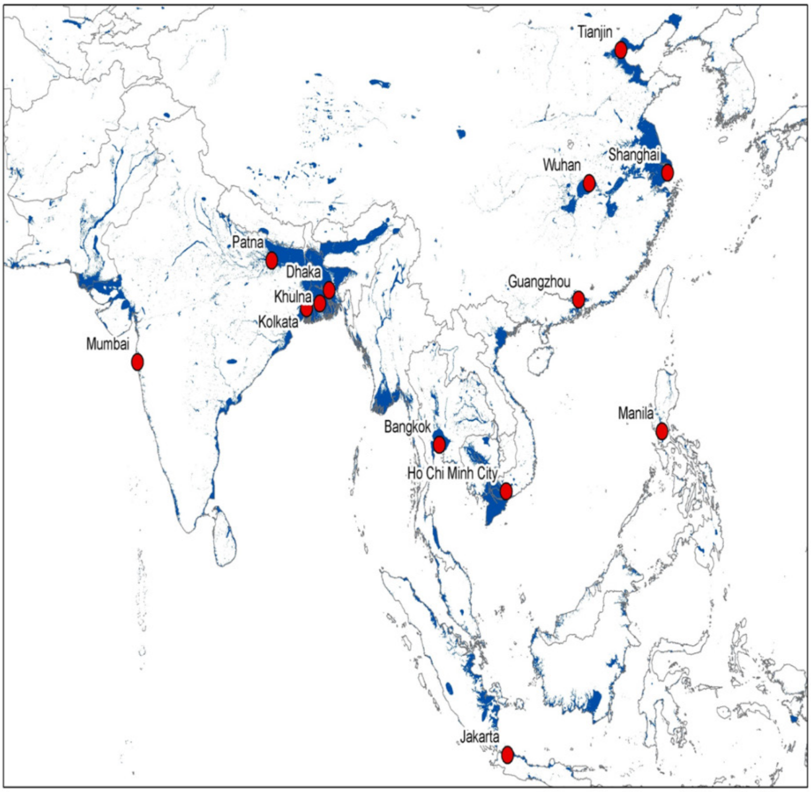
7 Climate change impacts

7.1 Sea-level rise and flooding

Today, 100-200 million people per year are victims of floods, droughts and other water-related disasters (affected or killed); almost two-thirds are attributed to floods. The number of people at risk from floods is projected to rise from 1.2 billion today to around 1.6 billion in 2050 (nearly 20% of the world's population). The economic value of assets at risk is expected to be around USD45 trillion by 2050, a growth of over 340% from 2010. These are the results of the flood module of the IMAGE model (MNP, 2006). In the flood module, different climate scenarios can be explored to show which areas are more likely to have a higher frequency of flooding both due to peak flows of rivers and coastal flooding from the sea. The impacts can then be expressed in (additional) people and assets at risk making use of gridded maps of population and GDP. The link to food security is made by looking at the agricultural areas at risk for flooding which can form a threat to food production. This flood module has a global coverage and is applied to Vietnam further by advanced downscaling techniques.

Figure 7.1 depicts the location of major cities in Southeast Asia as well as areas with a high risk of being flooded. By combining the resulting future flood map with spatial data on population and GDP the people and assets at risk are determined (Van Vuuren et al., 2007; Hilderink et al., 2008). To calculate the most vulnerable cities the results of population and assets at risk were combined with a world cities map (OECD, 2012b). All cells were ranked from 0 to 1 based on the absolute number of people at risk (highest risk is ranked as 1) and the absolute GDP at risk as a proxy for adaptive capacity (lowest GDP is ranked as 1). Hence, the assumption is made that world cities with a low GDP have only limited capacity to build the infrastructure such as levees, dikes and sluices, that are required to resist flooding. Both ranking results were summed. This resulted in a list of cities most vulnerable to floods, i.e. those with a high score on both the ranking of population and value at risk. Ho Chi Minh City is in the list of Southeast Asian cities that has a high risk of being flooded.

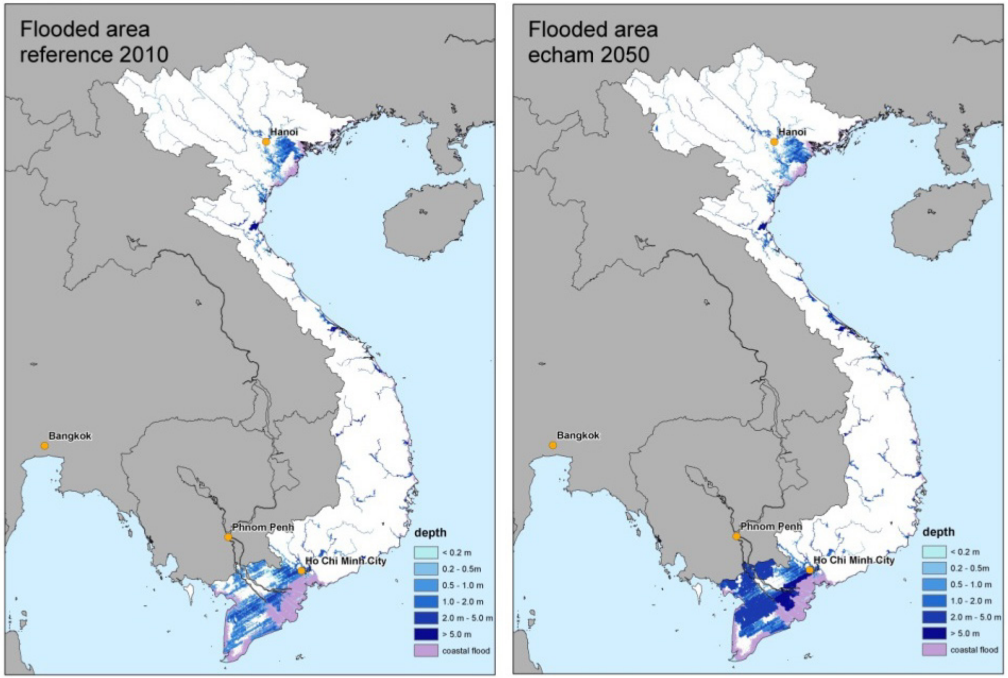
Figure 7.1	Cities in Asia most vulnerable to flood risks



Source: See text.

For Vietnam, flooding does not only form a risk for Ho Chi Minh City, the whole Mekong River Delta and the Red River. In the Mekong River Delta, there will not only be an expansion of areas at risk, also the land use intensity in the Delta is at risk. Figure 7.2 depicts the area and the intensity (depth of the floods) for 2010 (left panel) and for 2050, estimated by using the ECHAM climate scenario. An area is under risk of being flooded if it is subject to flooding once over a 30 period (i.e. 3.33% annual chance).

Figure 7.2 **Flooded area 2010 and 2050 by depth of flooding**

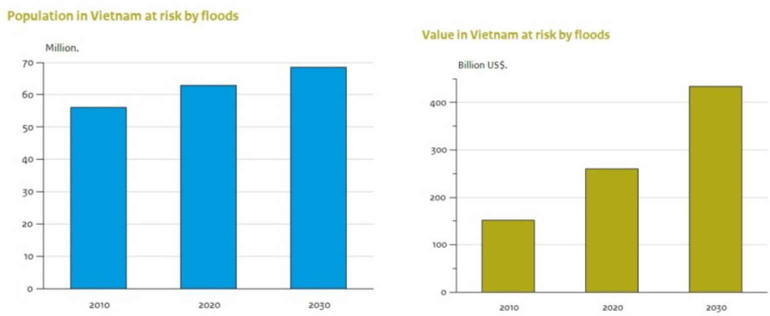


Source: See text.

The associated population at risk is expected to increase from 55 million in 2010 to almost 70 million (66% of total population) in 2030, under the assumption that there are no adaptation and hydraulic structures remain the same. The relatively high population growth in the deltas, including Ho Chi Minh City and Hanoi, is responsible for this increase. The value at risk, expressed in GDP (2005 USD) shows a much higher increase, from USD150 billion in 2010 to more than 400 billion in 2030. This is the result from more people being at risk and thus more assets, but more important a much higher income in 2030. In these calculations, the income differences between urban and rural populations have not been taken into account which could even worsen the picture.

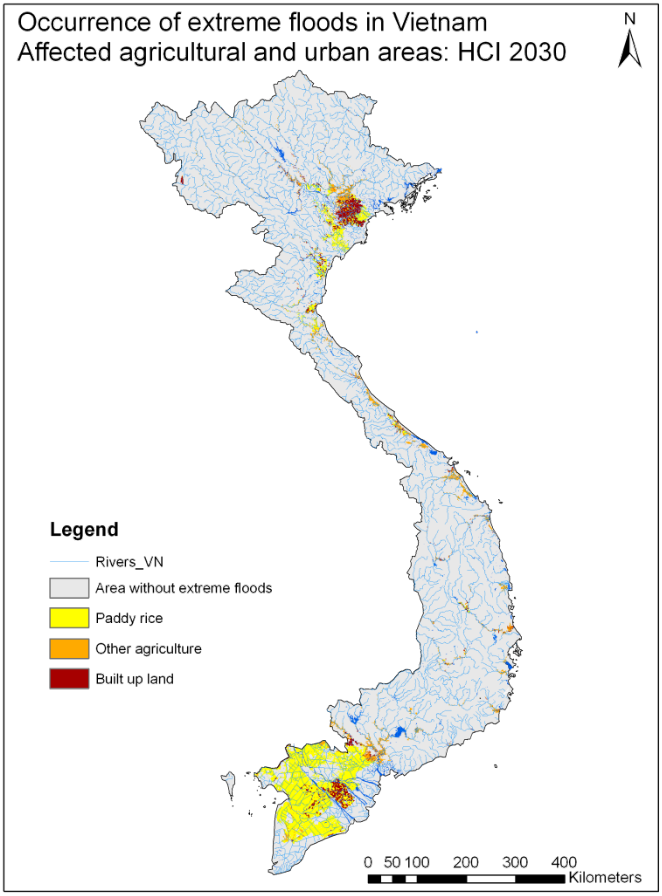
The Mekong River Delta is a low-lying region in southern Vietnam. Around half of the Mekong River Delta is less than 2 m above sea-level, making it vulnerable to fluvial flooding, storm surges and saline intrusion.

Figure 7.3 **People and Value at risk by floods in Vietnam**



Source: See text.

Figure 7.4 **Agricultural and built-up areas with high flood risk in HCI scenario, 2030**



Source: HCI land-use map and flood map.

Table 7.1	Total area and population with high flood risk in HCI scenario, 2030		
Land class	**Total area**	**Area with high flood risk**	
	Km²	**Km²**	**%**
Paddy rice	40,268	22,860	57
Other agriculture	49,535	6,336	12
Built-up area	15,487	5,008	32
Total	105,290	34,204	32

Source: See text.

By combining the land-use map of the HCI scenario and the flood risk map one can identify the agricultural (paddy rice and other agriculture) and built-up areas that have a high risk of being submerged with sea-level rise in 2030 (Figure 7.4 and Source: HCI land use map and flood map Table 7.1). The map shows that the paddy rice fields in the Mekong River Delta are much more vulnerable to flooding than those in the Red River Delta. One the one hand this is due differences in the flood risk profile between the two regions. On the other hand, this also has to do with the decrease in paddy rice area in the Red River Delta, which has been converted to built-up land. In total 22,860 km^2, equal to 57% of total paddy rice area in Vietnam faces the risk of being flood. The map also shows that 6,336 (13%) of Other agricultural area, mainly located along the East coast but also in the Mekong River Delta, and 5,008 (32%) of built-up land are potentially affected by floods.

Extreme floods threatens rice production in a number of ways (Wassmann et al., 2004; Zhu, 2010). During the rainy season, excessive water levels and prolonged inundation will negative affect the performance of certain rice varieties (Mua and He Thu crops). In addition, it also complicates the double or triple cropping system because of delays in planting, eventually reducing yields. During the dry season, the main threat is salinity intrusion, which in too high concentrations, will adversely affect the winter-spring rice crops (Dong Xuan).

7.2 Emissions and climate change mitigation options

Worldwide carbon dioxide (CO_2) emissions account for around 75% of all greenhouse gas emissions. Most CO_2 emissions come from energy production, with fossil fuel combustion responsible for most of the of global CO_2 emissions.

Today's rapid economic growth is largely dependent on increased use of carbon-intensive coal-fired power, driven by the existence of large coal reserves with limited reserves of other energy sources. Methane (CH4) is the second largest contributor to human-induced global warming, and is 25 times more potent than CO_2 over a 100-year period. Methane emissions contribute to over one-third of today's human-induced warming. Cultivating rice fields is an important source of methane emissions. Over the last decades, the average annual emission of methane due to rice cultivation is 1,800 Giga tonnes per year and is by far the biggest source of methane emission. Another source of CO_2 emissions are land-use change (mainly deforestation driven by the expansion of agricultural land).

Vietnam's Second National communication to the United Nations Framework Convention on Climate Change (MONRE, 2010) shows that with 43%, agriculture accounts for the largest proportion of total greenhouse gasses measured in CO_2 equivalent, while LULUCF contributes to 10%. Within agriculture, rice cultivation makes up the largest proportion of greenhouse gas emissions (58%). All figures are for the year 2000, the latest year for which data is available. The report predicts that greenhouse gasses will almost quadruple up to 2030, mainly due the growing demand for energy and fuels. Emissions from agriculture will increase with more than 10% while LULUCF is estimated to become a net sink of CO_2 emissions as a consequence of continuing afforestation and reforestation initiatives.

With the combination of models used in this study, it is possible to provide detailed projections for CO_2 emissions under different scenarios. The MAGNET/GTAP model can be linked with a specially designed emissions database to estimate carbon emissions for agriculture, manufacturing and services sectors (Lee, 2002). Greenhouse gas emissions for agriculture, and in particular LULUCF, depend strongly on bio-physical characteristics of the landscape (e.g. land class, temperature and soil), management practices and land-use change dynamics (i.e. conversion of one land class into the other). For this reason, estimations can be refined by combining spatially explicit information on above and below carbon stocks with future land-use maps generated by CLUE. However it is out of the scope of this study to provide an in-depth carbon emissions assessment. Instead, some preliminary aggregate results are presented in

Table 7.2 to illustrate how the results of this study can be used for the analysis of climate change mitigation options.[1]

As mentioned above, methane emissions from rice cultivation are a major source of (agricultural) greenhouse gas emissions in Vietnam. Greenhouse gas emissions from a given area of rice are determined by a large number of factors, including cultivation period, soil type, temperature and fertiliser, which are variable within a country (IPCC, 2006). It has been found that water management has a strong effect on emissions, especially methane emissions, and is therefore of interest as a potential strategy to mitigate climate change. Wassman et al. (2000) conducted studies on methane emissions under various management conditions five Asian countries (not including Vietnam) and discovered that intermittent flooding and mid-season drainage resulted in lower emissions than with continuous flooding. These results are also found by similar studies that are undertaken in Vietnam (Van Trinh et al., 2010; see studies cited in IAE, 2011a).

Another frequently mentioned approach to reduce methane emissions from rice cultivation is the System of Rice Intensification (SRI). SRI is a farming system aimed at increasing the yield of irrigated rice by changing the management of plants, soil, water and nutrients. Particular features of SRI are a minimum use of water and limited application of chemical fertiliser. Although, there is no systematic evidence, there are reasons to expect that SRI will result in a reduction of greenhouse gas emissions (SRI-Rice, 2012). SRI was introduced in Vietnam around 2003 and spread rapidly thereafter (IAE, 2011b). In October 2011, MARD reported that there are over a million farmers applying SRI methods, representing 10% of all rice farmers in Vietnam (SRI-Rice, 2012).[2] A study to monitor greenhouse gas emissions in Vietnam found that CO_2 equivalent emissions decreased on average with 26% in comparison with conventional farming (IAE, 2011b).

Another source of greenhouse emissions in the rice sector is the burning of rice residues. In many South Asian countries, including Vietnam, straw and husks that remain as waste after the harvest are not recycled. Instead they are left in the open field to dry. Methane and nitrogen are the contributors to global warm-

[1] At the time of writing of this report IFPRI is undertaking such a project, analysing the impact of emissions strategies and options for a number of crops and livestock sectors under different scenarios (de Pinto et al., 2012). It will be interesting to compare their findings with the results of this study.

[2] For more information about the benefits of SRI in Vietnam see Castillo et al. (2012).

ing and climate change. CO_2 emissions are considered to have a neutral effect because of its photosynthetic uptake during plant growth (Gadde et al., 2009).[1] Regulations to reduce the burning of straw is a potential strategy to reduce greenhouse gas emissions from agriculture in Vietnam (IAE, 2011b).

Table 7.2 shows the change of GHG emissions from paddy rice between 2007 and 2030 for the BAU scenario and the impact of strategies to mitigate climate change. When it is assumed that GHG emissions per hectare of rice are constant over time and space, total emissions expressed in CO_2eq are expected to reduce with 22% because of the decrease in paddy rice area. GHG emissions can further be decreased by implementing policies to improve the water management of paddy rice farming and reduce inputs (e.g. SRI). This will contribute to 4.8-6.7% reduction in CO_2eq emissions. Finally, restricting the burning of rice has the potential to decrease emissions by an additional 3%. These figures are overestimations since they do not take into account the fact that 10% of the farmers already use SRI or other agricultural practices with low GHG emissions, and not all rice straw is burned in Vietnam.

Table 7.2 Options to mitigate GHG emissions from paddy rice, 2007-2030

	Mill. tonnes	Change in GHGs	
	CO_2eq.	mill. tonnes CO_2eq.	%
Reduction in GHG emissions (2007-2030)			
2007	36.0		
2030 (HCI)	27.9		
2007-2030		-8.09	-22
Options to reduce emissions (2007-2030)			
Farm management (SRI and irrigation)	21.0 to 23.1	-4.8 to -6.7	-11 to -17
Reduce rice straw burning	27.0	0.9	3
Total	20.1 to 22.1	-5.8 to -7.8	-14 to -19

Source: Emissions estimated using paddy rice area for the HCI scenario (Table 5.2) and GHG emission factors from IPCC (2000), Van Trinh et al. (2010) and IAE (2011b).

[1] See Nguyen et al. (1994) for an analysis of greenhouse gas emissions from rice straw burning in Vietnam.

8 Discussion

8.1 Socio-economic development

All three scenarios find that Vietnam will go through a process of profound structural transformation in which the economy becomes increasingly oriented towards services and manufacturing while the agricultural sector becomes less important. This growth pattern is a continuation of the rapid development that Vietnam experienced over the last decades and comparable to the experience of other emerging economies such as South Korea and Taiwan in the 1980s and the present China (Kim and Nelson, 2000) . Despite the declining relative importance of agriculture in the economy, the sector still grows and Vietnam continues to be one of the main exporters of rice in the world in 2030. Climate change has a negative effect on economic growth in Vietnam, in particular in the agricultural sector, and the rest of the world. It causes a slowdown in Vietnamese economic growth by 0.2pp per year in comparison with the BAU scenario. In the HEG, the reverse is observed; all sectors expand in size, especially agriculture where technical change results in higher yields. The finding of economy-wide effects (contraction in the HCI scenario and expansion in the HEG scenario) demonstrates the importance of input-output linkages between different sectors in economic growth and international trade. Climate change will both direct and negative effects on agriculture but also, through price and market linkages affect the development of the manufacturing and services sectors.

8.2 Land-use change

The agricultural wide effects of climate change and economic growth result in very similar (spatial) land-use change patterns between the three scenarios. One major difference is the assumption of rapid urbanisation that leads to a substantial expansion of built-up land in the HEG scenario. However, all scenarios show a considerable change in the landscape over time. Structural change and economic growth is accompanied by an increase in the demand for wood resources, which causes an expansion in production forest land at the expense of non-production forest and grass and shrub land. At the same time, changing diets and an increase in yields leads a decrease of paddy rice land and other agricultural lands, which are replaced by urban and industrial areas. Future land-use maps reveal that the land-use changes are not distributed evenly over the country; most of the urban growth is concentrated in the suburban areas of the Red River Delta resulting in a substantial decrease in paddy rice area. Also in the Mekong River Delta expansion of urban land leads to a loss of paddy rice fields. However, the decrease is much less as most of the growth is concentrated around the borders of Ho Chi Minh City. The growth of production forest area is mainly situated in the North Central Coast, Central Highlands and South Central Coast regions at the expense of non-production forest but also at the expense of shrub and grassland. The HEG scenario pointed out that almost half of the forest in Nature reserves, Ramsar sites and World Heritage sites (i.e. Special use forest) will be lost if protection is lifted. The expected conversion of non-production forest to production forest that characterises all scenarios, and especially the loss of protected forest areas, will have serious consequences for biodiversity in Vietnam.

More research is needed to improve the modelling of forest dynamics in CGE models. In this study a three-level Constant Elasticity of Transformation (CET) function with very low elasticities of transformation is used to model the demand for agricultural land. The elasticities reflect the difficulty to switch land between forestry and agriculture (and to a lesser extent between crops and livestock). Although this is the state-of-the-art in CGE modelling, it remains a simplification of forest growth and development, which requires a certain amount of time. Some of the observed price effects (e.g. land price change), which signify changes in relative scarcity, may therefore seem quite large. Finally, as has been discussed extensively, the research found serious discrepancies between the two main sources of land-use data and classification systems that are being used in Vietnam. After careful comparison, it was decided to use the 2007 FIPI land-use map as a baseline for the spatial analysis. However, this map still lacks detail with respect to certain agricultural land classes and the location of built-up areas does not completely correspond with other sources. These issues are cause for concern and should be taken into account when looking at the results of this study.

8.3 Food security

At the macro-economic level, food security, which is measured as the change in food consumption, improves in the BAU scenarios as food becomes cheaper. Similar to other emerging economies growth in income per capita is accompanied by a change in diets from rice to processed foods. These findings are even more pronounced in the HEG scenario, where food security improves even more. In both scenarios exports of processed rice to Sub-Saharan Africa expands substantially, thereby also positively contributing to food security in the region. In the HCI scenario, food security in Vietnam and the rest of the world deteriorates due to a rise in food prices. The differences between the scenarios show that increasing agricultural productivity is essential to combat the negative impact of climate change on food security. This underscores the need for the Vietnamese and other governments to boost investment in agricultural R&D and extension services to improve yields.

As mandated by the Resolution on national food security (No. 63/NQ-CP), Vietnam must keep at least 3.8 million hectares of rice land to meet domestic consumption and fulfil export demand in 2020. Despite the substantial decrease in paddy rice land this target is not jeopardised in any of the three scenarios. However, it must be noted that the paddy rice area in the 2007 FIPI map is somewhat larger than the area presented in the statistics published by MARD which is often used as official reference. Using this statistic and assuming a similar contraction in the paddy rice sector, it is doubtful if the target of 3.8 million ha of rice land will be met. Moreover, the analysis strongly points out that structural transformation is driving the conversion of paddy rice land into built-up land that is required for industrial expansion and urbanisation. This process is part of the economic development process of Vietnam and will continue in the future. Maintaining at least 3.8 million hectare of rice land will therefore require additional policies measures in the near future. Apart from economic development, it is shown that climate induced flooding poses a serious threat to rice production in Vietnam. In particular, the paddy rice fields in the low-lying Mekong River Delta and, to a lesser extent, the Red River Delta are susceptible to floods, forming a risk for domestic food consumption and international rice trade.

8.4 Climate change

Climate change is shown to slow down the economy of the country. The negative effect on yields causes agriculture (in particular crop sectors of paddy rice and vegetables, fruit and nuts) and associated processed food and wood product sectors to contract. Furthermore, an overlay of population density, future land use and flood maps shows that in particular the Red River Delta and the Mekong River Delta, both key agricultural and industrial regions in Vietnam, are threatened by floods, possibly jeopardising around 67% of the total population and more than USD400 billion in assets. Also up to 32% of built-up land, 47% of paddy rice areas and 32% of other agricultural land might be affected. These findings show that Vietnam is highly vulnerable to climate change with respect to flooding. A case study is presented to assess climate mitigation options for paddy rice - the largest GHG emitter in the agricultural sector. The contraction in paddy rice land between 2010 and 2030 will already lead to a 22% decrease in GHG emissions. A further reduction of between 14% and 19% can be achieved by improving agricultural practices and restrict the burning of rice straw. The analysis can be improved by combining the future land-use maps with spatially explicit GHG conversion factors.

9 Conclusions

Socio-economic development, land use, climate change and food security are all inter-connected at different scales. This study uses a novel global-to-local approach that combines an economic (CGE) model with a spatially explicit land-use model to capture change at the global, national and landscape level for the period 2010-2030. An important finding is that the process of structural change and urbanisation that has been evident in Vietnam since the 1990s (Giesecke and Nhi, 2009), will have major implications for the Vietnamese landscape in the future. In addition, the study highlights Vietnam's vulnerability to flooding and illustrates the linkages between land-use change and greenhouse gas emissions. Finally, the study shows different impact pathways of economic development, climate change and land-use change on future food security in Vietnam.

Decision makers in Vietnam need to be aware of the complex and uncertain relationships between global and local drivers of socio-economic change, and take a forward look when formulating food security and climate change mitigation and adaptation policies. As such this study presents a scenario and modelling approach that can support the development and implementation of the national Green Growth and REDD strategies. Nonetheless, the results of this study must be regarded as first approximation of possible future pathways for socio-economic development and land-use change in Vietnam. Only three scenarios are analysed, while many more futures may be relevant (see for example Nakicenovic et al., 2000; Carpenter et al., 2005). For example, this study has not assessed the impact of trade policies (e.g. the EU-Vietnam Free Trade Agreement that is currently being negotiated) that can have major consequences for economic growth and development.

Although scenario analysis and models can be a very powerful tool to assess the trade-offs between policy options, they remain a simplification of a complex reality and outcomes are heavily rely on the quality and coverage of available data. A key area of improvement are the Vietnamese land-cover and land-use maps, which exhibit a number of inconsistencies. In particular, there is a need to develop one consistent classification system that harmonises the different sources of spatial data and inventory data in Vietnam. Future research is also needed on the modelling of the land allocation, especially forest land, in CGE models. These issues should be borne in mind when interpreting and using the statistics and maps that are presented in this report.

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Appendix 1

Modelling Framework

Analysing and modelling the dynamics of future land-use change is not easy due to the interplay of a wide range of processes including socio-economic, climate and biophysical change that interact at the global, national and local level. To capture these processes at various scales a computable general equilibrium (CGE) model - Modular Applied GeNeral Equilibrium Toolbox or MAGNET - is linked up with a spatially explicit local land-use model - the Conversion of Land-use change and its Effects or CLUE model.

MAGNET model description

MAGNET has been developed by LEI Wageningen UR and is based on the GTAP (Global Trade Analysis Project) model. The GTAP model, which has been documented in Hertel (1997), captures the behaviour of three types of agents: households, firms and government, in each country or region of the world. Households' behaviour is captured via a 'representative regional household', which in search for maximising its utility, collects all income that is generated in the economy and allocates it over private households and government expenditures on commodities, and savings for investment goods. Income comes from payments by firms to the regional household for the use of endowments of skilled and unskilled labour, land, capital and natural resources. The regional household also receives income from (net) taxes paid by the private household (on private consumption and income), firms (taxes on intermediate inputs and production) and the government (on its expenditures). Firms seeking to maximise profits, produce commodities by employing the aforementioned endowments and intermediate inputs from other firms using a constant return to scale production technology[1] so as to sell them to private households, the government and other producers. Domestically produced goods can either be sold on the domestic market or to other regions in the world. Similarly domestic intermediate, private household and government demand for goods can be satisfied

[1] This means that as firms grow, they do not become more or less efficient.

by domestic production or by imports from other regions in the world (Armington assumption). These come with their own import and export taxes. Sourcing of imports happens at the border, after which - on the basis of the resulting composite import price - the optimal mix of import and domestic goods is derived.

Demand for and supply of commodities and endowments meet markets, which are perfectly competitive and clear via price adjustments. Natural resources and land are assumed to adjust sluggishly between sectors, whereas capital and labour are fully mobile. The assumptions regarding labour, land and capital markets are discussed below as they are different from standard GTAP. With all markets in equilibrium, firms earning zero profits and households being on their budget constraint, global savings must equal global investments. Investments are computed on a global basis, via a 'global bank' which assembles savings and disburses investments, so that all savers in the model face a common price for this savings commodity. In GTAP, global savings determine global investments, i.e. the macro closure is savings driven and essentially neoclassical in nature. Since the CGE model can only determine relative prices, the GDP deflator is set as the numéraire of the model, against which all other prices are benchmarked. Changes in prices resulting from the model simulations thus constitute real price changes.

Since GTAP is essentially a comparative static model, investments only influence the pattern of production (via investments as a demand category) and are not installed so as to add to the productive capacity of industries over time. To carry out a dynamic analysis over time for the period 2007-2030 projections into the future are obtained by allowing the exogenous endowments of capital, land, natural resources and labour, and the productivity of these factors, most notably yields, to grow according to a specific growth path. Since the base year of MAGNET is 2007, the scenarios are run for the period 2007-10 to project the model towards 2010, and then up to 2030 divided up into two periods of equal length, 2010-2020 and 2020-30.

The MAGNET model has been expanded/improved relative to the standard GTAP model by adding more sophisticated production structure and consumption structure, segmented capital and labour markets and a more sophisticated specification of the land market.

The MAGNET model has a flexible Constant Elasticity of Substitution (CES) nesting structure for production, according to which the ease with which different inputs into production may be substituted in the production of final goods, as measured by the substitution elasticities, may differ across nests. Whereas different sectors may have different nesting structures, for this study a simple three-level nesting structure has been chosen for all sectors and in all countries/regions of the world. Specifically, in the top nest value added and intermediate inputs are combined into production. In the second nest, land and non-land value added are combined into value added. In the third nest, capital, skilled and unskilled labour and natural resources are combined into non-land value added. The distinction between land and non-land value added, to account for inherent differences in the degree of substitutability between land and non-land factors, is new relative to standard GTAP. The value of the elasticity of substitution increases as inputs used in production become more similar (and so can more easily be substituted). In the top nest, the substitution elasticity is assumed zero (as in standard GTAP), so that inputs cannot be substituted and are used in production according to fixed input-output coefficients. In the value added nest, the substitution elasticity equals 0.1 and in the non-land value added nest in between 0.25 and 1.36 depending on the commodity in question.

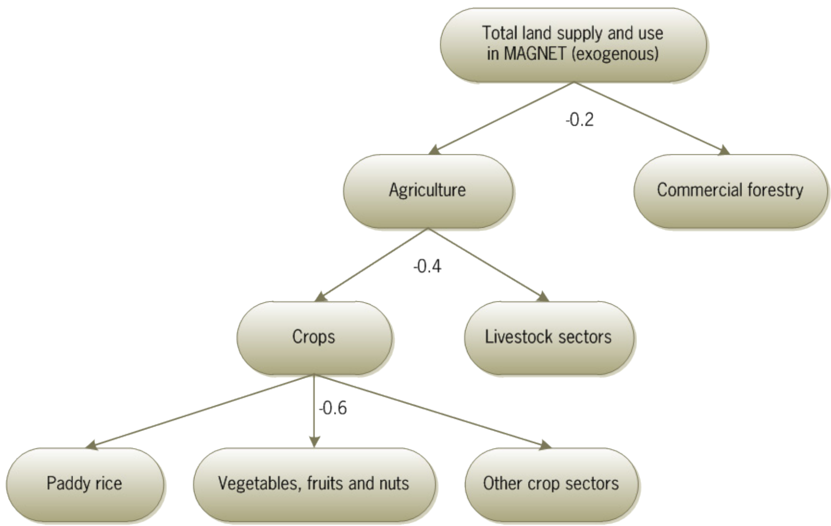
In GTAP private (household) consumption behaviour is modelled via a Constant Difference of Elasticity (CDE) function, which is a more flexible, non-homothetic function allowing for non-constant marginal budget shares, and is calibrated using data on income and price elasticities of demand. Since the use of the CDE function in practice results in constant income elasticities over time - leading to unrealistically high consumption of food items in fast growing economies - in MAGNET income elasticities are dynamically adjusted using real GDP per capita (in the form of a decreasing function). The services sector is used as a residual to guarantee that the sum of the income elasticities is one. The updating of income elasticities takes place in each step of the Euler optimisation routine used in solving the model, and preserves the welfare calculations as present in the GTAP model.

In standard GTAP, capital and labour are assumed to be fully mobile across sectors. In reality, however, there's limited movement of capital and labour between agricultural and non-agricultural sectors, in contrast to relatively free movement within these sectors. This is evident from, for example, the differences in wage levels for unskilled labour in agriculture compared to industry and services sectors. MAGNET allows for the modelling of such segmented factor markets, by introducing a nested Constant Elasticity of Transformation (CET) function for capital and labour, which includes a nest for agriculture and non-agriculture. Within these nests, capital and labour are assumed to be perfectly mobile, but between these nests it is more difficult to move. A consequence of this approach is that unskilled and skilled) labour and capital receive different remunerations (i.e. wage and rental rate respectively) in agricultural and non-agricultural sectors. The elasticity of transformation, which governs the sluggishness of movement of these factors across sectors, is set at a level of minus one (Hertel & Keeney 2005).

In standard GTAP, total land supply is fixed and is assumed to adjust sluggishly between sectors (with an elasticity of transformation equal to -0.5, as for natural resources). MAGNET can refine this approach by allowing for the incorporation of different degrees of sluggishness between different types of land, again using a nested CET function. Generally, the ease with which land is allocated from and to agricultural sectors differs for different types of land. A relatively simple three-level nested-CET approach is adopted, which in the top nest allocates land to commercial forestry and agricultural sectors, in the second nest allocates agricultural land to crops and livestock, and in the third nest allocates cropland to paddy rice, vegetables, fruits and nuts and other crops (Figure A1.1). The elasticities of transformation increase in absolute value at lower levels of the tree, indicating it becomes more easy to transfer land between sectors. This approach creates different land prices in each level of the tree. The elasticities are obtained from GTAP.

A novel feature of the land allocation specification is that it includes commercial forestry in the top level as an economic land using sector. Whilst commercial forestry harvests are flexible in that extra harvests are possible, it is assumed that it is difficult to reallocate land from agriculture to commercial forestry (by means of the relatively low elasticity of transformation), thereby doing justice to the long term nature of the decisions in the forestry sector.

Figure A1.1 **MAGNET land allocation**



The extent to which land can be reallocated between agriculture and forestry and between different agricultural sectors depends very much on the country's land property regime. Vietnam's land tenure system has been reformed under the economic reform process known as *Doi Moi*. In this process, land has been re-assigned from collectives to small-scale farmers, establishing their land rights in a Land Law and enhancing tenure security via inheritable land rights that also asserted women's rights. Despite the agricultural liberalisation process important challenges remain which ensure that the actual land allocation over different land using sectors in Vietnam is still far from smooth and market driven. First land allocation still seems very much planned and regulated by national, regional, provincial, district and commune level authorities, each with their own, often inconsistent, land use plans, which do not match socio-economic plans and construction plans (scoping workshop, Hanoi). Also, whilst legal systems are in place, they are not always operational in practice for a variety of reasons. As a result, it is unclear whether one can speak of a real market for land in Vietnam, with (sectoral) demand responding to a price and with price adjustments assuring equilibrium between demand and supply.

Two main points of importance to the global-to-local land-use modelling emerged from the discussions with Vietnamese land use planners and stakeholders (scoping workshop, Hanoi). Firstly, land reallocation in agriculture is often not instantaneous and easier between some sectors relative to other sectors. This is secured in MAGNET via low levels of substitution, which increase for more similar commodities (Figure A1.1). And secondly, once a year the central government establishes the (official) price for land. It was suggested that two systems operate in parallel, the market with a 'market' price and an official system with an official price. The market price is not monitored on a regular basis and so the valuation of land by the government in terms of an official price is generally not in line with market developments. Given that it is impossible to model these two systems at the same time, the lack of information on land prices, and given that the focus of this study is on implications of global, national and local drivers on land use patterns, it is decided to keep the land market in (i.e. land use across sectors, albeit sluggish, is an endogenous outcome of the model and responds to changes in prices, and land prices adjust so as to ensure equilibrium). The land prices or land rental rates and changes therein that emerge from MAGNET are thus best interpreted as (changes in) shadow prices for land, signifying (changes in) relative scarcity and pressures for land.

CLUE model description

To downscale the aggregate information on land use from MAGNET to a map, the CLUE model is used which was developed by Wageningen University and the Institute for Environmental Studies part of the Free University of Amsterdam.[1] CLUE allocates land-use changes by combining scenario data with spatial data on the bio-geophysical and human drivers of agricultural land use with current land use patterns and information on land-use conversion and spatial policies.

At the spatially disaggregated level, land-use change is also dependent on biophysical conditions (e.g. soil, slope and infrastructure) as well as specific spatial policies such as the location of protected areas and restrictions on land conversion. These issues cannot be taken into account by MAGNET as it only provides results at the aggregate country level. For this reason CLUE is used to project land-use data from MAGNET on a map with a spatial resolution of 1 by 1 km^2. To ensure consistency between the global analysis with MAGNET the FIPI 2007 land-use map is also adopted for the analysis in CLUE.

[1] See http://www.ivm.vu.nl/en/Organisation/departments/spatial-analysis-decision-support/Clue/index.asp [Accessed May 14, 2012] more information on the CLUE model.

The structure of the CLUE methodology is presented in Figure A1.2. It consists of four building blocks in which the main parameters are set: Spatial policies and restrictions, Land use requirements, Conversion settings and Location characteristics. Once these parameters have been determined the model can be run and starts its land-use change allocation procedure.

Quantified land use scenario data are converted into a demand table in the building block 'Land use requirements'. Information on growth of the land needed for Paddy rice, Other agriculture and Production forestry is taken from MAGNET, while change in land use for the other classes: Non-production forest, Shrub and grassland, Built-up land and Other land, is set exogenously depending on the scenario.

Land-use drivers are selected in the 'Location characteristics' building block. By linking GIS based information on location characteristics that reflect biophysical and human land-use drivers with a land-use map, a suitability map is generated that identifies the most probable allocation for the seven land classes for which information is available.
A1.1 provides an overview of the various land-use drivers that are included in the analysis. With the help of the statistical software package SPSS a logistic regression is run for each land-use class to test the relationship between land use and land-use drivers. Driving factors with a low correlation are excluded from further analysis. The remaining driving factors are tested for overall correlation with each land-use class, resulting in a so-called ROC value or Goodness of Fit factor. A ROC factor lower than 0.6 shows a poor relation between the land-use class and driving factors, between 0.6 and 0.7 reasonable and above 0.8 a good relation. Table A1.2] shows the ROC values for each land-use class. The 'Other land' class is excluded from the analysis as it is set to remain constant throughout the analysis. The regression analysis is used to construct a probability map, which indicates the likelihood ('suitability') a grid cell will be converted into a certain land class (Figure A1.3).

For the prediction of future built-up areas use has been made of additional scenario information for the larger cities. In Vietnam the largest growth can be seen in the larger cities, especially in cities such as Hanoi and Ho Chi Minh City (UNDESA, 2012). There are two ways in CLUE to give the surrounding of existing urban areas a higher probability for future urban area. One is by use of the neighbourhood analysis which calculates a higher probability for allocation of future urban pixels in the neighbourhood of existing urban pixels and the second method is to make use of location preference maps, in this case of zones around existing urban areas. For this analysis location preference maps have been designed based on expected growth of larger and smaller towns. The potential location zones around the larger cities are bigger than these zones around the smaller urban areas. The width of the zones is dependent on the expected urban growth and the size of the existing urban pixel clusters. Between 2010 and 2030 the urban area is expected to grow with 82% for the BAU and HCI scenario. The probability in the potential location zone is increased with 0.4. To avoid that the model will only use areas within the location preference maps for its future urban area allocation, the zone width is reduced to 30% of the total expected growth. This leads to a zone width of 3,000 m for urban clusters of 300-400 km^2, a zone of 2,000 m for clusters of 100-300 km^2 and a zone of 1,000 m for clusters of 10-100 km^2.

In the building block 'Land use type specific settings' assumptions are made for all seven land classes about the expansion or contraction over time with the help of a so-called land-use conversion matrix and setting of conversion elasticities. With help of the land-use conversion matrix it is determined which classes can be converted into one or more of the other land-use classes and the time it takes to convert one land class into another. For some classes the conversion is possible (e.g. from natural forest to crop land), for others this will be time consuming (e.g. conversion of pasture to commercial forest only possible after 10 years) and for yet others it might be unlikely or impossible (e.g. from built-up land to paddy rice). Elasticities determine the specific behaviour of the land-use conversion. A low elasticity for one land use type indicates that all changes for that land use type are allowed, independent from the current land use of a location. This means that a certain land use type can be removed at one place and allocated at another place at the same time, e.g. shifting cultivation. The higher the value, the higher the preference that will be given to locations that are already under this land use type. This setting is relevant for land use types with high conversion costs, e.g. from forestry to agriculture or from a perennial crops to annual crop. If an elasticity for a land use type is set to 1 it means that grid cells with one land use type can never be added and removed at the same time. This is relevant for land use types that are difficult to convert, e.g., urban settlements and primary forests. A value of one stabilises the system and prevents that in case of deforestation other areas are reforested at the same time. CLUE also makes it possible to 'block' the conversion of certain areas (grid cells), which is useful to simulate land use policies that do and the protected parks. These settings are determined in the building block 'Spatial policies and restrictions'.

Finally, after setting all parameters in each of the four building blocks CLUE is run to create future land-use maps for each scenario. For this Vietnam analysis future land-use maps have been generated for three scenarios, covering the period 2007-2030.

Figure A1.2 **CLUE model structure**

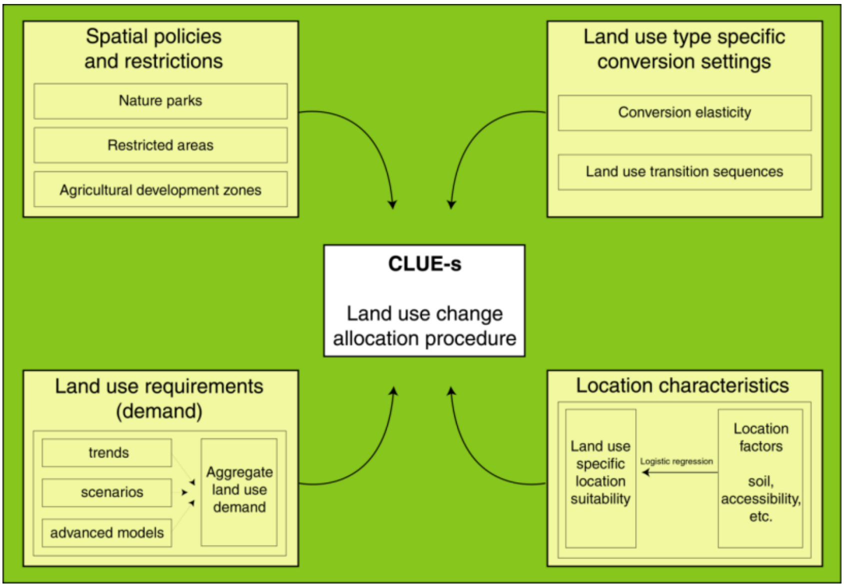
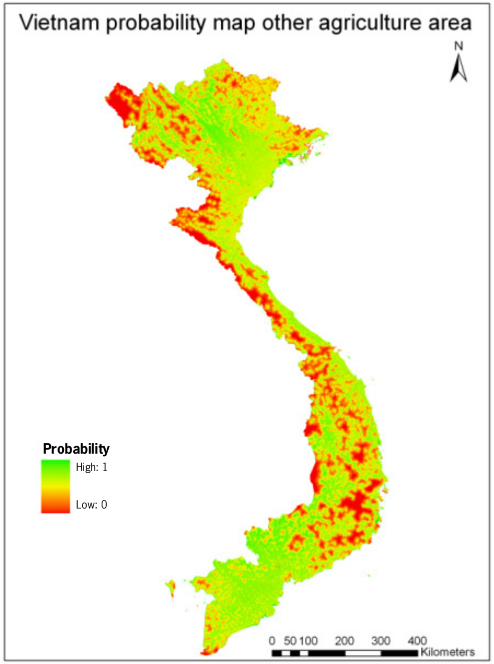


Table A1.1	CLUE land-use drivers
Land-use drivers	
Elevation	
Slope	
Rainfall	
Distance to community centres	
Distance to major water bodies	
Distance to road	
Distance to coast	
Population density	
Soil	
Temperature	

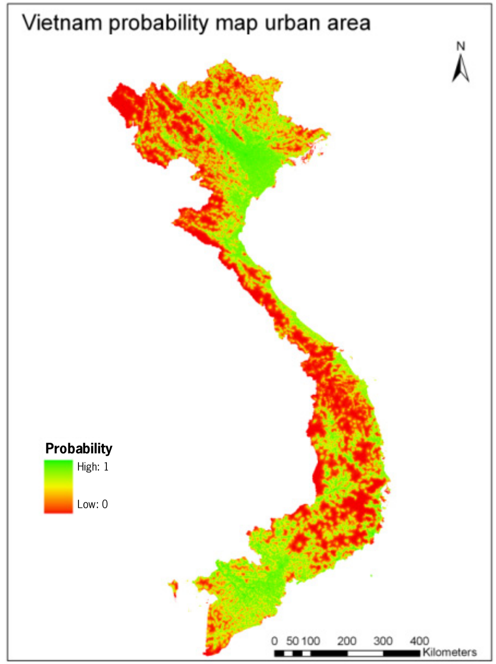
Table A1.2 Land-use drivers and ROC values for logistic regression per land-use class

CLUE land-use class	Land-use drivers included in logistic regression										ROC
	1	2	3	4	5	6	7	8	9	10	
Production forest	x	x	x	x	x	-	x	x	x	x	0.74
Non-production forest	-	x	x	x	x	x	x	x	x	x	0.72
Other agriculture	x	x	x	x	x	x	x	-	x	x	0.71
Paddy rice	x	x	x	x	x	x	x	x	x	x	0.90
Shrub and grassland	x	x	x	x	x	x	x	x	x	x	0.69
Built-up land	x	x	x	x	x	x	x	x	x	x	0.82
Other land	-	-	-	-	-	-	-	-	-	-	-

Figure A1.3 **Probability maps by land-use class**

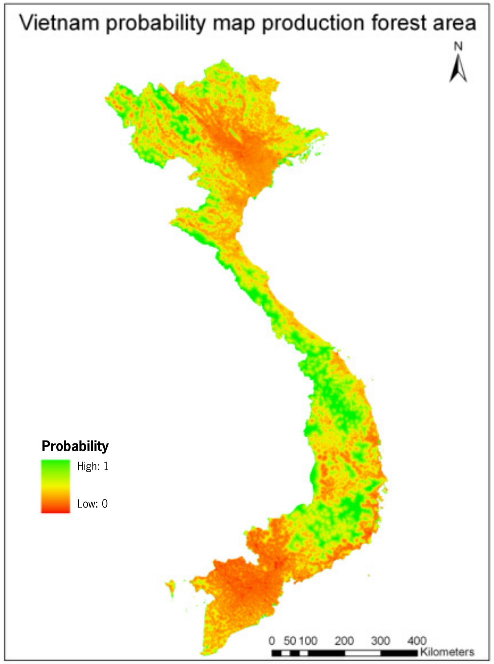


Note: Goodness of fit value ROC = 0.82

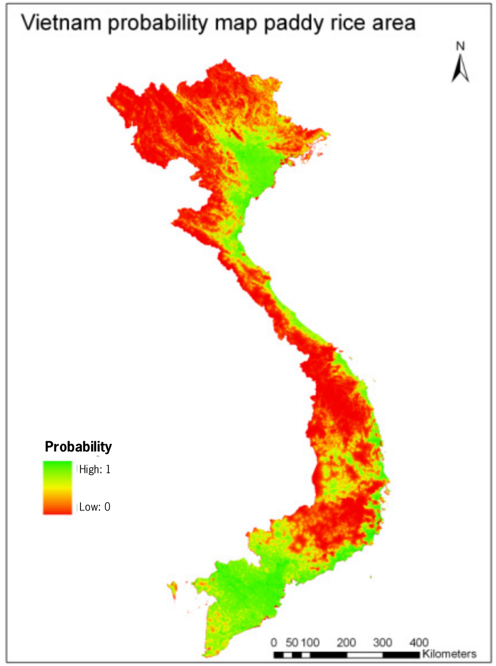


Note: Goodness of fit value ROC = 0.71

Figure A1.3 **Probability maps by land-use class**



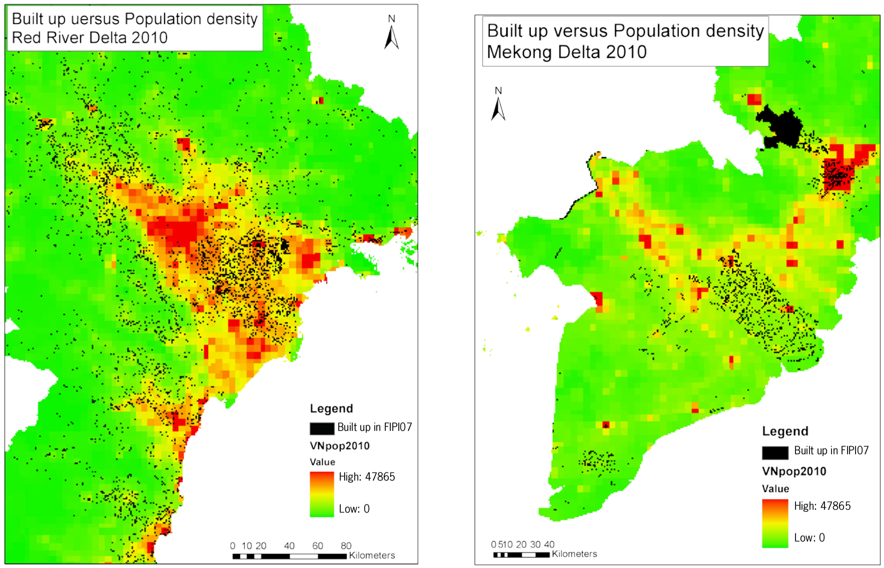
Note: Goodness of fit value ROC = 0.90



Note: Goodness of fit value ROC = 0.74

Appendix 2

Figure A2.1 **Comparison between built-up areas and population density maps**



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