The spatial distribution and interregional dynamics of vegetable production in Thailand

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"The total vegetables, produced over the infinite plain, would be infinite; but after transport cost, only a finite amount will get through to any inner radius"

Paul A. Samuelson (1983, p. 1480) using a highly stylized counterexample to refute the general supposition that goods with high transport rates are always produced close to the centre of demand and vice versa.

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I. Zusammenfassung

Verbunden mit dem raschen Wirtschaftswachstum in Thailand zeigt auch der Gemüsebausektor eine dynamische Entwicklung. Es ist das Ziel dieser Arbeit, die Faktoren, die die Mobilität der Gemüseproduktion und die künftigen Produktionsstandorte im Hinblick auf eine rückläufige Produktion in den traditionellen Anbaugebieten um die rasch wachsende Hauptstadt zu bestimmen. Darüber hinaus soll auch der Zusammenhang zwischen einer Verlagerung der Produktionsstandorte und der Adoption umweltfreundlicher Produktionsverfahren ermittelt werden. Schließlich werden auch Möglichkeiten für staatliche Eingriffe mit dem Ziel, negative Externalitäten der gegenwärtig dominierenden Technologien zu reduzieren, untersucht.

Der Strukturwandel der thailändischen Volkswirtschaft in Verbindung mit dem schnellen Wirtschaftswachstum hat dazu geführt, dass der Anteil der Landwirtschaft am Bruttosozialprodukt in den vergangenen 40 Jahren von 80% auf 10% gesunken ist, während noch immer etwa 40% der Erwerbstätigen in diesem Sektor beschäftigt sind. Dies hat zu einem beträchtlichen Einkommensgefälle zwischen städtischen und ländlichen Einkommen geführt. Zugleich haben aber Urbanisierung und steigende Pro-Kopf-Einkommen zu einer höheren Nachfrage nach hochwertigen Nahrungsmitteln, einschließlich Gemüse geführt. Gemüse hat eine vergleichsweise kurze Kulturdauer und wird mit hoher Intensität von ertragssteigernden Produktionsfaktoren wie Dünge- und Pflanzenschutzmitteln produziert. Das hohe Einsatzniveau von Pflanzenschutzmitteln und unsichere Handhabung führen dabei zu erheblichen Risiken für die Beschäftigten im Gemüsebau und die Konsumenten. Obwohl Gemüse prinzipiell überall in Thailand angebaut wird, war die Produktion traditionell doch vorwiegend um die Städte, insbesondere westlich und nördlich von Bangkok konzentriert. Auch im kühleren Klima der höheren Lagen Nordthailands wird ein größerer Anteil des Gemüses produziert. Zwischen den späten 1980er Jahren und 2000 ist ein signifikanter rückläufiger Trend bei der Produktion in Bangkok und den benachbarten Provinzen feststellbar. Während des gleichen Zeitraums nahm der Anteil der Produktion in etwas weiter entfernten Provinzen im Westen und etwa 300 km entfernt im Nordosten von Bankok zu. Der ohnehin sehr bedeutende Anteil des Nordens an der Gesamtproduktion hat sich dabei kaum verändert. Insgesamt bedeutet dies, dass sich der Gemüseanbau graduell aus den peri-urbanen in weiter entfernte rurale Gebiete verlagert.

Um diese Entwicklungen vor dem Hintergrund der Fragestellung zu analysieren wurde ein regionalisiertes Programmierungsmodell für Angebot und Nachfrage entwickelt, das die wesentlichen Eigenschaften des Sektors abbildet. Es umfasst 23 Gemüsearten und berücksichtigt deren Produktion und Nachfrage in acht über Transportaktivitäten verbundenen Regionen und deckt damit etwa 90% des Produktionswertes des Gemüsesektors zu loco-Hof-Preisen ab. Das Modell minimiert die variablen Kosten der Gemüseproduktion und –transformation unter

Berücksichtigung regionaler Nachfragemengen. Die Kapazitätsbeschränkungen der regionalen Produktion sind aus Daten des Agrarzensus und weiteren Sekundärdaten abgeleitet worden. Die Produktionstechnologie wird durch regional definierte Parameter der Produktionsaktivitäten abgebildet. Diese Daten wurden im Rahme von Expertenworkshops mit Gemüsebauern und Fachleuten der landwirtschaftlichen Offizialberatung erhoben. Das Modell wurde mit Hilfe der positiven mathematischen Programmierung auf die im Basisjahr beobachteten Aktivitätsumfänge kalibriert.

Die Ergebnisse der Modellsimulationen zeigen, dass im Durchschnitt nur 43% der regionalen Gemüseproduktion innerhalb der Ursprungsregion verbraucht werden. Bedingt durch die regional unterschiedlichen Produktionsbedingen wird Gemüse über durchschnittlich 293 Kilometer transportiert. Damit verursacht der Transport etwa 245.000 Tonnen CO_2-Emissionen pro Jahr. Weiterhin zeigen die Modellergebnisse, dass die Intensität des Pflanzenschutzmitteleinsatzes in Nordthailand bereits das Niveau der traditionellen Anbaugebiete um Bangkok erreicht hat und damit etwa 11,8 kg an aktiven Substanzen pro Hektar und Jahr ausgebracht werden.

Die Auswirkungen von Veränderungen in verschiedenen exogenen Variablen sind durch parametrische Simulation untersucht worden. Es zeigt sich, dass die regionalen Anteile an der Gemüseproduktion vergleichsweise stabil sind. Sowohl steigende Nachfrage, als auch verbesserte Transporttechnologie und eine Beschränkung des Gemüseanbaus in Bangkok führen zu einer stärkeren Verlagerung von den marktnahen zu weiter entfernten Produktionsstandorten. Dagegen wirken steigende Energiepreise und eine Pestizidreduktionspolitik darauf hin, dass die Produktion auf marktnahen Standorten zunimmt.

Um eine Aussage über die künftige Entwicklung zu treffen, wurde ein plausibles Szenario für das Jahr 2011 definiert, das von steigender Nachfrage, zunehmenden Energiepreisen, steigenden Löhnen, abnehmenden Gemüsebauflächen in Bangkok und Umgebung, steigenden Erträgen und weiterer Adoption umweltfreundlicher Produktionsverfahren ausgeht. Das Ergebnis für dieses Szenario zeigt, dass die Gemüseproduktion in allen Regionen etwa gleichmäßig zunimmt, wohingegen die Landnutzung und Nachfrage nach Arbeitskräften bedingt durch die Ertragssteigerungen sinken. Die marginalen Kosten des Gemüseangebots auf den zentralen Großmärkten steigen dabei um durchschnittlich etwa 10%, bedingt durch steigende Löhne und Transportkosten. Die Intensität des Düngemittel- und Pflanzenschutzmitteleinsatz wird dabei sogar zunehmen, insbesondere in Regionen mit einem bereits hohen Einsatzniveau. Eine Fortsetzung der gegenwärtigen Entwicklung führt demnach zu weiter steigenden externen Kosten der Gemüseproduktion.

Die Wirkung von drei ausgewählten Politikmaßnahmen mit dem Ziel, diesen Trend umzukehren, wurde mit Hilfe des Modells untersucht. Die Ergebnisse zeigen, dass eine Politikmaßnahme, die den Anbau von Gemüse in Stadtnähe (um Bangkok) beschränkt, dazu führt, dass zwar die absoluten Einsatzmengen in dieser Region sinken, aber die Intensität auf den verbleibenden Flächen und in anderen Regionen steigt. Die Festlegung eines

Pestizidreduktionsziels ist mit gegenwärtig verfügbarer Technologie bis zu einem Reduktionsziel von 30% möglich, führt aber zu deutlich höheren marginalen Kosten des Gemüseangebots. Eine Pigou-Steuer auf der Basis der Umweltwirkung einzelner Pestizide zeigt sich in den Simulationen als wirksame Maßnahme. Der Anstieg der marginalen Angebotskosten ist dabei mäßig und kann durch weitere Adoption umweltfreundlicher Produktionstechniken gesenkt werden.

Schlagworte: Thailand, Gemüsebau, Agrarsektormodell

II. Abstract

In line with a rapid development of the Thai economy, also the vegetable sector has been subject to considerable dynamics. The purpose of this research is to identify the factors that determine the mobility of vegetable production and the future vegetable production locations vis-à-vis the declining trend of production around the expanding capital. Furthermore, the link between a shift of vegetable production locations and the adoption of environmentally friendly production technologies shall be assessed. Finally, also the policy options to facilitate a reduction in negative externalities are investigated.

The structural change during a rapid economic growth of the Thai economy in the past 40 years involved a decline in agricultural GDP contribution from 80% to about 10% whereas 40% of the labour force continue to be employed in the sector, involving a substantial discrepancy between rural and urban incomes. At the same time, urbanization and rising per capita incomes have lead to a rising demand for high value crops including vegetables. Vegetables are mostly short cycle crops grown with high intensities of labour and yield increasing inputs such as fertilizers and pesticides. The high level of pesticide use and unsafe practices have lead to substantial health risks to farm labourers and consumers. Although vegetable production is virtually ubiquitous, production has traditionally been concentrated closely around cities, especially to the west and north of Bangkok. Moreover, highland production areas in northern Thailand contribute a major share of supplies. Between the late 1980s and 2000, a significant decline in the supply share from Bangkok and surrounding provinces can be observed. At the same time supply shares increase in provinces further west of the city and about 300 km northeast of Bangkok. These trends imply a significant shift from the peri-urban production locations to more rural areas.

A programming model of regional supply and demand has been developed that depicts the major characteristics of the sector. It covers supply and demand of 23 vegetable crops in 8 distinct regions covering about 90% of the farm gate value of national vegetable supply. The model is based on a minimization of total variable cost of vegetable supply under fixed regional demand constraints. The resource constraints for the model are derived from agricultural census data and other secondary sources. Production technology is represented by regionally specific parameters of production activities. Data for these parameters have been obtained from a field survey and expert workshops with farmers and extension specialists. For calibrating the model to observed baseline activity levels, a positive mathematical programming approach was used.

The results of the model simulation reveal that on average only 43% of vegetable production is consumed within the same region. Due to regionally different production conditions, vegetables are on average transported over a distance of 293 kilometres involving carbondioxide emissions of 245,000 metric tons annually. The results show furthermore, that the intensity of pesticide use

in Northern Thailand has reached a level comparable to the traditional peri-urban production sites around Bangkok, which involves 11.8 kg of active ingredient of pesticides applied to one hectar per year.

The impact of changes in selected variables has been assessed by parametric simulation and has revealed that regional vegetable supply shares are rather stable. The effect of a growing demand, improving transport efficiency and a zoning policy that reduces vegetable area in Greater Bangkok accelerate the shift of production to more remote areas. Increasing fuel prices and a pesticide reduction target lead to an increasing supply share from the regions closer to the centres of demand.

In order to predict future developments a likely scenario for the year 2011 was defined by combining demand growth, rising energy prices and labour cost, declining land resources in Greater Bangkok, yield increases through technical progress and further adoption of more environmentally friendly technology. The model simulation of this scenario reveals that vegetable output will grow in all regions whereas land use and labour demand decrease due to the assumed yield increase. The marginal supply cost of vegetables will increase by about 10% on average as a result of increasing labour and transportation cost. The intensity of external input use will, however increase in particular where it has been high before. The current development path is therefore likely to lead to a further increasing aggravation of negative externalities of vegetable production.

The effects of three policy measures to reverse the tendency to further intensification of external input use were simulated. The results for a zoning policy that limits vegetable area in Bangkok to increasing extent show that a decrease in absolute levels of pesticide use is attained but intensity on the remaining land and in other regions increases. A pesticide reduction policy that fixes a national reduction target is able to reduce the environmental effects of pesticide use by 30% from present levels with existing technology. A Pigouvian tax approach that is based on a compound environmental impact indicator of pesticides was found to be most effective. The rise in marginal supply cost associated with such a policy can be contained by further increasing adoption of environmentally friendly production technology. Depending on the reduction target, the effect of a pesticide tax on farm incomes and the marginal cost of vegetable supply at the wholesale market are low to moderate, especially if further adoption of environmentally friendly technology is assumed.

Keywords: Thailand, vegetable production, agricultural sector model

III. Tables

IV. Figures

V. Abbreviations

AI	Active ingredient
AVRDC	World Vegetable Center (formerly: Asian Vegetable Research and Development Center)
AVRDC-ARC	AVRDC Asian Regional Center, Kampaengsaen, Nakhon Pathom Province, Thailand
BK	Greater Bangkok model region
CE	Central model region
c. p.	Ceteris paribus, i.e. all other things being equal
DANIDA	Danish International Development Agency
DoA	Department of Agriculture, Ministry of Agriculture and Cooperatives
DoAE	Department of Agricultural Extension, Ministry of Agriculture and Cooperatives
DW	Data warehouse application
EI	Environmental impact
EIQ	Environmental impact quotient
ENE	Eastern part of Northeast Thailand (a model region)
ESTJ	Enke-Samuelson-Takayama-Judge spatial price equilibrium
FAO-RAP	Food and Agriculture Organization, Regional Office for Asia and the Pacific
FFS	Farmer field school
GAMS	General Algebraic Modeling System
GDP	Gross domestic product
ha	Hectare
IFCN	International Farm Comparison Network
IPM	Integrated pest management
IPPM	Integrated production and pest management
l	Litre
LN	Lower north model region
LP	Linear programming
kg	Kilogramme
km	Kilometre
MASL	Meters above sea level
md	Man days
MDS	Microdata sample – here referring to a 1% sample of the Agricultural Census 2003, National Statistical Office
MoAC	Ministry of Agriculture and Cooperatives
MoPH	Ministry of Public Health
NESDB	National Economic and Social Development Board
NLP	Non-linear programming
NSO	National Statistical Office, Ministry of Information and Communication Technology
OAE	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives
PMP	Positive Mathematical Programming
QP	Quadratic programming
SO	Southern model region

t	Metric ton
t km	tonne-kilometre
THB	Thai Baht. Exchange rates:

	2001	2002	2003	2004	2005	2006	2007	10/2008
1 US$	44.43	42.96	41.48	40.22	40.89	36.43	33.75	34.79
1 €	39.79	40.57	46.89	49.99	48.56	48.05	49.68	44.38

Source: IMF representative rates, http://www.imf.org/external/np/fin/data/param_rms_mth.aspx

TDRI	Thailand Development Research Institute
TEI	Thailand Environment Institute
TVSM	Thai Vegetable Supply Model
UN	Upper north model region
UNE	Upper part of Northeastern Thailand (a model region)
VFH	Vegetables, flowers and herbs, a land use class used in the agricultural census
WHO	World Health Organization
WNE	Western part of Northeastern Thailand (a model region)

1 Introduction

Vegetables have become an important crop in Thai agriculture. Growing per capita income has fostered an increase in demand for higher value food commodities with better nutrient content. Some types of vegetable are also becoming increasingly important as export commodities for markets in other emerging Asian economies, the United States and Europe. As determined by the "von Thünen principles" of location theory, vegetables have been produced traditionally around, near or in urban centres. With the introduction and widespread use of yield increasing external inputs such as mineral fertilizers and chemical pesticides, vegetable areas have become major sources of water pollution. Furthermore, the high level of pesticide use often leads to considerable health hazards for farmers, farm labourers and consumers. Also, the spread of urban areas for industrial zones and private housing has increased the demand for land in the vegetable areas in the vicinity of Bangkok. In addition, vegetables are labour intensive crops and urban labour markets make it increasingly unattractive to work on vegetable farms in urban areas. In response to economic factors and government programmes, vegetable production has shifted from peri-urban to more remote sites. Especially in the mountainous areas of Northern Thailand, the government has promoted vegetable production as an alternative income source for hill tribe populations. While many studies were conducted for specific vegetable production systems, no adequate analysis has previously been carried out to explain the existing spatial arrangement of vegetable production and the driving forces for trends in production locations in the context of overall agricultural development in Thailand. Such research is needed in order to help policy makers to assess the effect of environmental and health policies on vegetable production, prices and externalities.

This study conducts an analysis of the structure of vegetable supply under changing economic and environmental conditions. It is complementary to another research that analyses the effect of changing consumer preferences on the demand for vegetables produced with environmentally more benign and safer production practices (VANIT-ANUNCHAI, 2006).

The objectives of this research are:

1. to identify the factors determining spatial mobility of vegetable production in Thailand,
2. to identify the major vegetable production locations in view of the declining importance of traditional peri-urban production locations,
3. to assess the relationship between a shift away from peri-urban production locations and the adoption of environmentally friendly vegetable production technologies, and
4. to identify policy options that can facilitate the reduction of negative externalities without reducing vegetable supply.

To meet these objectives this study uses a comprehensive framework that includes the resource base of the agricultural sector in Thailand, a description of vegetable production systems including technologies, their level of productivity and intensity. In addition, a linkage is established with the external environmental and economic factors and the institutional setting and policy environment that preconditions the development of the vegetable sector in Thailand. A major undertaking was the generation of a database that would meet the requirements of plausibility and economic theory. The results of this research will help to establish a baseline for assessing the impact of policy intervention on the role and relative importance of vegetables in Thailand. The study is organised as follows:

In chapter two the economic theory relevant for explaining the changing role of agriculture in a growing economy such as Thailand is introduced. Moreover, the theory used for analysing the location of agricultural production and interregional trade and general approaches to modelling these phenomena are presented.

Chapter three offers a description of the development trends of agriculture in Thailand and a detailed analysis of the vegetable sub-sector based on secondary literature and statistical data. A brief characterization of domestic and export demand for vegetables is followed by a brief account of the current distribution, transportation and marketing system based on available secondary information. Finally, the description turns to vegetable production in terms of predominant production systems, and spatial agglomeration of production and problem areas identified in the literature.

Chapter four introduces the underlying concept for an interregional programming model. For this purpose the approach followed in this study for modelling supply response of the vegetable sub-sector is discussed in detail. Next, the methods of data collection and processing for model parameterization are explained. The chapter concludes with the formulation of likely development and policy scenarios to be analysed by means of the model.

Results of the analyses are discussed in chapter five, beginning with an interpretation of the baseline solution and the spatial structure of supply. Thereafter results of partial parametric analyses for technical and policy factors are presented to provide an assessment of the relative strength of their influence on the cost of supply, resource use and the environment. Then, the effects of policy strategies are addressed with respect to three intervention measures. The chapter concludes with the outcome of a likely future development scenario for 2010.

Chapter six presents the conclusions that can be drawn from the comparative analysis of scenario results. Implications for policy formulation to improve on unsustainable production systems without jeopardizing the goals of a growing supply and acceptable farm incomes are discussed. The research concludes with some recommendations for future studies.

2 Economic theory for analysing vegetable supply in Thailand

This chapter prepares the basis for the subsequent analysis by presenting the relevant economic theories. With respect to the above research objectives, economic theory from three specific fields is deemed most relevant. Firstly, development economics contributes concepts dealing with the role of the agricultural sector and more specifically the changes the sector is facing in a rapidly developing economy such as Thailand. They provide the background for understanding the dynamic frame conditions under which the vegetable sub-sector operates. In line with the importance attributed to the spatial arrangement of vegetable production in the exposition, in a second step the theories dealing with the spatial structure of the economy and relevant for agriculture will be presented. Thirdly, concepts dealing with the spatial mobility of goods are briefly reviewed. This discussion facilitates the presentation of modelling approaches that explicitly consider the spatial arrangement of economic activity concluding this chapter.

2.1 Agriculture in a rapidly growing economy

The role of agriculture in the course of economic development has been subject to considerable debate in development economics discipline, and policy strategies have changed accordingly (HAYAMI and GODO, 2005, p. 88). Based on the postulate of inefficient resource use and particularly slack labour in agriculture, LEWIS (1954) and RANIS and FEI (1961) argued that growth was a result of capital accumulation in the non-agricultural sector and labour could (and had to be) withdrawn from agriculture until its marginal productivity equalled that in the industrial sector. This dualistic view classified agriculture as the traditional sector lagging behind the non-agricultural sectors where resources were allocated efficiently, and had its due impact on development strategies, which were consequently geared towards fostering the industrial sector (TIFFIN and IRZ, 2006). In spite of arguments that given the technology available and their resource endowments, farmers were efficient (SCHULTZ, 1953), it was not until the early eighties that agricultural growth was recognized as a (pre-) condition of overall economic growth and development. The causal effect of agricultural growth on GDP growth was proved for many developed countries based on panel data (TIFFIN and IRZ, 2006). Thailand's present stage of development with a GDP share of the agricultural sector around only 10%, renders that debate hardly relevant for this study, whereas the related phenomenon of a rural-urban income disparity remains important.

Schultz (1953), argued that low income economies were faced with the 'food problem', i.e. the risk of food shortage in view of a rapidly growing population and still high food demand elasticities. In such conditions, the large expenditure share for food makes it a wage good, whose price directly affects real wages. Thus, policy makers are concerned with keeping food prices low in order to keep wages low, which in turn improves the competitiveness of industries. On the other hand, in high income economies food demand is stagnant as population growth is slow and according to Engel's law, food expenditures decline in relative terms. Concurrently, agricultural production in such economies takes advantage of technically advanced means of production and hence shows high levels of productivity, which has contributed to low real food prices. The resulting gap between agricultural and non-agricultural incomes has been used as an argument for protective policies that stabilize prices or subsidize agriculture in order to reduce the gap ('the protection problem') (HAYAMI, 2007, p. 4). HAYAMI argues that in high-performing economies of Asia a third problem occurs during transition between the above-mentioned states. As productivity in agriculture lags behind non-agricultural sectors, income disparity between these sectors increases. The share of food expenditures on the other hand is still considerable and thus real incomes continue to depend on food prices while the government budget in relation to a still large rural sector is not sufficient for financing measures that bridge the gap. The 'disparity problem' between agricultural and non-agricultural incomes or, put differently, a high incidence of relative poverty in rural compared to urban populations bears the threat of social unrest and is therefore a very relevant concern for policy makers in middle-income countries (HAYAMI, 2007, p. 5f).

Aside from these general changes in agriculture, especially high-value agriculture has undergone a remarkable evolution in Southeast Asia (BARRETT *et al.*, 2001; BOSELIE *et al.*, 2003; GULATI *et al.*, 2006, p. 2), whose underlying factors will be reviewed in the following.

Evidently, population growth and rising incomes lead to rising demand for food. But initially highly elastic food demand declines with increasing incomes according to Engel’s law in line with physiologically limited food requirement (HAYAMI, 2007, p. 3). Bennet's law adds to this that the demand for staple foods declines with increasing incomes as households switch to high-value food items, i.e. those more expensive with respect to calorie content, including milk, meat and fish, fruits and vegetables (REARDON and BARRETT, 2000; FUGLIE, 2004). The income effect has been shown to be superimposed by a change in preferences that goes along with urbanization, another meta-trend that applies to many economies (REARDON and BARRETT, 2000). From a panel data set for Taiwan, urbanization was distinguished as a factor separate from income that explained the increasing demand for high-value food with less caloric content and more prepared and convenience food against decreasing staple rice demand. Such structural change in food demand can be explained by more sedentary occupations in cities versus physical labour involved in rural occupations, and changing lifestyles — including a rising female workforce participation and cultural diversity leading to more diversified food demand (HUANG and BOUIS, 2001; GULATI *et al.*, 2006, p. 4).

Beyond these effects, urbanization also reshapes the structure of the retailing sector. REARDON *et al.* summarize evidence on the expanding role of supermarkets in three developing regions and find that within only one decade retail systems had been transformed from traditional forms of mom and pop stores, street fairs and central markets to include a significant share of supermarket chains - first in Latin America, then with a lag of 5-7 years in East- and Southeast Asia and finally Africa (2003). Among other factors, the increasing percentage of women in the workforce and subsequent need for further processed foods and convenient one-stop shopping are important demand-side determinants of supermarket expansion as the procurement of processed food is subject to scale economies (REARDON and BARRETT, 2000). On the supply side, foreign investment, which grew by factor five to ten on the whole – and proportionally also in the retail sector over many countries in three regions, was dominated by a few global retail multinationals (REARDON, 2003). This is manifest in the involvement of foreign companies in most retail chains operating in Thailand (WIBOONPONGSE and SRIBOONCHITTA, 2004, p. 10f). Adding to this, new technology in logistics, computerized inventory control and supplier-retail coordination that evolved in developed countries was also transferred or imitated by chains in the developing world and has boosted efficiency over traditional market chains. Efficiency gains translated into profits that enabled further development and expansion of the system and intensifying competition – and reduced prices for consumers (REARDON, 2003).

Analogous to the case of European and US retail sector changing the structure of the upstream parts of the supply chain, the conditions for farmers in the developing world have changed with the rise of supermarket retailing in their domestic markets (BOSELIE *et al.*, 2003; REARDON, 2003). Under intense pressure to efficiently ensure the year-round supply of diverse food items of guaranteed quality in a competitive segment with low margins, supermarket procurement officers aim at reducing transaction costs on the one hand and ensuring and improving quality aspects of the products on the other (REARDON, 2006, p. 90). In line with these aims and a growing size of chains, procurement systems change from a per-store basis to the establishment of distribution centres (BOSELIE *et al.*, 2003; REARDON, 2003; WIBOONPONGSE and SRIBOONCHITTA, 2004). The establishment of stable supplier relations through contracts often implies the listing of fewer but larger 'preferred' suppliers (BOSELIE *et al.*, 2003). Centralized distribution facilities are sometimes run in co-operation or as joint venture between different retailers or wholesale companies (REARDON, 2003) and perform not only tasks such as washing, packaging and labelling but also producing pre-cut mixes for stir-frying and salads (BOSELIE *et al.*, 2003). Apart from direct contracting of producers, large retailers may also contract specialized wholesalers - either by side-stepping or transforming traditional wholesale systems and thereby reduce their transaction and search costs (REARDON, 2006, p. 93f).

Direct contracting of farmers may meet difficulties where formal contractual relations are novel to farmers (BOSELIE, 2002; BUURMA and SARANARK, 2006). In contrast, the highly specific quality requirements for processing make formal contracts, which include close monitoring or entail substantial investment, more attractive for both sides and are the rule rather than the exception. Broiler production in Thailand, for instance takes place virtually exclusively under contract (GULATI *et al.*, 2006, p. 18). But supermarket suppliers are also required to comply with increasingly strict product quality and/or process quality standards (BOSELIE *et al.*, 2003). The conceptual framework for the diffusion of standards laid out by REARDON (2006, p. 95f) distinguishes private standards as those defined and imposed by private sector firms for the market they control, and public standards that are defined and enforced by public authorities. Incentives for the implementation of private standards are threefold: Firstly the absence of public standards (or their enforcement), which is an obstacle for product differentiation, in some legal environments a source of risk from liability for health hazards and the involved loss of consumer confidence. In the absence of public safety standards the introduction of a credible private standard presents a tool in competitive strategies. Secondly, private standards are an instrument of product differentiation demanded by consumers. Thirdly, the definition of standards is a means of coordinating chains and reducing transaction costs as they provide a framework for implementing quality control and risk reduction (REARDON, 2006). In line with these incentives, a trend away from technical norms imposed for reducing transaction costs towards instruments of product differentiation, and hence from public to private standards, can be observed. Moreover, the purpose of conveying experience characteristics is eclipsed by the function of communicating credence characteristics, including food safety or social standards. Accordingly the focus of standards shifts from product standardization to process standardization (REARDON *et al.*, 1999). On the producer side the compliance with product and process standards usually involves investment in physical structures (packing facilities etc.) and learning and substantial fixed cost for certification and inspection (BOSELIE *et al.*, 2003; REARDON, 2006, p. 102), which may be prohibitive for small-scale producers unless they organise in groups or cooperatives (BOSELIE *et al.*, 2003). On the other hand, the capacity building involved in these chains also offers opportunities for participation in a growing domestic market and compliance with international standards required in export markets (BOSELIE *et al.*, 2003; REARDON, 2006, p. 102). As empirical studies generally did not find economies of scale in agricultural production (BARRETT *et al.*, 2001) and they are unlikely to apply to high quality crops and organic production (BOSELIE *et al.*, 2003), the concentration in retail and processing (which are subject to economies of scale) (BARRETT *et al.*, 2001) and the associated standard compliance do not necessarily exclude small-scale farmers from the benefits of participation in these chains (see e.g. GULATI *et al.*, 2006, p. 28). A marginalization of small-scale producers is therefore not a necessary result of the observed developments on the downstream part of the value chain.

In summary, the rapid economic development of Thailand puts agriculture under dynamic conditions characterized by (a) a disparity between agricultural and non-agricultural wages that continues to be substantial and results in pressure on agricultural wages, (b) changing demand from staple foods towards high-value, prepared or processed foods with increasing quality requirements and demand for diversified foods, (c) a concentration in the food retail trade implying changes in the whole chain including more market power of retailers, increasing prevalence of contract farming with individuals or groups, tightening requirements on standards, safety and timing of supply. Finally, (d) the export markets also demand more consistent compliance with various standards.

These developments apply particularly to vegetables as high value agricultural commodities. Given a relatively high labour-intensity, agricultural wages strongly affect production cost. On the other hand, domestic demand can be expected to grow further and to diversify in terms of the variety of vegetables and degree of processing. The concentration in the retail sector and the associated streamlining of the supply chain and the increasing importance of standards pose new challenges for small-scale vegetable producers, thereby adding to the dynamic conditions in which vegetable farms operate. For a discussion of the involved spatial dynamics, the next section presents the theories dealing with the location of agricultural production.

2.2 Location theories

In order to develop a suitable conceptual model for the analysis of the dynamics of the vegetable sector, economic theories of the spatial arrangement and location of economic activity are discussed in this section. The theories on location fall into two broad categories, one of which is directed at the optimum choice for the location of individual economic units. The other set comprises those theories concerned with explaining the pattern of economic activities in space, or put another way, the spatial structure of the economy (SCHÄTZL, 1998, p. 27), which is the relevant subset in the context of this thesis. Before going into the details, the basic concepts to which some of these theories make reference are introduced.

The existence of cities and industrial agglomerations can been explained by positive internal and external economies of the spatial concentration of economic activities (SCHÄTZL, 1998, p. 32). The former refer to *economies of scale*, i.e. declining unit cost of output when an existing enterprise in a given location is expanded, e.g. by specialization or improved utilization of machine capacity. For activities subject to economies of scale, expansion of production at existing locations is more profitable than opening up new production locations, which contributes to spatial concentration. External economies have been introduced by Marshall (MARSHALL, 1920, p. IV.X) and have later been classified further into localization and urbanization economies, which lead to decreasing cost of purchasing inputs, production or sales. Concentration of businesses of the same industry results in *localization economies*, on the one hand through "[…] thick markets for specialized skills and backward and forwarded linkages associated with large local markets" (FUJITA *et al.*, 1999, p. 5). On the other hand, close location of enterprises of the same trade enables knowledge spillovers, which in turn foster productivity growth[1]. *Urbanization economies* are linked to the advantages arising from concentration more generally, comprising enterprises of different businesses, whose presence improves infrastructure and the supply of (public) services in general (SCHÄTZL, 1998, p. 32). The effect of positive internal and/or external economies is increased agglomeration and one would expect a positive feedback once an agglomeration has been established (FUJITA *et al.*, 1999, p. 4). Internal and external economies from agglomeration can, however, also take on a negative sign. For instance through congestion or increasing costs of man-

[1] No doubt localization economies have played an important role in shaping the specialized vegetable growing locations, e.g. in Damnoen Saduak district, Ratchaburi province. The supply of a variety of produce attracted middlemen acting as wholesalers, who in turn provided easy access to the market by their presence. Knowledge spillovers are likely in agriculture, because cropping practices are generally easily observable.

agement they exert a de-centralizing influence. Although agglomeration factors have so far been found difficult to quantify, their effect on the production of high-value crops, such as vegetables is highly suggestive. Being a (relatively) knowledge-intensive activity requiring highly specific inputs (e.g. seeds) and output marketing channels, vegetable production will most likely benefit from localization and urbanization economies.

2.2.1 Theories on the spatial structure of the economy

With his theory on the location of agriculture as developed in his "Isolated State" (1826) J. H. VON THÜNEN laid the foundation for a theory on the location of economic activity. His theory and its subsequent developments will be treated in more detail in the next subchapter. On the basis of this work, LÖSCH (1940) and CHRISTALLER (1933) developed their theories of hierarchical systems of central places for the secondary and tertiary sectors, which in essence explain the existence of a more or less regular pattern of cities by the trade-off between economies of scale and transportation cost. Even though these theories deduce for a certain set of assumptions that a hexagonal lattice of market areas around cities is economically efficient, they fall short of explaining the emergence of the predicted spatial patterns from self-interested behaviour of individual economic units (FUJITA *et al.*, 1999, p. 27), and met with limited response in the discipline of economics. It was only in the 1990s, that the "curious disdain of location theory on the part of mainstream economics" (BLAUG, 1997, p. 621) turned into a revived interest in the spatial features of the economy. The field of *new economic geography*, which evolved at this time, links micro-behaviour to the equilibrium of spatial concentration of economic activity and allows for a generalized reformulation of the VON THÜNEN theory (FUJITA *et al.*, 1999, p. 133ff). The subsequent discussion of location theories will, however, be confined to the contributions dealing with the location of agricultural production under an exogenously given pattern of spatial concentration.

2.2.2 A partial model of the location of agriculture

The publication of VON THÜNEN'S "The isolated state" in 1826 marks the inception of location theory. In this work and its later editions VON THÜNEN developed his reasoning on the factors determining the pattern of agricultural activities using a strictly idealized model of an isolated and completely homogeneous plain with only one town in its centre. Moreover, he on the one hand specifies further assumptions, such as rational (i.e. profit maximizing) behaviour of agricultural producers. On the other hand, he presents sample calculations and descriptions of production systems of different intensity with reference to production and transportation technology of his time and parameters obtained from accounting data he meticulously collected himself on his own farm. As a result, he arrives at a partial model of the location of agricultural production, which is parameterized based on historical observations to fit the conditions of his time but nonetheless allows a number of conclusions of general validity.

A simple von Thünen model

In a simple VON THÜNEN model with a single crop, transportation cost can be assumed to be a linear[2] function of distance depending on weight and perishability of the goods transported. Under the presuppositions specified above, the local price for a commodity in any given radius from the city is determined by its price in the city less transportation cost. The land rent accruing to an owner-operator or the maximum a tenant farmer could bid for using a unit of land is then defined as the residual after production and transportation costs have been deducted from the revenue of a unit of land as given by equation (2.1). THÜNEN thus developed – independently of RICARDO – the concept of differential rent: "The land rent of a farm springs from its superiority, in soil or location, over the least favoured farm which is still producing for the market." (THÜNEN, 1966, p. 147). Given his assumption of homogeneous soil fertility in the isolated state, differential rents can only be a function of distance from a centre of demand.

$$R(r) = y(p - c) - ytr \tag{2.1}$$

where

R(r): location rent per unit area of land at distance r from the centre of demand

y: yield of a given crop per unit area

p: market price per unit of output at the centre (r = 0)

c: average production cost per unit of output

t: average rate of transportation cost per unit of commodity and distance

r: distance of the production location to the centre of demand (BISSETT, 2004, p. 7)

Assuming further that the constant production costs per unit area yc include the tenant's or owner-operator's labour cost, the marginal land rent R at every location in distance r from the centre is a linear function decreasing in r. Land rent becomes zero at the distance $r = r_m$, the marginal site of production, where revenues are fully offset by production and transportation costs. A positive land rent accrues to all land use within the distance $r < r_m$, i.e. where land is scarce. Land at the margin is abundantly available, because no production takes place beyond r_m.

If more than one crop is considered, different marginal rent curves depending on the respective transport rates and prices at the central market will be obtained (Figure 1). Land in each location will be utilized so as to maximize the rent from each unit of land, leading to sharply demarcated concentric rings, in which the single activity – or cropping system – yielding the highest rent prevails. For the case of three crops, Figure 1 shows the marginal rent curves for each crop and the resulting dominant rent curve (dashed line) composed of the segments of individual crops' rent curves. Under the conditions of his time, VON THÜNEN postulated that the inner

[2] Thünen's original model implies transportation cost to be non-linear in distance, because draft animals were supposed to consume part of the load during transport (THÜNEN, 1966, p. 17).

ring around the town is used for 'free cash cropping' including intensive vegetable production with imported nutrients (THÜNEN, 1966, p. 9), a pattern also found around Bangkok (cf. p. 37).

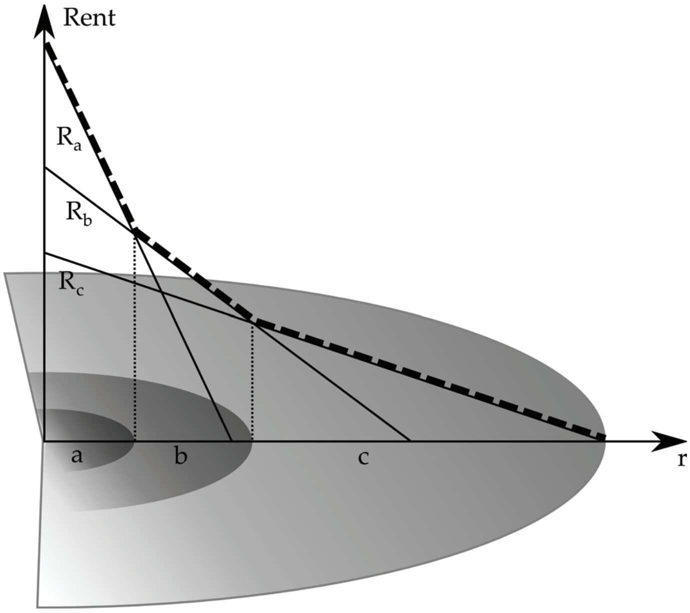

Figure 1: Land rent in a three crop system with linear rent curves

Source: SCHÄTZL (1998, p. 65)

A microeconomic reformulation of the VON THÜNEN model

Further analysis and explanation of the conditions under which a given crop might be produced concurrently at different distances from the centre of demand as observed in reality requires a relaxation of some of the restrictive assumptions underlying the above models. For this purpose, it is useful to restate THÜNEN's reasoning in the language of a microeconomic model. Numerous approaches to such a formulation are reported (DUNN, 1954; ALONSO, 1964; BUHR, 1970; BÖVENTER, 1979; BISSETT, 2004) and reviewed e.g. in BUHR (1983) and BISSETT (2004). In the following the reformulation of BISSETT (2004) will be presented, which allows for input substitution by virtue of a rather general production function. It assumes that land N and labour L enter a linear-homogeneous production function (2.2) with constant returns to scale (2.3) (BISSETT, 2004, p. 12).

$$Y = Y(L, N) \tag{2.2}$$

$$Y(\lambda L, \lambda N) = \lambda Y \tag{2.3}$$

The profit function in any distance r from the centre is then given by

$$\Pi(r) = pY(L, N) - wL - trY(L, N) \tag{2.4}$$

where w is the wage rate, p the output price at the centre and t the transportation rate. Assuming further that in a competitive land market the farmers' maximum bid for using the land is just their profit, all profits are finally passed on to the owner of the land[3]. Hence, the rent to a unit of land is given by

$$R(r) = \frac{pY(L^*, N^*) - wL^* - trY(L^*, N^*)}{N^*} \quad (2.5)$$

where L^* and N^* denote the profit maximizing allocation of labour and land. In (2.5) land rent, i.e. the price for using a piece of land, depends – among others – on the optimum allocation of land, which is defined by equating marginal value product to factor price. This circular dependence is resolved by conducting the analysis on the level of a unit of land, which is permissible under constant returns to scale and homogeneous and infinitely divisible factors (BISSETT, 2004, p. 12). With $N := 1$, equation (2.5) simplifies to

$$R(r) = y(l^*)(p - tr) - wl^* \quad (2.6)$$

where y and l^* refer to the yield and optimum labour input per unit of land area.

Next, the properties of equation (2.6) will be explored graphically in Figure 2. On a given amount of land, the marginal product of labour is expected to first increase and then decrease according to the law of diminishing returns. By inverting the partial production function with respect to labour and multiplying by the constant wage rate the simple total cost function $TC = wl(y)$ and its associated average and marginal cost functions are obtained. The supply curve of a profit maximizing firm acting as a price-taker in both input and output markets is given by the upward sloping branch of the marginal cost curve above the average cost curve. Hence, starting at y_m, the firm will adapt output by varying labour input so as to equate marginal cost to marginal revenue. As before, the latter is a linearly decreasing function of r given an exogenous market price at the centre and a constant transportation rate. At the marginal location r_m, marginal revenue equals marginal and average cost, leading to zero profits. Right at the centre of demand r_0 where marginal revenue equals p, labour intensity is increased until $MC(y_0^*) = wl'(y_0^*) = p$, resulting in increased output per unit area $y_0 > y_m$. At any intermediate distance r_i, an intermediate optimum labour intensity and corresponding output y_i prevail. The profit $\Pi(r_i)$ per unit area at distance r_i is given by equation (2.7) and corresponds to the shaded area in Figure 2.

$$\Pi(r_i) = y_i^* p - tr_i - wl(y_i^*) \quad (2.7)$$

As discussed above, profits correspond to land rent, when the land market is perfectly competitive. As a consequence of allowing for factor substitution and assuming that the law of diminishing returns holds for single factor variation, a rent function convex to the origin is obtained.

[3] This implies that the entrepreneurial income is subsumed under the labour cost wL and further leads to the coincidence of the definitions of land rent from the residual theory of profit on the one hand and marginal productivity theory on the other (BUHR, 1983).

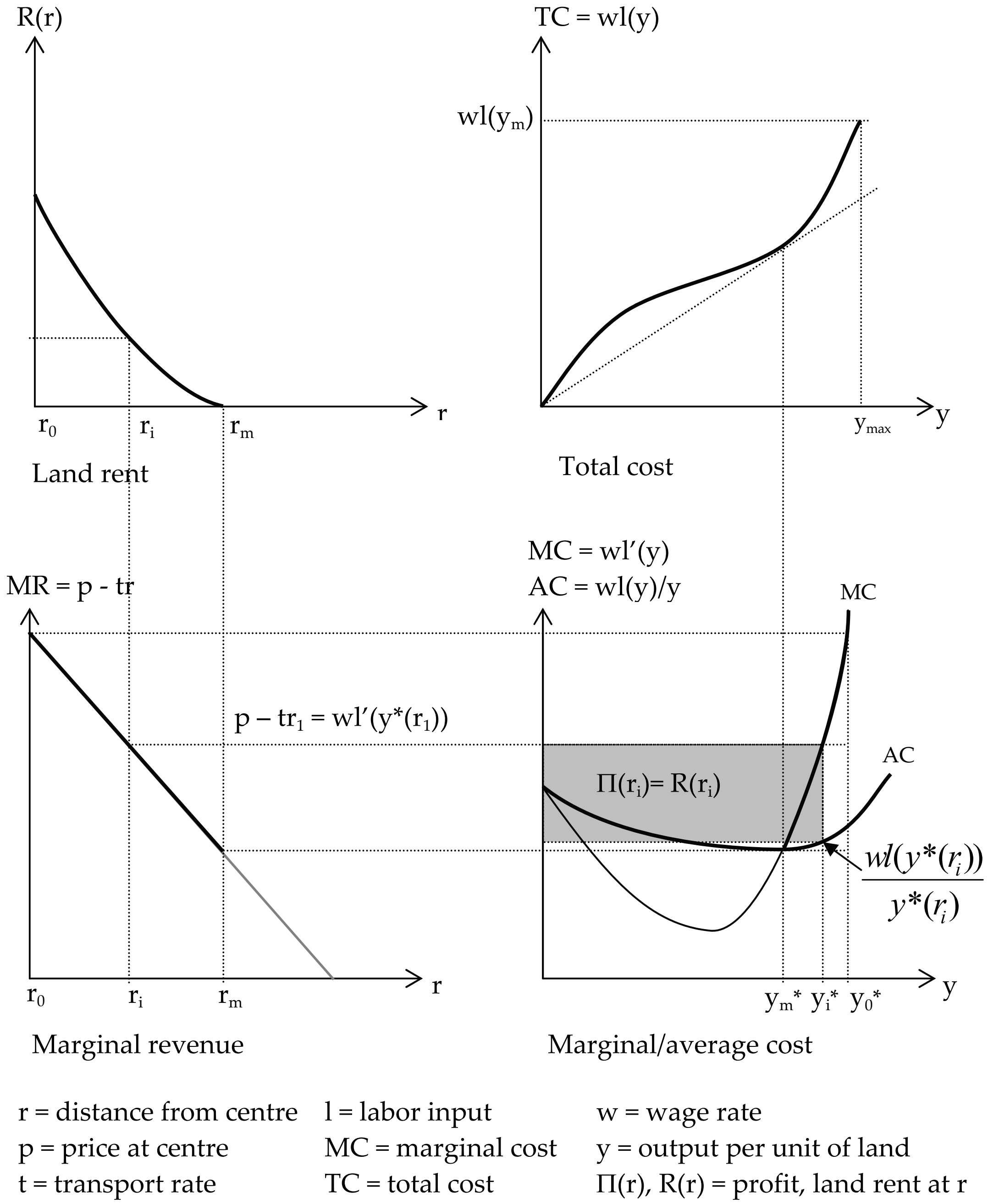

Figure 2: Total, marginal and average costs, marginal revenue and land rent in a simple THÜNEN model

Source: BISSET (2004, p. 19)

A notable implication of convex rent functions is that in a model with more than one crop, a crop can dominate in more than one non-adjacent Thünen ring. This case is represented in Figure 3, where crop a dominates in the distance intervals $r_0 \le r < r_1$ and $r_2 \le r < r_3$, whereas in between crop b is dominant. Evidently, crop a dominates crop b, when produced at both very high and extremely low (labour-) intensity.

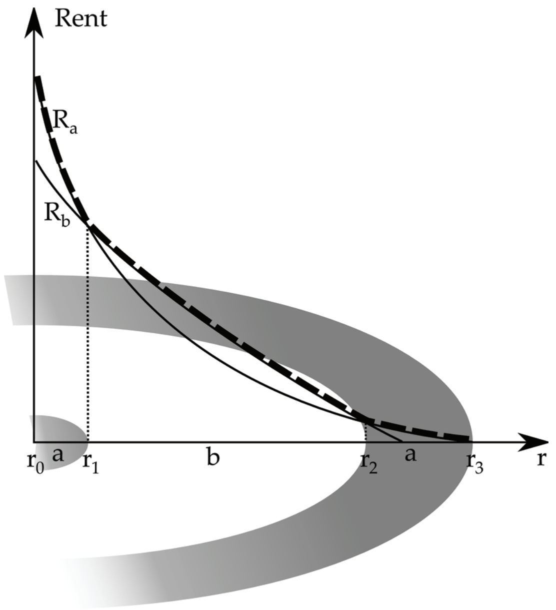

Figure 3: Thünen rings in a two-crop system with convex rent functions

Source: after BISSET (2004, p. 22)

The analysis above further implies the general result that the intensity of labour use and output per unit area increase – though at decreasing rates – as one approaches the centre of demand - at least in a single product case (BISSETT, 2004, p. 27). On the other hand, at the margin of production, labour intensity l_m* and output level y_m* are determined independently of the wage rate, output price and transport rate but solely by the properties of the production function (BISSETT, 2004, p. 15). With this formulation, the discrete treatment of intensity by comparing cropping systems of differing intensity in THÜNEN's analysis has been generalized to a continuous model of factor substitution, which is plausible for agricultural technology and relevant for the case of vegetable production, which is characterized by varying intensity of land use even for the same crop (cf. p.31).

Non-homogeneous land quality

While THÜNEN developed his concept of differential land rent with respect to location assuming homogeneous land quality, RICARDO analysed the consequences of non-homogeneous land quality in the course of development of an aspatial economy. He supposed that the most fertile soils would be cultivated first. With a growing population and diminishing returns in agriculture, agricultural product prices would increase until production on lower quality land would become profitable (NEEDHAM, 1981). Figure 4 depicts this case in terms of marginal cost curves for producing an agricultural good on land of different qualities. Unless the price for the good rises up to p_1, cultivation remains restricted to the fertile land a. When the price increases to p_1, production becomes profitable on the lower grade land b. Without further adaptation, a rent corresponding to the area between the price line and the marginal cost curve R_a^q accrues to the producers due to the better land quality. Profit maximizing producers will, however, increase intensity of production so as to equate marginal costs to marginal revenue (now at p_1), leading to an additional rent component R_a^i (indicated by the hatched area) due to the increased intensity of production. Only beyond p_1, low quality land b will yield a rent R_b. The differential rent of land a over land b amounts then to the difference between the respective areas between the marginal cost curve and the price line, i.e. the area marked by light grey shades.

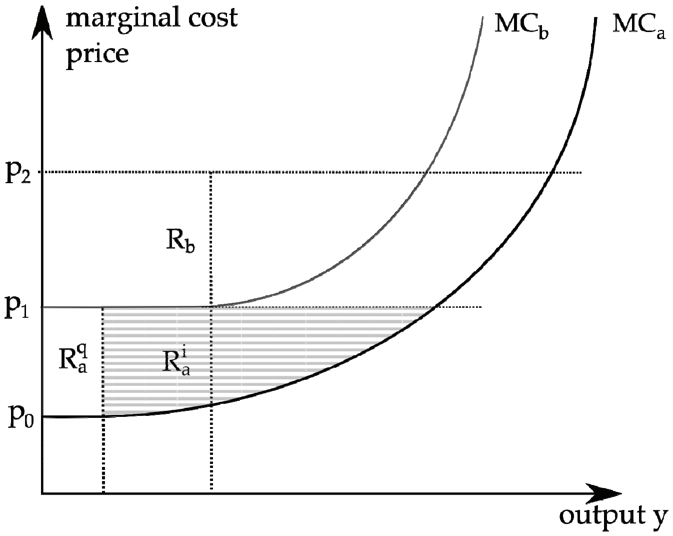

Figure 4: Marginal cost curves for different land qualities

Source: after TURVEY (1955, p. 347)

The progressive utilization of land in the order of diminishing quality postulated by RICARDO, holds only when high fertility is unambiguously associated with low (marginal) cost of production. When advantages like a lower distance to the market dominate, less fertile land might be used for agriculture even in the presence of more fertile (but distant) lands as observed by H. C. CAREY in the sparsely populated 19th century United States (e. g. DAWSON, 2000). Figure 5 shows an alternative pattern of marginal costs, where up to just over p_1, production on land b is possible under lower marginal cost than on land a. At higher prices, land a bears the superior marginal cost conditions.

With CAREY'S arguments, the scope of analysis is extended by allowing market distance and fertility to vary simultaneously. Distance from a pertinent market could be subsumed as a specific aspect of land quality in a comprehensive definition as their implications for the land rent are analogous (see above and BUHR, 1983). The course of the marginal cost curves for different land qualities would still remain ambiguous, especially when a wide range of uses is considered, which demand different aspects of quality, as argued for the theory of urban land use by NEEDHAM (1981). Therefore it is unlikely to observe the pattern of concentric THÜNEN rings in a reality characterized by heterogeneous land quality (in a comprehensive sense). Moreover, these results imply that a meaningful analysis of the location of agricultural production requires a simultaneous consideration of all relevant aspects of land quality, i.e. its distance to the pertinent markets and its productivity in the relevant alternative uses.

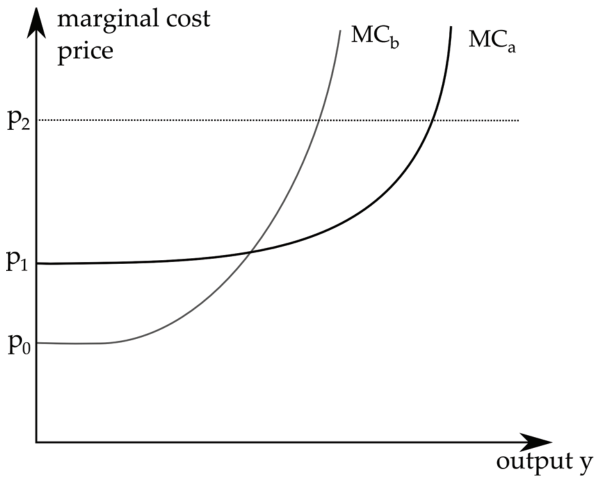

Figure 5: Alternative shape of marginal cost curves for different land qualities

Source: after TURVEY (1955, p. 347)

2.2.3 Total models of the von Thünen type

Although THÜNEN hints at the process that determines market prices in the city (THÜNEN, 1966, p. 144f) and sketches a two-sector equilibrium model, his explicit analysis remains partial (NERLOVE and SADKA, 1991) and does not solve the problem that the supply resulting from the exogenously given market prices might not tally up with demand. Although in the context of this thesis comparable bounds limit the analysis, for the sake of completeness the line of development to general equilibrium models is briefly outlined here.

DUNN (1954) and ISARD (1956) pioneered the extension to a general spatial equilibrium model, although without a proof of feasibility of their models. This shortcoming is avoided by the mathematical programmes by BÖVENTER (1962), STEVENS (1968) and BUHR (1970), which are however limited to at most a quasi-continuous representation of space. A closed form general equilibrium model considering one agricultural and one manufacturing product is used by BECKMANN (1983) to derive the size of the area covered by the respective sectors. A growth in population leads to an increase in the area utilized for both sectors, prices for both products increase, whereas nominal wages remain constant. In effect, real wages decline while land rents increase and income distribution changes, comparable to the early phases of economic development (BECKMANN, 1983, p. 638). SAMUELSON (1983) obtains the same result from his general equilibrium formulation of a barter economy with one manufactured good (cloth) and two agricultural products (vegetables, grain). Moreover, he covers the questions of how the population situated in a given ring is supplied with the goods produced in other rings and the contentious issue of whether labour intensity (with respect to land) is under all conditions monotonically decreasing in r (cf. also the results of the partial model presented above). He arrives at two concentric zones, the inner one exclusively devoted to vegetable production and the outer ring producing both grain for export to town and vegetables for self-sufficiency. As a general rule, he proves that the good with the higher transportation rate will drive out the one cheaper to transport from the inner-most ring, even though the latter one might be less land intensive (with respect to labour). The opposing supposition that the products cheap to transport are always found in the most distant locations does not universally hold. If vegetable production required only land, no labour, it would become the dominating crop in the inner ring as well as in the most distant locations, thereby providing the counter-example: "… stretching forever without limit, comes the model's final zone of vegetable production." (SAMUELSON, 1983, p. 1480).

A more recent comparative static general equilibrium analysis by NERLOVE and SADKA (1991) emphasises the duality aspect of the THÜNEN economy stemming from the asymmetric dependence of agricultural and industrial sectors on immobile land. They relate the results of this asymmetry to the dual economic development hypothesis (LEWIS, 1954; RANIS and FEI, 1961; DIXIT, 1973). The analysis is based on a set of assumptions similar to the above plus a restriction on factor substitution in agricultural production and homothetic preferences to unit elasticities. They find that "falling transportation costs are sufficient to induce a movement of labour from the rural/agricultural to the urban/industrial sector" (NERLOVE and SADKA, 1991, p. 97), which is c. p. accompanied by increased real wages, reduced labour use in agriculture and falling yields. The role attributed to decreasing transportation cost and the agricultural sector for rural-urban migration in this equilibrium model provides a contrast to the notion of a stagnant agricultural sector associated with the dual economic development hypothesis (NERLOVE and SADKA, 1991).

For the completely different purpose of analysing the endogenous emergence of a spatial pattern of agglomeration, New Economic Geography builds on the Dixit-Stiglitz model of monopolistic competition (DIXIT and STIGLITZ, 1977) to allow for increasing returns to scale in manufacturing (FUJITA *et al.*, 1999). For modelling a monocentric, yet dual economy with immobile, homogeneous land and perfectly mobile and homogeneous labour as the only production factors, FUJITA *et al.* (1999, p. 133ff) assume a diversity of manufactures to be produced by labour only, under increasing returns to scale. The "residual" agricultural sector is supposed to produce a single good with a fixed labour/land ratio and constant returns to scale under perfect competition. Transportation cost is incorporated in the "melting iceberg" form (SAMUELSON, 1983) to avoid the need for a separate transportation industry, i.e. goods "melt away" at a specified rate during transport. Below a certain threshold of population size, the monocentric structure is the only stable equilibrium outcome. For population growth from low initial levels, concomitant growth of manufacturing is beneficial in terms of increasing real wages. At higher population levels, the disadvantages from the outward shifting agricultural production frontier will dominate the advantages from a bigger manufacturing sector (cf. also BECKMANN, 1983). Finally, when a critical population threshold is exceeded, the formation of new centres becomes economically viable – destroying the monocentric structure (FUJITA *et al.*, 1999, p. 133ff).

In spite of a considerable simplification to a two-sector economy involved in these models and the consequential failure to account for the effect of increasing factor productivity in the tertiary sector on real wages, real interest rates and even land prices, these models explain the location of economic activities based on different sets of assumptions. In addition, they provide the conceptual link between the theories of location and of economic development mentioned above (cf. p. 3).

2.3 Theories on the spatial mobility of goods

In the preceding section on the location of agricultural production, restrictive assumptions were imposed on the mobility of factors and goods. Land is immobile by its very nature and has been treated as such. At the other extreme, perfect mobility at zero cost was assumed throughout for labour, while product movement was subject to transportation cost, driving much of the model results. SAMUELSON (1983) contrasts this set of assumptions with those of Ricardo's theory of interregional trade, which is based on factor immobility but perfect mobility of goods. These assumptions have their impact on the outcome of general equilibrium analysis (cf. SCHÄTZL, 1998, pp. 105, 9ff). The confinement of this study to a partial analysis of the vegetable sub-sector of Thai agriculture requires the treatment of regional demand, labour and capital as exogenously given variables. The discussion here will therefore concentrate on the theory dealing with the mobility of goods and interregional trade.

The reasons for interregional trade have been subsumed under the following categories. Firstly, the supplying of certain goods might be temporarily or permanently impossible from one region irrespective of prices and costs. A permanent unavailability of goods might be due to adverse natural conditions or unavailability of mineral resources. Temperate vegetables, such as red cabbage, present an example of commodities whose production is restricted to the higher elevations in Northern Thailand due to the cooler climate. A lack of technology or human capital required to produce a good leads to temporary unavailability of that good (SCHÄTZL, 1998, p. 120).

Secondly, trade theory explains interregional trade by price differences between regions sufficient to allow for transportation between regions. On the demand side, differences in income and preferences between regions figure importantly in determining price differences. Regional supply might be subject to different production costs, reflecting dissimilar factor endowments or factor productivity, which in turn arise either from the extent to which economies of scale are exploited or quality differences of factors (SCHÄTZL, 1998, p. 121). Notably, as shown by RICARDO, comparative advantage is sufficient for making trade between regions welfare improving, which can be illustrated by a simple two-product example: Consider the following table giving the cost of production for one ton of salad and tomatoes, respectively, measured in man days required for production:

	Salad	Tomato
Northern Region	12 md	10 md
Central Region	15 md	20 md

We find that both, tomatoes and salad are produced at lower cost in the North, which has an absolute advantage over the Central region. Moreover, the opportunity cost of – say – an extra ton of salad in terms of tomatoes foregone amounts to 12/10 = 1.2 in the North, whereas it is only 15/20 = 0.75 in the Central region. Hence, the Central region has a comparative advantage in producing salad. Assuming zero transportation cost between regions, the gains from trade for both regions can be seen from the following example: Suppose that in the North 240 man days are available and divided equally on the production of salad and tomato. Let the Central region's labour force of 300 man days be evenly split among the crops as shown in the following table:

Autarky		Salad		Tomato	
	labour available	labour (md)	production (t)	labour (md)	production (t)
North	240	120	10	120	12
Central	300	150	10	150	7.5
Total	540	270	20	270	19.5

If trade is permitted and labour is assumed to be mobile within each region, specialization according to comparative advantage becomes possible. Salad will then be produced in the central region, leading to a total production of 20 tons if its total labour force is allocated to the crop. On the other hand, tomatoes will be produced in the North, yielding a total production of 24 tons if all labour is allocated to tomatoes.

Trade		Salad		Tomato	
	labour available	labour (md)	production (t)	labour (md)	production (t)
North	240		0	240	24
Central	300	300	20		0
Total	540	300	20	240	24

Comparing a situation with trade to autarky, an additional 4.5 tons of tomatoes can be produced with the same labour input by specializing according to comparative advantage. Hence, even in a situation where one region has an absolute advantage in all products, welfare gains in both regions can be attained by trade as long as relative costs of production differ among regions. How the welfare gain is distributed among the regions depends on the prevailing rate of exchange given both supply and demand in each region. Its determination hence requires additional knowledge of the regional demand functions and will be shown below.

Finally, a third explanation for interregional trade applies above all to developed economies, which trade large volumes of similar goods among countries with similar economic conditions (e.g. automobile exports from France to Germany and vice versa). In this case, comparative advantage falls short of explaining the observed trade pattern. New trade theory rationalizes this trade pattern as follows. In the course of development of an economy, consumer preferences become more diverse and induce suppliers to diversify their products. When suppliers operate under increasing returns to scale, the market takes the form of monopolistic competition. Such a market expands on the one hand through a growing number of firms (increasing product variety) and on the other hand by growing firms benefiting from economies of scale. As trade expands the size of the market, firms are able to reap more scale-economies, which under the assumed market conditions eventually benefits consumers through declining prices (KRUGMAN, 1979).

Spatial price equilibrium

For a freely traded commodity, price differences between spatially distinct markets are bounded from above by transportation cost. This can be shown for the simple case of a single product and two regions by putting two regional market diagrams back to back like in Figure 6. In the absence of trade, regional equilibria are attained at the respective intersection of demand D and supply functions S at prices p_1^0 and p_2^0, respectively. Note that the quantity axes are shifted by the transportation rate T_{12}. Subtracting regional demand from regional supply for every price yields the regional excess supply curves ES_1 and ES_2, which at the respective regional equilibrium prices are at Q=0. If trade becomes possible, commodities will flow from the region with the initially lower price (1) to the region with the higher price. Given the shift by T_{12} for the price scale of region 1, excess supply and excess demand match at point B, the quantity transferred from region 1 to region 2 equals $E_{12} = - E_{21}$.

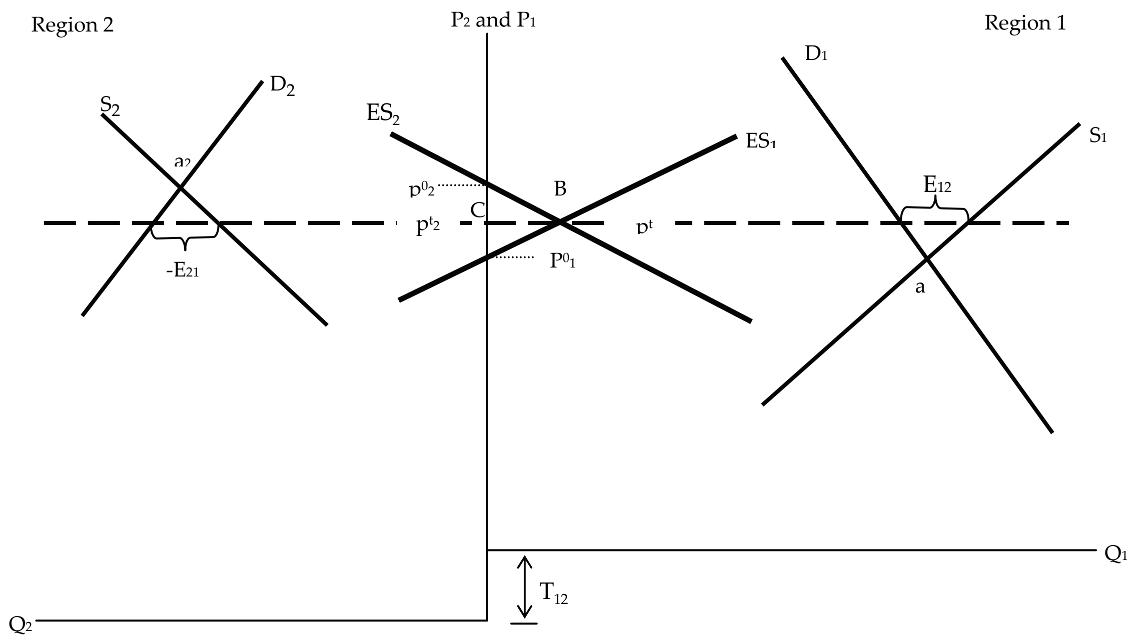

Figure 6: Market equilibrium in a two-region model with and without trade

Source: SAMUELSON (1952, p. 286)

The equilibrium price with trade amounts to 0C, increasing the pre-trade price in region 1 and lowering pre-trade price in region 2. The regional price difference equals just the shift between price scales, i.e. unit transportation cost T_{12}. This definition of spatial price equilibrium under competitive markets and in the absence of trade barriers is the underlying concept of the applied spatial equilibrium models presented in the following section.

2.4 Computable models of regional supply and demand equilibrium

The partial models introduced above have so far been restricted to the analysis of a single factor under *ceteris paribus* conditions, in line with their primary aim of identifying the general effect of single factors on the pattern and intensity of land use. Their results are thus generally valid under the imposed set of assumptions (cf. also WEINSCHENCK and HENRICHSMEYER, p. 207). The same is true for the general equilibrium models discussed so far. In spite of a complete specification of equilibrium conditions, their rigid assumptions preclude their direct application to empirical phenomena. Since the 1950s, interest has turned to empirically tractable models of spatial equilibrium.

This branch of development was initiated by ENKE'S equilibrium of spatially distinct markets by electric analogue (ENKE, 1951) and its reformulation as a maximization problem by SAMUELSON (1952). The "Samuelsonian objective function", i.e. the maximization of non-linear producer and consumer surplus became the keystone to implementing market equilibrium in sectoral models. As at the time algorithms for solving non-linear problems were still unavailable, iterative algorithms were used by a number of modellers (HAZELL and NORTON, 1986, p. 184). The first computable quadratic multi-market model with interdependent demand functions by TAKAYAMA and JUDGE (1964) was based on explicit linear supply and demand functions and maximization of consumer and producer surplus. A linear formulation of supply and fixed regional and national demand was first used in a model of the US crop sector by HEADY and EGBERT (1959). The models of ENKE, SAMUELSON, TAKAYAMA and JUDGE (ESTJ) have in common the condition that prices vary with an upper bound defined by the cost of arbitrage as long as trade flows are not limited (cf. section 2.3 above) and their implication of a perfectly competitive long-run equilibrium (BARRETT, 2001). They have become the conceptual basis of numerous applications to agricultural sector modelling (see e.g. HENRICHSMEYER, 1966; VON ALVENSLEBEN *et al.*, 1985; BAUER and KASNAKOGLU, 1990; HENRICHSMEYER *et al.*, 1996).

BAWDEN (1964) distinguishes "standard equilibrium" formulations and "activity analysis models". Both types share the representation of transportation (unit transfer cost between discrete points of supply and demand) and demand (completely inelastic to price elastic demand functions). The former, however, captures supply response by explicit – and in complex representations interrelated – supply functions of present or lagged prices (e.g. TAKAYAMA and JUDGE, 1964; VON ALVENSLEBEN *et al.*, 1985; KYI, 2000). The supply functions in turn may be derived from econometric estimation or from a programming model.

One part of the econometric approaches to supply analysis has been based on longitudinal data and estimates simultaneous equations of factor demand and output supply as a function of lagged or contemporaneous prices, cross-prices in the factor and product markets (HALLAM, 1998; COXHEAD and PLANGPRAPHAN, 1999; KAOSA-ARD, 2001). By their very nature, they are demanding in terms of economic time series data, which are often available only on highly aggregated levels. Structural changes or sweeping technological innovations not embodied in historical data might invalidate time series data for forecast purposes (HALLAM, 1998). The other part of econometric approaches is based on production theory and estimates profit functions from cross-sectional data, often augmented by longitudinal data to better capture price variation (e.g. PUAPANICHYA and PANAYOTOU, 1985; HALLAM, 1998).

In contrast, activity analytical programming models depict supply by directly incorporating discrete (linear) production activities in discrete regions and their utilization of a set of fixed resources (BAWDEN, 1964; HAZELL and NORTON, 1986, p. 138). Their advantages are a natural suitability for capturing the extraordinarily strong cross-supply effects in agriculture due to the competition for the same fixed resources (like land, labour, capital, water) by different activities, their parsimonious data needs and a great flexibility for incorporation of technical progress, structural changes and policy options (HENRICHSMEYER, 1966; HANF, 1989; HENRICHSMEYER *et al.*, 1996; JACOBS, 1998; BUYSSE *et al.*, 2007). As mathematical programming always involves an optimisation algorithm, its normative application as a prescriptive tool is highly suggestive and often perceived as its primary purpose (MCCARL and SPREEN, 2004, p. 1.4). A prescriptive application is, however, rare in practice, among others because acceptance of results by decision-makers turned out to be low in many circumstances (BUYSSE *et al.*, 2007). Its value and frequent application is therefore rather the prediction of outcomes for changing parameters or sensitivity analysis[4] (MCCARL and SPREEN, 2004, p. 1.5). As the optimisation approach of programming models mirrors the optimising behaviour of economic agents postulated in neoclassical economics, the various forms of programming models are very apt tools for predicting decision-makers' choices even under more complex objective functions than simple profit or utility maximization. They have therefore been widely used in modelling the aggregate sectoral response to exogenous economic and policy variables in agriculture (HALLAM, 1998; BUYSSE *et al.*, 2007). Activity analytical models can be developed on a minimal set of data (HAZELL and NORTON, 1986) but depending on the purpose and level of analysis, farm types, production activities and regions can as well be considered to arbitrary detail, while model structure ensures that simulation results are consistent with the resource constraints. On the downside, aggregation bias, i.e. the overestimation of resource mobility by the inevitable aggregation of economic units with inhomogeneous factor endowment ratios, invariably leads to overspecialization of model results in the most profitable crops (HOWITT, 1995), which in the past has prompted modellers to contrive a number of workarounds to ensure their model calibrates to observed data. A formalized way to calibrate programming models based on observed quantitative data has been introduced by HOWITT (1995), thereby bridging the gap between the activity analytic and econometric approaches and contributing to a revived interest in programming models as tools for agri-environmental analysis (HENRY DE FRAHAN, 2005). Moreover, a comparison of econometric and activity analytic approaches in a propitious data environment for Californian field crops by SHUMWAY and CHANG (1977) has shown that supply elasticities derived from a comparatively simple linear program-

[4] As HECKELEI and WOLF (2003) point out, the frequent contraposition of 'normative' programming models and positive econometric models is misleading because the purpose of sectoral programming models is generally a positive, namely the explanation of observed or the prediction of future behaviour of economic agents.

ming formulation maximizing profits without flexibility constraints are on average similar in range to econometric estimates. Although individual estimates from the approaches differ widely, results did not confirm earlier conjectures that elasticities from programming models would be generally biased upwards. From a comparison of the predictive quality of models based on either source of elasticity estimates, a preference for one or the other could be inferred (SHUMWAY and CHANG, 1977). The observation that elasticity estimates from econometric models are lower than those resulting from activity analytic models is often traced down to different levels of aggregation. Whereas the data demanding first model group often refers to crop aggregates, the latter in general operates at the crop level. Resulting elasticity estimates for aggregates should be lower, as substitution effects within the aggregate are not observed at the surface of the aggregate, whereas supply elasticities for individual crops reflect substitution within the aggregate and thus are higher (HECKELEI, 1999). It is thus less a matter of methodology than of the close correspondence of commodities under consideration and the choice of methodology is determined rather by the acceptable degree of aggregation for the problem in question (HECKELEI, 2001).

2.5 Review of agricultural sector models and applications in Thailand

After the theoretical background of equilibrium models has been discussed, practical applications of this approach to Thai agriculture are briefly reviewed in this section.

Econometric models of supply response of Thai agriculture is the estimation of a system of normalized restricted profit functions for the five main crops based on cross-sectional survey data of 800 farmers by PUAPANICHYA and PANAYOTOU (PUAPANICHYA and PANAYOTOU, 1985). A different approach based on longitudinal data uses a system of area share equations for various crops and was first applied in Thailand by the TDRI project "Dynamics of Thai Agriculture, 1961-1985" (TDRI, 1988). An extended and updated version of this model for analysing dry season land use in the Central Plain also included the price of a vegetable aggregate for cross-price effect estimation. Own price elasticities of 1.182 and 1.148 were estimated for rice and field crops, respectively, whereas cross price elasticity with respect to vegetables was -0.478 and +1.327 for field crops (KAOSA-ARD, 2001; SATTARASART *et al.*, 2001). A similarly structured model was utilized by COXHEAD and PLANGPRAPHAN in an analysis of the relation between growth of agricultural and non-agricultural sectors (1999). In line with a generally demanding data requirement of these models, vegetables have been included in the analysis as a residual aggregate at most.

On the contrary, programming models that involved a vegetable component have been used at various levels of aggregation. The Thailand agricultural models (THAM-I and THAM-II) consisted of a dynamic regional general equilibrium model and a separate supply module implemented as a static linear programme, in which soybean, mungbean and ‘other vegetables’ were considered (Anonymous, 1980; SIAMWALLA *et al.*, 1991). Aside from this, literature reports applications of programming models only at the levels of watersheds or individual farms.

For a typical farming system in Phayao province, MUNGKUNG (2002, p. 121) has used a one-period profit maximization model with a satisfactory calibration to observed income and labour productivity levels to assess the effect of different policies on land rights on resource allocation and household incomes. A profit maximization model covering six highland vegetable crops and additional rice and field crop activities in monthly disaggregation was used in studying the likely developments on the resource use in agricultural systems practised by ethnic minorities in a small watershed of northern Thailand. It is concluded from simulation results that with respect to water constraints, and to a lesser degree labour constraints, agricultural incomes can be improved by further substitution of irrigated paddy production by cash crops including vegetables, strawberries and flowers (POTCHANASIN and JANEKARNIJ, 2002). Goal programming, i.e. a minimization of weighted deviations from pre-defined targets, was used in a further study of a different watershed area in Northern Thailand and resulted in recommended farm plans for different elevation zones in the watershed (PRANEETVATAKUL and SIRIJINDA, 2007). Thus, literature exists on historical applications of activity analytic models to Thai agriculture at the sector level in positive analysis, whereas recent reports refer only to optimisation models at the watershed level with both positive and normative purposes.

The use of agricultural sector models as a tool for informing policy design has a long tradition (BUYSSE *et al.*, 2007; HENRY DE FRAHAN *et al.*, 2007). In line with the high level of public subsidy in the agricultural sectors of developed countries (see above) numerous models of various types and at different levels of the economy have been designed for informing policy design and evaluation. Many combine economic and physical components in order to simultaneously assess economic and environmental consequences in the light of environmental awareness on the side of consumers and taxpayers and justification of subsidization based on the multi-functional nature of agriculture (BUYSSE *et al.*, 2007). A broad typology of these approaches is compiled in Table 1 with reference to the above mentioned models and examples from the 'model family' of the German federal agricultural research centre, which are included for their broad coverage and complementarity. On the one hand, models can be distinguished with respect to the economic unit they are concerned with, ranging from single farms over watersheds and regions to the sector level and even the global economy. Models pertaining to a region or watershed optimise activity levels for the whole region, i.e. resource endowments of individual economic agents within the region are aggregated and a common objective function is assumed. A representative farm on the other hand refers to an average farm of a region or a group of farms in a region, i.e. one with average resource endowments and production technology, whose optimisation results are then representative of the population. This approach is problematic if heterogeneous farm types, i.e. those with different relative resource endowments (land/labour ratio, capital/labour ratio) or technologies (small, large farms) are averaged (HAZELL and NORTON, 1986, p. 145ff). On the one hand results are likely over-specialized in the most profitable activities, because resource mobility is overestimated (HOWITT, 1995) and on the other hand, the statistical average farm might be difficult to accept and deal with as it is likely to exhibit numerous minor production activities, which would be below profitable thresholds at the individual farm level (HEMME, 2000). As an avenue for avoiding implausible average farms, the definition of typical farms has been used. In this approach, a farm type characterized by a certain size range, factor endowment ratios and technology that is typical for a group of similar farms in a region is identified such that the resulting resource endowments and activity levels are consistent within the farm. Such a typical farm cannot be representative in a sense that scaling up results in consistent reproduction of regional or farm group totals for resource endowments and output.

Table 1: Typology of activity analytical models and examples from the FAL[5] model family and applications in Thailand

Distinctive attribute	Characteristics and examples
Object of research	• typical farm(s): TIPI-CAL • representative farm: MUNGKUNG (2002) • region: PRANEETVATAKUL (2007) POTCHANASIN (2002) • sector: RAUMIS, THAM • global economy: GTAP(HERTEL, 1997)
Adaptation mechanism	• optimisation: RAUMIS, BEMO-2, MUNGKUNG (2002), PRANEETVATAKUL (2007), POTCHANASIN (2002) • simulation: TIPI-CAL
Objective function	• NLP: RAUMIS • Goal programming: PRANEETVATAKUL (2007) • LP: RAUMIS, POTCHANASIN (2002), MUNGKUNG (2002)
Data source	• National agricultural accounts: RAUMIS • representative farm: BEMO-2, MUNGKUNG (2002) • typical farms: TIPI-CAL • farm sample: PRANEETVATAKUL (2007), POTCHANASIN (2002)
Temporal dimension	• comparative-static: RAUMIS, BEMO-2, PRANEETVATAKUL (2007), POTCHANASIN (2002) • dynamic: TIPI-CAL • recursive: THAM ('exchange module') (Anonymous, 1980)
Price determination	• Endogenous (partial equilibrium models): GAPSi • Endogenous (general equilibrium models): THAM (Anonymous, 1980) • Exogenous: RAUMIS,

Source: Own presentation after MANEGOLD (1998), HEMME (1997) and HENRICHSMEYER (1966)

The second criterion for model categorization is the adaptation mechanism driving model results. Few models are used for simulation of user-defined parameterizations only, as e.g. in the case of TIPI-CAL a multi-period model of typical farms used by the international farm comparison network IFCN (DEBLITZ *et al.*, 1998). In this application the model is really a calculation aid

[5] German Federal Agricultural Research Institute

that feeds back the consequences of adaptations suggested by a group of experts. Contrarily, programming models are based on optimisation algorithms, which differ, however, with respect to the objective function. A technical distinction refers to whether the functional form is linear or non-linear or involves integer decision variables. But the target variable to be optimised is also a criterion. For farm models, profit maximization has often been assumed to be the appropriate objective function, but approaches that consider risk in coefficients or resource constraints and multiple objectives have also been considered (HAZELL and NORTON, 1986; PIECH and REHMAN, 1993; ARRIAZA and GOMEZ-LIMON, 2003; BUYSSE *et al.*, 2007). In standard sectoral models, market equilibrium is attained via maximization of total consumer and producer surplus (Samuelsonian objective function) (HAZELL and NORTON, 1986), but variations of this concept have also been applied.

The data source used for constructing the model might be considered a separate criterion in spite of its close natural link to the object of research. As mentioned above, especially for farm level models, a choice of data source exists. Based on a sample survey or census of farms in a region or watershed, either individual farm models, or representative farm models can be formulated. The definition of typical farm has to be based on alternative sources, because no statistical procedure for deriving a definition exists. The expert panel procedure used for TIPI-CAL (HEMME *et al.*, 1997) and an adapted version used for data collection in this study are reported in detail in chapter 4. A further distinctive feature of supply models refers to the time horizon covered. Comparative static models are static because only a single period is considered for optimisation. The approach is 'comparative' in the sense that analysis is based on a comparison of results of separate optimisation runs for exogenous parameter variations, which might represent changing conditions over time or policy interventions. More suitable for medium- and long-term problems are models with explicit consideration of subsequent periods whose initial conditions depend on the outcomes of the respective preceding period as represented by dynamic and recursive models, which differ clearly in their approach and application. Whereas dynamic models operate over the whole time horizon and simultaneously optimise activity levels in all periods according to a long-term objective function, recursive models optimise for separate periods subsequently. The former approach is therefore suited to normative applications of recommending long-term optimum decisions and the latter fits positive purposes, because it better reflects behaviour of subsequent one-period optimisation (HEIDHUES, 1966). Finally, Table 1 concludes with the very basic distinction of the economic scope of the model, whether it replicates a partial equilibrium with endogenous price determination or a general equilibrium that also determines factor incomes (as e.g. within THAM-I and II). Not only farm or watershed level models, which by virtue of their object of interest do not comprise a market representation, but also several sector models are based on profit maximization with exogenous prices are included. RAUMIS, a regionalized sector-consistent model of German agriculture, for instance, is used in combination with a trade model (GAPSi) that supplies commodity prices. Although prices are determined exogenously, the iterative feedback between the supply and market components leads to convergence of supply and price estimates (MANEGOLD *et al.*, 1998).

Such coupled use of otherwise independent models is regarded as a promising approach to expanding the predictive capabilities of models with different strengths and weaknesses. Even econometric and activity analytic approaches can be combined by coordinated and iterative use of different model types for increasingly aggregated levels ranging from individual farms to the world market (MANEGOLD *et al.*, 1998). Thus, national level supply models can be coupled with EU-wide or more comprehensive market models to appropriately consider the common market in EU and the effects from the world market. Farm-level models make use of the prices determined within equilibrium models and in turn can be used to inform assumptions on producer behaviour and adaptation strategies in aggregated models. Another line of development integrates regional sector models with geographic information systems (GIS), which on the technical side facilitate the handling of spatial data and improve the interaction and communication of results among different stakeholders (DABBERT *et al.*, 1998; KÄCHELE and ZANDER, 1998; WINTER, 2005).

This chapter has discussed the theoretical framework for a supply analysis of the Thai vegetable sub-sector and for this purpose highlighted the developments in demand for high-value agricultural commodities in rapidly growing economies and the associated changes in the value chain, theories on the location of agricultural production and of interregional trade. Finally, the methodological avenues for supply analysis have been presented along with experience of their application. Before turning to a more detailed discussion on the methodology applied in this research, the present state and characteristics of the Thai agricultural sector in general and more specifically of vegetable production will be presented in chapter 3.

3 Factors influencing supply and demand

3.1 Development trends of agriculture

Agriculture has long been the most important sector and in spite of its declining share in GDP continues to be a vital part of the Thai economy. At present, Thailand's agriculture occupies roughly 40% of the country's land surface of about 514,000 km², corresponding to about 21 million hectares (OAE, 2006). Traditionally, Thai agriculture is based on paddy rice, which is also an integral part of the culture (FALVEY, 2000, p. 17) and still takes up about half of agricultural land resources. Rice production is most intensive in the central region, which is dominated by the Chao Phraya and Mae Khlong rivers and its tributaries. Two rice crops per year can be grown on irrigated land, which amounts to about 27%[6] of Thailand's agricultural land (OAE, 2006). In 2005 a fifth of agricultural land was planted to upland crops among which sugar cane, oil seeds, maize and cassava are the most important. Another 21% are covered by tree crops such as rubber, coconut, oil palm, rambutan and durian in the south, whereas temperate zone fruit trees like longan, lychee and others dominate on the higher elevations in northern Thailand. Agricultural statistics report a minuscule share of about 1% of agricultural area allocated to vegetables and ornamental plants (OAE, 2006).

From a 38% GDP share in 1951, the relative contribution of agriculture continuously declined until 1997 in spite of absolute growth (Table 2). Being outpaced primarily by the rapidly developing manufacturing sector, agricultural contribution to GDP declined continuously to less than 10% in 1994. Only for a short period after the financial crisis in 1997 did its share rise again above 10% and declined to its all-time low of 8.9% in 2006 (Figure 7). At the same time, agricultural exports have grown in terms of value from the 1960s onward to the currency crisis 1997 at annual rates between 3.6% and 5.4% and even by 20.7% during the 1970s (HONMA and HAGINO, 2004, p. 418). In spite of a considerable growth in absolute terms, the share of agricultural exports steadily declined from 80% in the 1960s (HONMA and HAGINO, 2004, p. 420) due to a more rapid growth of exports from manufacturing, especially in the 1980s, and has been stagnating at around 10% since 2000. In contrast the decline in the share of labour force employed in agriculture from 80% in 1960 to below 40% since 2003 was significantly slower. Such disproportionate development in GDP share and labour force allocation implies a growing discrepancy between agricultural and non-agricultural incomes[7]. This 'disparity problem' of middle-income countries (HAYAMI, 2007, p. 11) leaves policy makers in the dilemma of either following a policy suppor-

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[6] Less than 20% of agricultural land is irrigated under large-scale projects of the Royal Irrigation Department.

[7] In 1990, for instance the average income from agriculture of 7,137 THB was significantly lower than average non-agricultural incomes with an average of 85,343 THB per year. In addition, regional income inequalities within the agricultural sector were also high with average incomes ranging from 4466 THB in the North-East and 11,007 THB in the South (DIXON *et al.*, 2001, p. 9; BOSELIE *et al.*, 2003; GULATI *et al.*, 2006).

tive of the urban poor by keeping food prices low or aiming at limiting the widening gap by increasing agricultural output prices. In spite of a trend in policy shifts towards the latter, as for instance the reversal of the rice premium (an export tax) in 1986 into a (minor) export subsidy and-the establishment of a commodity credit programme for rice show, such policies are not expected to close the rural-urban income gap as budget constraints and the adverse effect of rising prices on the urban poor limit such policies (HAYAMI, 2007, p. 12). In the recent food price crisis of 2007/08 the Thai government imposed export restrictions among other measures in order to keep domestic prices low to avoid discontent among the urban population (BENSON *et al.*, 2008, p. 37).

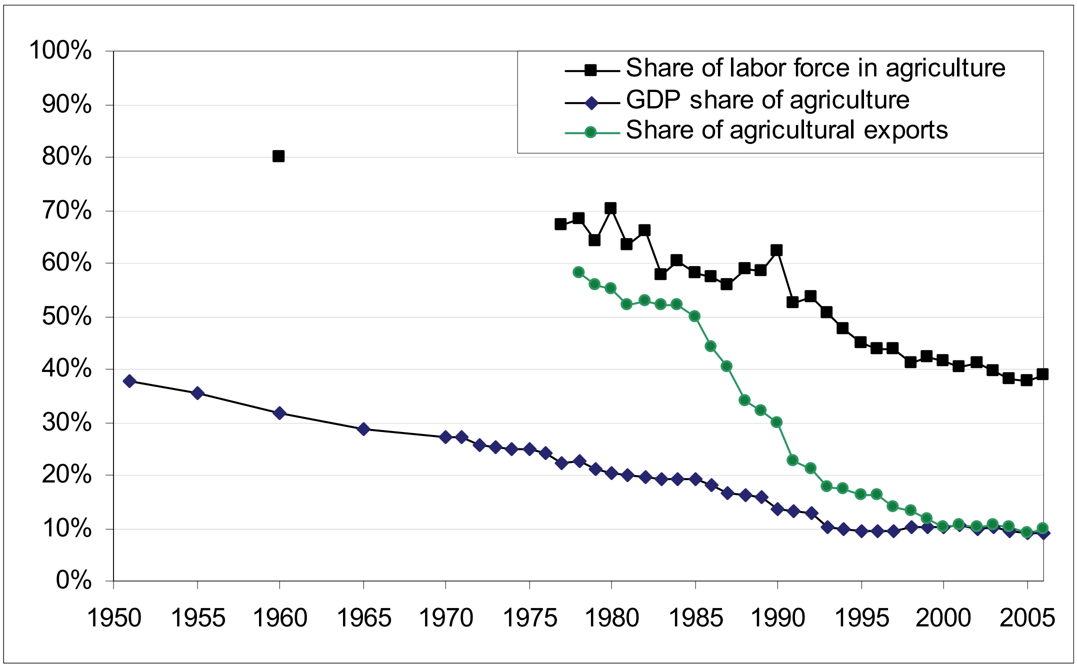

Figure 7: Development of agricultural share of GDP, export value and labour force
Data source: NSO (2008), NESDB (2007)

Some authors have identified 'Dutch disease' problem with the rapid (non-traded) asset price increase and its effect on agriculture, advocating that the withdrawal of labour from agriculture had been too fast, especially in the early 1990s, when looking back from the financial crisis in 1997 (COXHEAD and PLANGPRAPHAN, 1999). Based on a simultaneous equation model for a panel data set ranging from 1961 to 95 they conclude that labour demand in agriculture responded less to investment in agriculture than to investment in non-agriculture. They estimated that for each 4 Million Baht (THB) investment outside agriculture, one agricultural labourer migrates out of the sector. Also, planted area declines in response to such investment and a factor withdrawal at a ratio of 25 labourers per hectare was estimated (COXHEAD and PLANGPRAPHAN, 1999). They contend that irreversibility of investments in mechanization and migration from rural to urban areas have undermined labour market ability to cope with the crisis. A simple comparison of growth rates of agricultural inputs between the periods 1971-81 and 1981-95 (MUNDLAK *et al.*, 2002, p. 46) confirms a reversal from a labour-using to labour-saving innovation.

POAPONGSAKORN (2006) qualifies such statement based on evidence of a declining rural-urban migration rate, a more pronounced reverse migration[8] and a surge of rural unemployment rates, especially of young female workers in the aftermath of the crisis. In contrast, when urban unemployment returned to normal rates in 2000, agricultural unemployment followed with some time lag. He concludes that the rural economy provided a safety net for returning migrants although it was unable to fully absorb their labour (POAPONGSAKORN, 2006, p. 18).

Table 2: Thailand's GDP and selected agricultural components in constant 1988 prices (Billion THB) and percentage shares of GDP in current prices

	1960	1970	1980	1985	1990	1995	2000	2004	2005	2006*
Gross domestic product	226	478	914	1,191	1,945	2,935	3,008	3,688	3,855	4,052
from agriculture	71	131	185	227	264	317	310	354	334	361
from crops	51	76	114	147	160	185	163	194	182	190
from vegetables/nurseries[9]	n.a.	n.a.	13	13	14	17	21	24	25	26
GDP share of agriculture (%)	31.5	27.3	23.2	15.8	12.5	9.5	9.0	10.3	10.3	10.7
Vegetable/nursery products share in crop GDP (%)			11.6	9.9	12.5	12.1	13.8	18.4	18.9	18.6
Per capita GNP (THB)			19,493	22,731	34,415	48,833	48,011	53,899	58,240	58,240
Per capita income			11,164	15,791	27,180	45,762	52,893	66,333	71,787	78,457
Population	26,258	34,397	46,718	51,580	55,839	59,401	62,236	64,197	64,763	65,233

Source: National income of Thailand, NESDB (2007), *: projected data

Besides the above mentioned changes in sectoral GDP, contribution the impressive economic growth at an average rate of 6.5% between 1960 and 2006 was accompanied by structural changes within agriculture. As population growth slowed down (Table 2) and per capita incomes rose, domestic demand for income inelastic staple foods stagnated and in fact per capita rice consumption declined from 145 kg in the early 1970s to 105 kg in the 1990s (MUNDLAK *et al.*, 2002, p. 19). Although export demand sustained a market for further growing production from intensification and multiple cropping, GDP contribution from rice has steadily declined since the 1960s. Rapid population growth of around 3% per year led to an increasing pressure to convert forests into crop land. Being upland less suited for rice production, this process involved a 'natural' diversification by more or less newly introduced field crops such as cassava, sugar cane, maize and fibre crops (TDRI, 1995, p. 5). A different pattern of diversification is observable from the mid 1980s, when non-traditional high value crops and livestock products gained importance and exports of primary products were complemented by frozen chicken, sugar and canned pineapple. Besides products from aquaculture and marine fishing other crops such as coffee, pepper, ornamental plants, fruits and vegetables also contributed to an increasing extent to export earnings.

This pattern reflects the diversification out of rice into high-value crops or export oriented cropping as it is driven by the relative product and factor price signals farmers receive where

[8] Anecdotal evidence for reverse migration from rural surveys are reported among others by WALTER-ECHOLS (2005).

[9] Beginning in 2001, the item vegetables has been subsumed under "Growing vegetables, horticultural specialties, nursery products", leading to a marked increase between 2000 and 2004 from a change in industry classification.

markets are well developed. This is in contrast to conditions of incomplete or weakly integrated markets where diversification of income portfolios of individual households is an important component of risk management. DELGADO and SIAMWALLA (1997) argue that the former conditions apply to most Southeast-Asian countries and the latter likely prevail in sub-Saharan Africa. Under reasonably well functioning markets, policy makers may remain focussed on equity considerations, as small and large, peripherally and centrally located farms are likely to face different transaction costs due to different access to input and output markets, technology and information - and more so for high value added crops that involve some degree of processing and perishability (DELGADO and SIAMWALLA, 1997). They specifically name horticultural products as prominent examples for such diversification as they are likely to be more income-elastic than staple foods. The scope for policy interventions is then the reduction of such differentials in transaction costs by providing infrastructure (roads) and improving information with respect to technology and markets. In the specific situation of Thailand, increasing competition between industrial, urban and agricultural users of water calls for a more efficient use of irrigation water (SATTARASART *et al.*, 2001). Under such conditions, the substitution of a second rice crop in irrigated lands of the central region by more water-efficient vegetables might be a policy option (SIRISUP and KAMMEIER, 2000).

Moreover, rural-urban migration in response to wage differentials led to a duplication of urban population between 1980 and 1995 (SIRISUP and KAMMEIER, 2000). While official population estimates maintain that 36% live in urban areas, a more comprehensive definition including commuters and migrants who continue to be registered in their home provinces suggests that half of the population is already living in urban areas (Anonymous, 2007; KONGRUT and AP, 2007). Urbanization involved also a concomitant development of marketing systems and higher expenditures on goods and services (ISVILANONDA, 1992). Accordingly, domestic demand for higher value crops such as fruits, vegetables and ornamental plants has grown rapidly, especially in the 1990s, further augmented by additional exports (POAPONGSAKORN, 2006, p. 22) as highlighted by the share of vegetables in the crop component of GDP (measured in current prices) reported in Table 2. In spite of a hardly changed land use share close to 1%, vegetable share in crop GDP rose from 11.6% in 1980 to 13.8% in the year 2000. The marked increase between 2000 and 2004 is partly due to a change in sectoral classification in national accounts. Since 2001 vegetables are reported as part of an aggregate with nursery products and horticultural specialties (NESDB, 2007), which results in a 3.7% increase between 2000 and 2001. Since 2002, vegetables, nursery products and horticultural specialties contribute more than 18% of GDP from crops. The remainder of this chapter will concentrate on this group of high-value crops and highlight the most relevant features of the supply chain.

3.2 Trends in vegetable production

3.2.1 Characteristics

There is no clear and scientifically agreed upon definition of vegetable crops. Generally the term is used to refer to plants that are consumed fresh or cooked as side-dishes with a starchy staple (SIEMONSMA and PILUEK, 1994, p. 8). For the purpose of this study, vegetables as a commodity are defined according to the list of commercially produced vegetables of the Department of Agricultural Extension (DoAE). Unlike other sources[10] these statistics include chilli pepper, coriander, celery and ginger as vegetables, which is reasonable due to their analogous production and use in consumption (DOAE, 2008). Vegetables are characterized by their high water content, between 70% and 95 % of total weight and hence a low dry matter and nutrient content compared to staple crops. Vegetables also contain minerals, vitamins and dietary fibre (FAO, 2008a). Generally vegetables are harvested while still immature, including soft leaves and stems. The highly perishable nature of vegetables contributes to a high potential waste during transport and handling. Before consumption as fresh or cooked vegetables, a substantial portion is often discarded in preparation, such as pods, seeds, peel, stems and damaged leaves. Along with other high-value crops, they are sold through specialized markets and characterized by high perishability and their quality-specific value (CGIAR, 2005, p. 39).

The production of fresh vegetables is generally characterized by a short cultivation period, and hence quick amortization of a comparatively intensive input use in terms of labour and external inputs such as seeds, mineral fertilizer, pesticides (e.g. MUNGKUNG, 2002, p. 77ff; PRANEETVATAKUL and SIRIJINDA, 2007). As vegetables are harvested as a fresh produce from an immature plant during the growth process (except for many roots and tubers), the time frame for harvesting is short and high perishability requires temporal coordination with market demand. As a consequence, vegetable prices vary seasonally, especially with fluctuations in supply. Sometimes even within one day prices are highly volatile depending on the actual supply situation. Differently from fruit, and aside from few exceptions such as asparagus, vegetables can be grown with little initial investments. In connection with a high return per land unit relative to food and feed crops, vegetable production can flexibly adjust to demand. On the other hand the high quality-specific requirements of the market, the importance of timing and the complex production system are demanding in terms of management skills. Skilled and experienced vegetable farmers are therefore considered a decisive factor in vegetable production.

Vegetable production is less demanding with respect to agro-ecological conditions and extends over all FAO agro-ecological zones (MIDMORE and POUDEL, 1996). As limited or unstable natural precipitation can be overcome by irrigation, it is high night temperatures that effectively limit the production of specific vegetables (MIDMORE and POUDEL, 1996) as shown in Table 3. Even though plant breeding has produced more heat-tolerant varieties through which vegetable pro-

[10] FAO production statistics group dried chilli pepper and ginger under the separate category of spices, but includes mushrooms and truffles in the vegetable group (FAO, 2008b).

duction increasingly extends to tropical lowlands (KETELAAR and KUMAR, 2002, p. 2), production of some crops remains constrained to either the cool season or highland areas with lower night temperatures (e.g. cabbage, garlic, onion and head lettuce in Thailand).

Table 3: Optimum night temperature requirements of selected vegetables

Temperature range (°C)	Crops
7-13	Asparagus, cabbage, cauliflower, celery, garlic, leek, onion, pea, spinach, lettuce
13-18	Snap bean, chilli pepper, carrot, radish, soybean, tomato, Chinese cabbage
18-30	Cucurbits, okra, ginger, sweet corn, sweet potato, taro, tropical spinach, yard-long bean, sweet corn, eggplant, lima bean, winged bean, hyacinth bean, cowpea

Source: MIDMORE and POUDEL (1996, p. 57)

The numerous vegetable crops can be grouped according to different criteria depending on the intended purpose. In this research, three groups of vegetables will be distinguished according to the part of the plant that is consumed as follows: (a) leafy vegetables - including those grown for consumption of their stem, buds or heads, (b) fruit vegetables and (c) root and bulb vegetables including those grown for consumption of their tubers (ginger, Chinese radish). The overview in Table 4 lists examples and some common characteristics with respect to production, transport and handling of the crops.

Table 4: Vegetable groups with examples and typical characteristics

Vegetable group	leafy vegetables	fruit vegetables	root and bulb veget.
Examples	asparagus, cabbages, coriander, spring onion, morning glory	brinjal, chilli, tomato, beans	carrot, garlic, ginger, onion, shallot
Growing period	mostly short	medium - long	medium - long
Susceptibility to mechanical damage	medium - high	high	low
Susceptibility to wilting	high	low	very low

Source: Own presentation

The most comprehensive statistics on crop production in Thailand by the DoAE differentiates 48 types of commercially produced vegetable crops. These crops are listed along with indicators of importance in Table 4. Because of its unique coverage this data source is used as a reference throughout the thesis. The remainder of this section therefore describes production structure and systems with respect to the vegetable crops in Table 4. The respective scientific and Thai names are provided in Table 55 on p. 216 in the appendix.

Table 5: Commercial vegetable crops according to DoAE statistics 1998/99-2000/01.

Common name	TVSM code[11]	Group	Area planted[12] (ha)	Production[12] (t)
Angled gourd		fruit	6,286	41,599
Asparagus	asp	leafy	*7,570*[13]	44,988
Baby corn	bcorn	fruit	27,754	186,872
Brinjal		fruit	5,268	48,228
Cabbage	cab	leafy	11,769	206,887
Cantaloupe		fruit	616	11,734
Carrot		root/bulb	1,090	13,920
Cauliflower	cflr	leafy	3,043	38,738
Celery	corcl	leafy	2,512	18,737
Hot chilli 2-3 cm	c3	fruit	12,739	125,454
Hot chilli 3-5 cm	c3	fruit	59,219	304,784
Large chilli (5+ cm)	c5	fruit	18,128	146,535[14]
Chinese bitter gourd		fruit	2,241	23,062
Chinese mustard cab-bage	ccb	leafy	5,685	88,572
Chinese cabbage	ccb	leafy	5,391	75,326
Chinese chives		leafy	*10,002*[13]	38,165
Chinese kale	ckale	leafy	20,436	225,080
Chinese flowering mustard	cfmst	leafy	15,005	141,223
Chinese radish	cradsh	root/bulb	3,959	58,101
Coriander	corcl	leafy	7,001	41,813
Cucumber (fresh)	cuc	fruit	20,089	216,434
Garlic	grlc	root/bulb	23,355	272,133[14]
Ginger	gngr	root/bulb	10,473	161,493
Large Cucumber		fruit	7,584	104,876
Lettuce	lett	leafy	3,435	28,266
Morning glory	mglry	leafy	14,400	95,079
Okra		fruit	613	9,361
Onion		root/bulb	3,094	53,911
Plate brush eggplant	eggp	fruit	1,071	9,238
Pumpkin	pmkn	fruit	13,129	167,477
Shallot	shlt	root/bulb	19,826	268,666[14]
Snake egg-plant	eggp	fruit	3,975	48,101
Spring onion	son	leafy	12,885	154,192
Tomato, fresh	tom	fruit	3,371	44,346
Tomato, proc.		fruit	6,157	160,882
Watermelon	wmel	fruit	27,372	458,916
Water morning glory		leafy	*8,331*[13]	50,429
Waxgourd		fruit	5,166	65,316
Yard long bean	ylbn	fruit	22,370	181,114
Others [15]			4,393	29,881
Total			**436,802**	**4,459,931**

Source: Own calculation based on DoAE (2001)

[11] Codes identify commodities considered in the TVSM (Thai Vegetable Supply Model, cf. chapter 4).
[12] Average of crop years 1998/99 to 2000/01.
[13] For perennial crops area harvested instead of area planted is reported.
[14] Production is reported in terms of fresh product. Other sources might report the quantity of the dried product.
[15] Others include French beans, sugar peas, bell pepper, mild pepper, Chinese leek, cucumber for processing, broccoli, and roselle.

3.2.2 Spatial structure of vegetable production

An overview of the spatial arrangement of vegetable production is provided on the map in Figure 8. Production statistics for 48 vegetable crops are available at the district level from the DoAE (2001). The area planted to these vegetables and total production for a three year average of crop years 1998/99 to 2000/01 is overlaid on a physical map of the country. In spite of a more or less regular pattern of triangles representing the area planted to vegetables in districts, the distribution of output is highly skewed. About half of total production comes from only 12% of the districts. On the other hand, half of the districts produce only 9% of total vegetable supply. Concentrations of vegetable farms are identified to the north and northwest of Bangkok (Pathum Thani and Nonthaburi provinces[16]) and further to the west in Nakhon Pathom, Ratchaburi, Kanchanaburi and Suphanburi provinces. Other large concentrations are found in lowland areas of the Ping river valley around Chiang Mai (Chiang Mai and Lamphun provinces), in the Highland areas west and southwest of Chiang Mai and important upland production sites to the north and northwest of Chiang Mai (Chaiprakarn and Fang districts, Chiang Mai province and several districts of northern Chiang Rai province).

Highly concentrated production areas are two districts in Tak province on the western border about 250 km south of Chiang Mai, which are known for their specialization in temperate vegetables such as cabbages (Sakornsinthu, 1997). A further concentration is observed in the Pasak river valley and higher elevations of Phetchabun province on the border between Northern and Northeastern Thailand and in adjacent districts of Phitsanulok and Loei provinces. In Chaiyaphum and northern Nakhon Ratchasima province, larger land areas planted to vegetable crops and comparatively low output is related to low physical yields of the predominant chilli pepper production. For the remainder of Northeastern Thailand significant vegetable area and output is found, especially close to larger cities such as Nakhon Ratchasima (Mueang district), Khon Kaen, Udon Thani and Ubon Ratchathani. By analogy, spots of notable vegetable production on the southern peninsula are bound to urban centres such as Hat Yai, Nakhon Si Thammarat and Surat Thani.

In a nutshell, vegetable production is concentrated on the one hand in close neighbourhood to urban centres - favourably located in short distance to demand - and on the other hand in highland areas that offer favourable climatic conditions for production of specific vegetable crops such as cabbages, carrots, head lettuce and tomatoes.

Transport distance and climatic conditions affect different crops to varying extents. Many leafy vegetables for instance grow well under tropical lowland conditions but are more susceptible to transport losses (cf. Table 4 on p. 32) compared to some root and bulb vegetables (garlic, shallot, onion, carrots), which require a cooler climate but being storage organs are better suited for transport.

[16] For a map of administrative units cf. to Figure 72 on p. 218.

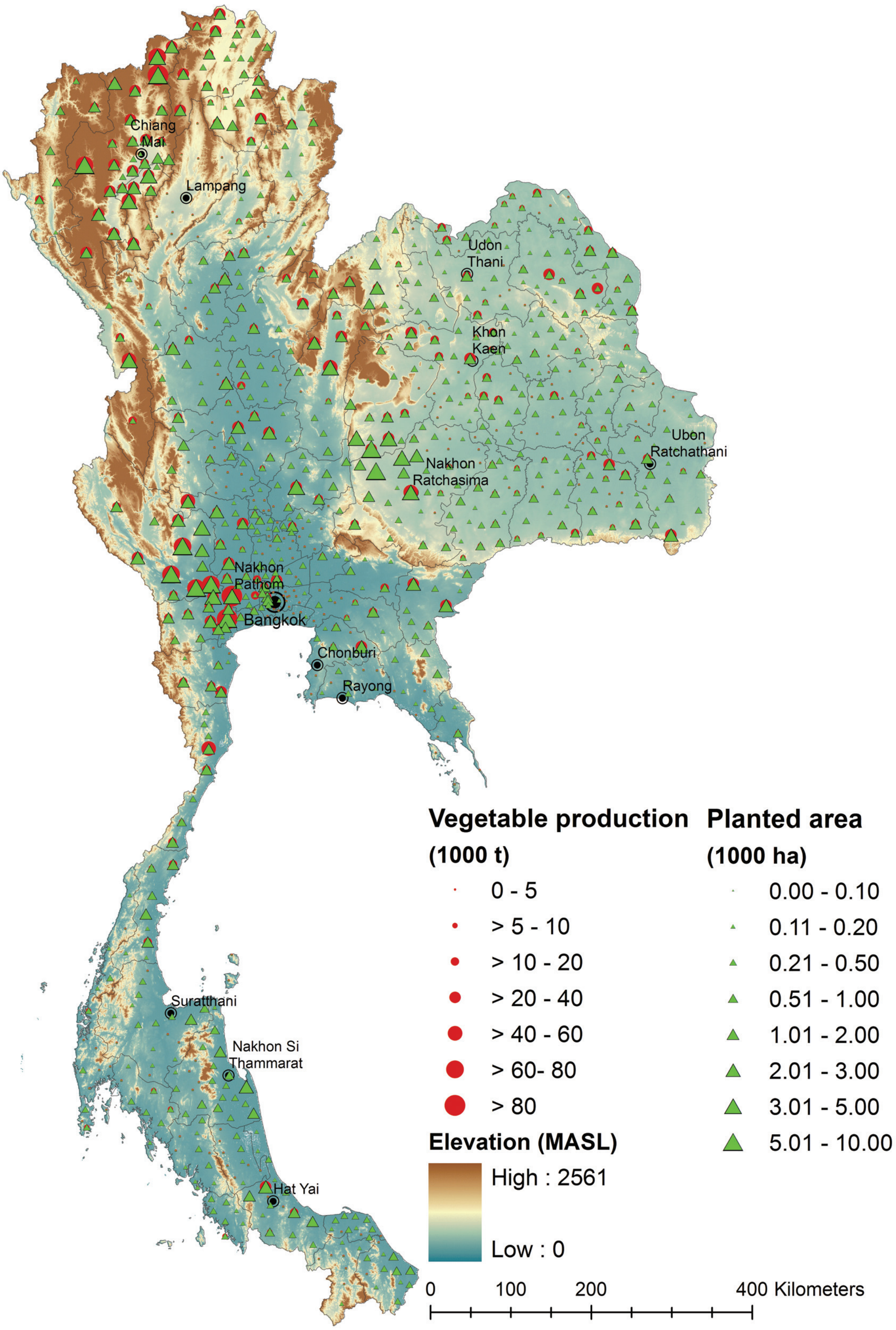

Figure 8: Average area planted to vegetables and production by district 1998/99-2000/01

Source: Own presentation based on DoAE (DoAE, 2001). GIS data: NSO (2002)

Mapping the area planted to the broad vegetable groups introduced above yields Figure 9. According to panel (a) substantial production of leafy vegetables is located in Bangkok, adjacent Nonthaburi and Nakhon Pathom and Kanchanaburi provinces to the west, whereas fruit vegetable production (Figure 9b) is less pronounced in Bangkok and Nonthaburi, but instead in more distant Suphanburi province. Concerning root and bulb vegetables (Figure 9c), a group dominated by garlic, shallot, onion and ginger, production is concentrated nearly exclusively in the upper northern provinces of Mae Hong Son, Chiang Mai, Chiang Rai and Lamphun, which offer the required cooler climate conditions. Only Sisaket province in Northeastern Thailand is visible as a root and bulb vegetable production spot for its traditional production of garlic after the rice crop, although yields are generally lower than in the North of Thailand (OAE, 2006).

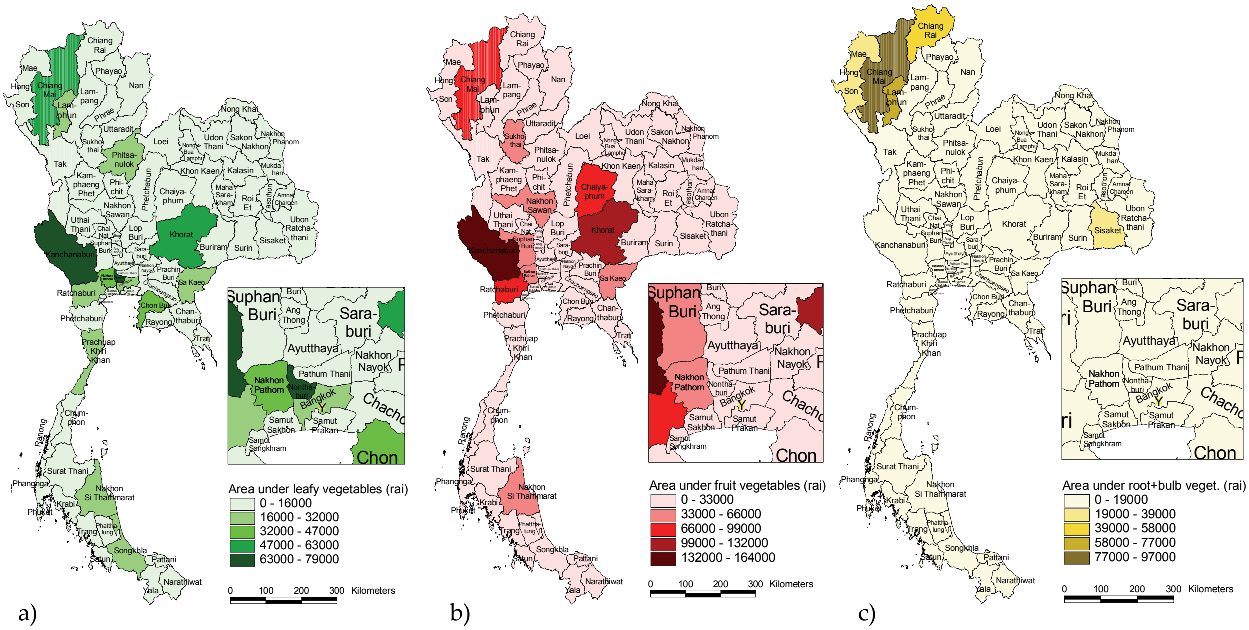

Figure 9: Vegetable area by province in 1998/99 crop year for (a) leafy, (b) fruit and (c) root and bulb vegetables

Source: Own presentation based on DoAE (DoAE, 2001)

Data collected on a smaller scale for the sub-district level in the greater Bangkok region (Chunnasit *et al.*, 2000) have been mapped in Figure 10 and show the distribution of vegetable and fruit production at the urban fringe of the capital. The pattern of concentration of these activities within the comparatively small map area is striking. In Pathum Thani province north of Bangkok, for instance, fruit production is high in the eastern part, whereas vegetable production is concentrated in the west of the Province (Nong Sua district). Together with Nonthaburi and the south eastern part of Bangkok province (Taling Chan district), this area forms the closest contiguous vegetable production site, as the urban sprawl already extends far into Nonthaburi and Pathum Thani province. Separated by the Tha Chin river, another concentration of vegetable production is found in the western part, especially the southwest of Nakhon Pathom province, whereas the south and adjacent parts of Samut Sakhon province are specialized in fruit production that developed between 1979 and 1987 (Hung and Yasuoka, 2000). According to the authors, farmers from the south of Bangkok bought land for fruit tree plantations because of good natural conditions and infrastructure combined with relatively low land prices. On the other hand, fruit tree plantations to the southeast and the west of the province (Thanyaburi, Khlong Luang districts) had been converted to residential and industrial land use when urbanization accelerated particularly in these districts (HUNG and YASUOKA, 2000). This history and the fact that vegetable production involves less investment than fruit plantations suggests that the latter is feasible only on owned land and under expectation of slower urbanization, whereas vegetable production takes place even on land held for speculation but rented out to vegetable farmers, in order to gain the benefit from a low land tax applicable to agricultural land use (OTA, 1998, p. 226). Thus the distinctive land use pattern in Pathum Thani province can be explained, whereas the clear cut division between vegetable and fruit growing areas in Nakhon Pathom and Samuth Sakhon remains unclear.

As the examination of agricultural land use in Bangkok and vicinity has shown, a dynamic view contributes to an explanation of observed land use patterns and will therefore be applied to the distribution of vegetable production at the national scale in the following section.

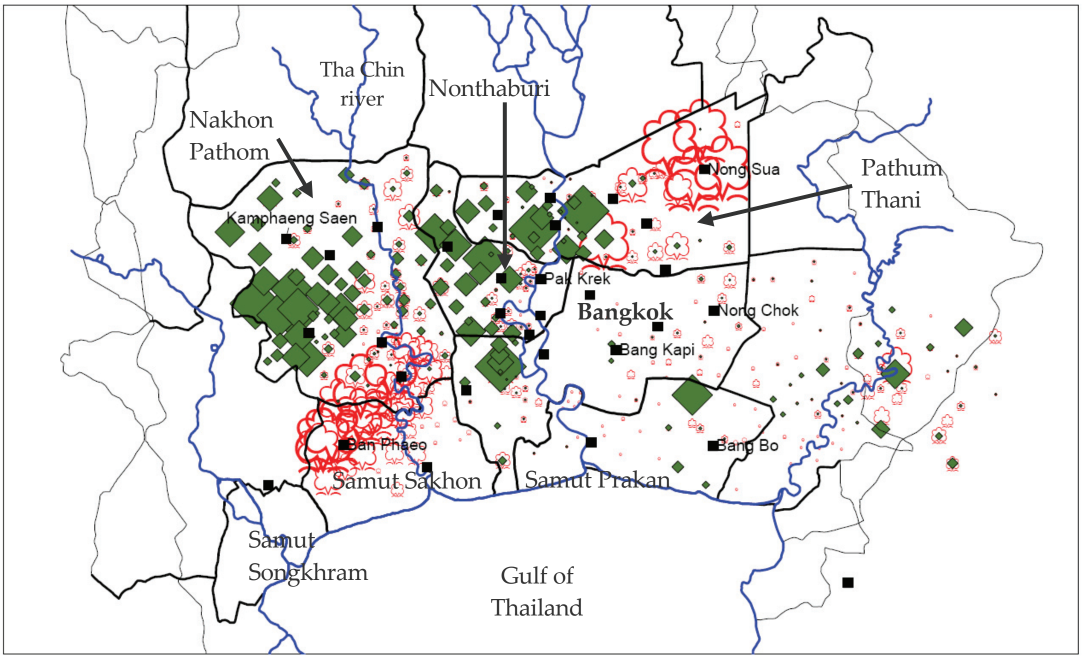

Figure 10: Distribution of vegetable and fruit production in Bangkok and vicinity
Source: (CHUNNASIT et al., 2000, p. 9)

3.2.3 Trend analysis

The dynamic development in Bangkok and vicinity highlighted above is likely to present an extreme example as the most rapid urbanization took place in this region. But vegetable production displaced by urban land use was compensated for by supply response in other regions - a fortiori as urbanization and rising incomes contribute to rising demand for these products. For an analysis of these dynamics at the national scale, the trend of the vegetable area share by province over the crop years[17] 1988/89 to 2000/01 have been analysed for a linear trend. Vis-à-vis an overall growth in planted area in this period, the change in relative contribution is a more meaningful indicator for a change in the spatial structure. The results are presented in Figure 11: those provinces with positive slope parameters significant at the 5% level are represented by blue shading, and those with a significantly declining share are represented by red shading. Large white areas on the map reveal that growth of vegetable area took place at average rates in large tracts of northern Thailand, the northern and eastern parts of central Thailand as well as parts of the Northeast. Bangkok and vicinity, i.e. the study area presented in Figure 10 except for Pathum Thani province, experienced a significant decline in their vegetable area share over the period, especially pronounced in Bangkok and Samut Sakhon, where the area planted also declined in absolute terms, mainly concerning leafy vegetables. In contrast, the area planted to vegetables in Nonthaburi and Nakhon Pathom increased in absolute terms, albeit at a significantly slower rate than the average. In spite of demand from baby corn and okra canneries located in Nakhon Pathom, the area planted to fruit vegetables, including baby corn, decreased in these areas in favour of leafy vegetable types, which suggests an outward movement of the production areas for the most perishable crops induced by Bangkok's urban sprawl. At the same time, baby corn production increased dramatically in neighbouring Kanchanaburi province. These findings fit well with the pattern found for the greater Bangkok region presented above.

Relative declines are significant in Saraburi and Prachin Buri in the eastern periphery of the central plain, where the vegetable area remained stagnant at low absolute levels. In the southernmost province of central Thailand, Prachuap Khiri Khan, overall stagnant area planted led to a significant downward trend in the contribution to vegetable area. A growing area planted to leafy vegetables was offset by declines, especially in fruit vegetables and ginger, while in the neighbouring province, Phetchaburi, area and production growth of fruit vegetables like yard long bean, cucumber, brinjal and tomato outpaced average growth.

In northeastern Thailand, a contiguous strip ranging from Nong Khai to Sisaket exhibits a consistent negative trend in area share as a result of an altogether stagnant area planted, mostly at low levels. Only in Sisaket, which had a noticeable share above 3% in the early nineties, planted area declined in absolute terms, due particularly to a decline of shallot production.

Positive trends on the other hand are reported for Kanchanaburi, Suphan Buri and Ayutthaya, west and north of the Bangkok metropolitan area. In the former two provinces, baby corn area increased very rapidly to make up for the drop in Nakhon Pathom province mentioned above. Leafy vegetable area such as for spring onion, coriander, Chinese kale and morning glory has increased in all these provinces. The two least peripherally located provinces of Northeastern Thailand, namely Chaiyaphum and Nakhon Ratchasima, show an above average growth in vegetable area, which can be traced to a large increase in the area planted to hot chilli.

[17] The crop year from April to March of the following year is the usual reference period of agricultural statistics in Thailand.

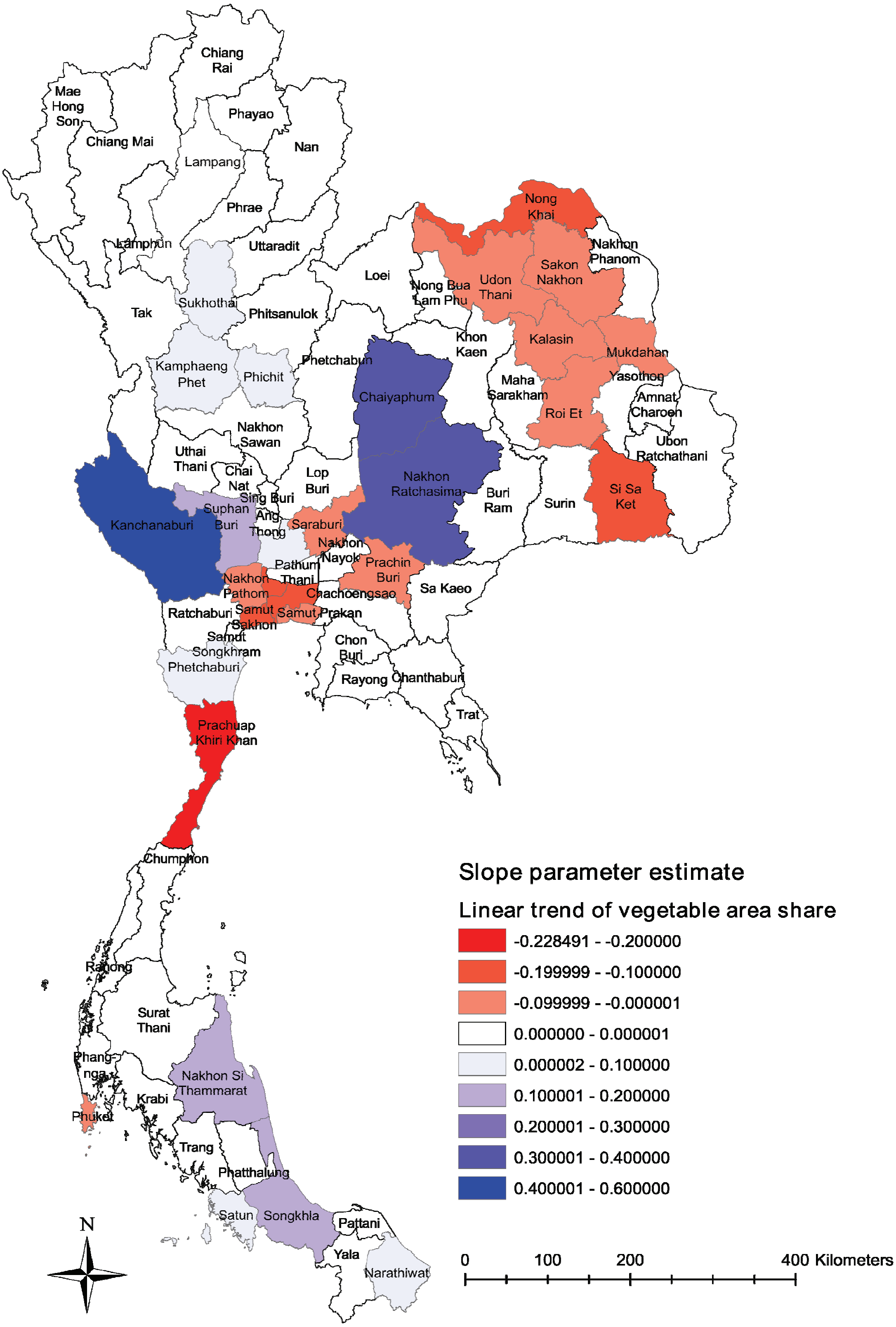

Figure 11: Provinces exhibiting significant linear trends of vegetable area share 1988/89 – 2000/01

Red and blue shades indicate a significant (α<0.05) negative and positive linear trend, respectively. Source: Own calculation based on DoAE production statistics (DoAE, 2001)

Finally, vegetable area has increased remarkably in the southern provinces of Nakhon Si Thammarat, Songkhla and to a lesser extent also in Narathiwat and Satun, where particularly fruit vegetables (e.g. yard long bean, chilli and cucumber) and – to a lesser extent leafy vegetable types – have contributed to growth in vegetable area.

Summing up, the growth of vegetable area and production over the crop years 1988/89 to 2000/01 on a national scale has been unevenly distributed. Bangkok and its neighbouring provinces have lost in relative terms – and in some cases also in absolute terms – in favour of more remote areas. In the far north, where vegetable production enjoys generally favourable conditions, growth rates close to the national average sustained the area's leading role as a vegetable supply region. However, the relative contribution to national vegetable supply did not increase significantly, either in terms of production or area planted. The analysis of production statistics over about a decade thereby supports and complements the evidence from past studies on local or regional scale (e.g. BOONMA *et al.*, 1974; SONGSAKUL, 1991; OTA, 1998; CHEYROUX, 2000; HUNG and YASUOKA, 2000) that vegetable production is rather mobile and vegetable farmers continue to shift production away from locations close to consumer markets to more distant areas.

3.3 Characteristics of production systems

3.3.1 Resource use

3.3.1.1 Land

Vegetables are grown on less than 1.2% of total agricultural land in Thailand. However, vegetable production is feasible on both upland and lowland. For year-round production, in the latter case, soil formations that provide for sufficient drainage and protection against flooding are required. For this purpose the Chinese ditch and dike system has been established in many places and covers an area of 8120 hectares in 2006 as reported by the Royal Irrigation Department (OAE, 2006). This is not used for vegetable production alone, but also for fruit and less frequently for other crops (CHEYROUX, 2000). Closely linked to land quality is the issue of water and irrigation. For year-round vegetable production a sufficient supply of water in addition to natural precipitation is required. Where access to irrigation canals is not available, the high value of vegetables allows for profitable production using ground water that is pumped up from wells by electric or motor pumps in places where sufficient groundwater supplies are viable and quality is sufficient. An important feature of production systems in the lowland delta areas of the rivers (e.g. Mae Khlong, Chao Phraya, Ta Chinh river and even near Chiang Mai and Nakhon Ratchasima) is the ditch and dike system, s.t. also referred to by its Thai name 'rong jeen' or Sorjan (FOOD AND AGRICULTURE ORGANIZATION, 2002, p. 105). By a special layout of the field characterized by alternating raised beds and ditches and a surrounding dike, flooding that occurs during the rainy season is prevented from affecting vegetable production in the protected polder. Vegetables are part of the diversification strategy in the central plains as they make more efficient use of irrigation water, for which competition has increased notably with industrial and urban developments downstream (SATTARASART *et al.*, 2001). Whether water saving is possible is at least doubtful given a case study of asparagus production in raised beds that consumed about 16,800 m^3 as opposed to 14,000 m^3 estimated for two rice crops (MOLLE *et al.*, 1999).

3.3.1.2 Labour

Differently from land, labour often limits vegetable production because the activity is very labour intensive. This is due to the need for specific timing of harvest and other cultural practices on the one hand, and growing non-agricultural wages that put pressure on agricultural wage labour on the other. Migrant labourers from Northeastern Thailand provided about two thirds of monthly hired labour in peri-urban vegetable farms in Pathum Thani province in 1990 (SONGSAKUL, 1991, p. 50). The contractual arrangements are diverse, ranging from daily hired labour to fixed contracts and piece-work contracts. Individual case studies report on groups specializing in planting, weeding/thinning and harvesting, often paid piecework by acreage or quantity of produce (FUJIMOTO, 1998, p. 161f), which offers advantages to both employer and employees, who can attain attractive daily wages. Migrant workers from neighbouring countries, especially Burmese, often illegally enter the country and work under substandard conditions and low wages in peripheral areas (KASEM, 1996; SAKORNSINTHU, 1997, p. 24).

3.3.1.3 External inputs

In the course of development and as a consequence of an increasing area under cultivation and a decreasing labour/land ratio, pesticide use in Thai agriculture has been continuously increasing since the late 1970s. The total real value of pesticide imports has grown by an average of 6.9% between 1995 and 2006 (Figure 13) after even faster increase by 8.8% p.a. for the period from 1982 to 1992 (JUNGBLUTH, 1997, p. 7). Among the pesticide groups, herbicides rank first in terms of quantity, value and growth rates ahead of insecticides, fungicides and other agrochemicals. As only a single active ingredient is produced within the country[18] (CHUNYANUWAT, 2005), import figures are suitable indicators for pesticide use in Thai agriculture, which is not otherwise reported in statistics. Disaggregated pesticide use data by crop are hence also unavailable, except for case studies. In 1994, an 18% market share of insecticides were used in vegetable production, and 21% of market volume of fungicides as opposed to share of 7% in farm gate value of crop production from vegetables in 1993 (JUNGBLUTH, 1997, p. 8). As pesticides continue to be cheap[19], there has been little economic incentive to switch to alternative strategies of control. This is also observed for vegetable production for which case studies from different regions have consistently reported extremely high use levels.

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[18] The active ingredient is paraquat, a herbicide.

[19] In fact the average formulated product cost less than US$2/kg, which is the 4th lowest out of 15 countries from the Asia-Pacific region (WALTER-ECHOLS, 2005).

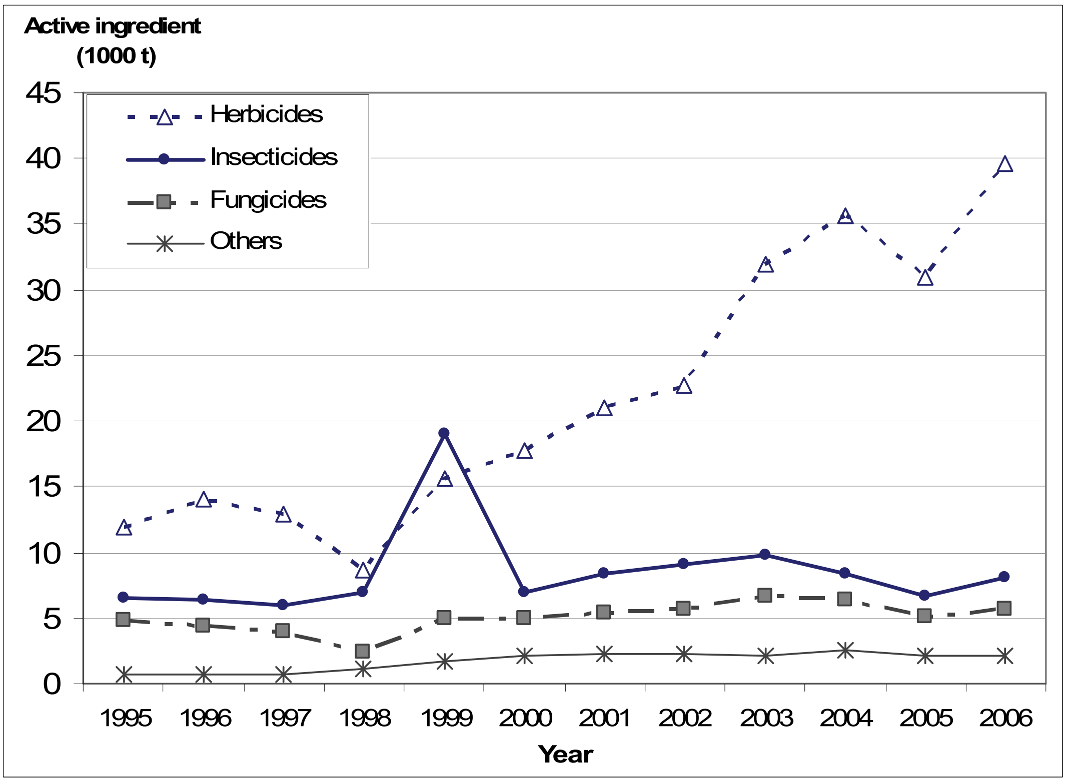

Figure 12: Imports of agrochemicals – quantity of active ingredient by group[20]

Data source: DoA (DOA, several years)

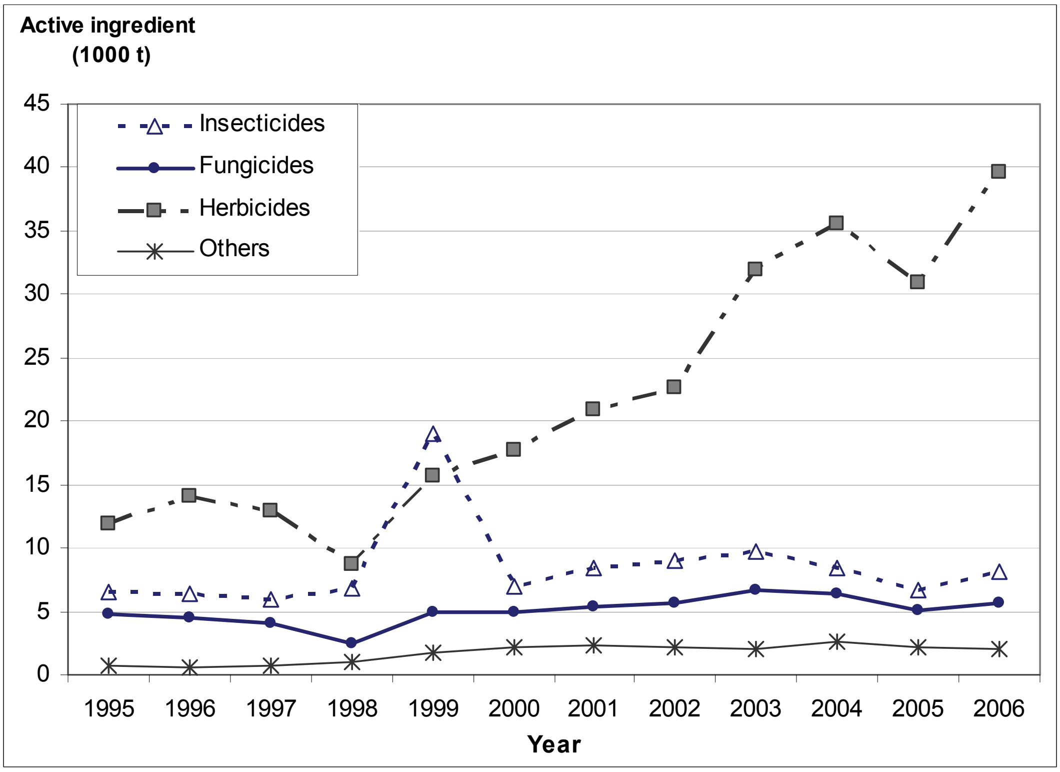

Figure 13: Value of pesticides imported in constant 2002 prices by group[20]

Data source: DoA (DoA, several years)

[20] Others include acaricides, molluscicides, rodenticides, nematicides, fumigants and plant growth regulators.

Evidence on pesticide use in vegetable production

According to an early case study in Ratchaburi province, depending on the crop, between 8% and 37% of variable production costs were reportedly spent on pesticides (BOONMA *et al.*, 1974, p. 40f). For Pathum Thani, a full cost share of 12.5%-19.2% for pesticides in vegetable production was reported (SONGSAKUL, 1991, p. 57). Moreover, she described a history of resistance development in the key pest of the leafy crucifer vegetables, the diamond back moth (Plutella xylostella), in which farmers switched from chlorfluazuron (1984) to *Bacillus thuringiensis* (a biological pesticide) until 1989 and then used abamectin in increasing doses (SONGSAKUL, 1991, p. 64). According to SUBHADRABANDHU and PILUEK (1988, p. 106), peri-urban production of vegetables became impossible in some lands where crucifers had been produced due to increased pest and disease pressure, so that producers had to switch to flowers or fruit tree cultivation. Although historical evidence is weak, it is likely that the heavy use of pesticides developed in peri-urban intensive vegetable production as rotations became less balanced with increasing pressure on land[21]. Contrary to tropical lowland conditions in peri-urban production locations, more remote areas benefit from less scarce land that allows for extended rotations and at least partly enjoy a cooler climate more conducive for the production of temperate vegetables (cf. also Table 3) (KETELAAR and KUMAR, 2002). Notwithstanding such natural advantages, weak enforcement of regulatory provisions in the more remote mountainous areas has fostered a likewise extreme pesticide use, often involving highly hazardous and outdated pesticides. From extensive literature that proves high frequency of sprays, the use of highly toxic pesticides and active ingredients that had been banned, Table 6 reports selected examples for various vegetables and different parts of the country.

The high level and frequency have been explained by various reasons. According to KETELAR and KUMAR (2002) indiscriminate pesticide use can lead to resurgent and secondary pests, which prompt farmers, who are targeting a spotless product according to market demand, to increase the dosage or use more frequent sprays. This leads to a calendar-based spraying schedule (cf. Table 6), which often continues until shortly before harvest in disregard of waiting periods - either due to ignorance or purposively to safeguard an attractive appearance of the produce, which is deemed preferable by the consumer (KETELAAR and KUMAR, 2002). In order to save labour during application and to increase the effect, a mix ('cocktails') of various pesticides is often used. The use of highly toxic pesticides is often connected to a preference for a quickly visible effect ('knock-out' pesticides) (KAMNALRUT *et al.*, 2000). The cultural practices and the level of pesticide use have directly observable effects on farmer health and the quality of the produce.

[21] Already in Thünen's model. the closest peri-urban ring was predicted to be used for cash crop production without specific rotations (cf. p. 10).

Table 6: Selected literature sources on pesticide and nitrogen use in Thai vegetable production

Crop	Location	Pesticide use	Nitrogen use	Reference
Chinese kale	Khon Kaen peri urban	mix of 3-4 pesticides, a. o. Mevinphos (Ia), Parathion (Ia) applied every 3 days	356 kg N/crop of 45 days	(FUJIMOTO, 1998, p. 156)
	Pathum Thani	once a week or more,		(SONGSAKUL, 1991, p. 23)
	Nakhon Ratchasima	10 sprays, WHO classes Ia and II		(HARDEWEG and WAIBEL, 2002)
	Suphan Buri, Nakhon Pathom		44-65 kg/ha and crop, surplus 33-49 kg/ha and crop	(PHUPAIBUL *et al.*, 2002)
	Lake Songkhla basin		1280 kg/ha	(KAMNALRUT *et al.*, 2000)
Cauliflower	Khon Kaen periurban	Mevinphos (Ia), Carbofuran (Ib), Endosulfan (II), every 5 days		(FUJIMOTO, 1998, p. 157)
3 vegetable crops in 1 year	Mae Sa Mai watershed, Chiang Mai	Ib: 0.14 AI kg/ha, II: 4.18 kg AI /ha III: 3.21 kg AI /ha U: 3.21 kg AI /ha Total: 9.0 kg AI/ha		(ZEDDIES and SCHÖNLEBER, 2007)
Carrots (single crop)			69-260 kg/ha, surplus 50-188 kg/ha	
Chinese cabbage (single crop)			131-718 kg/ha, surplus 56-600 kg/ha	
Chilli	Suphan Buri, Nakhon Pathom		supply: 220-285 kg/ha surplus: 213-276 kg/ha and crop	(PHUPAIBUL *et al.*, 2002)
	Lake Songkhla Watershed	Ib: 3.75 l/ha, II: 12.5 l/ha*	820 kg N/ha (480 kg from manure)	(KAMNALRUT *et al.*, 2000)
Yard long bean			60-90 kg/ha and crop, 73-77 kg/ha and crop	(PHUPAIBUL *et al.*, 2002)

* The source remains unclear whether quantities refer to active ingredient or formulated product and whether pesticides listed are all applied in one crop.

Occupational health

The implications of pesticide use for the applicators and farm workers working on treated plots are often less easily captured as they are not always linked to the agents, or health problems are not recorded in official statistics when no treatment is sought in hospitals. Official data on pesticide intoxication with severe and fatal effects are likely to underestimate the magnitude of the problem (THAPINTA and HUDAK, 2000; PANYAKUL, 2002, p. 179). After a dramatic increase during the 1970s and 1980s (PANYAKUL, 2002, p. 179), the officially reported number of poisonings declined markedly between 1999 and 2006 (Figure 14).Out of 1640 reported cases of poisoning, 1321 were recorded in agriculture, out of which 47% occurred in the Northern Region, 35% in the Northeast and only 16% in Central Thailand (Pollution Control Department, 2005).

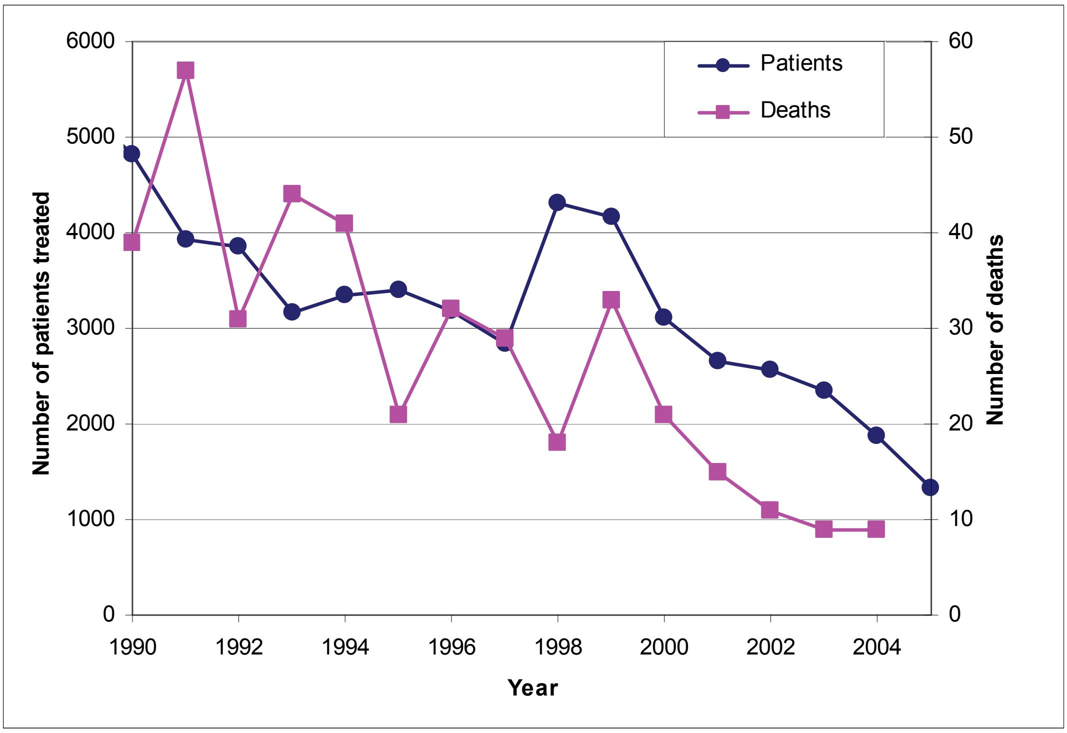

Figure 14: Number of patients treated and number of deaths due to pesticide poisoning between 1990 and 2005

Source: Pollution Control Department (2005), 1990-1996 data cited in TAPHINTA and HUDAK (2000)

In contrast to a declining number of patients treated for poisoning, occupational health surveillance finds increasing incidence of sub-acute poisoning as reflected in blood cholinesterase inhibition at unsafe levels that has continually risen from 13.4% in 1999 to 29.4% of sampled farm workers in 2003 (CHUNYANUWAT, 2005). Low levels of cholinesterase activity indicate the exposure to and hazard from organophosphate and carbamate insecticides (KUNSTADTER *et al.*, 2007, p. 109). In line with the high level of pesticide use in vegetables, case studies in vegetable farming areas find significantly higher incidence of risky or even dangerous levels of cholinesterase inhibition.

A DANIDA-funded project aiming at the promotion of IPM (see below) for instance has surveyed pesticide use and farmer health in 2003 and 2004 in several regions where vegetables are an important component of cropping systems. According to the survey, protective clothing and proper handling practices are not in widespread use and there is a significant potential for reducing the health risk to farmers by selecting less toxic pesticides (DANIDA, 2006). The frequency of pesticide use by WHO acute toxicity class and the level of intoxication are reported in Table 7. Only 43%, 21% and 16% of monitored farmers showed normal levels of cholinesterase levels and risky levels were observed in 19%, 25% and 33% of cases. Between 20% and 80% of farmers used highly toxic pesticides and were exposed to pesticides at least once a week in most regions. An earlier survey among farmers belonging to the Hmong ethnic minority in Chiang Mai found only in 6% of the population normal cholinesterase activity, whereas 39% had low levels categorized as risky or unsafe (KUNSTADTER *et al.*, 2001). The health hazard and the awareness on the employees' and employers' side is reflected in wage premiums for pesticide applicators. In larger highland vegetable farms, for instance, a wage premium of 100% is paid to Burmese migrant labourers for spraying pesticides (SAKORNSINTHU, 1997, p. 75).

Table 7: Selected results of occupational health surveillance with respect to pesticide use among farmers with vegetable production

Location	Sample size (share of vegetable farmers)	Use by WHO toxicity class (% of farmers)					Exposure: Number of days with spraying p.a. (average)	Incidence of self-reported poisoning symptoms: total (details)	Level of blood cholinesterase inhibition[22]
		Ia	Ib	II	III	U			
Mae Wang district, Chiang Mai 2003	124 (87%)	6	20	87	52	67 (37)	2 - 75	98.4% (79.8% moderate)	20.8% normal 54.2% safe 25.0% risky
Chai Prakan district, Chiang Mai 2003	109 (67%)	6	37	85	21	61 (57)	1 - 103, (25)	94.5% (53.2%: moderate , 0.9% severe symptoms)	42.9% normal 38.1% safe 19.0% risky
Petchabun 2004	79 (49%)	16	80	91	57	14 (35)	3 -73, (21)	88.6% (23% moderate symptoms)	n.a.
Chanthaburi Chiang Mai Kamphaeng phet Rayong Sukhothai Suphanburi 2003-2004	606 (18.2%, and 24% with garlic and onion production)	16	39	81	37	58 (58)	24%: 21-120 days p.a. 30% 12-20 days p.a.	94.4%	(N=187) 16% normal 39.6% safe 33.2% risky 11.2% dangerous
Chiang Mai Hmong* farmers 1999-2000	395 (n.a.)							n.a.	6% normal 54% safe 29% risky 10% unsafe

Sources: DANIDA (2004, 2005b, a), *KUNSTADTER *et al.*(2001)

Residues

Whereas effects of pesticides on the applicators can be minimized by proper protection equipment, the residues of pesticides on the produce and in the environment can be managed only by the proper selection of the pesticide and appropriate application rates and frequencies. Residue monitoring in the environmental compartments of soil and water in 2004 have revealed that out of 98 samples from water resources in Fang and Chaiprakarn districts of Chiang Mai province, two major producers of horticultural products, more than 90% of water resources had residues of organochlorines, carbamates, pyrethroids or paraquat, which were traced to orange orchards

[22] Low levels of cholinesterase activity indicate the exposure to and hazard from organophosphate and carbamate insecticides (Kunstadter et al., 2007, p. 109).

(CHUNYANUWAT, 2005). Also, the analysis of surface water bodies in highland areas with intensive horticultural production has revealed that in most of the samples analyzed pesticide residues were present and for endosulfan (an organochlorine insecticide) exceeded the EU threshold for drinking water. Moreover the use of more persistent[23] active ingredients such as metalaxyl and vegetable cropping on steep slopes contribute to a more than proportionate contribution to residues in run-off water from vegetable production (ZEDDIES and SCHÖNLEBER, 2007). The fact that high levels of cholinesterase inhibition were also found in blood samples of non-farming parts of the population hints at a severe contamination of air, water and food in parts of the highland areas of Chiang Mai (KUNSTADTER *et al.*, 2001; KUNSTADTER *et al.*, 2007, p. 126f).

Residue levels in food are monitored by the Food and Drug Administration and the Department of Medical Sciences, MoPH. Between 1994 and 2003, pesticide residues were found in more than half of the samples of conventional vegetables and most of the time also in vegetables that were certified to be safe from excessive pesticide residues (Table 8). Out of the conventional vegetables up to 37% were unsafe for consumption because they exceeded maximum residue limits. The incidence of excessive residues in certified vegetables was much lower, but still reached up to 13%. No trend of an improvement is recognizable from the data.

Table 8: Residue monitoring results from conventional and certified vegetable samples between 1994 and 2003

Year	Conventional vegetables			Certified vegetables[24]		
	Sample size	Samples with detectable residues (%)	Samples with residues above MRL[25] (%)	Sample size	Samples with detectable residues (%)	Samples with residues above MRL(%)
1994	n.a.	n.a.	n.a.	38	40	11
1995	27	48	7	29	34	7
1996	49	61	20	22	55	9
1997	n.a.	n.a.	n.a.	36	22	0
1998	37	60	5	16	6	0
1999	43	67	16	47	64	11
2000	44	68	37	40	65	13
2000-2003*	193	64	n.a.	166	52	n.a.

Source: Department of Medical Science, MoPH, 1994-2000 cited in VANIT-ANUNCHAI (2006, p. 47), * 2000-2003 cited in ATISOOK *et al.* (2006).

Nitrogen

In comparison with grain production, vegetable cultivation generally involves a high supply of external nitrogen, because unlike grains, vegetables are harvested at an immature stage when the plant is still growing and continuing to absorb nutrients. This requirement of the crop may lead to groundwater contamination, especially in highly intensive production areas and under exces-

23 Persistence describes the time a substance remains in the environment before it is decomposed. A higher persistence implies a longer effectiveness on the plant but on the other hand a higher risk of side effects on the environment.

24 See below for a review of certification programs.

25 MRL: Maximum residue level according to national food standard.

sive precipitation or irrigation (CHATUPOTE and PANAPITUKKUL, 2005). In China, particularly in vegetable producing areas, excessive levels of nitrate content in ground water of up to the six-fold the allowable limit of 50 mg l^{-1} pose a health risk to the population. These residue levels were associated with application rates of 500 to 9000 kg ha^{-1} and crop N uptake below 40% of that supplied (ZHANG *et al.*, 1996). In a study of vegetable cropping on a ditch and dike system along the Tha Chin river in Central Thailand Phupaibul et al. (2002) analysed nitrogen and phosphorus balances of vegetable crops and found very high application rates of e.g. 200-300 kg ha^{-1} for one crop of only Chinese kale. In a 18-month-long monitoring, the recovery rate for nitrogen (i.e. the share of the externally supplied nutrient removed from the field with the product) ranged between 21% and 25% for Chinese kale, around 20% for bitter gourd, 18-19% of yard long bean and only just above 3% for chilli. For phosphorus, recovery rates are far lower, ranging from below 1% in chilli to 12% in bitter gourd (PHUPAIBUL *et al.*, 2002). Another case study in a sub-catchment of Lake Songkhla in southern Thailand, reports annual application rates of up to 1280 kg ha^{-1} for five consecutive crops of Chinese kale(KAMNALRUT *et al.*, 2000), Chinese cabbage and Chinese mustard. Asparagus in raised beds in Damnoen Saduak received an annual 561 kg N of mineral fertilizer and an addition of cow manure (MOLLE *et al.*, 1999). Crop monitoring in a high-land watershed area revealed that a single crop of carrots and Chinese cabbage implied an excess supply between 50 and 188 kg N/ha for the former and between 56 and 600 kg N/ha for the latter. In spite of a considerable cost involved with mineral fertilizers in vegetable production (e.g. 22% in 1990 (SONGSAKUL, 1991, p. 57)), farmers consistently use high amounts of nitrogen fertilizer to ensure a soft texture in leafy vegetables. The evidence presented here consistently implies that nitrogen in vegetable production is applied in amounts far beyond recovery by the crop. With respect to the findings of ZHANG *et al.* (1996), it is very likely that groundwater quality is also jeopardized in the intensive vegetable production regions of Thailand.

3.3.2 Farming systems

Before turning to a description of the structure of vegetable farms, a brief overview is given of the relevant farming systems[26] that define the choices farm decision makers face and the available development options. This will facilitate understanding the conditions under which farmers operate. Although vegetables have traditionally been part of home garden production (TANTISIRA, 1988, p. 453), the further discussion will exclude this part of vegetable production, whose importance has further declined with urbanization and the development of transport and marketing infrastructure (ISVILANONDA, 1992, p. 16). For a description of the commercial production systems this section relies on the available literature, which has been used as a reference during data collection and analysis. In the literature, descriptions at varying level of detail describe farm types that can be summarized in four groups:

[26] "A farming system [...] is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate." (PUNTASEN and PREEDASAK, 1998; DIXON *et al.*, 2001)

1. Intensive peri-urban lowland vegetable farm
2. Intensive upland contract farming vegetable production
3. Seasonal vegetable production in a rice-allium system
4. Intensive highland vegetable production

3.3.2.1 Intensive peri-urban lowland vegetable farms

One of the most detailed descriptions of a vegetable farming system deals with one that developed early in the 20th century under very specific conditions in Damnoen Saduak district, Ratchaburi province about 75 km south-west of Bangkok (BOONMA *et al.*, 1974). Chinese immigrants with limited access to land and capital settled in this area of the flood plain of the Mae Khlong river and started vegetable production on the Chinese ditch and dike system (BOONMA *et al.*, 1974, p. 15). This system enables farmers to grow vegetables on soils with poor drainage and a highly fluctuating water table as found in the lower Mae Khlong basin by the establishment of special soil structures. Vegetables are produced on up to 1 m high and 1 to 4 m wide beds separated by ditches. They are used for semi-automated irrigation by motor pumps mounted on boats, which are manually pulled along the beds. The farm area is surrounded by a dike usually high enough to prevent flooding of the polder during the rainy season (BOONMA *et al.*, 1974). Water management in such systems is complex and involves pumping water out of the polder to drain excess water and addition of water from irrigation canals during the dry months of the year (MOLLE *et al.*, 1999). Before completion of the Great Mae Khlong project in the 70s, flooding occurred in the area for up to four months per year (CHEYROUX, 2000), resulting in the deposition of silt and organic matter, which contributed to maintaining fertility. A great variety of vegetables used to be planted in complex rotations and intercropping arrangements based on market demand on the one hand and productivity considerations on the other (BOONMA *et al.*, 1974, p. 30f). Market access was facilitated by the concentration of vegetable farms in a comparatively small area that allowed for efficient collection of the fresh produce by merchants along the Damnoen Saduak canal, which provided a water transport directly to Bangkok (CHEYROUX, 2000). About two thirds of all farmers sold their produce to merchants according to previous contractual agreements involving the input supply by the merchant (BOONMA *et al.*, 1974, p. 30f). Already at the time of their analysis, increasing pest and disease incidence emerged as a main problem. According to Boonma *et al.* (1974, p. 15), farmers were seeking paddy land in other areas for converting it to the ditch and dike system and continuing vegetable farming on new land.

A more recent study describes lowland vegetable farms in the Mueang district of Pathum Thani province north of Bangkok producing on similar land formation. Here also, Chinese immigrants started commercial vegetable production around 1930 but over time local farmers and workers also adopted vegetable production (SONGSAKUL, 1991, p. 29). At the time of the study, pressure from land competition and employment opportunities in the rapidly developing non-agricultural sectors had left only 35 farms in the district, all of which were growing vegetables and their farm land was surrounded by housing estates or factories. Other farmers had given up farming in favour of wage labour in the nearby developing industries (SONGSAKUL, 1991, p. 15).

For a comparable area, Bang Bua Thong and Bang Rak Pattana districts in Nonthaburi province, where urban development proliferated during the 1990s, Jitsanguan (1998, p. 225f) found that land rent remained low even though infrastructure development changed the opportunities for land use. He explains that landlords wait for further land price appreciation while they still collect rents from a second-best use by rice, fruit or vegetable production. Land prices in 1993 ranged from 1000-1500 THB/rai for paddy fields and 1500-3000 THB/rai for land suitable for vegetable or fruit production. On the other hand, PHUPAIBUL *et al.* (2002) report that farmers had begun to move to more distant areas from Bang Bua Thong district to Bang Plama district of Suphanburi province, because of increasing costs for land rent and hired labour.

Due to an intensive year-round vegetable production with rotations becoming less elaborate as land pressure increase, this system developed a high dependence of chemical inputs such as mineral fertilizers and pesticides (BOONMA *et al.*, 1974, Songsakhul, 1991 #81; WAIBEL and SETBOONSARNG, 1993).

3.3.2.2 Intensive upland contract farming vegetable production

Less detailed evidence is available for the example of asparagus contract farming and the presentation here is based largely on NARITOOM (2000). Processing plants located in Nakhon Pathom province (west of Bangkok) have – together with substantial support from the agricultural and provincial administrations – enabled production of comparatively high value crops for processing and subsequent export, e.g. to the Japanese market. Since 1989 asparagus has been grown in contract arrangements with three processing companies. The contracts provide for a guaranteed price for graded qualities of asparagus for one year in advance, commits farmers to follow certain agricultural practices (e.g. minimize pesticide use, observe waiting periods) and provides extension services on production. The contract is concluded between the company and a farmer group that is based on voluntary membership and acts through a group leader. Often government officials (the provincial head of the extension service or the provincial governor) are present and act as symbolic witness. Besides asparagus for processing baby corn for the local market is also grown under contract - in this case with local middlemen, who both supply inputs such as seeds, fertilizer and pesticides and collect the produce for peeling and subsequent sale in Bangkok (NARITOOM, 2000).

Due to the perennial nature of the asparagus crop, the farming system is characterised by the year-round production of asparagus on some part of the land, sugar cane production on upland and two rice crops on paddy land – depending on the individual farm endowment. Depending on the situation, 4-5 crops of baby corn or other vegetables are grown in addition. The per hectare gross margins of the crops differ widely from US$454 from two rice crops to over US$3,500 for four crops of baby corn and to US$7,440 for asparagus. Notably, asparagus area per farm is on average rather constant at around 0.4 ha over different groups (NARITOOM, 2000) as a consequence of the high labour intensity and the need for very regular (daily) harvesting effectively possible only through family labour. In spite of comparatively high quality standards and the quality standards of processing firms, more recently a 'paradigm shift' towards less intensive use of pesticides has also been observed in asparagus grower groups (NARITOOM, 2003).

3.3.2.3 Seasonal vegetable production in a rice-*Allium* system

The seasonal production of vegetables from the *Allium* family (e. g. garlic, shallot and onion) in the cool and dry season after a rice crop is found in many parts of lowland areas of the Northern region, particularly in the provinces Chiang Mai, Lamphun, Chiang Rai, Mae Hong Son and Uttaradit. It is also practised in some areas of Sisaket province of northeastern Thailand. Beyond mere references (TANTISIRA, 1988; PANYAKUL, 2002, p. 177) there is little descriptive information in the literature and a description is provided based on the expert survey results of this study in chapter 4.

3.3.2.4 Intensive highland vegetable production

A few case studies exist on highland vegetable production systems and they differ in terms of crop specialization and also sometimes relate to the preferences of the particular ethnicity of farmers, as highland areas in Thailand are populated by various ethnic minorities among which Hmong and Karen are the more populous groups. Historically, hill tribes practised swidden agriculture, i.e. opening new land by clearing the forest, cultivating it for a few years until fertility went down and moved to new lands. Another historical feature is the cultivation of opium poppy, which the government tried to substitute with horticultural crops vegetables, fruits and flowers during the 1970s by both substitution programmes providing extension and inputs on the one hand and strict enforcement of law against illicit poppy production on the other.

SAKORNSINTHU (1997) has studied vegetable producers of Chong Kab sub-district in Tak province located in the lower part of northern Thailand. This area developed as an important supplier of leafy vegetables, especially Chinese cabbage, cabbage and Chinese kale because of favourable natural conditions (elevation: 300-750 MASL) and shorter distance to urban demand in Bangkok (560 km) compared to the upper North (SAKORNSINTHU, 1997, p. 19). Production took place partly on illegally cleared forest land and often involved employment of illegal migrants from neighbouring Myanmar at wage rates below official minimum (SAKORNSINTHU, 1997, p. 24). Vegetable production in this area has been the subject of newspaper coverage on the high pesticide use and illegal employment of migrant labourers (KASEM, 1996). In a case study encompassing a few villages in a catchment area, PRANEETVATAKUL and SIRIJINDA (2007) describe different farming systems of Hmong farmers depending on the elevation and land endowment. On average, farms covered 2.3 hectares of slightly to highly sloping lands planted to lychee trees (1.4 ha), upland crops (e.g. maize, upland rice) and about 0.3 ha planted to vegetables - especially those preferring temperate conditions such as cabbage, Chinese cabbage, radish, carrot, potatoes and lettuce varieties. Two to three successive vegetable crops planted on terraced or sloping land were found to provide the highest gross margins (PRANEETVATAKUL and SIRIJINDA, 2007).

3.3.3 Farm structure

The description of farming systems above has highlighted typical characteristics of vegetable farms in Thailand but lacks quantitative data on the relevance of these systems and the available resource base. Such an assessment based on statistical sources is hampered by a lack of detail in published data of agricultural censuses, the variety of vegetable crops and the multiple crops in one period. This section compiles the available statistical data on the resources used in vegetable production and relates these to the farm types presented above where possible.

The most recent agricultural census of 2003 reports a total of 370,000 farms growing vegetables, flowers and herbs and a total land area of 221,000 hectares designated for the production of vegetables, flowers and herbs (Table 9). This land area does not include off-season land use for the production of these crops, because such land is subsumed under rice or field crop land. Although the agricultural census provided limited capacity for recording the planted area in the case of multiple crops, the information can be used to approximate the vegetable share on this land. On the national level a total planted area of vegetables amounted to 396,000 hectares out of 426 000 hectares planted to vegetables, herbs and flowers (NSO, 2005b). We can therefore conclude that 93% of this land use category is actually used for vegetable production and in the absence of more detailed information will assume this ratio to also apply to the number of holdings growing vegetables out of those with vegetable, flower or herb production, which leaves 344,500 vegetable farms.

Against a total farm population of about 5.8 million, the number of farms with vegetable production in 2003 corresponds to 5.95% and vegetable land to 1.3% of total farm land. In comparison with 1993 the number of farms increased by 2.9% but those with vegetable production have increased by 35% over one decade - most rapidly in the South (+58%) and the Northeast (+46%) and least in northern Thailand (+17%). Vegetable land has increased by only 23% in total. In contrast to the number of farms, however, vegetable land in Northeastern Thailand has increased by only 5%. Such discrepancy may result from an adoption of off-season vegetable production by farmers who had been growing only rice or field crops before.

Table 9: Farms growing vegetables, flowers and herbs in 1993 and 2003

Region[27]	Number of holdings growing vegetables, flowers and herbs		Vegetable, flower and herb area				
	1993	2003	1993		2003		
			ha	%	ha	%	ha per farm
Central	78,265	111,716	64,374	36	81,975	37	0.73
North	102,027	119,589	56,307	31	74,946	34	0.63
Northeast	78,923	115,002	50,946	28	53,476	24	0.47
South	15,308	24,145	7,759	4	10,184	5	0.42
Total	274,523	370,452	179,386	100	220,581	100	0.60

Source: Agricultural Census (NSO, 2005a)

27 Regions and provinces are shown in Figure 72 on p. 218

A detailed description of specialized vegetable farms is presented in Table 10 based on individual farm data from a 1% sample of the 2003 census. For this table only those farms with at least 50% of the holding area planted to vegetables have been considered. It can be seen that less than 40% of all vegetable growing farms belong to this specialized group, most of these located in the northern and central regions, whereas in the northeast, only 16% of vegetable growing farms are specialized. According to Table 10, average household size is comparatively homogeneous between 3.5 and 3.8 persons in all regions and about half of household members are employed on holdings of an average size around 1.2 ha in most regions and only 0.8 ha in the South. Holding size is thereby only about 40% of the average Thai farm but is used to the largest share for vegetable production on between 0.5 ha in the South and 0.9 ha in the central region. Utilization of the remainder is comparatively homogenous: field crops and permanent crops cover 0.1 ha in most regions, though the former are absent in the South and the latter do not play a role in the Northeast. On the other hand, rice area is largest in the Northeast, and the North, where seasonal production of *Allium* species after rice plays an important role. The agricultural census also reports specialized vegetable farmers actually rent in more than half of the land they cultivate in spite of their smaller holdings; this is especially high when compared to the national average of all farms at 23% and implies a higher spatial flexibility for vegetable farmers than owned land (SONGSAKUL, 1991, p. 72).

Table 10: Socio-economic characteriztics of vegetable farms

	Thailand	Central	North	Northeast	South
Population					
Estimated number of farms[28]	142,217	54,335	61,566	18,735	7,581
Share (%)	100	43	40	12	5
Total vegetable land (ha)	111,148	51,573	43,512	12,526	3,538
Share of contract farming (%)	11	9	16	7	1
including price agreement	9	7	12	6	1
input support	6	3	11	2	-
Average farm					
Age of household head (years)	47.6	49.2	46.2	47.7	47.7
Household size (persons)	3.7	3.8	3.7	3.6	3.5
Family labour (persons)	1.9	2.0	1.8	1.8	1.7
Farm holding size (ha)	1.2	1.3	1.2	1.3	0.8
Paddy land (ha)	0.2	0.1	0.3	0.4	0.1
Field crop land (ha)	0.1	0.1	0.1	0.1	0.0
Permanent crop land (ha)	0.1	0.1	0.1	0.0	0.1
Vegetable, flower and herb land (ha)	0.8	0.9	0.7	0.7	0.5
Share of rented land (%)	68.9	74.8	73.2	52.1	31.7
Area planted to vegetables (including multiple crops) (ha)	1.4	1.6	1.1	1.2	1.3

Source: Own calculation based on microdata sample from the 2003 census (NSO, 2004).

[28] Data reported refer to farms with at least 50% of total land designated to vegetable production according to a 1%sample of the 2003 agricultural census (1,703 observations).

Moreover, the multiple cropping index – the ratio of vegetables planted per unit of vegetable land – shows that cropping is most intensive in the South where on average 2.6 crops are planted on the same land. The multiple cropping index in Central and Northeastern Thailand is close to the average of 1.75, whereas it is lower at 1.57 in Northern Thailand as a result of off-season vegetable crops planted on rice land. Finally, we find that the share of farms maintaining contract farming arrangements varies drastically among regions. The highest share of 16% and an incidence of input support in 11% of the farms is observed in Northern Thailand, where potato and tomato processing companies contract farmers to grow specific varieties and provide the required seeds and inputs. The Central region ranks second at 9% in line with notable vegetable processing capacity for asparagus, baby corn and okra in Nakhon Pathom and Ratchaburi provinces to the west of Bangkok. Contract farming plays a lesser role in the Northeast and a negligible role in the South where processing companies are less frequent.

3.3.4 Alternative production systems

In order to round out the picture of vegetable production, this section briefly reviews new technology that has been and is still being introduced to deal with pest management problems, the health and environmental cost of a chemical-based plant protection strategy. Alternatives to pesticide-based crop protection have been developed, disseminated and partly adopted to some degree. The most radical shift away from the Green Revolution agriculture involving such high external input use is represented by *organic agriculture*, which is a holistic approach that aims at growing crops in a balanced agro-ecosystem under a closed nutrient cycle without the use of external inputs (SETBOONSARNG and GILMAN, 1998). Another – rather intermediate approach – is represented by integrated pest management (IPM) or more comprehensively defined as integrated production and pest management (IPPM) (KETELAAR and KUMAR, 2002). Integrated pest management does not completely exclude the use of synthetic pesticides but uses specifically targeted pesticides only as a last resort. Preferred pest management methods involve preventive measures such as suitable soil preparation, crop rotations, the selection of resistant or less susceptible varieties adapted to local conditions, the support of natural enemies by the provision of retreat areas, the release of predatory or parasitic species that control the pest or the mechanical exclusion of pest organisms from the crop by protective structures[29]. Chemical pesticide use is reduced to a large extent and limited to conditions when pest populations reach specific economic thresholds. In principle, IPM substitutes external inputs by knowledge and better understanding of the agro-ecosystem by the decision makers.

The successful dissemination of IPM technology by a learner-centred, participatory approach called the farmer field school (FFS) in Indonesia since 1989 has made this method the standard for implementation of IPM programmes (PONTIUS *et al.*, 2002, p. 14). The FFS approach involves a season-long training of a group of farmers that meets regularly and involves studying crop

[29] Protected cultivation of tomato under tropical lowland conditions near Bangkok has been the subject of a DFG funded research group between 2001 and 2007 (POEHLING, 2007).

growth, field observations and field trials facilitated by a trainer. The objectives have been summarized as (1) grow a healthy crop, (2) conserve natural enemies (3) conduct regular field observations and (4) become IPM experts (PONTIUS *et al.*, 2002, p. 14). In contrast with rice IPM, whose general strategy might be described as 'informed non-intervention' because the production system of the indigenous rice crop is comparatively stable, IPM in vegetable production instead requires 'informed intervention' (KETELAAR and KUMAR, 2002 p. 5).

With a recognition of sustainable agriculture in the National Social and Economic Development Plan since its eighth inception (1997-2002) IPM and organic farming became part of official government policy (PANYAKUL, 2002, p. 181). While FFS had been implemented on rice IPM by FAO since 1992, actual government support became effective only in 1999, when the Department of Agricultural Extension started its own programme of FFS in rice and vegetable IPM (PRANEETVATAKUL *et al.*, 2007, p. 7f). In this programme between 1999 and 2006, 710 FFS courses on vegetable IPM had been conducted in the northern, 105 in the western region and 215 in other regions, summing up to 1,030 nationwide, even more than the 810 FFS courses in rice. Assuming that an average 25 farmers participated in these FFS[30], this corresponds to a total of 25,740 farmers or 7.5% of vegetable farmers who have been trained up to 2006. With a restructuring of the DoAE in 2003, the budget allocated to training activities was substantially cut, however (PRANEETVATAKUL *et al.*, 2007, p. 9), and training between 2005 and 2007 has been changed to include good agricultural practices (GAP) as a preparation for certification, which was found to be less succesful[31]. In spite of such significant training efforts, the adoption of IPM has been very slow (KRASUAYTHONG and WAIBEL, 2006) as is obvious from a small decline in pesticide residues and continued reports of widespread pesticide overuse. A perception of IPM technology as inherently more risky by refraining from using high intensities for risk-reducing agro-chemicals has been conjectured as a reason for widespread non-adoption or dis-adoption by vegetable farmers in Northern Thailand (KRASUAYTHONG and WAIBEL, 2006). KRAMOL *et al.* (2006) found in a small IPM FFS project that even after passing an IPM-FFS and implementing the technology successfully in one season, different conditions during the hot and wet season have caused nearly all farmers to return to old practices. Only one farmer who stuck to IPM through a whole year had eventually gained the experience to successfully generate a stable income. When vegetable IPM means 'informed intervention' this experience conveys the difficulties involved in the successful application of theoretical and even practical knowledge in this specific crop It might require more time for farmers to gain a sufficient practical experience to provide the required degree of confidence and decisiveness to stick to the technology.

Organic production goes beyond a change in management strategy and involves a paradigm shift towards a stable agro-ecosystem with functioning nutrient cycle and balance of pests and

[30] In 2004, 185 vegetable IPM-FFS were organised with 4,623 participating farmers, which corresponds to an average of 25 participants (UPANISAKORN, 2008).

[31] According to an evaluation in 2008, FFS participation in 2005-07 was less successful as attendance was low among farmer groups in contract farming arrangements and frequent infringement of GAP, which lead to an overhaul of the training curriculum (UPANISAKORN, 2008).

their natural antagonists. Specifically, organic production is based on less intensive crop rotations, including green manures and the supply of organic matter through recycling of on-farm organic waste. Weeds are controlled by crop rotations, undersown crops and mechanical means, whereas pests and diseases are managed by maintaining and supporting natural populations of beneficial organisms, selection of resistant varieties and other mechanical or biological means. Organic production refrains from using mineral fertilizers and chemical pesticides.

Although originally initiated during the 1980s by farmers and local NGOs (KRAMOL, 2006), organic farming in Thailand developed only slowly and gained some momentum with official policy change in the 8th development plan. The total area under organic production was estimated to be less than 2,700 ha in 2001 and but has then rapidly increased to 21,000 ha in 2006, corresponding to about 0.1% of the total agricultural land according to WILLER and YUSSEFI (2008). As government support of organic agriculture developed only lately in response to rapidly increasing domestic and export demand, a national standard called 'Organic Thailand' was established only in 2000. In spite of consideration of international standards such as IFOAM, European Union standard EC 2092/91 during formulation (VANIT-ANUNCHAI, 2006, p. 33f), it has so far not been accredited by IFOAM. According to registration lists of 2008, the two Thailand based certification bodies[32] DoA and ACT have issued 850 certificates for a total of 8,356 hectares (DEPARTMENT OF AGRICULTURE, 2008) (ACT, 2008) corresponding to 39% of the total organic area. Table 11 reports the number of certificates issued to farms or groups with vegetable production. As mixed farming prevails in many of these farms, the reported farm land represents an upper limit of vegetable land amounting to a total of 1,097 hectares in 2008 including land under conversion. For the DoA-certified farms, the land of specialized vegetable farms amounts to 377 hectares and is therefore the lower limit of organic vegetable production among these farms.

Table 11: Land area and number of farms in organic crop production - total and farms with vegetable production for selected certification bodies

	Total organic agriculture			ACT-certified # vegetable farms		DoA-certified vegetable farms	
	Area (ha)	Farms	Share of crop land (%)	Area (ha)	Certificates (farms/groups)	Area (ha)	Certificates (farms/groups)
2001	2,682[1]	750[1]	0.01	14 (+31)[2]	30[2]	n.a.	n.a.
2003	13,900[3]	2,500[3]	0.07[3]	n.a.	n.a.	384[4]	n.a.
2006	21,701[5]	2,498[5]	0.10[5]	n.a.	n.a.	410[4]	n.a.
2008	n.a.	n.a.	n.a.	192 (+16)[2]	102[2]	889[4]	75[4]

Sources: 1: PANYAKUL (2002, p. 185), 2: List of ACT certified operators 2001 (September) and 2008 (February) (ACT, 2008) Figures in brackets refer to land in conversion. 3: WILLER and YUSSEFI, (2006; 2007; 2008), 4: List of Organic Thailand certified operators, Organic Thailand project (DoA, unpublished lists 2003-2006), Registration database (DEPARTMENT OF AGRICULTURE, 2008).

[32] As of 2008, there are 4 IFOAM accredited certification bodies for Thailand: Australian Certified Organic (AU), Bio-AgriCert (IT), Soil Association Certification (UK) and Organic Agriculture Certification Thailand (TH). (IOAS, 2008).

Assuming that vegetable production takes place on half of the 1,097 hectares reported for vegetable growing farms and that they are certified by the domestic certification bodies in the same proportion as other crops (39%), vegetable land can be estimated at 1,400 hectares, which in turn corresponds to about 0.7% of total vegetable land. Organic production therefore plays only a minor role so far.

Performance of alternative productions systems

Given the variety of vegetable species and varying seasonal and annual conditions and management capacity of farmers, a general assessment of the performance of the above mentioned production systems requires an extensive dataset covering both cross-sectional and longitudinal dimensions. Although comprehensive studies are lacking, a few case studies reveal that alternative production systems are competitive even when health costs are not fully accounted for. In a comparison of farmers' conventional practices and alternative pest control agents in highland production of leafy vegetables for instance, SAKORNSINTHU found that an IPM strategy substituting broad-spectrum insecticides by specifically targeted and less toxic alternatives increased production cost by 1% in Chinese kale and 12% for Chinese cabbage, while at the same time yields could be increased and a price premium for the product quality could be attained. Cultivation under a protective net attained an even higher gross margin but required investment in net house structures (SAKORNSINTHU, 1997, p. 95f). Also, the comparison of individual farm budgets shows that IPM practices do not entail lower gross margins or returns to labour (HARDEWEG and WAIBEL, 2002). On the performance of organic vegetable production, published data are lacking so far, but it is likely that management practices are usually more labour intensive (mechanical or manual weeding, application of manures instead of concentrated mineral fertilizers) and require a price premium for the produce for viable competition with conventional and IPM strategies.

This brief outline of the developments in production technology has shown that alternative technology exist for vegetable farmers. Their adoption depends, however, on numerous factors, among which economic incentives and the access to the technology play important roles. Due to the small scale of adoption of organic agriculture, it is not further considered separately in this thesis. The IPM technology that is reflected in production practices observed in field survey and expert workshops conducted for this study is part of the production practices referred to in the subsequent chapters.

3.4 Vegetable demand

3.4.1 Domestic demand

Economic development and the associated changes in incomes, household composition and urbanization also involve a nutritional transformation (HUANG and DAVID, 1993). This includes (1) a lower calorie requirement as urban occupations often involve less physical labour than rural ones, (2) a tendency towards more diversified diets as a result of increased exposure to foreign cultural influences on urban populations and availability of foods and (3) an increasing share of prepared foods as occupations involve absence from home and employment opportunities for women contribute to higher opportunity cost of food preparation at home (HUANG and BOUIS, 2001; GULATI *et al.*, 2006). A separate assessment of the effect of these changes on the structure of food consumption and that of increasing income for consumption data from Taiwan in 1981 and 1991 has revealed, that demand structure is strongly affected by the demographic changes (HUANG and BOUIS, 2001). The nutritional transformation is also observable in Thailand's Household Socio-Economic Survey, which reveals a nationwide trend from home-prepared to ready-to-eat foods bought in the market and expenditures for eating out. Obviously this development was most pronounced in the urban centres, where in 1999 prepared food accounted for 50% of total food expenditures (KOSULWAT, 2002). The survey reports details of expenditures for home-prepared foods in which vegetables take a slightly increasing share from 9.01% in 1992 to 10.27% in 2002 (VANIT-ANUNCHAI, 2006, p. 22).

For the expenditures for fresh vegetables Schmidt and Isvilanonda estimated an elasticity with respect to food expenditures based on the 1998 cross section of the Household Socio-economic Survey (SCHMIDT *et al.*, 2004). Their results and the implied expenditure elasticities with respect to income[33] are presented in (Table 12) and reveal that rising incomes lead to moderately increasing consumption expenditures for vegetables of all categories. Among the vegetable groups, expenditures for dried and pickled vegetables are least affected by rising incomes, whereas expenditures for leafy and fruit vegetables are more responsive than root and bulb vegetables. These differences indicate that further income growth will also change the structure of vegetable demand towards leafy and fruit vegetables.

Table 12: Elasticity estimates of vegetable demand

Aggregate	Share in food expenditures	Elasticity of expend. share w.r.t. food expenditures	Implied elasticity of expenditures w.r.t. income
All vegetables[a)]	9.05%	0.326	0.184
Leafy vegetables [a)]	2.92%	0.449	0.227
Fruit vegetables [a)]	2.42%	0.401	0.201
Root and bulb vegetables [a)]	1.12%	0.330	0.185
Dried and pickled vegetables [a)]	2.21%	0.036	0.083
	Share in total expenditures	**Income elasticity**	
Vegetables and fruits [b)]	22%	0.620	
Food, beverages, tobacco (1996) [c)]		0.653	

Sources: a) SCHMIDT and ISVILANONDA (2004), b) MANPRASERT (2004), c) SEALE *et al.* (2003)

[33]From $\frac{\Delta c_v}{c_v} = \varepsilon_{v,c_f} \frac{\Delta c_f}{c_f}$ and $\frac{\Delta c_f}{c_f} = \varepsilon_{f,Y} \frac{\Delta Y}{Y}$, it follows that $\frac{\Delta c_v}{c_v} = \varepsilon_{v,c_f} \varepsilon_{f,Y} \frac{\Delta Y}{Y}$ or $\varepsilon_{v,Y} = \varepsilon_{v,c_f} \varepsilon_{f,Y}$.

An attempt at using the expenditure data from the above source for an estimation of physical quantities demanded is beset with difficulties. Expenditures for vegetables are recorded only as such for home-prepared food, whereas those contained in the very significant expenditure share for prepared dishes are not recognizable as such. Moreover, as seasonal vegetable retail price variation is significant and the survey records detailed expenditure data only for a fortnightly period in a given household, seasonal fluctuations are not appropriately captured. Apart from the above-mentioned nutrition survey data, quantification of vegetable demand in Thailand has therefore been based on production statistics and net exports (ISVILANONDA, 1992; SOOTSUKON *et al.*, 2000; VANIT-ANUNCHAI, 2006). The resulting average quantity of vegetables available per capita as reported in Table 13 is, however, substantially overestimated as it is based on gross production data, which neglect the seed bulb and tuber use within the sector for garlic, ginger, spring onion and shallot on the one hand and transport and handling losses between farm gate and consumption on the other. For the level of production reported in 1999-2001, a volume of seed bulbs and tubers of 82,000 metric tons in these crops has to be accounted for (cf. chapter 4). Moreover, an average loss of 7% between farm gate and wholesale level and another average 10% loss have to be accounted for further transformation to the retail level, which leaves availability far below the recommended 200g per capita and day (ALI and TSOU, 1997) throughout the considered periods.

Table 13: Per capita availability of vegetables in Thailand (ignoring transport loss)

	Production	Export	Import	Net availability	Population	Per capita daily availability
	1,000 t	1,000 t	1,000 t	1,000 t	1,000 persons	g/cap./day
1983-1985[1]	2,977	67	4	2,915	50,502	158
1986-1988[1]	2,270	130	6	2,146	53,407	110
1989-1991[1]	3,009	211	7	2,805	56,018	137
1992-1994[1]	2,972	212	11	2,772	58,058	131
1995-1997[1]	4,405	330	33	4,108	60,131	187
1998-2000[1]	5,109	330	48	4,827	61,669	215
1998-2000[2]	3,097	302	25	2,819	61,748	125
2001-2003[2]	3,245	351	77	2,970	63,155	129
2004-2005[2]	3,374	458	191	3,107	64,480	132

Sources: [1] Production, export, import: DoAE, Population: NSO (cited in: VANIT-ANUNCHAI, 2006, p. 23).
[2]FAOSTAT database on production and trade (FAO, 2008c), Population: NESDB (2007).

In addition Table 13 reveals large differences between data sources. Whereas according to DoAE data vegetable production has grown considerably by an annual average of 14% between the periods 1992-1994 and 1995-1997 and then by still about 5% until 1998-2000, FAO production statistics exhibit a much slower growth. The resulting per capita availability is therefore significantly lower when the data reported to FAO are considered. More recent data from the DoAE crop production database seem to vary unreliably (cf. Table 53 in the appendix) and regional data gaps are documented (DOAE, 2008). Only for the crop year 2007/08 is a reasonable estimate of 3.57 million metric tons available (DOAE, 2008).

3.4.2 Export and import

According to FAO statistics, vegetable foreign trade expanded substantially between 1990 and 2005, including a 56% growth of exports between 2000 and 2005 (Table 14), mostly due to sweet corn, which in 2005 accounted for 23% of vegetable export volume. Over the same period vegetable imports of have more than doubled every five years and in fact increased 4.8-fold between 2000 and 2005. Most of this change is due to rapidly increasing imports of garlic and onion since 2003, when the bilateral free trade agreement with China ('Early Harvest Programme') became effective. On the one hand the Thai export surplus to China has increased, but on the other hand, competing with imports of temperate crops from China became difficult especially for farmers in the North (POAPONGSAKORN, 2006, pp. 4,52). In fact garlic has been imported in substantial quantities only since 2003.

Table 14: Quantity of vegetable exports and imports 1990-2005

Unit: 1,000 metric tons	1990	1995	2000	2005	Share 2005
Exports	**192.18**	**293.3**	**296.36**	**459.22**	
Asparagus	2.18	1.82	3.83	15.76	3%
Sweet Corn prepared or preserved	0.04	10.41	25.87	103.97	23%
Onions, dry	18.29	20.53	22.34	67.74	15%
Tomatoes	11.46	14.35	10.69	6.02	1%
Vegetable Frozen	14.42	33.08	29.42	36.13	8%
Vegetables in Vinegar	34.26	33.02	20.19	13.27	3%
Other vegetables, otherwise prepared, not frozen	91.44	145.5	132.75	143.39	31%
Other vegetables	20.09	34.59	51.27	72.94	16%
Imports	**7.6**	**19.0**	**50.5**	**240.8**	**100%**
Carrots and turnips	0.1	0.2	7.6	38.1	16%
Chillies and peppers, dry	3.1	2.1	7.9	29.1	12%
Potatoes fresh and frozen	0.4	6.9	19.5	33.6	14%
Garlic	0.6	0.0	0.0	47.8	20%
Onions, dry	0.6	0.0	3.8	35.9	15%
Others	2.7	9.8	11.6	56.3	23%
Net exports	**184.6**	**274.3**	**245.9**	**218.4**	

Source: FAO (2008c)

As a consequence, net exports of vegetables declined to 218,000 metric tons in 2005. The average value of exports in 2006/07 reached 22.4 Billion THB or 2.1% of agricultural export value, the value of net exports amounted to 16 Billion THB (cf. Table 56 p. 217) (OAE, 2006; OAE, 2008). Apart from the few separately listed vegetables like baby corn, asparagus, *Allium* species with respective value shares of 7.6%, 4% and 3.1%, little is known on the composition of the types that contribute to the categories of prepared or preserved vegetables, fresh and chilled and frozen vegetable categories, which make up two thirds of the exported quantity and 72% of value in 2006/07 (cf. Table 56 in the appendix).

3.5 Transport and marketing

The conventional marketing system for fresh vegetables is rather complex and often involves many actors and stages (TANTISIRA, 1988; UATHAVEEKUL, 2007). Two examples of the most common chains for conventional vegetable are presented in Figure 15 with the left panel referring to the case of the surplus producing and with respect to Bangkok more distant concentration of vegetable production. In this case farmers either deliver directly to wholesalers in the markets or sell at the farm gate to local assemblers. These transactions are also organised in different ways. Sometimes farmers are paid an agreed price on the spot, whereas in other cases farmers receive payments only after the goods have been sold in the wholesale market and the farm gate price is determined by the wholesale price less an agreed margin for the trader. Only a minor share of the production is sold directly to retailers. Most of the produce collected by local assemblers is then sold to wholesalers in the provincial wholesale market. These wholesalers then sell to other wholesalers in the same market, who then distribute to retailers or – to a minor degree – sell directly to consumers from their stalls. About 40% of production is sent from the wholesale level in Chiang Mai province to wholesalers in Bangkok (WIBOONPONGSE and SRIBOONCHITTA, 2004, p. 24). It is worth noting that 90% of production goes through at least two wholesale agents and 40% through an additional local assembler, who might a farmer himself and collect the produce from fellow farmers. Often the local assemblers or middlemen are specialized traders (WIBOONPONGSE and SRIBOONCHITTA, 2004, p. 25), who not only buy the produce but act also as a source of credit or input supply on credit (NATH *et al.*, 1999, p. 24; CHEYROUX, 2000, p. 9). A similarly complex chain – or rather network of traders – is involved in vegetable marketing in Bangkok and vicinity (Figure 15b).

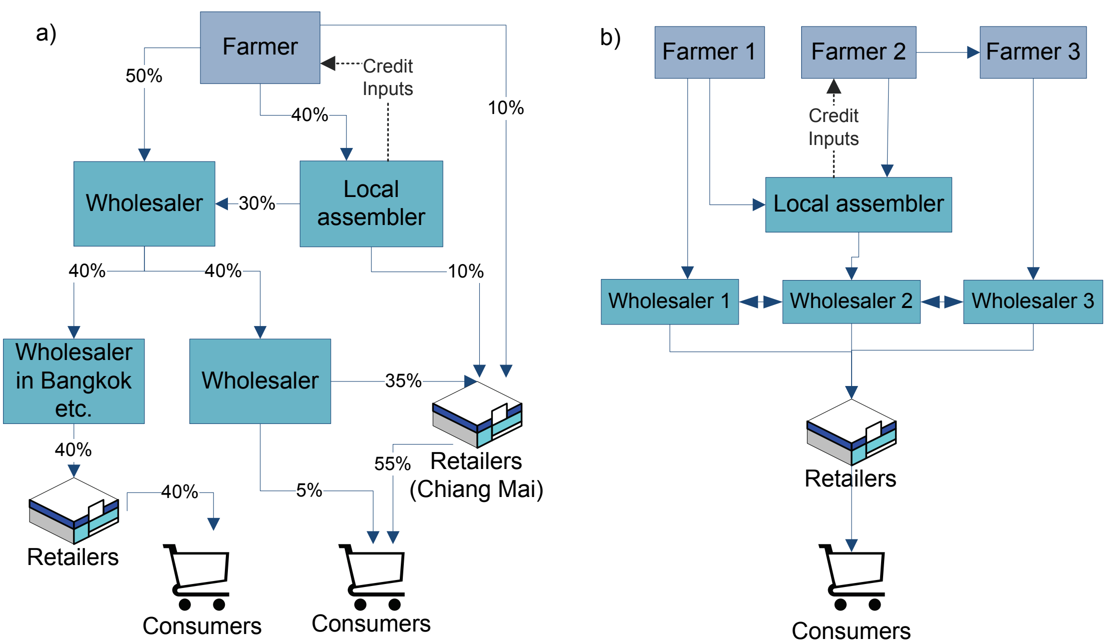

Figure 15: Generic presentation of vegetable marketing channels

Source: Own presentation based on (a) KHADKAEW (1999, cited in (WIBOONPONGSE and SRIBOONCHITTA, 2004) and (b) Marketing channels for vegetables in Bangkok and vicinity (TANTISIRA, 1988; FUKUI and ISVILANONDA, 1996; OTA, 1998)

While studies with quantitative indications more recent than Tantisira (1988) are lacking, it is documented that farmers from adjoining provinces sell their produce and sometimes that of a group of farmers directly in one of the central wholesale markets in Bangkok (SONGSAKUL, 1991, p. 24; OTA, 1998). Thereby they become less dependent on a few local assemblers and improve their access to market information. Although generally characterised by free market transactions, and a large number of actors involved, small volumes of a given crop in a given place may limit the number of middlemen buying at the farm gate (FUKUI and ISVILANONDA, 1996; OTA, 1998, p. 95).

Specific marketing chains exist for crops such as garlic, baby corn and onion. As by far the major part of garlic production takes place only once a year in winter and the product can be stored in dry condition, storage of this crop is a distinguishing feature among vegetable crops. Specialized garlic traders buy the produce mostly after an initial drying at the farm gate and store it in dry and well ventilated sheds. It is then sold at varying prices over the year (FUKUI and ISVILANONDA, 1996). Besides a substantial capital bound in the storage, their profession requires a profound knowledge of the market and involves risk taking as the profit depends on their capability to forecast the market and a good timing of sales considering the quality-dependent rate of weight loss due to transpiration and respiration. It is likely also that garlic traders had to adapt to the effects of the free trade agreement with China that led to a sudden increase of garlic imports that had been negligible before (POAPONGSAKORN, 2006, pp. 4,52). Onion is a special case as its production has been regulated by controlling the import of onion seeds, which cannot be produced within the country. Only onion growers' cooperatives in Chiang Mai and Kanchanaburi are eligible to receive and distribute the government-allocated quantity of seeds. These cooperatives play a role not only in seed distribution but also serve to collect the harvest from their members and sell it in larger lots to local wholesalers and wholesalers located in Bangkok (TANTISIRA, 1988, p. 474; OTA, 1998, p. 112f and field survey 2001).

In the traditional fresh vegetable chains, wholesale markets play an important role as a spot market in which market clearing prices are determined. As of 2003, 14 wholesale markets out of the 67 central wholesale markets regulated by the Ministry of Commerce (WIMOLRAT, 2000, p. 2) were specialized in vegetable and fruit trade (DEPARTMENT OF INTERNAL TRADE, 2003). Four central wholesale markets are located in or in close vicinity to Bangkok alone and two more to the east and west of the Central region. In the Northeast, two markets each in Kalasin and Nakhon Ratchasima, two in the North and another two in the South play major roles in vegetable exchange (Table 54, p. 215). In all these markets, the operators are responsible for providing the infrastructure such as space, stalls, water and electricity supply, garbage collection and transport service within the market compound. In turn they collect rental fees for stalls, lots in the open yards, fees for transport and entry fees for cars of both buyers and sellers (FUKUI and ISVILANONDA, 1996). The market operators do not interfere in the trade and there is no auction system for vegetables (FUKUI and ISVILANONDA, 1999) and so far collect only price information (Thai Agro Exchange Ltd., 2008). Instead, prices are determined based on the wholesalers' observations of the quantity of incoming goods and numbers of buyers, their experience of seasonal demand fluctuations and the prices attained by fellow traders (FUKUI and ISVILANONDA, 1999). As a consequence, prices for product batches similar in quality and size are rather homogeneous among traders (FUKUI and ISVILANONDA, 1999). As prices are agreed individually for every transaction, long-term customer relationships are a means of reducing transaction costs and are therefore built up using personal relations, discounts and additional services such as credit or provision of market information. The experience required for successful trading in the highly perishable crops constitutes a significant barrier to market entry (FUKUI and ISVILANONDA, 1999; WIBOONPONGSE and SRIBOONCHITTA, 2004, p. 24). In spite of such barriers, the wholesale markets have been characterized as monopolistically competitive as the number of agents on all levels is large (FUKUI and ISVILANONDA, 1996, p. 13). A study on price formation involving five regional wholesale markets based on a 1985 to 1997 time series of wholesale price data for two leafy and three fruit vegetables has revealed a significant integration of the markets in five regions (WIMOLRAT, 2000).

At the retail level, a substantial structural change has been initiated by the development of large retailers in urban centres since the early 1990s. By 2000 foreign-affiliated retailers (food and non-food) were estimated to hold a share of 25% in Thai retail sales (NISSEN, 2006) and in 2004 the share of food sold through 'modern retail' outlets reached 35% (WIBOONPONGSE and SRIBOONCHITTA, 2004, p. 10). As the involvement of large retailers in value chains is consistently linked to shortening the chains by excluding wholesale stages and imposing more functions (grading, consignment) on the primary producer (BOSELIE *et al.*, 2003) and the requirements of large retailers with respect to quality management are different, these developments are expected to affect the role of wholesale markets. While in 2004 large retailers had established distribution centres in wholesale markets (SHEPHERD and GÁLVEZ, 2006, p. 310) and continued to buy vegetables and fruits in the wholesale market (POAPONGSAKORN, 2004), large retailers aim at contracting preferred suppliers, direct delivery and stricter management of the supply chain (BOSELIE *et al.*, 2003; GULATI *et al.*, 2006, p. 14). In a reaction to the needs of large retailers, Talad Thai[34] for instance, considered establishing a laboratory for pesticide residue testing (SHEPHERD and GÁLVEZ, 2006, p. 310) although until 2004 the turnover had not been affected by changes at the retail level (TEJATHAVON, 2004).

For specific qualities such as the various certified products subsumed by Vanit-Anunchai under the term "environmentally friendly produced vegetables (EFPV)", the chain is developing more independence of traditional wholesale markets (VANIT-ANUNCHAI, 2006, p. 41). Traditional wholesale markets remain part of only one of several channels through which modern retail outlets procure their fresh produce. Direct delivery by large farmers or farmer groups plays an important role. The latter is especially true for specialty or 'Green shops' focusing specific product

[34] Talad Thai is one of the major vegetable and fruit wholesale markets located north of Bangkok in Pathum Thani province.

qualities (VANIT-ANUNCHAI, 2006, p. 29) and therefore targeting customer segments with special concern for a healthy lifestyle and food quality.

In a case of vegetable procurement for TOPS Thailand supermarkets, BOSELIE *et al.* found that shortened chains involving preferred suppliers are able to improve information flow on projected demand with respective benefits to both producers and customers (BOSELIE *et al.*, 2003). TOPS was able to cut down the number of individual suppliers of fresh produce by three quarters and streamline chains by direct delivery to a distribution centre, where value is added by grading, cleaning, packaging and labelling and also further processing to produce pre-cut mixes and pre-washed salads. In spite of successful streamlining in the supply chain, they also report that integrating small-scale farmers who had participated in FAO-IPM farmer field schools (FFS[35]) into the list of contracted suppliers remained unsuccessful because farmers failed to meet standards. Contrary to FFS alumni, small-scale producers of organic vegetables had an advantage through their long standing practice of crop rotations and ability to choose resistant varieties (BOSELIE *et al.*, 2003). In spite of the high cost involved in the coordination of an atomistic supply chain and a tendency to consolidate such chains through exclusion of small scale producers, they continue to be involved in these chains (BUURMA *et al.*, 2000; BOSELIE *et al.*, 2003).

3.6 Transportation system

Today commercial vegetable transport is based on truck transport via Thailand’s well-developed road network (BOONYAKIAT, 1999; WIMOLRAT, 2000). More detailed indicative data on the prevailing transport system was elicited as part of this research in a small survey among 30 wholesalers, middlemen in three wholesale markets in and around Bangkok and food logistics companies in Chiang Mai. The survey has shown that the preferred means of transportation depends on lot size and transportation distance. Generally farmers selling their own produce or from a group of farmers deliver to the Bangkok wholesale markets from distances as far as Nakhon Ratchasima (260 km) by pick-up truck, which carries payloads up to 1.8 metric tons. Longer distances are mostly covered by traders using 6-wheel and 10-wheel trucks carrying payloads of 6 and up to 15 metric tons, respectively. Logistics service providers charged between 71 and 88 THB per metric ton and 100 km for vegetable transports. Fuel cost was estimated to make up a share of 33-40% out of the full service fee. Refrigerated transport is used only for temperate crops from highland production areas in northern Thailand.

Packaging depends on the crop and the mode of transportation. Most vegetables are packaged in plastic bags of 5 kg to 10 kg, which are then stacked on the load floor of the truck. Lettuce is mostly transported in large baskets with layers of newspaper and sometimes ice for cooling in between, whereas bundles of spring onion, and especially cabbages and Chinese radish, are transported to the wholesale market without packaging. Cleaning the produce by removing

[35] IPM farmer field schools refer to farmer training programmes aiming at enhancing farmers’ management capacity with special emphasis on crop protection.

outer leaves and re-packaging takes place in the markets. This procedure entails substantial losses during transportation and handling as vegetables are often immature parts of the plant with a soft texture, which makes them susceptible to mechanical damage and infection from micro-organisms during post-harvest handling (BOONYAKIAT, 1999). Losses occurring during handling and transportation can be attributed to a) weight loss from transpiration, b) damage (bruising, rotting), c) trimming. While leafy vegetables in particular are trimmed in order to maintain fresh appearance at all stages of marketing, other vegetables usually undergo much less processing. Few studies have so far assessed the post-harvest processes for the whole vegetable sector in Thailand. The Royal Project, which integrates the whole chain from farm extension, collection, processing, distribution and retailing, has conducted studies on post-harvest losses and appropriate packaging for temperate vegetables (BOONYAKIAT, 1999). Compared to an earlier study (BOONYAKIAT *et al.*, 1987), where losses ranged from 17% for tomato to 71% for head lettuce during transportation from Chiang Mai to Bangkok, improvements have been reported, especially for head lettuce with loss rates of below 40% in summer and around 50% during rainy and winter seasons (BOONYAKIAT, 1999). For selected tropical leafy and fruit vegetables, losses for the whole chain from farm gate to retail levels were found to range from 12% to 24%, with the higher loss rates pertaining to leafy vegetables (TANTISIRA, 1988; AMUTRIRATNA and PASSORNSIRI, 1992) (see Table 15). More recently, a study on wholesale marketing of vegetables estimates losses in general at 10% for the vegetables transported from Chiang Mai to a Bangkok wholesale market and at 5% for handling and transport from Nakhon Ratchasima to Bangkok (WIMOLRAT, 2000, pp. 41,3).

Table 15: Loss estimates for selected vegetables in Thailand

crop	[a] farm –wholesale			wholesale - retail					total	[b]		
	weight loss	defects	total	weight loss	bruises	rot	trim-ming	total	farm - retail	farm – whole sale	Whole-sale to retail	total
Cucumber	2.55	3.77	6.32	2.43	4.71	0.07	0.00	7.21	13.53	6.40	7.21	13.61
Hot chilli		n.a.		2.56	4.56	0.20	0.14	7.46		7.40	8.46	15.86
Tomato	3.33	6.89	10.22	0.41	9.03	0.05	0.00	9.49	19.71	10.22	9.49	19.71
Cabbage	1.49	3.19	4.68	0.64	3.26	0.18	7.01	11.09	15.77	4.20	11.09	15.29
Chin. kale	3.41	4.83	8.24	1.22	2.55	0.14	8.21	12.12	20.36	8.84	12.42	21.26
Lettuce	2.87	2.58	5.45	1.32	2.48	0.00	2.50	6.30	11.75	5.50	6.80	12.30
Yard long bean		n.a.		1.61	2.42	0.00	0.00	4.03		7.80	4.03	11.83
Chin. chives	2.88	2.35	5.23	1.28	3.18	0.15	5.63	10.24	15.47	5.83	10.24	16.07
Chin. cabbage	1.57	3.32	4.89	1.92	2.95	0.11	4.48	9.46	14.35	15.40	4.89	20.29
Spring onion	4.81	4.49	9.3	1.45	3.11	0.43	4.33	9.32	18.62	9.80	9.82	19.62
Cauliflower		n.a.		0.98	0.62	0.00	9.76	11.36				
Leaf mustard		n.a.		3.92	4.69	0.29	4.11	13.01		5.64	8.07	13.71
Chin. radish		n.a.		1.91	1.38	0.22	6.44	9.95				
Coriander										16.20	7.62	23.82

Sources: [a] AMUTRIRATNA (1992), [b] TANTISIRA (1988)

In essence, developments in transport modes and associated loss rates are lacking except for the special case of temperate vegetables where the Royal Project that covers the whole chain provided for data collection. Moreover, the effect of more recent developments of a market segmentation and the emergence of specific supply chains for large retailers on transport efficiency is so far not documented in the literature even though case studies (BUURMA *et al.*, 2000; BUURMA and SARANARK, 2006) exist.

3.7 Summary

The developments reviewed in this chapter show that the rapid growth of the Thai economy was associated with a substantial decline of agricultural contribution to GDP and export earnings, while a substantial share of the population continues to depend on incomes from this sector. Domestic vegetable demand is growing slowly with incomes and urbanization. It furthermore becomes more diversified for specific quality aspects with an increasing awareness of health, safety and environmental concerns by consumers. Exports have been growing in the recent decade in terms of physical quantity, but faster in terms of value as high value exports such as frozen and prepared vegetables gain importance. Production has expanded only slowly and at regionally different paces, leading to significant relative decline of vegetable production in Bangkok and vicinity in favour of more distant production areas. How these dynamics affect the well documented environmental and health hazards of current vegetable production practices has not been addressed by research so far and will therefore be part of the analysis in the subsequent chapters. The description of the Thai vegetable sector and its economic environment in this chapter provides the basis for formulating a model of vegetable supply tailored to address the research questions of this study. Therefore the subsequent chapter dealing with the structure and parameterization of the model relies on the background information and data presented above.

4 Conceptual Framework

This chapter develops the conceptual framework for a supply analysis of the vegetable sector in Thailand and then assesses the merits and disadvantages of alternative approaches in relation to the research objectives stated in chapter 1. After that, the chosen mathematical programming approach is presented in detail and the procedure of developing a non-linear programming model of vegetable supply (TVSM) is documented. This includes a description of the data elicitation and definition of vegetable production units according to the concept of typical farm models.

4.1 Choice of modelling approach

The two basic methodological avenues for supply analysis based on closed-form econometric models on the one hand, and activity analytical mathematical programming approaches on the other, have been mentioned in relation to the relevant economic theory in chapter 2. This section is concerned with the appropriate choice of modelling approach for the problem at hand and therefore considers both methodological advantages and shortcomings, as well as data availability, which presents a real constraint to the choice of methodology.

The programming approach is based on explicit optimisation, whereas econometrically estimated models are based on representations of closed-form solutions to an economic optimum. In spite of their different structures and procedures, the underlying hypotheses and objectives (e.g. profit maximization) are not necessarily different (HECKELEI and WOLFF, 2003). Although they have common theoretical roots, the econometric approach has the advantage of being firmly based on observed behaviour and established mathematical estimation procedures. On the downside, the approach requires a large database and is therefore often constrained to models at comparatively high aggregation levels and thus allows only for a comparatively crude specification of policies and new technologies, which – depending on the purpose – might involve an overly simplified structure.

A different approach is taken by studies that derive land use information from satellite image classification, complemented with survey data, to explain land use change by spatial econometric estimation (e.g. NELSON and GEOGHEGAN, 2002). One of the challenges involved is the combination of socio-economic data with spatial data at a feasible and at the same time acceptable scale (MÜLLER and ZELLER, 2002). The scope for the application of this approach is moreover determined by the resolution and detail of classification feasible for the satellite data. Studies have therefore been concerned with deforestation (CHOMITZ and GRAY, 1996; MÜLLER and ZELLER, 2002; NELSON and GEOGHEGAN, 2002) or urbanization (BELL and IRWIN, 2002), which can be based on clearly discernible reflectance characteristics of the land cover. Even though a distinction of crops is possible with ground survey calibration to some degree (NELSON and GEOGHEGAN, 2002), an application to vegetable production would be hampered by the multitude of vegetable crops and multiple crops grown simultaneously and in sequence on the same plot. As a consequence that approach was discarded for the purpose of this research.

A mathematical programming approach can be applied even when data constrain the appropriate representation of policy interventions or technology (HECKELEI and WOLFF, 2003), which is, obviously, the case for the problem at hand. Not only are consistent time series for input use, input and output prices lacking, but also the need for an assessment of technology choice and the impact of policy instruments on the environmental impact of vegetable production call for a programming approach, even though this comes at the cost of being unable to validate the whole model by established statistical procedures. Notwithstanding such disadvantages, programming models have been widely used for the purpose of evaluating the effect of new technology and policy options. Examples include the plant nutrient policies in Germany (STROTMANN, 1992) or the Netherlands (HELMING, 2005), potential nitrogen and pesticide leaching, habitat loss and gas emissions from agriculture (WEINGARTEN, 1995), impact of changes in the EU subsidy-schemes (ARFINI *et al.*, 2003), water pricing in California (HATCHETT *et al.*, 1991) and Morocco (DOUKKALI, 2003). Overviews of applications and implementation provided by BUYSSE et al. (2007) and HENRY DE FRAHAN *et al.* (2007) conclude that the programming approach is well established by a large number of applications and enjoys renewed interest since a more stringent calibration procedure is available through positive mathematical programming.

The multi-agent systems (MAS) proposed by BERGER *et al.* for targeting development policies can be regarded as extension of the programming approach[36] that uses separate models for each decision-making unit (e.g. farm households) and considers the interaction among them (BERGER *et al.*, 2005). Spatially explicit MAS are capable of reflecting spatial heterogeneity, heterogeneous decision rules and the interaction among agents and between agents and the environment, and are therefore well-suited to bio-economic models. Their application is recommended where heterogeneity and interactions of agents and environment are expected to play a significant role (BERGER *et al.*, 2005).

With respect to characteristics of the object of research and the purpose, the model structure has to fulfil several requirements. The interest in a spatial equilibrium requires a consistent representation of supply and demand and therefore a model that in principle (a) encompasses the whole sector and (b) differentiates several regions for supply and demand. The perishable nature of vegetables on the one hand, and the feasibility of multiple crops per year and seasonally fluctuating production as a consequence of climatic conditions on the other hand, are appropriately captured by short-term equilibrium models (WEINSCHENCK and HENRICHSMEYER, p. 216) and require (c) seasonal disaggregation (VON ALVENSLEBEN, 1986). Finally, as interregional trade takes place at the wholesale level, a sufficient representation requires inclusion of (d) only production and wholesale levels of the value chain. As vegetable production represents only a minor part of

[36] Apart from mathematical programming algorithms MAS can implement arbitrary decision rules.

agricultural resource use and demand for external inputs, (e) a completely elastic supply of land and unskilled (hired) labour can be assumed. As according to these definitions the interaction of agents (farmers) is restricted to the market and an interaction between production and environment is not taken into account, a MAS type model is not required, and a regionally disaggregated sector model is deemed appropriate for the purpose of this study.

For a parameterization of such a model, the following data items are required: (a) a seasonally and regionally disaggregated specification of vegetable demand, (b) resource availability by region for vegetable production and family labour as the relevant source of skilled labour in particular, (c) technical coefficients for all crops by technology, region and season and (d) baseline production data for model calibration.

Whereas resources are reported in sufficient detail in the agricultural census (NATIONAL STATISTICAL OFFICE, 2005b), and baseline production data are available from the crop production database of the Department of Agricultural Extension (DOAE, 2001), production technology and demand are only weakly documented in secondary data. Whereas past export demand is available from customs statistics on an annual basis and partly disaggregated by crops (OAE, 2008), domestic demand is reported only in terms of expenditures for a number of vegetable crops per household and year for the five regions of Thailand from the bi-annual Household Socio-Economic Surveys (NATIONAL STATISTICAL OFFICE, 2003a). A seasonal breakdown is therefore not straightforward and further hampered by seasonally fluctuating prices. In spite of existing evidence on income elasticity of vegetable demand, the responsiveness of vegetable demand to own-price and cross-price fluctuations is unavailable. Deriving price elasticities by the Frisch methodology (SADOULET and DEJANVRY, 1995, p. 36f) is not an option as individual vegetables are likely to exhibit substitutive or complementary relationships and the assumptions of the Frisch methodology would not be met by the problem at hand.

In order to avoid arbitrary assumptions on demand elasticities required for a standard formulation of sectoral equilibrium with endogenous price determination, it was deemed more appropriate to assume fixed quantitative vegetable demand and to focus on an appropriate depiction of supply response instead. As an alternative to the Samuelsonian objective function, the minimization of total variable cost of vegetable supply was therefore utilized, which under perfect competition is equivalent to profit maximization (HENRICHSMEYER, 1966, p. 129ff).

How the different data sources are used and have been augmented by primary data collection is reported in detail below, after the mathematical model structure has been developed in the following section.

4.2 A regional programming model of vegetable supply in Thailand (TVSM)

4.2.1 Definition of model boundaries

In order to keep the model tractable and limit data needs to a feasible number of activities, the 48 commercial vegetable crops considered in the DoAE crop production data base at the time of the survey have been ranked according to farm gate value and total production[37]. The cumulative shares of crops in terms of value and production are shown in Figure 16. In order to reduce complexity, similar crops have been grouped together; e.g. hot chilli varieties have been grouped together and coriander and celery are aggregated. As coverage of 91% of farm gate value of vegetable production was attained by including 23 crops and aggregates, corresponding to 85% of total production, these were the crops deemed appropriate for detailed consideration in the model. The crops excluded by this procedure are in part those used for processing (tomato, cucumber, okra and roselle) or temperate crops such as sugar pea, bell pepper, carrot, French bean, and broccoli, which are confined to specific highland production systems. As production locations for these crops are bound to either close vicinity of processing plants or the highland areas, their spatial mobility is lower and determined by other factors than for most vegetables. It is therefore deemed appropriate to exclude these crops from the explicit analysis.

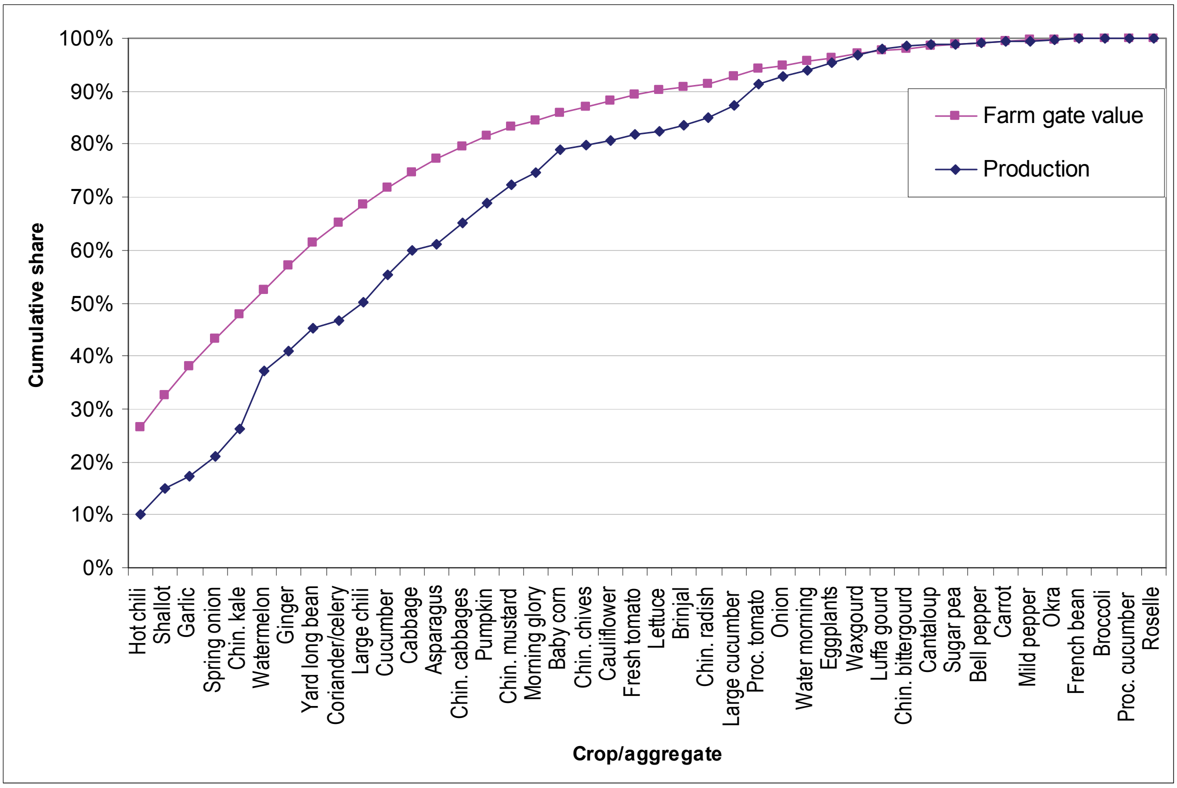

Figure 16: Average cumulative share of production and farm gate value by vegetable for the crop years 1998/99-2000/2001

Source: Own presentation based on production (DoAE, 2001) and farm gate price statistics 1999-2001 (Office of Agricultural Economics, unpublished).

[37] A ranking by area is less suited, because area planted ignores the duration of the crop, which varies between 2 and 12 months. Using the area harvested leads to double counting of the same crop depending on the harvesting period.

For the 23 main vegetable crops, the value chain from production to the regional wholesale level is covered explicitly in the model. Due to lack of spatial and temporal disaggregation, wholesale demand is derived in analogy to BAUER and KASNAKOGLU (1990) according to the following formula on a monthly basis:

domestic production
- transport loss
- raw equivalent of exports
+ raw equivalent of imports
- agricultural use (seeds)

= demand at the wholesale level

The generally high perishability of vegetables means that long-term storage of vegetable crops is non-existent. Short-term storage that bridges the production gap of garlic and shallot during the hot and wet seasons on the other hand is important, and is therefore considered as an explicit transformation activity. It is further assumed that production is adequately captured in the production statistics of DoAE, notwithstanding some inconsistencies for yield levels in the raw data. Together with import and export figures as reported in the agricultural trade statistics, these data will be used to derive wholesale demand.

4.2.2 Mathematical structure of the model

The TVSM considers production and transformation activities for selected vegetables and is specified for separate regions of supply and demand. Production is assumed to follow a Leontieff functional form for single activities but considers alternative technologies for producing the same output. Demand for vegetable products at regional wholesale markets is assumed to be completely inelastic. The objective function is to minimize total variable cost of production and transformation activities. Under perfect competition, market prices will just equal the marginal cost (including production and transportation cost) of the marginal producer (HENRICHSMEYER, 1966, p. 128ff). The most important resource constraint is assumed to be qualified labour (i.e. family labour), which can - up to a certain ratio - be substituted by hired labour. Land endowment of vegetable farms is also considered, but land can be rented in by vegetable farmers from those growing rice and field crops. The initial linear model structure is defined by Equations (4.1) to (4.13), and will be described in detail below.

The objective function represents the total variable cost of production and transformation from the farm to the wholesale level as given by equation (4.1). The first term calculates total on-farm variable cost by multiplying activity level with appropriate unit accounting cost c_{jrst}^{f} plus the sum of explicitly modelled purchased inputs used in the crop. The second sum represents the cost of the aggregation activities for vegetables. As explained in detail below, this term is 0 in the original specification and used at a later stage for calibration of total regional supply of vegetables to observed baseline data using a PMP formulation.

The third sum expression characterizes the cost of transformation, including transportation and handling at the wholesale level, as linear function of the level of transportation activities defined for each vegetable, combination of source r and sink region r' and month. The unit cost of transportation is calculated from the transportation cost per metric ton and km and the respective travel distance between regions/within regions

$$\text{min! } tvc = \sum_{jrst} (c^f_{jrst} + \sum_n i_{njrst} p^i_{njrst}) \cdot X_{jrst} + \sum_{vrm} c^s_v \cdot S_{vrm} +$$

(4.1) $$\sum_{vrr'm} ((c^t + a^{fuel} p^i_{fuel}) \cdot d_{rr'} + c^h_v + a^{lab}_v p^{lab}_r) \cdot T_{vrr'm} + \sum_{vrm} c^q_{vrm} \cdot Q_{vrm}$$

(4.2) $$\sum_{jst} a_{jrstkm} X_{jrst} \le b_{rkm} \quad \forall r,k,m$$

(4.3) $$\sum_{st} o_{jrstm} X_{jrst} \ge Q_{rjm} \quad \forall r,j,m$$

(4.4) $$Q_{rvm} + I_{rvm} - \sum_{r'} T_{rr'vm} - S_{rvm} + a^s_v S_{rvm-1} \ge 0 \quad \forall r, v(j), m$$

(4.5) $$\sum_{r'} (1 - l^h_v - l^t_v \cdot d_{rr'}) T_{r'rvm} - \sum_{v'st} i_{v'vrstm} X_{v'rst} - E_{rvm} \ge dem_{rvm} \quad \forall r, v(j), m$$

(4.6) $$\sum_{jst} a_{jrst,hlab(k),m} X_{jrst} \le b_{r,flab(k),m} \cdot r_{hlab} \quad \forall r, hlab(k), m$$

(4.7) $$I_{rvm} \le im_{rvm} \quad \forall r, v(j), m$$

(4.8) $$E_{rvm} \ge ex_{rvm} \quad \forall r, v(j), m$$

(4.9) $$\sum_{stm} Q_{r,fc(j),m} \ge dem_{r,fc(j)} \quad \forall r, fc(j)$$

(4.10) $$\sum_{jstm} (o_{jrst} p^f_{jrm} - (\sum_n i_{njrst} p^i_{njrst}) - c_{jrst}) \cdot X_{jrst} \ge Y^{min}_r \quad \forall r$$

(4.11) $$\sum_{jst} (i_{njrst} X_{jrst}) \le inp^{max}_{nr} \quad \forall n, r$$

(4.12) $$Q_{rvm} \le \hat{Q}_{rvm}(1+\varepsilon) \quad [\lambda_{rvm}] \quad \forall r, v, m$$

(4.13) $$E_{rjm}, I_{rjm}, Q_{rjm}, T_{rr'jm}, X_{jrst} \ge 0 \quad \forall r, r', j, m, s, t.$$

Where indices are:

j: farm activities with subsets

- *v(j)*: vegetable crops
- *fc(j)*: rice and field crops
- *hlab(j)*: labour hiring activity

k: resources

m: month of the year (period)

n: purchased inputs

r: regions

s: season

t: production technologies

Decision variables are:

E_{rvm}: Export activities

I_{rvm}: Import activities,

Q_{rvm}: Aggregate supply of vegetables

S_{rvm}: Storage activity level

$T_{rr'vm}$: Transported quantity of vegetables v from region r to r'

tvc: total variable cost

X_{jrst}: Farm activity levels.

Parameters are

$i_{njrst}p^{i}_{njrst}$: requirement and price of purchased input n

c^{f}_{jrst} : variable production cost at the farm level

c^{q}_{vrm} : variable cost of aggregation activity, $c^{q}_{vrm} := 0 \quad \forall v, r, m$

c^{s}_{v} : variable cost of storage per metric ton and month

c^{t} : fixed per km cost of transportation,

$a^{fuel} p^{i}_{fuel}$: fuel requirement and fuel price per metric ton and kilometer

$d_{rr'}$: average road travel distance between regions and within regions

c^{h}_{v} : wholesale market handling cost

$a^{lab}_{r} p^{lab}_{r}$: wholesale labour cost (labour requirement times price)

a_{jrstkm} : technical coefficient of crop j in region r grown in season s by technology t for resource k in month m.

b_{rkm} : resource endowment by region, resource type and month

o_{jrstm} : output per unit activity level in a month m

im_{vrm}, ex_{vrm} : imports and exports

a^{s}_{v} : technical coefficient of storage, a conversion rate (1-loss rate)

l^{h}_{v}, l^{t}_{v} : loss rate of handling and per km transported, respectively

$i_{v'vrstm}$: input requirement of one production activity v' for vegetable v

dem_{rvm} : domestic demand for vegetables and $dem_{rj(fc)}$: minimum field crop production of vegetable farms

r_{hlab} : maximum hired to family labour ratio

p^{f}_{jrm} : farm gate price of crops, $Y^{\min}_{r}$: minimum income constraint

$inp^{\max}_{nr}$: regional external input use bound (for certain policy scenarios).

The set of resource constraints (4.2) ensures that within each region r and for each month m, the total use of resources k (land and labour), which is given by the level of farm activities X_{jrst} and per unit resource requirement a_{jrstkm} does not exceed the available resource level b_{rkm}. Equation (4.3) aggregates the output of a given crop j in region r and month m into variable Q_{rjm}, which is at a later stage calibrated to baseline data of regional supply. For each vegetable in each region and month, a supply balance is given by equation (4.4). Total supply Q and, for importing regions the level of importing activities less all crops transports $T_{rr'vm}$ out of the region (from r to r') less quantity stored S_{rvm} but augmented by the quantity that is taken out of the store, which is what has been stored the month before times the storage efficiency a^{s}_{v}, must sum to zero.

Regional demand balances are represented by equation (4.5), in which the first sum expression represents the quantities arriving from farm production in other regions and the region itself. Only production less the crop-specific handling and distance and crop-specific transportation losses is available at the wholesale level. Furthermore, the seed requirements for garlic, ginger and shallot, and exports are deducted. The remaining wholesale supply has to be greater than or equal to demand for each vegetable in a given region and month.

Equation (4.6) implements a restriction on the amount of hired labour. As explained above, hired labour is assumed to be limited to a certain ratio of family labour, i.e. skilled labour. Import and export activities I_{rvm} and E_{rvm} are limited to a fixed amount of imports and exports by equations (4.7) and (4.8), respectively. As field crops leave the farm via different channels, the demand for field crops is defined separately by equation (4.9) as indicated by the field crop subset index fc(j). A minimum gross margin constraint to ensure sufficient income is introduced by equation (4.10), which states that the revenue (yield o_{jrst} times farm gate price less the cost of purchased inputs and other variable costs c_{jrst}) times the activity level is not less than a defined minimum income of the farm. The limit was defined such that the returns to household labour are greater or equal to the wages for hired labour. For certain policy scenarios, equation (4.11) is used to limit the use of certain external inputs by exogenously set bounds (cf. section 4.4.3). Finally, non-negativity is imposed on all activity variables in the model by equation (4.13).

Solving the linear programming problem defined by equations (4.1) to (4.13) results in an overspecialized solution for regional supply quantities that deviates significantly from observed production patterns of the base year as expected for this type of model, and requires a calibration procedure.

4.2.3 Model calibration

4.2.3.1 Available methodologies

Due to their nature as simplified representations of real systems, all models build on a limited information base. Sector models are developed to represent the behaviour of economic agents who take their individual decisions according to their objective function, within the bounds of constraints and based on expectations about their economic environment. In the course of developing a sector model of aggregate supply response, aggregation of smaller decision units (farms) to regions (regional farms) or groups of farms (representative farms) is a required step, which results in inaccuracies due to the following reasons: (1) The objective functions of individual agents might differ. Often profit maximization is assumed, whereas risk considerations or subsistence requirements might play a role. (2) Individual farms are usually modelled appropriately as price-takers, input and output prices are exogenous variables, while at the sector level the market mechanism has to be taken into account (BAUER and KASNAKOGLU, 1990), which requires a suitable description of the demand side behaviour. (3) Different resource endowments and economic conditions of farms (e.g. soil qualities, distances to markets, managerial or agronomic ability of the manager) result in adapted production programmes. In sector models, the variation of resource qualities can be captured only to a certain extent for the aggregates (BAUER and KASNAKOGLU, 1990).

The aggregation of farms with different proportions of resource endowments consistently leads to an overstatement of the degree of resource mobility, which is not available at the individual farm level and moreover suggests that the included technologies are available to all farms of the aggregate, called *aggregation bias* (HAZELL and NORTON, 1986, p. 145). It can be avoided only under a set of certain restrictive conditions listed e.g. by Day (1963): technological homogeneity, pecunious and institutional proportionality, where the first term refers to the requirement that all aggregated farms use the same technology characterized by homogeneous technical coefficients and resource constraints. Pecunious proportionality requires that decision makers' expected unit returns to activities are proportional, whereas institutional proportionality requires proportional constraint vectors of individual farms (HAZELL and NORTON, 1986, p. 145f). Meeting these conditions exactly would ultimately require modelling all farms individually. Therefore, HAZELL and NORTON conclude that "in practice, the aggregation criteria usually are reduced to grouping farms according to a few simple rules. Chief among those rules are (1) similar proportions in resource endowments, (2) similar yields, and (3) similar technologies" (HAZELL and NORTON, 1986, p. 147), which is the approach followed here.

As a consequence of the overrated resource mobility, the resulting models yield solutions overspecializing in the most profitable activities. HOWITT (1995) presents a formal proof that models with a lower number of constraints than independent activity variables in the base period generally do not calibrate to observed base year data. The need for calibration of correctly specified programming models to observed baseline data has generated a plethora of pragmatic approaches such as arbitrary flexibility constraints, additional rotational requirements, the inclusion of risk-averse behaviour or downward sloping output demand functions and even entirely arbitrary modifications of model parameters (see for a more comprehensive treatment BAUER and KASNAKOGLU, 1990). All of these methods suffer from limited theoretical justification or foundation on data and strongly influence the model's simulation behaviour (BAUER and KASNAKOGLU, 1990).

With the development of Positive Mathematical Programming (PMP) (HOWITT and MEAN, 1983) a theoretically sound and empirically feasible solution to the calibration problem became available and was rigorously formulated by HOWITT (1995). It bridges the gap between programming and econometric modelling approaches by combining them in a consistent manner.

UMSTÄTTER (1999) presents in detail alternative ways to implement non-linear terms in the objective function, either by assuming decreasing marginal yields and two different specifications of increasing marginal costs. The PMP formulation with decreasing marginal yields corresponds to the Ricardian concept of heterogeneous land quality and a decreasing quality once more land is brought into cultivation – or alternatively – more land is planted to a given crop. The concept of increasing marginal costs is related, as increasing marginal costs could also be due to decreasing marginal land quality, which requires higher use of external inputs to sustain a given yield level.

In the following, the standard PMP approach is briefly described for the increasing marginal costs scenario. PMP operates in a three stage procedure. In the first stage, a (linear) mathematical programming model is calibrated to observed activity levels by introducing (upper) bounds to the activity levels. Adopting the notation from PARIS and HOWITT (1988), an initial linear model can be stated as

$$\max_{\mathbf{x}} Z = \mathbf{p}'\mathbf{x} - \mathbf{c}'\mathbf{x} \tag{4.14}$$

subject to

$$\mathbf{Ax} \leq \mathbf{b} \quad [\mathbf{y}] \tag{4.15}$$

$$\mathbf{x} \leq (\mathbf{x}_0 + \boldsymbol{\varepsilon}) \quad [\boldsymbol{\lambda}] \tag{4.16}$$

$$\mathbf{x} \geq 0 \tag{4.17}$$

where Z is the value of the objective function, **p** and **c** are (n x 1) vectors of unit output prices and variable cost per unit of output, respectively, **x** is a (n x 1) vector of non-negative activity levels measured in units of output, **A** is a (m x n) matrix of resource (and policy) constraints, **b** is a (m x 1) vector of resource capacities. Equation (4.16) is the calibration constraint with the (n x 1) vector of observed base-year activity levels x_0 and a vector of small positive perturbations **ε**. The associated dual variables are represented by the vectors **y** and **λ**, respectively. It is assumed here that net benefits per unit activity are positive, otherwise a lower bound would have to be included in equation (4.16).

The model defined by equations (4.14) to (4.17) calibrates (apart from the small ε perturbation) perfectly, but is constrained by the calibration bounds. The marginal cost vectors **y** and **λ** contain the shadow prices of limiting resources and the differential marginal costs, respectively. PMP interprets the marginal cost of production at the specified output vector $\mathbf{x}_0$ as the sum of **λ** and variable cost **c**. According to the notion of PMP, an unspecified (unobserved) part of the marginal cost information is implicit to the observed activity levels. In the second step of PMP, the objective function is augmented by a non-linear term such that the marginal costs of activities at their observed levels $\mathbf{x}_0$ equal their respective revenues. The calibration constraints are removed but the model will still reproduce the base year data. Figure 17 shows the marginal gross margins (MGMs) for a simple model with two activities *a* and *b* under a single resource constraint for land as a function of activity levels. In the LP model the marginal gross margins MGM_a and MGM_b for both crops are constant irrespective of activity levels, and the model would overspecialize in crop *a* with the higher gross margin. The PMP formulation introduces a non-linear term such that at observed activity levels $\hat{x}_a, \hat{x}_b$, the MGM of the preferred activity a is reduced to equal the MGM of crop *b*. In the case presented, total gross margin remains unchanged from the LP to the PMP model (area under the solid and area under the dashed line), but the marginal crop *b*, which is constrained by the resource capacities, lacks a non-linear cost function specification. Treating marginal crops differently from preferred crops is theoretically not justified and would lead to inconsistent model response in scenario calculations. Therefore, the calibration of marginal crops has to rely on other information.

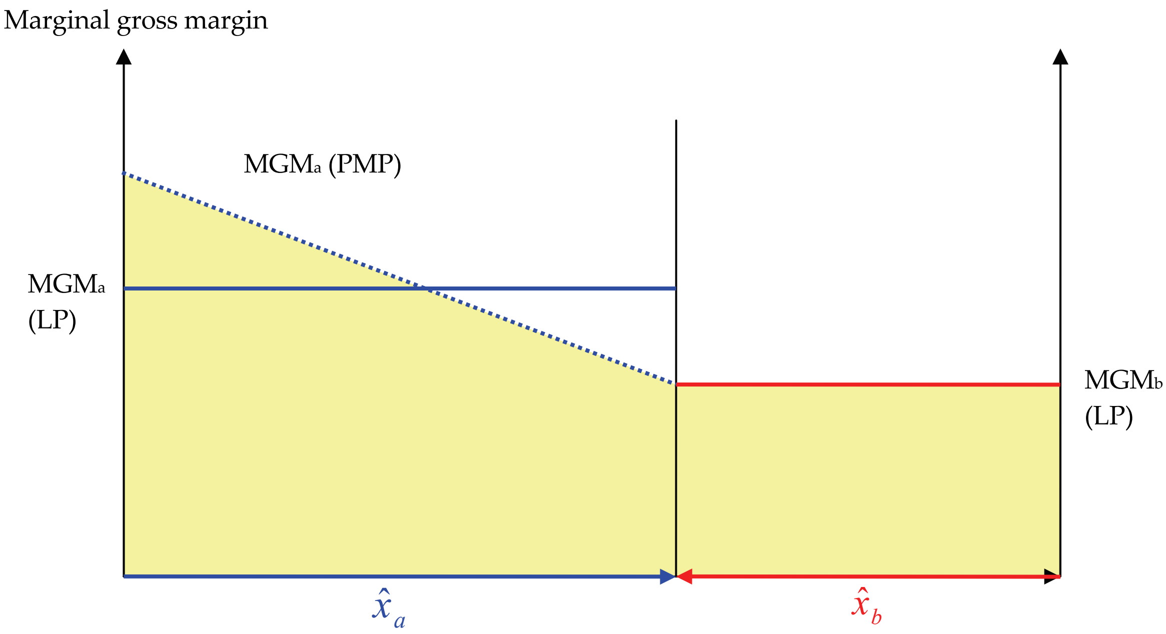

Figure 17: Marginal revenue of LP and PMP formulation for a two activity case

Source: adapted from UMSTÄTTER (1999, p. 32)

In order to also calibrate marginal activities, a non-linear cost term can be derived from estimates of supply elasticity, or the calibration term is based on the observed variable cost as proposed by PARIS (1988). As there are no estimates for the elasticity of vegetable supply available, only the latter can be applied for calibration of the TVSM. Graphically, this approach is shown in Figure 18, which also reveals that the total gross margin of this PMP formulation (area under the dashed lines) is greater than that of the prior LP model (area under the solid lines). Mathematically, this can be expressed as follows. Instead of a linear cost term, a quadratic cost function of the form (4.18) is introduced. The parameter of the associated marginal cost function is then defined such that at the observed activity levels $\hat{\mathbf{x}}$ the marginal cost mc(x) equals the sum of accounting cost c and the marginal value of the calibration constraint λ (4.19).

$$\mathbf{c}(\mathbf{x}) = \tfrac{1}{2}\mathbf{x}'\mathbf{q}\mathbf{x} \tag{4.18}$$

$$\mathbf{mc}(\hat{\mathbf{x}}) = \mathbf{q}\hat{\mathbf{x}} = \mathbf{c} + \boldsymbol{\lambda} \tag{4.19}$$

The PMP version of the LP problem in (4.14)-(4.17) can then be written as:

$$\max_{\mathbf{x}} Z = \mathbf{p}'\mathbf{x} - \tfrac{1}{2}\mathbf{x}'\hat{\mathbf{q}}\mathbf{x} \tag{4.20}$$

subject to

$$\mathbf{A}\mathbf{x} \le \mathbf{b} \quad [\mathbf{y}] \tag{4.21}$$

$$\mathbf{x} \ge 0 \tag{4.22}$$

Given that the matrix $\hat{\mathbf{q}}$ fulfils equation (4.19), the PMP problem defined by (4.20)-(4.22) calibrates to observed baseline levels without a calibration constraint[38].

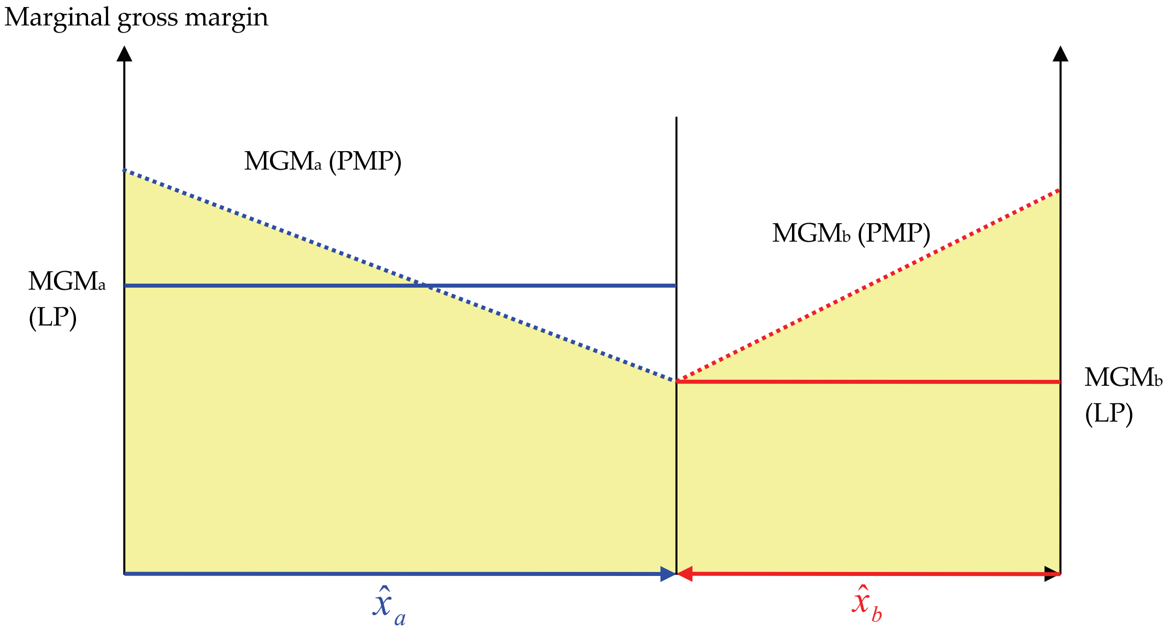

Figure 18: Revision of marginal gross margins by PMP according to PARIS (1988)

Source: Adapted from Umstätter (1999, p. 62)

As the matrix **q** has the dimension (n x n), where n is the number of activities and only n observations of base year activity levels exist, the system of equations implied by (4.23) is underdetermined. One solution to this problem has been to assume that all non-diagonal elements of q are 0. Then only n parameters remain to be estimated. This assumption implies that cross-supply effects are ruled out, i.e. it is assumed that the marginal cost of extending one activity by one unit is independent of the level of other activities. Another solution has been to use a maximum entropy (ME) estimation (PARIS, 1988). This approach allows for also estimating the off-diagonal elements. HECKELEI and BRITZ (2000) however, argue that unless more than one observation is used in the ME approach, the resulting **Q** matrix must be identical to the one obtained by the standard PMP approach, as no additional information on the off-diagonal elements of **Q** is provided. They further reason that the non-zero off-diagonal elements of **Q** obtained by PARIS from a single observation depend on the applied method of decomposing the matrix. For the present case of the TVSM, statistical data on production, and hence activity levels, are available, but all cost data are available for one year only. As cross sectional data are not sufficient for the approach outlined in HECKELEI and BRITZ (2000), a maximum entropy estimation cannot be used.

The standard PMP approach, which assumes zero cross supply effects, has been extended by RÖHM and DABBERT (2003) for the case of regional or sectoral models, including activities that are more closely related than others. This is likely the case in agri-environmental modelling, where alternative production activities for the same crop (e. g. high intensity versus low intensity) are

38 Formal proofs are provided in UMSTÄTTER (1999) and HENRY DE FRAHAN *et al.* (2007).

specified in order to analyse the effects of alternative environmental policies or incentives. Instead of treating all activities equally in deriving the coefficients of the non-linear marginal cost term, this extended approach separately models the marginal cost function for the crop as a whole on the one hand and for the alternative activities (within the crop) on the other. While calibration to the baseline scenario is obtained by both the standard and the extended approaches, it is argued that by the standard methodology, the model's simulation behaviour would be more inelastic towards environmental incentives than should be expected (RÖHM and DABBERT, 2003). As the TVSM includes alternative and competing production technologies, the extended approach would be in place. However, data on single activity levels for vegetable production in Thailand are unavailable.

4.2.3.2 An approach for calibration of a model of Thai vegetable production

The most detailed statistical aggregates available for model calibration are regional monthly supply data by vegetable from the DoAE production statistics (DOAE, 2001). Therefore, the standard technique is modified such that aggregate supply activities are calibrated by introducing a non-linear objective function term, whereas a linear variable cost term for individual production activities is retained. This approach builds on the property that PMP calibration can be implemented at different levels of aggregation in a nested programming model (HOWITT, 2005, p. 93f). The calibration is implemented as follows.

In the statement of the original problem, equation (4.3) ensures aggregation of crop output in a given month and region into an aggregate supply variable Q_{rjm}. The initial constrained LP problem is defined by equations (4.1) to (4.13), where calibration constraints (4.12) put an upper bound on the level of regional aggregate supply at the observed baseline supply levels $\hat{Q}_{jrm}$. The vector of shadow prices associated with the calibration constraint is denoted by λ_{rvm}. In the second stage, a non-linear cost term has to be defined such that at the observed activity levels the marginal costs of aggregation activities are identical. As discussed above, the formulation proposed by Paris (1988) is used here to avoid distinct specifications for non-marginal and marginal crops. Accordingly, the coefficient γ_{vrm} for the marginal cost term for all non-zero aggregation activities is defined according to equation (4.24).

$$\text{(4.24)} \qquad \gamma_{vrm} = \frac{c^{Q}_{vrm} + \lambda_{vrm}}{\hat{Q}_{vrm}}$$

Without further modification, the variable unit cost c^{Q}_{vrm} of the artificially introduced aggregation activities is zero, however, which leads to zero coefficients for all marginal activities. This problem can be remedied by considering the dependency between production and regional supply aggregation activities expressed in inequality (4.3). A part of the variable cost associated with production can be transferred to the respective aggregation activities on the grounds that these are common to all production activities whose output enters the aggregation activity, irrespective of the technology and planting season of the particular production activity. The approach taken here is to transfer a share of the variable cost of production proportional to the output share of the production activity in a given month and proportional to its contribution to output in that month in the baseline solution as shown in equation(4.25).

$$(4.25) \qquad c^Q_{vrm} = \rho \cdot \sum_{st} c^f_{vrst} \hat{X}_{vrst} \cdot \frac{o_{vrstm}}{\sum_m o_{vrstm}} \cdot \frac{1}{\hat{Q}_{vrm}}, \; where \quad 0 < \rho < 1,$$

At the same time, the variable unit costs of all vegetable production activities have to be reduced by a commensurate share, which is attained by adapting the objective function as shown in equation (4.26):

$$(4.26) \qquad \begin{aligned} tvc = & \sum_{j \in (fc,hlab),rst} (c^f_{jrst} + \sum_n i_{njrst} p^i_{njrst}) \cdot X_{jrst} + \sum_{vrst} ((1-\rho)c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst}) \cdot X_{vrst} \\ & + \sum_{vrm} c^s_v \cdot S_{vrm} + \sum_{vr'm} ((c^t + a^{fuel} p^i_{fuel}) \cdot d_{rr'} + c^h_v + a^{lab}_v p^{lab}_r) \cdot T_{vrr'm} + \sum_{vrm} c^q_{vrm} \cdot Q_{vrm} \end{aligned}$$

The first sum over the non-calibrated farm activities in equation (4.26), i.e. field crops and labour hiring, remains unchanged. For vegetable production activities, whose aggregate output is calibrated, the variable cost term is reduced to $(1-\rho)c^f_{vrst}$. It is easily shown that this approach leads to an equivalent definition of the objective function at the observed baseline activity with reference to the parameter definitions (4.24) and (4.25). For this purpose the objective function can be written without the terms that are unaffected by the above modification (4.27). Employing the definitions for γ_{vrm} (4.24) and c^Q_{vrm} (4.25) to (4.27) yields (4.28), which at the observed activity levels $Q_{vrm} = \hat{Q}_{vrm}$ and $X_{vrst} = \hat{X}_{vrst}$ reduces to (4.29).

Because of $\frac{1}{\sum_m o_{vrstm}} \sum_m o_{vrstm} = 1$, (4.29) can be written simply as (4.30):

$$(4.27) \qquad tvc = \cdots + \sum_{vrst} ((1-\rho)c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst}) \cdot X_{vrst} + \cdots + \sum_{vrm} c^Q_{vrm} Q_{vrm}$$

$$(4.28) \qquad \begin{aligned} tvc = \cdots + & \sum_{vrst} \left((1-\rho)c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst} \right) X_{vrst} + \cdots \\ \cdots + & \sum_{vrm} \rho \cdot \sum_{st} \left(c^f_{vrst} \hat{X}_{vrst} \cdot \frac{o_{vrstm}}{\sum_m o_{vrstm}} \cdot \frac{1}{\hat{Q}_{vrm}} \right) \cdot Q_{vrm} \end{aligned}$$

$$(4.29) \qquad tvc = \cdots + \sum_{vrst} ((1-\rho)c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst}) \cdot \hat{X}_{vrst} + \cdots + \sum_{vrst} \rho \cdot c^f_{vrst} \hat{X}_{vrst} \cdot \frac{1}{\sum_m o_{vrstm}} \sum_m o_{vrstm} .$$

$$(4.30) \qquad tvc = \cdots + \sum_{vrst} ((1-\rho)c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst}) \cdot \hat{X}_{vrst} + \cdots + \sum_{vrst} \rho \cdot c^f_{vrst} \hat{X}_{vrst} .$$

Equation (4.30) is equivalent to the original formulation in equation (4.1) above, with variable cost coefficients c^f_{vrst} for all production activities and zero coefficients c^q_{vrm} for aggregation activities.

Having shown that a transfer of a certain proportion of variable production cost to the aggregation activities according to equations (4.25) and (4.26) does not alter the objective function value, this approach is suited to ensuring non-zero coefficients for the quadratic PMP objective function. Finally, the cost share ρ to be transferred to aggregation activities has to be established in the absence of clear-cut theoretical guidance. It can be argued, however, that the cost share should be low in order to minimize interference in the competition of alternative technologies, which among other factors is most importantly based on the associated cost information. Moreover, choosing a low share leads to a comparatively small coefficient of marginal aggregation activities, which is in line with the expectation that changes would be most pronounced in those marginal crops (cf. RÖHM and DABBERT, 2003). Therefore, ρ has been set to 0.1 for the simulation runs presented in this study[39]. The final form of the non-linear objective function used in the TVSM is given by equation (4.31).

(4.31)
$$tvc = \sum_{j\in(fc,hlab),rst} (c^f_{jrst} + \sum_n i_{njrst} p^i_{njrst}) \cdot X_{jrst} + \sum_{vrst} ((1-\rho) c^f_{vrst} + \sum_n i_{nvrst} p^i_{nvrst}) \cdot X_{vrst}$$
$$+ \sum_{vrm} c^s_v \cdot S_{vrm} + \sum_{vrr'm} ((c^t + a^{fuel} p^i_{fuel}) \cdot d_{rr'} + c^h_v + a^{lab}_v p^{lab}_r) \cdot T_{vrr'm} + \sum_{vrm} \tfrac{1}{2} \gamma_{vrm} \cdot Q^2_{vrm}$$

As shown above, the resulting non-linear model calibrates to observed aggregate regional supply, whereas the level of seasonal production technologies contributing to that aggregate is not affected by the calibration. In fact the outcome is similar to the approach of RÖHM and DABBERT (2003), because substitution among different production activities supplying the same vegetable in the same season into the aggregation activities is not affected by a non-linear cost term, and substitution among variant activities is not penalized for deviation from calibration levels. On the downside, the levels of variant activities might change abruptly when conditions are changed in simulated scenarios. In spite of this disadvantage, the approach exploits the statistical information from observed supply levels to effectively calibrate and smooth aggregate model response.

4.2.4 Model regions and transport distance

For establishing the model outlined above, the first step is a definition of the regions to be distinguished. As the official differentiation of Central, Northern, Southern and Northeastern region seemed sub-optimal because of different geographical extents, heterogeneous agro-ecological conditions within regions and different population size, some regions were divided for separate treatment in the model. The regions have been designed to cover a similar population size and to fit as far as possible to the above mentioned regional boundaries. As a result, the official Central

[39] A sensitivity analysis for different parameter values indicated that the direction of changes in results was consistent in the range of 0.1-0.5 and the magnitude of effects was comparable.

region has been divided into the Greater Bangkok (BK) consisting of Bangkok and surrounding provinces to which urbanization extends already and the Central (CE) model regions (see Figure 19 and Figure 72, p. 218). The Northern region has been separated into the upper (UN) and lower North (LN), the Northeastern region into three sub-divisions, namely the western (WNE), eastern (ENE) and upper (UNE) parts of the Northeast. The Southern region is defined as model region SO without any changes. As a result, the model differentiates eight distinct regions of production and consumption. According to the main mode of transportation, the cost distance between regions is estimated by the travel distance between representative locations for each region. These were determined by calculating the centroid (centre of gravity) of each of the regions by means of ArcView GIS 3.2. As the mere extent of administrative units represents the required flows of produce only to a limited extent, weighted centroids have also been calculated: a) based on provincial production according to 1998-2001 data and b) by population in order to account for the unequal distribution of production within the regions as well as population and demand. Figure 19 reveals that the centre of mass for regional demand (demand centroid) and production (production centroid) are located closely to each other in the model regions of North-Eastern Thailand. Therefore the centroids will be used to represent these regions.

Table 16: Mean travel distance in km between and within model regions.

Region	Abbrev.	BK	CE	LN	UN	WNE	ENE	UNE	SO
Greater Bangkok	BK	34	104	309	696	309	542	547	804
Central Region	CE	104	104	309	696	309	542	547	804
Lower North	LN	309	309	95	391	372	551	499	1,113
Upper North	UN	696	696	391	146	733	745	767	1,500
Northeast - west	WNE	309	309	372	733	84	281	238	1,113
Northeast - east	ENE	542	542	551	745	281	88	314	1,346
Northeast - north	UNE	547	547	499	767	238	314	78	1,351
Southern Region	SO	804	804	1,113	1,500	1,113	1,346	1,351	108

Source: Own calculation

In UN, the centre of gravity of production is shifted to Chiang Mai province, while the demand and unweighted centroids are located north of Lampang. Being a major surplus region and given that travel distance from other regions is comparable, Chiang Mai is selected as the representative point. In LN, production and demand are shifted to the west due to the mountainous forest areas near the western border. The midpoint of demand and production centroids, located on Highway 117 is used to represent LN. Due to its irregular shape, the Central region's centre of gravity is located in Bangkok town, while production has its centre of gravity 55 km to the west, indicating the stronger contribution to production of the western provinces. Accounting for the transportation cost within the region and to Bangkok relies on the proxy used for within-region transportation. For BK, its unweighted centre of gravity, located in Nonthaburi city is used as a representative point. Finally, for SO, the midpoint between demand and production weighted centres of gravity, located 67 km south of Nakhon Si Thammarat is used.

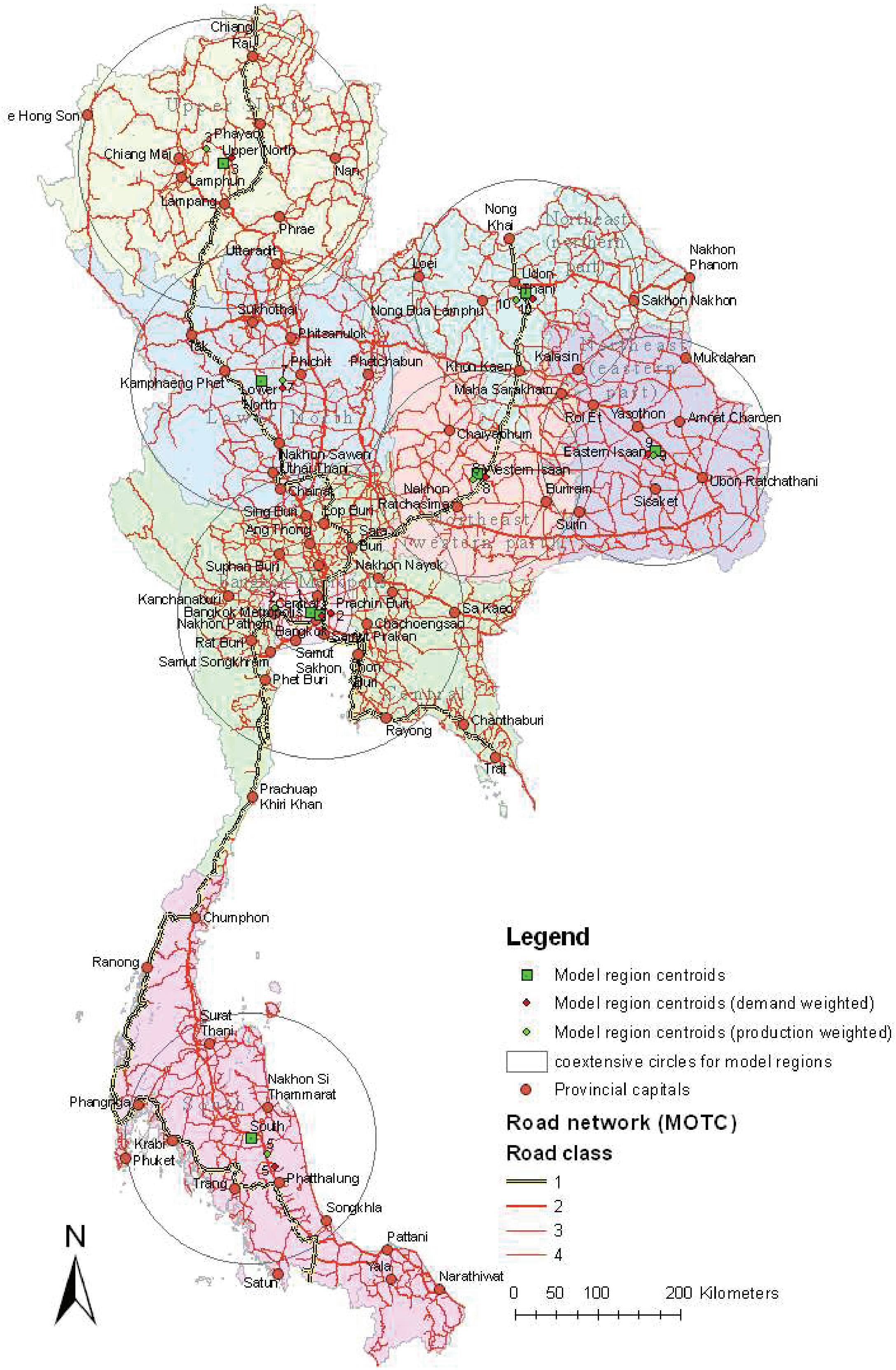

Figure 19: Map of Thailand for calculation of model region centroids and travel distance

Source: Own presentation based on the following datasets: Administrative Units (NSO, 2002), population (NSO, 2003a), road network (MoT, 2005), production of model vegetables 1998-2001 (DoAE, 2001), provincial capitals (TEI, 1996). Weighted centroids have been calculated by an ArcView Script (Solorzano, 2004).

4.2.5 Environmental indicators

In order to allow for an assessment of the environmental impact of vegetable production under different scenarios, indicators for pesticide and nitrogen fertilizer use are incorporated as endogenous variables in the model, which allows for simulation of the effects of policies limiting the level of pesticide or nitrogen use. For the latter, the average external supply of nitrogen per one rai and year is used as the relevant indicator. The intensity of pesticide use is captured by the quantity of active ingredients applied, differentiated by WHO acute toxicity classes (WORLD HEALTH ORGANIZATION, 2005) and the frequency of spraying. For a more comprehensive evaluation of the environmental burden of pesticide use, the environmental impact quotient (EIQ) is additionally used (KOVACH *et al.*, 2004). It combines acute and chronic effects on applicators and pickers, on consumers through consumption of contaminated crops and polluted ground water and on the ecosystem through aquatic and terrestrial pathways in a weighted indicator. The actual EIQ values for active ingredients used in the model are taken from KOVACH *et al.* (2004). In order to account for different formulations and application rates, individual pesticide applications are evaluated according to their EIQ field use rating (4.32).

(4.32) $$EIQ\ field\ use\ rating = EIQ_{AI} \cdot c_{AI} \cdot rX_{jrst}$$

(4.33) $$EI_{total} = \sum_{crop} A_{crop} \cdot \left(\sum_{AI} EIQ_{AI} \cdot c_{AI} \cdot r \cdot n \right)$$

where

EIQ_{AI}: EIQ for a given active ingredient,

c_{AI}: concentration of the active ingredient in the formulated product

r: application rate in kg or l per unit area

EI_{total}: total environmental impact of a given combination

n: number of applications

A_{crop}: area under a given cropping activity.

Production systems can be characterized by their total seasonal environmental impact, given by the total of field use ratings for all pesticide applications (KOVACH *et al.*, 2004). The environmental impact of the sector (EI_{total}) is obtained by aggregating that of the production systems weighted by the area under the system as reflected in (4.33). The absolute value of EI_{total} depends on the area unit chosen and the amount of production. Keeping these constant, EI_{total} varies in scenario runs according to the 'environmental efficiency' of the endogenously determined production activities. Therefore, its relative changes over the base scenario reflect commensurate changes in the environmental burden of pesticide use for vegetable production.

In addition, the quantity of active ingredient (AI) by WHO acute toxicity classification is calculated as an indication of physical quantity of pesticide use. The active ingredient content in commercial formulated products was obtained from registration data and pesticide use in production activities was aggregated by toxicity class Table 17. The absolute quantity used in vegetable production (metric tons of AI per year) is calculated from balance equations in the model, which aggregate the total quantities of AI used for the separate toxicity classes. Moreover, the pesticide use intensity (kg of AK per hectare) is calculated by relating total use to the land area employed for vegetable production. Besides quantities, frequency of pesticide application is also used as an indicator for the exposure of farm workers to health hazards from pesticides. High spraying frequencies increase not only the exposure of applicators but also of labourers working in the crop for weeding or harvesting, because compliance with prescribed waiting times becomes more unlikely.

Finally nitrogen (N) use is also considered, in terms of gross quantity of nitrogen applied to vegetable fields by mineral fertilizers and manures (Table 17). The quantity of external nitrogen supply to the production system can be interpreted as an indicator for the nutrient balance of production systems, which affect the risk of contamination of ground and surface water.

Table 17: Environmental indicators utilized in the TVSM

Category	Indicator	Variable	Unit
External nitrogen supply	Total annual nitrogen supply per metric ton of output at the wholesale level	N-intensity, N-supply per metric ton of produce	[kg N/ ha] [kg N/ t of produce]
Pesticide use and impact	Quantity of active ingredient by WHO classes I, II, III, and others[40]	AI_WHO1 AI_WHO2 AI_WHO3 AI_WHOO	[t AI / year] [kg AI / ha]
	Average number of sprays per week by WHO classes I, II, III, and others	NS_WHO1 NS_WHO2 NS_WHO3 NS_WHOO	[1 / week]
	Environmental impact based on EIQ field use ratings	EItotal	[1]

Source: Own presentation

The parameters presented in Table 17 are indicators for pollution potential from vegetable production but do not reflect actual pollution or the social cost associated with pollution. They rather provide a first step towards identifying the burden that is associated with the present production systems.

4.2.6 Data collection

After the model structure has been laid out in the preceding section, the data sources for deriving model parameters will be discussed and the calculation will be documented. A major task in the course of developing a sector model consists in establishing a consistent data set for use in the model (HAZELL and NORTON, 1986, p. 266f). Even in comfortable data situations as encoun-

[40] Others includes: WHO table 5 classification "unlikely to present acute hazard in normal use" (WORLD HEALTH ORGANIZATION, 2005)

tered in EU member states and characterized by regular surveys on farm structure, activity levels, yields, revenues and gross margins and annual representative farm performance parameters down to the district level, a data reconciliation step is required (HAZELL and NORTON, 1986, p. 266f; CYPRIS, 2000, p. 7). For a model of the Thai vegetable sector, this task is even more important, as the different data sources are based on differing definitions and rely partially on sub-optimal statistical procedures. Moreover, the variety of crops, multiple cropping and a subordinate representation in the official statistics with frequent data gaps present major obstacles in this process. The data sources that could be made available at different points of time during the research are summarized in Table 18.

Table 18: Data sources for model parameterization by provider

NSO	OAE	DoAE
2003 Census of Agriculture: a) Region summary reports b) 1%-sample microdata c) customized summaries from a statistical data warehouse	*Agricultural Statistics of Thailand* For 6 major vegetables[41] - area planted, area harvested - yield - farm gate price / value	*Crop production database* 1994-2001, monthly data on - area planted, area harvested, - average yield - production by district
1998 Intercensal survey raw data (1% sample of the farm population)	*Farm gate prices 1999-2001* for vegetables (unpublished)	
Household Socio-Economic Survey 2002: a) Expenditures by region b) Population by province c) Incomes by province		

Source: Own presentation

The main source of information is the crop production database of the Department of Agricultural Extension (DOAE, 2001), which is the only comprehensive source on vegetable production in Thailand (ISVILANONDA, 1992, 1996; SOOTSUKON *et al.*, 2000). It is collected by the sub-district extension officers (*Kaset Tambon*) and aggregated at provincial, regional and finally the central extension offices and contains monthly data on areas planted and harvested, average yields and production for 53 vegetables among a total of 98 crops.

Determining an appropriate set of constraints is a difficult task for the present modelling approach for two reasons. Firstly, it is not obvious from a theoretical perspective which factors present fixed constraints in the medium term for the vegetable sector, as vegetables can be grown on many land types and they are highly competitive compared to rice and field crops, which cover substantially larger areas. As described in more detail above, human capital – in particular the limited capacity of farmers who have knowledge and experience in growing vegetables – is expected to constrain the expansion of vegetable production, together with land quality and sea-

[41] The vegetables covered in the Agricultural Statistics of Thailand are: Garlic, shallot, onion, large chilli, baby corn and tomato.

sonal production conditions. Secondly, the quantification of such capacities for vegetable production in Thailand is not straightforward, because comprehensive data are unavailable. In order to demonstrate these difficulties and to document the procedure of determining the model constraints, the remainder of this section provides an overview of the relevant data sources and the justification for the selection of a database for the model.

The most important source for structural data in this study is the Agricultural Census of 2003. The census collects data on legal status, holding area by primary land use, land tenure and activity levels of livestock, rice, permanent crops, field crops, the group of vegetables, herbs and ornamental crops, and recently on freshwater aquaculture, from about 5.8 million farm holdings in Thailand. Moreover, for a 25% subset of farms, additional data on the use of fertilizers and pesticides, hired labour, machinery and equipment, household members and activity status, education and membership in agricultural activity groups and finally income and debt for agriculture are available.

Published reports of the Agricultural Census do not tabulate vegetable farms separately nor do they distinguish the area designated for growing vegetables, herbs and ornamentals. Therefore, a 1% microdata sample drawn from the full data set for a progress report was obtained to allow for specific analysis of vegetable farms. More recently, the full data set was made available through an online data warehouse application (NSO ,2005b), which allows for individual queries on the raw data but is still limited in terms of query definition and suffers from missing data for vegetable activities in most of Northern Thailand. Table 19 summarizes all farms with vegetable, flower and herb area for a comparison of data sources. Obviously, vegetable, flower and herb (VFH) areas listed in the regional reports and by the data warehouse (DW) are identical except for rounding errors and a minor difference for the Northeast. The sample estimates for VFH area are biased strongly upward for Central and Northern Thailand, to a minor extent for southern Thailand and slightly downward for the Northeast. The number of holdings with VFH area is not available from printed reports, but was retrieved from the DW for comparison with sample estimates. For the Central and Northern regions, estimates are again biased upwards, for the Northeastern and Southern regions slightly downwards.

The extent of the sample deviation limits the use of the sample for determining the resource base for vegetable farming in Thailand.

Table 19: Holdings with vegetable, flower and herb area according to the 2003 Census of Agriculture

	Vegetable, flower and herb area (rai)				Number of holdings with vegetable, flower and herb area		
	Report	DW	1%-sample	Sample deviation	DW	1%-sample	Sample deviation
Central	512,345	**512,345**	658,546	29%	111,716	126,381	13%
North	468,411	**468,410**	537,810	15%	119,589	135,034	13%
Northeast	334,204	**334,222**	325,640	-3%	115,002	112,137	-2%
South	63,652	**63,653**	65,432	3%	24,145	23,465	-3%
Kingdom	1,378,612	**1,378,630**	1,587,428	15%	370,452	397,017	7%

Source: National Statistical Office (2004; 2005a)

Table 20 presents data on vegetable growing holdings based on the data warehouse and the 1% sample. As data on Northern Thailand were incomplete (only 2 out of 17 provinces were present) in the data warehouse, country totals could not be calculated. The number of holdings growing vegetables according to the data warehouse exceeds the sample estimate for all regions. This could be traced to multiple counting of farms growing more than one vegetable crop in the data warehouse application, rendering the data source useless for the purpose of establishing the constraint set for the model.

Table 20: Holdings growing vegetables according to the 2003 Census of Agriculture

	Number of holdings growing vegetables			Area planted to vegetable including multiple crops (rai)			Vegetable, flower and herb area
	DW	1%-sample	Sample deviation	DW	1%-sample	Sample deviation	1%-sample
Central	158,745	110,846	-30%	715,611	762,151	7%	490,364
North	n.a.	174,587	n.a.	n.a.	789,107	n.a.	512,575
Northeast	198,439	156,032	-21%	417,812	488,552	17%	311,973
South	46,129	31,949	-31%	84,499	111,741	32%	57,219
Kingdom		473,414			2,151,551		1,372,131

Source: National Statistical Office (2004; 2005a)

Comparing the number of vegetable growing farms with the number of farms having vegetable, flower and herb area as reported for the sample in Table 19 yields the expected results. In Central Thailand, where specialized vegetable farms prevail and flower production is comparatively common, the number of vegetable-growing farms is lower than the number of farms having areas designated for vegetable, flower or herb production. In all other regions, there are more vegetable-growing farms, because seasonal vegetable production after rice or field crops is common practice. The area planted to vegetable crops as reported in Table 20 includes multiple consecutive crops and therefore allows for a comparison of sample estimate and DW results. Again, the sample overestimates the area in all regions. Unlike the previous case, the upward bias is particularly strong for the Northeastern and Southern regions.

Under the hypothesis that vegetable production is largely constrained by human capital, the relevant constraint data must relate to the number of farmers, family members and their management capacity. This type of data can only be extracted from the 1% sample of the agricultural census. The procedure used for deriving these data is shown in Figure 20.

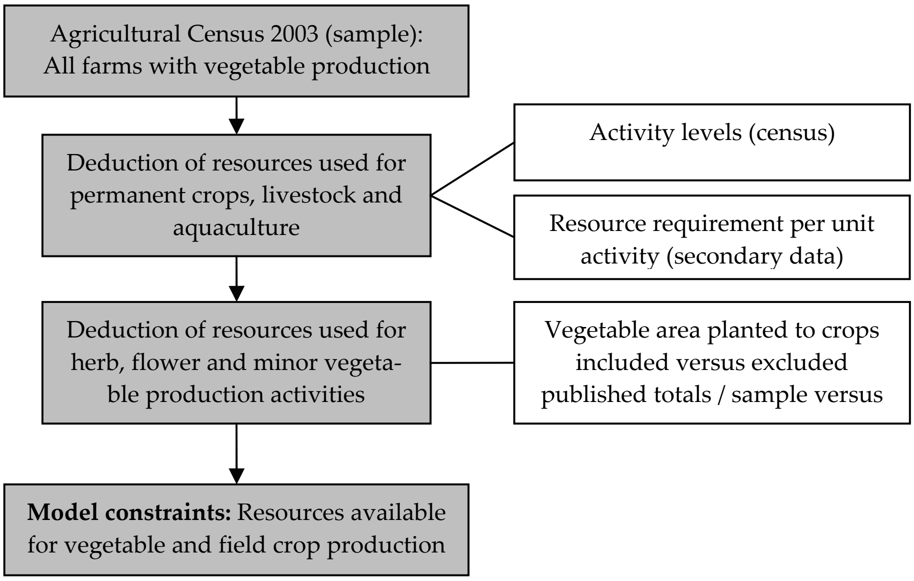

Figure 20: Derivation of model constraint set from the Agricultural Census 2003

Source: Own presentation

Accordingly, only farms with vegetable production were considered. Their family labour endowment was calculated according to the reported number of family labourers employed fully, mainly or only to a minor extent in the farm with the respective factors 1, 0.7 and 0.3 to obtain full-time labour equivalents. Then the labour required for livestock kept and permanent crops was deducted based on statistics of production costs (OFFICE OF AGRICULTURAL ECONOMICS, 2006). Then the area share of the vegetables considered in the model out of the area planted to all vegetables flowers and herbs according to the census was calculated. On the assumption that labour is on average required in proportion to area in these crops, the available labour capacity in the respective regions was calculated. The results listed in Table 21 form the resource constraints for the regional farms considered in the model.

Table 21: Regional resource capacities in vegetable farms

	BK	CE	LN	UN	WNE	ENE	UNE	S
Number of farms	26,042	70,470	58,466	109,710	44,348	58,919	41,542	29,693
Area share of vegetables included in the model	70	65	65	76	87	85	78	59
Area for rice and field crops (ha)	23,965	119,031	105,491	113,271	136,604	131,056	72,042	13,821
Full-time labour equivalents	56,346	134,471	115,583	188,815	91,574	135,216	88,985	46,750
family labour (1000 mh/month)	7,070	15,739	13,486	25,869	14,363	20,627	12,561	4,929
livestock labour use	116	223	104	210	211	423	187	86
permanent crop labour use	179	539	348	3,043	131	208	354	1,665
labour available for vegetables and field crops	6,776	14,977	13,034	22,615	14,020	19,996	12,019	3,178

Source: Own calculation based on NSO (2004) and OAE (2006)

4.3 Primary data collection and results

For activity analytic models the specification of production functions is essential, because they determine the efficiency and relative profitability of production activities and establish the physical properties of production. Secondary data are available only on a subset of the required parameters, such as yield data estimated in the production database (DOAE, 2001) and occasional gross margin analyses for selected crops (OFFICE OF AGRICULTURAL ECONOMICS, 2000). In the absence of a suitable and consistent secondary database, primary data were collected for the specific purpose of the model, using a comparatively novel approach, which is described in detail in this section. The data items needed are (a) physical input- and output data disaggregated by month, and (b) price information for inputs and outputs in order to derive economic indicators. These items are required for each of the 23 crops most important in terms of value and have to take into account differences in seasonal production conditions. Moreover, where appropriate the data should depict alternative production technologies, e.g. with different levels of dependence on pesticides.

Primary data collection for this research consisted of two steps. Firstly, a rapid rural appraisal was used for sketching an initial picture of production and marketing systems in the main production regions. The results of this survey were mainly used for a preparation of the second step, which consisted of expert workshops in the respective regions.

4.3.1 Indicative survey

For a purposive sampling of locations for a small scale survey, existing secondary literature (esp. TANTISIRA, 1988; SONGSAKUL, 1991; ISVILANONDA, 1992, 1996) and statistical data on the provincial level (DOAE, 1998) were reviewed. The survey then covered the most prominent vegetable producing regions and involved where possible interviews with Extension officers (Kaset Changwat/Kaset Amphoe), farm visits and farmer interviews, and where applicable a visit to local wholesale markets, farmer groups or co-operatives. Semi-structured interviews including farm resource endowments, crop calendar, marketing and one detailed crop budget were conducted with 48 farmers in ten provinces of Thailand (cf. Table 57, p. 219).

Farm data reflected a very substantial variation in vegetable production in terms of production systems and intensity of external input use. In Bangkok, Nonthaburi and parts of Ratchaburi[42], vegetables were produced in comparatively concentrated areas using the ditch and dike system. Apart from fruit trees sufficient for home consumption, usually only a few crops were grown apart from vegetables with generally strong specialization on two to three crops, mostly of the leafy type, e.g. Chinese kale, lettuce or Coriander. In some farms with larger land holdings, areas of 0.2 to 0.6 hectares were still planted to rice. Further to the west and north-west in Nakhon Pathom, and parts of Kanchanaburi and Ratchaburi, vegetables were grown like field crops. Outside public irrigation systems, farmers used ground water irrigation for dry-season vegetable crops. Farms generally are larger and usually involve rice production where paddy fields are available and field crop production (corn, sugar cane) in upland areas. Due to the location of processing companies in these areas, contract farming of okra, asparagus and baby corn, sometimes organised by farmer groups, was pronounced in this area.

Although only Nakhon Ratchasima province was surveyed in the Northeast, a wide range of farming systems was observed here. On the one hand vegetable production on the ditch and dike system close to Nakhon Ratchasima city was very intensive in terms of labour, and external input use in vegetables such as cauliflower, Chinese kale, Chinese flowering mustard and spring onion were very high. Farmers in Chalerm Prakiat district growing fruit vegetables such as yard long bean, cucumber and pumpkin often under rain-fed conditions after the main rice crop were much less market-oriented, and vegetable land was limited by family labour availability and access to irrigation water. On their comparatively large uplands, these farmers grow sugar cane and cassava. A third production system in Pak Chong and Wang Nam Khiao districts benefits from the higher elevations at the border of the Khorat Plateau. In this area truck farming of tomato and Chinese cabbage on comparatively large farms (12-16 ha) catering for Bangkok wholesale markets was observed.

In addition to farm surveys, semi-structured interviews of vegetable traders in wholesale markets were also conducted. The data from these interviews confirmed the structure reported in Chapter 3 but have also underlined the importance of farmers from places within a 250 km radius marketing their own produce and that of fellow vegetable growers in the wholesale markets by themselves, which indicated that farmers benefited from an improving transport infrastructure and the more convenient access to Si Mum Mueang and Talad Thai wholesale markets north of Bangkok. The more peripheral location allowed farmers to access the markets by themselves and improved their bargaining position as they took advantage of first hand knowledge on prices and qualities. Secondly, it was observed that Tak province was mentioned frequently as a

[42] A map of administrative units is available on p. 218, production data are mapped on pp. 36 and 37.

source of cabbage and Chinese cabbage, a hint at a possible under-estimation of the vegetable area by official statistics in this border province of Northern Thailand.

4.3.2 Using expert workshops for typical farm definition and parameter elicitation

4.3.2.1 Rationale for using the expert panel approach

In section 2.5 (p. 22) a short typology of farm and sector level models and their suitability for different purposes was discussed. According to this discussion a consistent representation of the sector can be attained by regional farms, i.e. sets of constraints representing the total resources available for agriculture in a given region and coefficients that represent the average technology in the region. When farm structure is heterogeneous in a region, especially in terms of disproportional factor endowments, separately treating several homogeneous groups of farms per region as decision units is more appropriate (HAZELL and NORTON, 1986, p. 145f). For that purpose the German spatially disaggregated agricultural sector model RAUMIS has been complemented by an analogous model with more disaggregated farm groups, which allowed also for a more appropriate prediction of income effects on specific groups, which is relevant in the context of legal obligation for the German government to monitor and report the income situation of the farming sector (JACOBS, 1998, p. 37). In addion, the other method of aggregating the results of individual models of typical farms by an elaborate weighting procedure and an iterative solving of individual farm models and a market equilibrium model in order to obtain a sectoral response, has been successfully applied (BALMANN *et al.*, 1998). For farm level models, the typical farm approach developed in the international farm comparison network IFCN (HEMME *et al.*, 1997, p. 9) has now been applied in different farm-level studies (HÄRING, 2000; HÄRING, 2001), in horticulture (MICHEL, 2001; HARDEWEG and WAIBEL, 2004) and also developing countries (MAHMOOD *et al.*, 2004). This is explained by a number of advantages over a representative farm or selected real farms. Different from representative farms derived from average survey data, typical farms are comprehensible to experts as they exhibit a consistent set of resource constraints and production activities. Moreover, the definition via expert panels is less time-consuming and data are more up to date. The degree of detail can be adapted to the requirements of the specific modelling purpose, whereas statistical averages are limited to the variable coverage of the respective survey or census. They can be formulated with more realistic functional relationships, including multi-dimensional objectives (HEMME *et al.*, 1997, p. 9; HÄRING, 2000; MICHEL, 2001). Also, at the farm level single existing farms could be considered as a data source, but often privacy considerations preclude such an approach. Moreover, the synthetic typical farm is better suited to avoid undue influences from annual fluctuations and characteristics that pertain only to the selected individual farm (HEMME, 2000).

These properties make the typical farm well suited to the primary data collection needs for this study compared to a survey. As a temporally disaggregated set of data for all 23 crops is needed for different regions and technologies, including physical quantification of input use and outputs, a survey with a sufficient number of samples for each of these activities would be expensive, time consuming and difficult in the absence of a suitable sampling frame. Typical farms constructed in expert workshops can provide the data at the required level of detail and can depict the separate technologies. It is furthermore expected that outliers in the data are avoided and it is more likely to obtain consistent data for complex production technologies, which often differ strongly in terms of intensity, from expert consensus than from a survey with a limited sample size covering such technology.

4.3.2.2 Implementation of expert workshops for data collection in Thailand

For the purpose of data collection for this study, the procedure developed by the IFCN (cf. HEMME *et al.*, 1997; HÄRING, 2000; ISERMEYER *et al.*, 2000; HÄRING, 2001) was adapted to fit on the one hand the specific data requirements and on the other hand social and organisational conditions in Thailand. The primary objective of workshops was to obtain a quantitative description of the production technology and constraints under which vegetable farms are operating in the respective regions. Unlike the IFCN, which is aiming at a medium term simulation of farm development, development perspectives and strategies were of minor relevance for the present research. The practical implementation had to accommodate the objectives and participants' requirements and organisational concerns. Statistical data and the results of the indicative survey have shown that a consideration of at least five different locations was required in order to capture the relevant production systems, which resulted in the organisation of five separate workshops.

In preparation for workshops, the statistics and the indicative survey of vegetable farms were used to sketch the expected farm types and the vegetable crops to be covered in the respective workshops, and also specified the area of expertise of farmers (Table 22). The number of participants in each workshop was adapted to the number of farm types that was anticipated in the respective regions and therefore included up to nine farmers in Nakhon Ratchasima province with the most diverse production conditions. Workshop organisation was conducted through a consultancy with central DoAE staff to ensure that the nationwide network could be used for selecting participating farmers according to the requirements listed in Table 22.

Each workshop was scheduled for two consecutive days and was managed by a professional moderator with experience in agriculture and in conducting participatory workshops with farmers. Besides farmers and local extension officers, the consultant and one other staff of the central DoAE responsible for local organisation, and the researcher, participated in each workshop. The workshops were conducted according to an agenda that involved plenary sessions for the introduction of workshop participants and the subject matter, the objectives of the workshop and statistical background information on vegetable production in the region. Moreover, the relevant farm types were identified in the plenary, before these typical farms with resource endowments and cropping patterns were specified in detail in separate groups. The results from discussion groups were then summarized in another plenary session. As a next step, a crop budget including all details from seeding to harvest of a sample crop was established in the plenary. Further crop budgets were then elicited in separate group sessions for the respective typical farm conditions. All results from the plenary and group discussions were continuously noted down on flip charts during the process to ensure efficient communication and documentation of the results.

Table 22: List of regions and farm types for coverage for the expert workshops conducted in 2001

Location	Participants	Crops to cover
Nonthaburi 19-20 November	Nonthaburi province: *lowland farms* (ditch and dike system): 2 specialized vegetable growers 1 farmer with a mixed farm, i.e. rice or field crops 2 extension agents (subject matter specialist and local advisor) Nakhon Pathom province: *upland farms* 2 specialized vegetable farmers 1 local extension agent 1 vegetable trader	Chinese kale, Chin. flowering mustard lettuce morning glory, water morning glory Chin. chives asparagus white radish
Kanchanaburi 22-23 November	Kanchanaburi province: *upland farms* 2 specialized vegetable farmers 1 seasonal vegetable grower or mixed farmer 2 extension agents (subject matter specialist and local advisor) Ratchaburi province: *lowland and upland farms* 3 specialized vegetable farmers 1 local extension officer 1 middleman from Ratchaburi	spring onion large and hot chilli yard long bean coriander celery Baby corn Chin. bittergourd snake eggplant angled gourd
Nakhon Ratchasima 29-30 November	Pak Chong or Wang Nam Khiao districts: *highland farms* 3 vegetable farmers Mueang district: *lowland farms* 3 specialized vegetable farmers Other districts: *seasonal vegetable farming* 3 seasonal vegetable growers 2 local extension agents 1 extension officer	hot chilli spring onion yard long bean cucumber tomato pumpkin
Chiang Mai 3-4 December	Lamphun province: 2 seasonal vegetable grower (different farm sizes) 1 extension officer (Khun Surachai) Chiang Mai province, e.g. Sara Phi district: 1 seasonal vegetable grower 2 specialized vegetable growers 2 local extension agents 1 trader in garlic, shallot and onion	garlic shallot onion hot chilli Chin. cabbage, Chin. flowering mustard cauliflower
Chiang Mai 6-7 December	Districts Mae Rim and Sa Moeng: *Highland farming* 4 vegetable growers from highland production regions in A. Mae Rim and A. Sa Moeng. 2 local extension workers 2 middlemen/collectors (one could be a farmer as well as a collector, also) 1 Officer from the Royal Project Doi Kham 1 staff from the Bio-Centre as a facilitator	cabbage ginger tomato Chin. cabbage Chin. flowering mustard other cabbages

Source: Own presentation

This also enabled the researcher and moderator to check for consistency and completeness of information when observing the respective group discussions. Final plenary sessions were used to validate price information in the large group and to elicit future expectations and strategies and to collect feedback from participating farmers. Furthermore, the revenues and costs as the most critical parameters required for the model database were summarized for the crop budgets during the workshop and reviewed in the plenary sessions. During group discussions, recurrent checks for completeness and consistency and the collaboration of several farmers in the process were deemed sufficient measures for ensuring valid results.

The experience with the expert workshops has been generally positive. Workshops resulted in detailed descriptions of cropping practices and data for separate seasons and the relation between farm resources and production technology. In concordance with HÄRING (2001) it is concluded from the workshop experience and the use of the data in the specification of a sector model that the expert panel approach can generate information more quickly and accurately depicting different farm types or technologies than is the case with surveys. As expert workshop results depend crucially on the participation of experts in the subject matter, the procedure of establishing participant lists is a very important step in the process, and depends on clear communication of the requirements and the farmer characteristics between organiser and researcher. The selection of a suitable workshop location is very crucial as travel distance for farmers must be kept low in order to limit disincentives for participation. In some cases it was impossible to win over farmers to stay the second day of the workshop as they had to take care of their crops and harvesting. Notwithstanding these difficulties, participating farmers were active and often enthusiastically engaged in discussions with their colleagues and as far as observable by the researcher, considered individual contributions in a balanced but critical way. Except for the few merchants who had been won over for participation, no reluctance to contribute expert knowledge has been observed. Farmers, however, had different degrees of experience and workshop participants comprised, 'progressive farmers', who are often better informed and more open to innovations and on average operate larger farms on the one hand, and participants sticking more to traditional farm management methods on the other. On some occasions this created a challenge for the moderator to avoid the dominance of a few active participants in a heterogeneous group of experts, which was resolved by splitting up the panel into smaller working groups that concentrated on specific production technologies.

Also, the role the extension agents played was rather heterogeneous, depending on their relative familiarity with specifics of the production technology and that of farmers. On some occasions the danger of suggestive contributions or questioning by extension agents influencing the outcome had to be countered through intervention by the moderator. In most cases, the extension workers, however, facilitated the discussion, especially in the sub-groups and contributed to a complete coverage of the crop budgets.

4.3.2.3 Results of expert workshops

During the expert workshops, 10 typical farms were identified and specified. During most workshops, two farm types were distinguished in line with recruitment of participants from at least two distinct locations. In the case of Nakhon Ratchasima province, participation of farmers from highland, peri-urban and more peripheral lowland districts resulted in three farm types with very different conditions.

Typical Nonthaburi farm

The typical farm is characteristic for the Bang Bua Thong district and encompasses 3.7 ha of paddy area on which two crops of rice are planted annually. Vegetables are produced in a polder of 0.8 ha size with the ditch and dike system (cf. Figure 73, p. 223). The area planted net of ditches and dike structures corresponds to about 84% of the gross land size. Irrigation water is available year round from public irrigation canals and is used to maintain the water level in the polder. Except in the rainy season, crops are watered using boat-mounted water pumps, which are manually moved along the ditches.

Two household members work on seven days a week for 10 hours in the farm. Three additional labourers are hired regularly but by short term oral contract for 120THB/8 hours. The main crops are basil, Chinese mustard, Chinese kale and lettuce. Crops are scheduled according to expected market demand without considering rotations. This involves repeated planting of the same crop in the same plot. Soil preparation before each crop involves lime and fertilizer application and only twice annually the supply of manure. Due to a comparatively short distance to the wholesale markets of 30km, farmers usually sell their vegetables themselves.

Typical farm in Nakhon Pathom

The typical vegetable farm in Nakhon Pathom province is rather small in size and grows vegetables on 0.64 ha of upland, out of which 0.16 ha (1 rai) is planted to the permanent crop asparagus. Only 1.5 full time labour equivalents of household labour are working on this farm, which constrains the area under asparagus, as harvesting is limited to the early morning and requires 4 man-hours per 1 rai every day. For harvesting other crops, farmers often rely on exchange labour, which for the present purpose has been valued at the opportunity cost of household labour. Other important crops grown are morning glory, Chinese kale, Chinese mustard, and the permanent crops basil and lemon grass.

These farms do not own machines for soil preparation but use a machine rental service for 2,500 THB/ha. Irrigation water is available from public irrigation canals and applied to the crop via a motor pump and sprinkler system. Asparagus is produced primarily for a processing company that contracts farmer groups and also supports them in setting up small facilities for washing, grading and packaging. As only a part of the production achieves the required quality standards, usually more than half of production is sold in the fresh market.

Typical specialised vegetable farm Ratchaburi

Similar to the Nakhon Pathom farm type, farmers in neighbouring Ratchaburi also grow asparagus under contract with a processing company located in close neighbourhood. On a total of just below 1 hectare of rented land, farmers also grow around 1 rai of asparagus and plant the rest to a mixture of crops. Two family members work fulltime on the farm. Asparagus harvesting is usually conducted by two hired labourers employed for three hours every day.

After a period of heavy reliance on pesticides, farmers started vegetable production with less pesticides in 1996 and continue to grow vegetables with less harmful pesticides like NPV, Bt-toxin and Neem extracts. Farmers practice a strict rotation in which cruciferous leafy vegetables are only planted twice per year on a given plot and a one month fallow period during the hot season is observed. Between crucifer crops, cucumber, yard long bean and spring onion are planted, often in a relay cropping arrangement that reduces soil preparation and increases land productivity. The technology represented by these farms is therefore environmentally friendly compared to conventional methods.

Some of these farmers rent additional land to grow Chinese radish in comparatively large lots of 1.6 hectares by employing more hired labour and using well irrigation where required. The produce is sold either at the farm gate to local merchants or sent to Nakhon Pathom wholesale market, which saves the merchant's margin of generally 2 THB/kg.

North-Eastern region

Typical highland farm

On about 1.6 ha farmers in higher elevations of Wang Nam Keaow and Pak Chong districts grow leafy and fruit vegetables. Household labour consists of 1.5 - 2 full time labour equivalents and is supplemented by temporary hired labour at a daily wage rate of 100 THB/8h, except for pesticide applicators, who are paid 120 THB per day. Irrigation water from wells, and less frequently from surface water, is usually applied using a mobile sprinkler system. Crop rotations are rather elaborate and include hot chilli planted in the hot season followed by an intercrop of garlic and coriander. Land is rented for 13,000 THB/ha for a full year in order to avoid successive tomato planting on the same land.

Rain-fed farm

Quite different from other the other types, farmers under mainly rain-fed conditions practise comparatively extensive vegetable cropping on parts of their land in the dry season. Usually farmers utilise a small area of 1.6 ha of paddy land for which irrigation is available outside the dry season. Only a fifth can be irrigated during the dry season and is planted to fruit vegetables like yard long bean and cucumber. Besides paddy land, farmers own about 11 ha of rain-fed lowland mainly occupied by frugal year-round crops like cassava and sugar cane. Before replanting, on about a fifth of the land, yard long bean, angled gourd or cucumber are grown. In general the short time to harvest makes vegetables a very profitable crop and farmers want to expand the area planted but are aware of the danger of oversupply during their main peak harvest as many farmers apply the extensive system.

Land rent for rain-fed lowland in the area is only 1,900 THB/ha.

Peri-urban vegetable farmers

Vegetable producers in Mueang district around Nakhon Ratchasima city grow their crops like Bangkok peri-urban producers in a ditch and dike system on around 0.5 ha. Typical crops grown in rotations depending only on price expectations are spring onion, Chinese flowering mustard, Chinese kale and Chinese celery or cauliflower.

Northern lowlands

The northern lowland typical farm is – as generally for farms in Northern Thailand – comparatively small with only 0.64 ha owned land and is found in the lowland areas of both provinces covered by the workshop participants. Half of this land has been converted to a longan orchard, but trees are still immature and the land in between is used for year round vegetable production. While gravity irrigation is available for rice during the wet season, dry season crops are irrigated by ground water. Two household members work full-time, i.e. between 8 and 10 hours per day on six days per week. While hired labour is available at a wage rate of 120 THB/day, most labour peaks are covered by exchange labour.

The typical crops planted on paddy land after the rice crop during the cool season are onion, shallot and garlic, usually planted between November and March. Shallot is also planted by some farmers in June and July. Hot and large chilli as well as cauliflower, cabbage, celery, Chinese kale and Chinese flowering mustard, eggplant and spring onion are planted all year round as catch crops between fruit trees.

Northern highland specialized vegetable farm

The specialized vegetable producing farm is located in elevations between 700 and 1250 m above sea level and comparatively accessible by road. Farmers grow vegetables on sloping and partly terraced land of 0.36-0.8 ha. Piped water for irrigation is available through communal investment in a water reservoir and a pumping station. Family labour consists of two full time labourers and is complemented by two permanent hired labourers, exchange labour and temporarily hired labour. Wage rates for both temporarily and permanently hired labour are approximately 100 THB/day.

Due to the cooler climate, temperate crops such as chayote[43], cabbage, Chinese cabbage, mustard, iceberg and cos lettuce are preferably grown. Typically two crops of cabbage and up to three crops of Chinese cabbages are grown per year, whereas other vegetables are planted all year round. Input intensity in these farms is lower as farmers have participated in IPM-FFS. For

[43] Chayote is a cucurbit grown for its shoots which are used in stir fries and its fruit that can be eaten raw in salads or cooked. The crop grows is cultivated for more than one year and needs trellises.

marketing, farmers have formed a group in which one member is responsible for transport and sale at the wholesale market in Chiang Mai.

Northern highland mixed farm

The mixed farm type is characteristic of more remote (>50 km from provincial capital) areas with wet-season irrigation systems and (terraced) paddy fields at the bottom of mountain valleys. Farmers own paddy fields of 0.5-0.8 hectares in which vegetables such as cabbage and garlic are grown during the cool and dry seasons. Another 0.16-0.32 ha of upland is regularly planted to hot chilli. Family labour endowment is highest in this farm type at 2.3 full time labour equivalents. Hired labour is available at 100 THB/day for harvesting, but a premium of 100 THB/day is paid for pesticide applications.

Production technology is comparatively simple and vegetables are planted on small dams to allow for distribution of irrigation water by gravity inflow to the field. On the other hand, cabbage production involves rather highly toxic pesticides, as reflected in the wage premium for applicators.

4.3.3 Crop budgets

Besides a specification of the structure of typical farms, the main outcome of the workshops was the definition of the prevailing production technology in these farms, expressed as crop budgets. These were elicited by drawing up a crop schedule and adding the crop management practices in the categories: soil preparation, seeding and planting, irrigation, fertilizer application, pesticide application, weeding, thinning, hoeing, trellising, harvesting and packaging and any other crop-specific practices. Details on timing, the amount, type and cash cost of inputs applied, the labour requirement of each activity and the quantities harvested were recorded for each crop. After checking for completeness, the differences by season in terms of application rates and frequencies and yield levels were included as additional information.

The quantitative information from these crop budgets was disaggregated by month and replicated for different seasons according to the procedure provided by workshop participants, in order to obtain the technical coefficients for specification of a Leontieff production technology. Fertilizer application was aggregated according to nutrient content, whereas pesticide applications were aggregated according to both WHO acute toxicity class and environmental impact quotient of the respective active ingredients. The resulting technological and financial parameters are summarized in Table 23. In addition to technologies typical at the time of the workshop, alternative technologies documented in the literature based on on-farm trials have also been incorporated for inclusion in selected scenarios (see below).

Table 23: Characteristics of cropping activities in the TVSM – Average values over all seasons

									Pesticide use[45]						
		Duration	Yield		Variable cost[46]		Labour		EIQ	WHO I	WHO II	WHO III	unclass.	Nitrogen	
Crop	Technology[44]	months	t/ha	t/ha/month[47]	THB/ha	THB/t	md/ha	md/t	1/t	g/t	g/t	g/t	g/t	kg/ha	kg/t
Asparagus	Ratchaburi	12	15	1.22	298,830	20,491	1,688	116	15,616	0	34	120	214	1,053	72.2
Baby corn	"New" techn.	2	8	4.20	37,456	4,460	100	12	3,268	0	0	179	0	460	54.8
	Kanchanaburi	3	8	2.80	48,963	5,830	38	5	7,414	0	0	107	238	230	27.4
Brinjal	Kanchanaburi	10	52	5.25	143,431	2,732	890	17	1,598	57	0	0	0	134	2.6
Hot chilli	"New" techn.	7	13	1.79	86,081	6,887	500	40	0	0	0	0	0	125	10.0
	Pak Chong	7	13	1.79	160,963	12,877	501	40	4,993	125	106	0	0	326	26.1
	North. Lowland	8	19	2.34	23,153	1,235	1,644	88	25,435	0	0	0	613	128	6.8
Large chilli	North. Lowland	3	7	2.19	18,153	2,758	192	29	72,463	0	0	0	1,747	81	12.3
Cabbage	North. Highland	4	21	5.15	23,102	1,122	161	8	2,768	2	0	0	59	239	11.6
Chin. cab-bage	"New" techn.	2	21	10.63	95,328	4,486	102	5	1,116	0	0	0	40	209	9.8
	Kanchanaburi	2	15	7.56	46,888	3,102	75	5	4,619	17	21	119	7	200	13.2
	North. Highland	2	21	10.63	20,828	980	99	5	4,045	99	41	0	0	138	6.5
Cauliflower	North. Lowland	2	13	6.38	47,255	3,703	160	13	5,487	88	9	0	118	147	11.5
Chin. mus-tard	Pak Chong	2	8	4.06	47,766	5,879	141	17	2,800	103	0	0	0	167	20.6
	North. Lowland	2	8	3.80	31,215	4,105	106	14	21,396	437	0	0	74	152	19.9
	Nonthaburi	2	9	4.38	110,729	12,655	101	12	1,560	57	0	0	0	190	21.7
Chin. kale	"New" techn.	2	16	8.13	68,934	4,242	322	20	0	0	0	0	0	198	12.2
	Pak Chong	2	8	4.06	48,933	6,022	141	17	2,800	103	0	0	0	167	20.6
	North. Lowland	2	7	3.41	30,053	4,405	87	13	6,158	151	46	0	23	144	21.1
	Nonthaburi	2	9	4.38	110,729	12,655	101	12	1,560	57	0	0	0	190	21.7

[44] Technology classifies the source of information and refers to the typical farm data obtained in the expert workshops (cf. Chapter …) and secondary literature ("New" technology.), respectively.

[45] Pesticide use indicators are environmental impact quotient (cf. chapter 4 and Table …), and the quantity of active ingredient applied per metric ton of produce for WHO acute toxicity classes I (aggregate of Ia and Ib), II, III and unclassified pesticides.

[46] Exclusive of labour cost

[47] As crop duration differs substantially the output per area unit and month often provides a better indication of physical land productivity

Table 23 continued

									Pesticide use						
		Duration	Yield		Variable cost		Labour		EIQ	WHO I	WHO II	WHO III	unclass.	Nitrogen	
Crop	Technology	months	t/ha	t/ha/month	THB/ha	THB/t	md/ha	md/t	1/t	g/t	g/t	g/t	g/t	kg/ha	kg/t
Coriander/	Kanchanaburi	4	9	2.23	37,094	4,158	190	21	1,846	0	0	101	0	203	22.8
Celery	Nonthaburi	4	11	2.71	49,853	4,591	234	22	1,517	0	0	83	0	203	18.7
Chin. radish	Ratchaburi	2	27	13.54	79,379	2,931	143	5	2,679	0	44	0	0	241	8.9
	Kanchanaburi	2	10	5.24	41,130	3,922	86	8	10,460	27	276	143	0	160	15.3
Cucumber	NE-rainfed	2	20	5.2	162,994	8,150	216	11	1,020	1	0	29	0	255	12.8
	Ratchaburi	2	10	5.24	42,833	4,084	82	8	28,081	27	276	143	534	160	15.3
Ginger	North. Highland	5	18	3.65	18,694	1,025	267	15	4,333	0	0	0	77	191	10.5
Garlic	North. Lowland	3	7	2.37	21,813	3,063	243	34	3,939	70	48	0	166	375	52.7
Lettuce	Nonthaburi	2	11	5.35	61,421	5,739	94	9	223	0	8	0	0	219	20.5
Morning	Nonthaburi	1	8	8.2	26,805	3,310	183	23	296	0	0	0	23	83	10.3
glory	Ratchaburi	1	10	7.49	17,618	1,680	183	17	229	0	0	0	18	81	7.7
Pumpkin	Pak Chong	4	4	1.09	27,938	6,401	42	10	6,521	57	12	0	92	38	8.6
Shallot	North. Highland	3	12	4.15	183,063	14,711	246	20	172	0	6	0	0	299	24.0
	North. Lowland	3	9	3.12	23,610	2,522	286	31	7,847	0	18	0	487	248	26.5
	North. Lowland	3	17	5.54	109,006	6,561	194	12	6,889	126	23	0	113	270	16.2
Spring onion	Nonthaburi	2	17	8.31	85,869	5,168	215	13	7,220	0	75	90	263	170	10.2
	Ratchaburi	2	10	5.24	33,928	3,235	215	21	11,437	0	119	143	417	170	16.2
Tomato	Pak Chong	5	31	6.11	275,031	9,008	301	10	5,572	61	0	0	61	896	29.4
	North. Highland	5	31	6.11	220,219	7,213	301	10	5,572	61	0	0	61	896	29.4
Watermelon	North. Lowland	3	19	6.16	60,610	3,242	112	6	9,137	0	187	0	255	113	6.0
	NE-rainfed	3	8	3.00	24,260	3,105	154	20	8,022	204	0	0	0	41	5.2
Yard long bean	Nonthaburi	3	8	2.50	100,391	13,385	101	13	19,148	0	63	4	354	124	16.5
	Ratchaburi	3	8	2.50	105,531	14,071	101	13	19,148	0	63	4	354	124	16.5

4.4 Exogenous variables and policy instruments for analysis

The structure of the mathematical model outlined in the preceding part of this chapter has been constructed such that regional production activity levels, transportation activities and associated marginal costs and environmental indicators are determined endogenously. Owing to its nature as a partial equilibrium model and its scope limited to a sub-sector, income and hence demand, factor supply, policy measures and technical progress are exogenous factors, whose effect on the endogenous variables can be studied by parametric simulation in a comparative static framework. The purpose of this section is to define the exogenous variables and their relevant value range for partial analysis. More importantly, a likely scenario for the combination of supply and demand factors in the year 2011 is constructed on the basis of current trends for studying the composite effects of several exogenous changes on model results.

Exogenous variables can be grouped into the categories of demand and supply side factors and policy variables as shown in Table 24. Here, only policy options that directly affect production and transportation are considered, whereas those related to consumer preferences are explored by complementary studies (e.g.VANIT-ANUNCHAI, 2006).

Table 24: Exogenous variables

A. Demand side factors	B. Supply side factors	C. Policy variables

• Population growth
• Migration/urbanization pattern
• Income growth
• Export demand
	• Farmer mobility
	• Technical progress
	  o in production
	  o transportation
	• Agricultural wage rate
	• Fuel price
		• Nitrogen price
		  o Balance requirement
		• Pesticide
		  o taxation
		  o Maximum limits
		• Fuel taxation

4.4.1 Demand side factors

Dynamics on the demand side stem from various sources, whose effects interact. The main components are demography with population growth, migration and continued urbanization on the one hand and increasing incomes on the other. Even though urbanization has been shown to affect the structure of demand (HUANG and BOUIS, 2001), in the absence of quantitative information on this effect for the case of Thailand, extrapolation will be based on the small amount of information available for vegetable aggregates.

Thailand has experienced a substantial population growth since the beginning of the last century, and declining rates of growth were observed only from the 1980s onward (Figure 21). For the decade between 2001 and 2010, a national growth rate of 0.62% per annum is projected (Table 25), with faster growth in the Southern, Greater Bangkok and Central regions and significantly lower growth rates especially in Northern Thailand. For 2020, the total population is projected at

69.4 million (INSTITUTE FOR POPULATION AND SOCIAL RESEARCH, 2003), which corresponds to an average annual growth rate of 0.43% from 2011 to 2020.

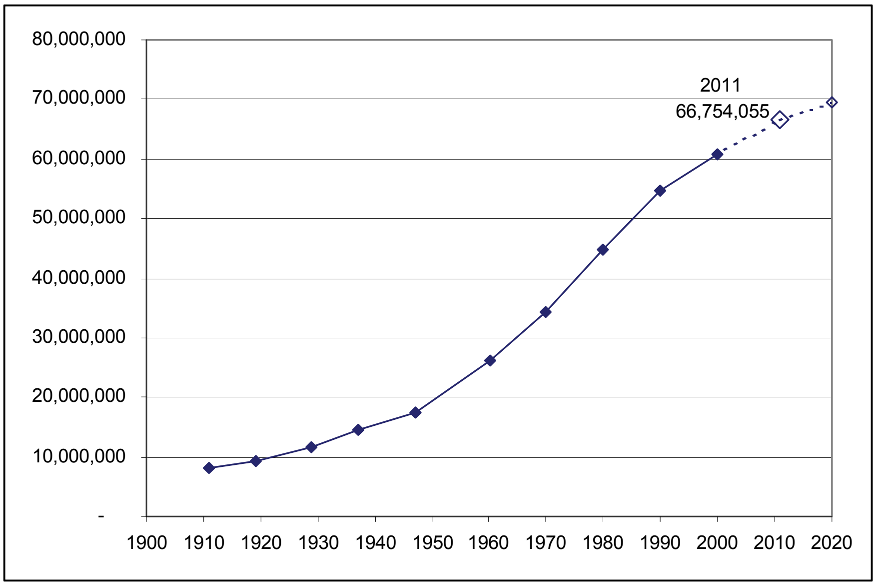

Figure 21: Population of Thailand between 1910 and 2000 and projections for 2011 and 2020

Sources: Population: (NSO, 2003b), Projection: (INSTITUTE FOR POPULATION AND SOCIAL RESEARCH, 2003)

Although the projections do not provide separate estimates for rural and urban population, the above average growth rates for Greater Bangkok and the Central region reflected in Table 25 suggest continuing urbanization.

Table 25: Population projection for 2011

Population in 1,000	2001	Projection 2011	Average annual growth rate
Greater Bangkok	10,547	11,307	0.70%
Central Region	10,581	11,348	0.70%
Lower North	5,956	6,208	0.41%
Upper North	6,062	6,277	0.35%
Northeast - western part	6,246	6,685	0.68%
Northeast - eastern part	8,020	8,530	0.62%
Northeast - northern part	7,059	7,491	0.60%
Southern Region	8,294	8,908	0.72%
Whole kingdom	62,765	66,754	0.62%

Source: (INSTITUTE FOR POPULATION AND SOCIAL RESEARCH, 2003)

In addition, per capita incomes have risen rapidly in the past decades in line with GDP growth, although with a short period of contraction during the Asian Crisis of 1997. Between 2001 and 2006, average annual per capita GNP growth was close to 5% for the whole country. Aggregating the estimated gross provincial product estimates of NESDB (2005) for model regions (Table 26) shows that economic growth was fastest in the central region with an average of 6.7% p.a., whereas it has been much lower (though on a high level) in Bangkok and neighbouring provinces. Gross regional product growth has been slowest in the eastern part of the Northeast and the upper North with growth rates below 3%. Assuming that GPP growth at the average rates continues until 2011 and entails proportional changes in per capita incomes, the overall increase until 2011 will amount to 26% to 92% of the baseline situation in the model regions and nearly 61% on average.

Table 26: Parameters for projecting vegetable demand by model region

Change in %	Real GRP growth rate[1)]	Per capita real income increase	Population growth[2)]	leafy vegeta-bles	fruit vegetables	Root- and bulb vegeta-bles
	Forecast			Expenditure effect[4)]		
	2001-06	2001-11	2001-11	$\varepsilon = 0.227$[3)]	$\varepsilon = 0.201$[3)]	$\varepsilon = 0.185$[3)]
Greater Bangkok	3.7	43.2	7.2	16.3	15.2	14.6
Central Region	6.7	91.7	7.3	24.3	22.2	21.0
Lower North	5.1	63.8	4.2	16.6	15.1	14.2
Upper North	2.8	32.2	3.5	10.3	9.5	9.0
Northeast - western part	2.9	33.6	7.0	14.3	13.5	12.9
Northeast - eastern part	2.3	25.9	6.4	12.1	11.4	11.0
Northeast - northern part	4.8	59.8	6.1	18.0	16.6	15.7
Southern Region	3.1	35.2	7.4	15.0	14.1	13.6
Whole Kingdom	4.9	60.9	6.4	18.5	17.0	16.1

Sources: [1)] Average annual growth rate of per capita gross regional product (NESDB, 2005)
[2)] Institute for Population and Social Research (INSTITUTE FOR POPULATION AND SOCIAL RESEARCH, 2003), [3)] SCHMIDT and ISVILANONDA (2004) [4)] Calculated assuming a semi-logarithmic form of the Engel-curve.

The sensitivity of demand to changes in income is commonly described by elasticity estimates. For vegetable demand in Thailand, estimates for the elasticity of the expenditure share for three vegetable sub-groups with respect to food expenditures are available (Table 12). Together with an estimate of food expenditure elasticity, these can be transformed into expenditure elasticities with respect to income[48], and are in the range between 0.185 and 0.227 for three groups of fresh vegetables and only 0.083 for dried and pickled vegetables.

Some caution is needed when the above mentioned elasticity estimates are used for extrapolating demand over a decade. Firstly, they have been estimated from cross-sectional data and therefore describe consumption patterns of different households in a given period and temporal dynamics are not captured in the estimate. Secondly, other socio-economic characteristics of households such as size, age structure, education and occupation which have been found to significantly influence vegetable demand (SCHMIDT *et al.*, 2004), may change considerably over a decade. In spite of these limitations, these estimates provide the order of magnitude in which vege-

[48]From definitions $\frac{\Delta c_v}{c_v} = \varepsilon_{v,c_f} \frac{\Delta c_f}{c_f}$ and $\frac{\Delta c_f}{c_f} = \varepsilon_{f,Y} \frac{\Delta Y}{Y}$, it follows that $\frac{\Delta c_v}{c_v} = \varepsilon_{v,c_f} \varepsilon_{f,Y} \frac{\Delta Y}{Y}$ or $\varepsilon_{v,Y} = \varepsilon_{v,c_f} \varepsilon_{f,Y}$. Hence, the elasticity of expenditures for vegetables with respect to income is the product of the original estimate of the vegetable

table demand responds to income changes, which is sufficient for developing a sensible range of demand scenarios. Moreover, they indicate that demand for leafy vegetables grows faster than for fruit vegetables, and root and bulb vegetable demand rises slowest when income increases and hence provide an indication of changes in demand structure.

Table 27: Elasticity estimates used for projecting vegetable demand

Aggregate	Share in food expenditures (%)	Elasticity of expend. share w.r.t. food expenditures	Implied elasticity of expenditures w.r.t. income
All vegetables[a)]	9.05	0.326	0.184
Leafy vegetables [a)]	2.92	0.449	0.227
Fruit vegetables [a)]	2.42	0.401	0.201
Root and bulb vegetables [a)]	1.12	0.330	0.185
Dried and pickled vegetables [a)]	2.21	0.036	0.083
	Share in total expenditures (%)	**Income elasticity**	
Vegetables and fruits [b)]	22	0.620	
Food, beverages, tobacco (1996) [c)]		0.653	

Sources: a) SCHMIDT and ISVILANONDA (2004), b) MANPRASERT (2004), c) SEALE *et al.* (2003)

Based on these estimates and assuming a semi-logarithmic Engel curve[49], expenditures for leafy vegetables will increase by 10% to 24%, for fruit vegetables between 10% and 22% and by 9% to 21% for root & bulb vegetables, depending on the region. If linear relationships were assumed, expenditures would increase by nearly 30% for leafy vegetables. The parametric analysis will therefore cover a range of increases between 2% and 50% for the various regions. In the absence of detailed data, a proportional change in demand for individual vegetables in the respective group is supposed.

4.4.2 Increasing fuel prices and transportation system

As mentioned above, Thailand's truck fleet has been judged outdated and an inefficient user of fuel, which makes transportation of vegetables expensive and sensitive to fuel price increases. Recent developments in the price of oil put emphasis on this parameter. Compared to 12 THB/l in the baseline year 2001, the rise to 28.7 THB/l in late 2007 (EPPO, 2007) corresponds to a real increase of 97% or an annual average of nearly 12%. It is assumed that between 2008 and 2011 the annual growth rate will be at 5%. As before, fuel prices are varied over a range while all other exogenous variables are held constant. In order to explore the range where model results converge, model simulations for fuel prices from the baseline level up to a 100-fold increase over the baseline scenario are shown. Fuel prices affect transportation most significantly, but also to a minor extent on-farm production costs through fuel used in soil preparation and pumping of irriga-

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tion water. For instance, the retail price of diesel has seen sharp increases, especially in 2005 and 2006.

4.4.3 Reduction target for the environmental impact of pesticide use

Secondly, because apart from yield growth that depends largely on plant genetic improvements, technical progress also involves improved crop management practices that reduce the excessive level of pesticide applications and to safeguard product quality and occupational and consumer health. The adoption of such technology has been far less than expected from the economic benefits for different reasons One factor that may play an important role is the high knowledge requirement associated with the new technologies. KRASUAYTHONG has modelled the adoption decision of cabbage farmers and found that in spite of intensive training in a farmer field school approach, the adoption of single practices or sets of practices in the crop-protection continuum depends on a variety of factors (KRASUAYTHONG, 2008). For a few crops the available technology has been incorporated in the model and the consequences for a few adoption rate scenarios are covered in this section.

4.4.4 A likely scenario for 2011

In order to simulate the supply response for a likely development scenario for the exogenous variables, the current trends of demographic development and economic growth are extrapolated for the year 2011, ten years from the baseline observation.

Table 28: Extrapolation of exogenous variables for the scenario "TVS 2011"

	2001	Average change rate 2001-2006	Applied Average annual change rate	2011
Population [a)]	62,774,538		0.62%	66,763,981
Per capita income (THB/month)	3,913 [b)]	4.1%[c)]	4%	5,792
Fuel price [c)] (THB/l)	12.1	12%	12% - 2007, then 5%	29.0
Agricultural wage [d)] (THB/month)	2,284	4%	4%	
Technical progress a) production	n.a.	n.a.	1.5% yield increase	1.16
b) transportation	n.a.	n.a.	-2% fuel consumption -1% loss reduction	
c) adoption of environmentally friendly technology	n.a.	n.a.	1%	
Vegetable farmer mobility	n.a.	n.a.	-1% for Greater Bangkok, -1% area loss	1.1

Sources: a) Population Projection for Thailand (Institute for Population and Social Research, 2003), (b) NSO (2003a), (c) NESDB (2007), (d) NSO (2008), (deflated)

Over the 10-year period, the above annual growth rates imply a real income increase of 48%, while regional population would grow by 3.55% (Upper North) to 7.25% (South). The resulting shift in vegetable demand then amounts to 58% (root vegetables in the upper North) and 71% (for leafy vegetables in the South) as shown in Table 26. Moreover, in the recent past, agricultural wages have grown much in parallel to average incomes by an average of 5.4% per year (NSO, 2008). Here it is assumed that the wage rate for hired labour increases at 5% every year between 2001 and 2011.

For technical progress that is expressed e.g. in terms of increased area yields or lower production cost, evidence on past developments is inconsistent. For East- and Southeast Asia, Weinberger and Lumpkin (2005) found average annual growth rates of 1.6% between 1970 and 2000. For Thailand, a comparison of averages over 1980-85 to 1995-98 reveals an annual yield increase of 3.2% over all crops and 4.3% for leafy vegetables. More recent agricultural statistics for selected crops report decreasing or stagnant yields for shallot and tomato between 1997 and 2006, but increases for garlic and large chilli. Therefore, a conservative assumption of a 1.5% annual growth in yields over all crops is used in this scenario.

The fuel price rise in 2004 and 2005 has created strong incentives to improve transportation efficiency. It is assumed that fuel requirement per tonne-kilometre can be reduced at an average rate of 2% per year, which corresponds to a 25% cut in 15 years (see e.g. UNEP, 1997). Even though empirical evidence is not available on the reduction of losses, a reduction in transportation losses at a rate of 1% per annum is considered in this projection.

The scenario combines changes in several variables whose individual effects might reinforce or compensate each other. Therefore, various combinations of factors will be analysed in order to ascertain the magnitude of individual effects. On the supply side, a constant resource endowment and regional distribution of farms except for a 1% annual decrease of vegetable land in Greater Bangkok and an out-migration of farmers at the same rate have been assumed. Technical progress is assumed to result in an annual increase of yield rates of 1%.

4.5 Summary

In this chapter the conceptual framework for a model of Thai vegetable supply (TVSM) has been laid out based on a mathematical programming approach. With respect to the purpose of this study and the availability of data, a model that considers eight distinct supply and demand regions connected by unconstrained transport activities under cost minimization approach was chosen. For calibrating the model to observed baseline activity levels a variant of the standard PMP approach was developed in order to accommodate the heterogeneous characteristics of vegetable crops, such as crop duration and multiple versus single harvests. The PMP formulation used here aims at calibrating aggregate seasonal and regional output instead of the level of individual activities, which is not available from statistical sources. By attributing a part of the variable cost of production to output aggregation activities the latter can be calibrated with a standard PMP approach.

Moreover, the data collection procedure for primary and secondary data to parameterize the model have been documented in this chapter. Besides secondary data sources, which were consulted for the definition of resource endowments and demand, the collection of primary data via expert workshops was discussed. The latter provided detailed information of the crop technology used in the field. These data were used to specify the technical coefficients of vegetable production activities in the model. Finally, the relevant scenarios for analysis by means of the developed model were identified, encompassing demand side changes, input price scenarios, technical change and policy interventions. The results of this analysis will be presented in the next chapter.

5 Results

This chapter reports the results of the study in three steps. First, the base scenario for the year 2001, which is used as a reference for the comparative static analysis, is presented in detail. While regional supply quantities have been calibrated to reproduce statistical averages, the baseline equilibrium provides new insights into the allocation of farm resources, volume and direction of transportation flows and aggregate environmental indicators. Secondly, the results of parametric simulations for several exogenous variables are presented for an assessment of their impact on the above indicators. These exogenous variables are subsumed under demand side factors such as income growth and demographic change on the one hand, and supply side factors such as energy prices, technical progress in production and transportation on the other hand. For each factor, parametric simulations have been conducted and model results are presented in terms of regional shifts in production, aggregate environmental impact and the effect on marginal cost of vegetable supply at the wholesale level. In a third step, selected conceivable policy interventions are assessed in terms of their impact on the relevant indicators, production structure and marginal cost of supply. The chapter concludes with the presentation of the compound effects of a conceivable future scenario for the year 2011 that combines likely changes in the parameter values mentioned above.

5.1 Base scenario of the model

The following section presents the results of simulation runs based on the Thai Vegetable Supply Model (TVSM) developed in the previous chapters, beginning with a simulation of the base period 2001. The model covers a subset of 23 vegetable crops representing a farm gate value of 85% of all vegetables in the period 1998-2000. The model is calibrated to reproduce the average production of 1999-2001 crop years as reported in the production statistics of the Department of Agricultural Extension (DOAE, 2001). The pattern of interregional trade and the importance of alternative production systems including environmental indicators are genuinely new results produced by the baseline run of the TVSM.

5.1.1 Regional distribution of vegetable production

Table 29 provides an overview of regional supply and demand in the baseline scenario. A total production of approximately 3.6 million metric tons at the farm gate level originates from similar shares of 24% and 23%, respectively, from the central (CE) and the upper northern (UN) model regions. The lower north (LN) and three north-eastern model regions (WNE, ENE and UNE) contribute around 10% each, while Bangkok Metropolis (BK) and the South (SO) account for 6% and 7% of vegetable supply, respectively. At the wholesale level, total demand for the vegetables considered in the model amounts to roughly 3.4 million metric tons and consists of about 3 million metric tons of domestic demand, about 0.3 million metric tons of net exports and 75 thousand metric tons of garlic, shallot and ginger required as seed stock[50]. The difference between farm production and total demand at the wholesale level corresponds to transportation and handling losses between these stages, which amount to an average of 5.2% of farm gate production.

Table 29: Regional supply and demand in the baseline scenario

Region		Production at the farm gate (1000 t)	Share (%)	Demand at the wholesale level (1000 t)	Share (%)	Share of regional supply consumed within the region (%)
Greater Bangkok	BK[51]	198	6	638	19	95
Central	CE	844	24	503	15	25
Lower North	LN	429	12	317	9	26
Upper North	UN	805	22	328	10	37
Northeast (west)	WNE	381	11	260	8	27
Northeast (east)	ENE	340	10	327	10	57
Northeast (upper)	UNE	324	9	289	9	66
South	SO	237	7	345	10	79
Net exports				293	9	
Seed stock[52]				75	2	
Total (Average)		3 560		3 375	100	(43)

In line with the distribution of population, the largest demand for vegetables of 638 thousand metric tons or 19% of national demand originates from BK. As a consequence 95% of local supplies are also consumed locally. Except for BK and CE, which account for 15% of demand, the remaining regions and net exports contribute up to 10% of demand each. Seed bulbs and tubers used as inputs for the production of garlic, shallots and ginger account for another 2% of total demand. The aggregate figures conceal, however, that even in the case of regional demand exceeding regional supply, vegetables are exported to other regions – depending on the seasonal pattern of supply. On a national average, 43% of production is consumed within the region of origin. This rate is much lower at around 25% in CE, LN and WNE. In spite of producing the largest net surplus, UN retains 37% of regional production to satisfy local demand. This is due to the fact that production conditions within the region are diverse and allow for year-round supply of all vegetable types, including those preferring temperate climate. Garlic, shallot and ginger are produced predominantly in the upper north (Table 30), whereas other regions have to import these commodities at all times.

The main annual vegetable flows are represented by arrows of proportional size in Figure 22a). Accordingly BK receives its main supplies of 344 thousand metric tons from the surrounding CE region. In addition, UN, LN, WNE, ENE and SO contribute 155, 129, 74, 50 and 23 thousand metric tons, respectively. Other significant flows take place, especially from UN to LN (145 thousand

[50] Seeds for other vegetable crops are imported or produced in specialized seed farms not considered in the model.
[51] In the remainder of this chapter, model regions will be referred to by their abbreviations.
[52] Ginger, garlic and shallot bulbs used in vegetable production.

metric tons) and CE (89 thousand metric tons) and moreover from LN (76 thousand metric tons) and WNE (78 thousand metric tons) down to CE. Conversely, 124 thousand metric tons of production from CE are transported to SO. In spite of numerous flows in opposite directions, the general direction of vegetable transportation is southward with Greater Bangkok and the southern peninsula as the main destinations.

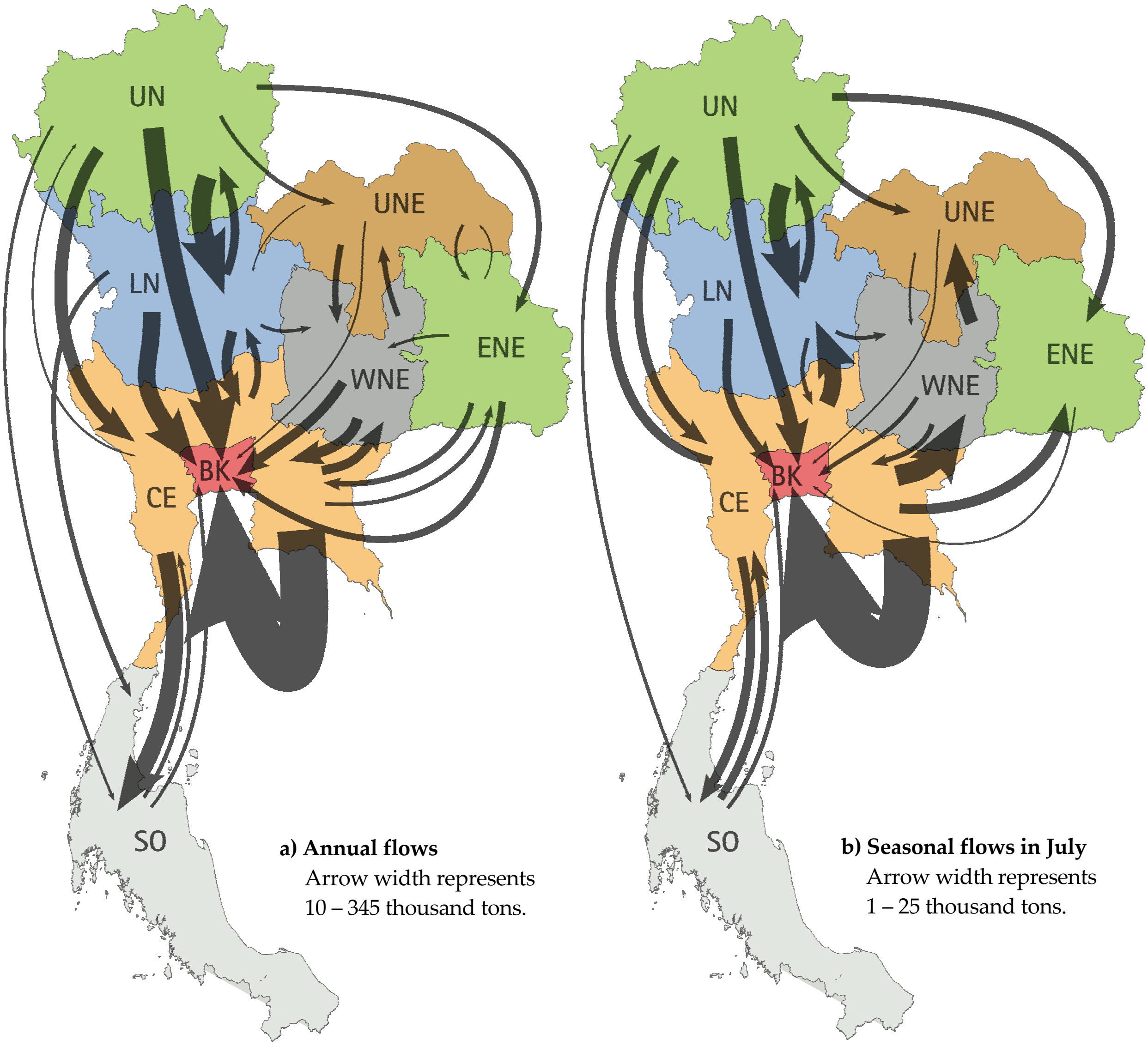

Figure 22: Major vegetable flows in the baseline scenario

In order to demonstrate seasonal differences, the flows during July are shown in Figure 22b. During this month of the rainy season, vegetable supplies from the UN, LN and WNE to BK play a relatively smaller role, whereas the central region continues to be the major supplier of the metropolis. It is moreover a supplier to the LN, WNE and ENE regions, where seasonal vegetable producers grow rice in the rainy season, whereas the specialized vegetable farms in the central region continue to supply vegetables throughout the year. Flows between central and southern regions are balanced during this time of the year, whereas over the year, the South receives nearly 100 thousand metric tons from the central region.

Concerning the composition of the regional vegetable crop portfolio, the model regions can be classified into a diversified group with a normalized Herfindahl index in the range of 0.04-0.06 and more specialized regions ranging from 0.09 to 0.13 (Table 30). The former group comprises CE, LN, UN and UNE regions, where vegetable production (measured in physical quantities of output) is distributed comparatively evenly over the modelled vegetable crops. By contrast, BK, ENE, WNE and SO show a higher degree of specialization in fewer crops. The main crops in BK are hot chilli, which approaches a quarter of local production, the leafy vegetables Chinese kale, Chinese mustard and morning glory (39%), yard long bean (6%) and lettuce (8%). For the latter, BK is the most important producer with a share of more than half of national supply[53].

Table 30: Production by crop and region in the baseline scenario

Unit: 1000 t

Crop	BK	CE	LN	UN	WNE	ENE	UNE	SO
Asparagus	2	41			1	2		
Baby corn	8	132	25	22	1		3	
Brinjal	2	23	7	1	2	3	6	3
Hot chilli	48	46	52	53	121	44	49	19
Large chilli	2	25	20	48	23	11	11	2
Cabbage	1	9	36	130	4	5	19	1
Chin. cabbage	2	23	31	61	15	13	13	5
Cauliflower	1	5	12	14	2	2	2	1
Chin. mustard	25	31	6	23	16	9	16	16
Chin. kale	36	84	33	14	22	7	13	16
Coriander/celery	7	20	7	6	9	5	6	1
Chin. radish	3	25	24		1	2	2	
Cucumber	8	105	20	9	25	10	7	33
Ginger		3	38	85			34	3
Garlic			6	92	2	2	2	
Lettuce	15			3		1	6	1
Morning glory	19	26	2	10	6	8	10	16
Pumpkin	1	55	7	37	8	23	15	21
Shallot			16	133	8	40	3	
Spring onion	7	47	3	17	37	13	28	4
Tomato	2	8	2	12	6	4	10	
Watermelon		53	74	28	63	120	51	70
Yard long bean	12	84	9	8	11	15	17	26
Total	**198**	**844**	**429**	**805**	**381**	**340**	**324**	**237**
H*[54]	**.09**	**.04**	**.04**	**.06**	**.11**	**.13**	**.04**	**.11**

In WNE, the specialization of seasonal producers in hot chilli results in a share of this crop at 32%. The second most important vegetable crop, watermelons, only make up half of this share (16%) followed by spring onions with a 10% share. In ENE, watermelons produced as an off-

[53] Note that iceberg and other lettuce varieties grown in high elevations of the upper north are not considered in the model and reduce the share of the lowland supplies in this vegetable group.

[54] The normalized Herfindahl index H* measures the concentration in a range from 0 to 1 and is calculated as

$$H^* = \frac{1}{1-\frac{1}{n}} \sum_{i=1}^{n} s_i^2 - \frac{1}{n}\,.$$

season crop after rice account for more than a third of total vegetable output of this region, followed by hot chilli (13%) and shallot production (12%), which traditionally has one of its centres in Sisaket and adjacent provinces. Finally, SO also exhibits a rather strong concentration on few crops due to climate conditions. Taken together, the *cucurbitacean* fruit vegetables watermelon, cucumber and pumpkin make up more than half of the region's vegetable production.

In contrast, production in CE is much more evenly spread over the different vegetable species. Baby corn – produced mainly for processing – holds the top share of 16% of regional supply, followed by cucumber (12%) and yard long beans and Chinese kale (10% each). The prevailing specialized vegetable farms in CE grow seasonally adjusted selections of vegetables all year round and hence contribute to a diversified aggregate supply. This pattern also applies to the LN and UN regions. UN especially takes advantage of large highland production areas in addition to the rice-*Allium* production system in the lowlands, which provide a wide range of production conditions. As a result, except for asparagus and Chinese radish that are produced primarily for processing and export and in Chinese kitchens, i.e. primarily close to Bangkok, all vegetables are produced in the upper North. The most important crops are shallot (17%), cabbage (16%), ginger and garlic (11% each) with respective shares of 17%, 16% and 11%.

5.1.2 Land and labour allocation

The seasonal nature of agriculture in general and vegetable production in particular lead to a corresponding fluctuation in land and labour utilization that is characteristic of the prevailing production systems. The most characteristic regional patterns of land utilization are presented in Figure 23. The top chart of Figure 23 reveals that out of a total farm land of 120,000 ha in about 70,000 vegetable farms in CE, only up to around 32,000 ha are utilized for vegetable production (hatched area). Most of the remaining farm land is used for rice and field crop production, with large parts of the area not utilized during the hot season between May and June. In contrast, a substantial share of cropped area between July and December extends on rented land. The area newly planted to vegetables oscillates around an average of 8,000 ha per month, while the total area utilized by vegetables amounts to 27,800 ha per month on average. This implies an average duration per vegetable crop of 3.5 months, slightly higher than in BK, where an average of 3.2 months is due to the larger share of short-term leafy vegetable crops.

The very different production system prevailing in UN is expressed in a stronger seasonal fluctuation of land use on the one hand and a different land allocation to vegetable and non-vegetable crops on the other. The farm land of 113,000 ha is fully used only in September, whereas at the end of the dry season in April just a quarter of farm land is in use. This pattern reflects the limited relevance of gravity irrigation in the region and explains the dominant land allocation to vegetable crops between January and April.

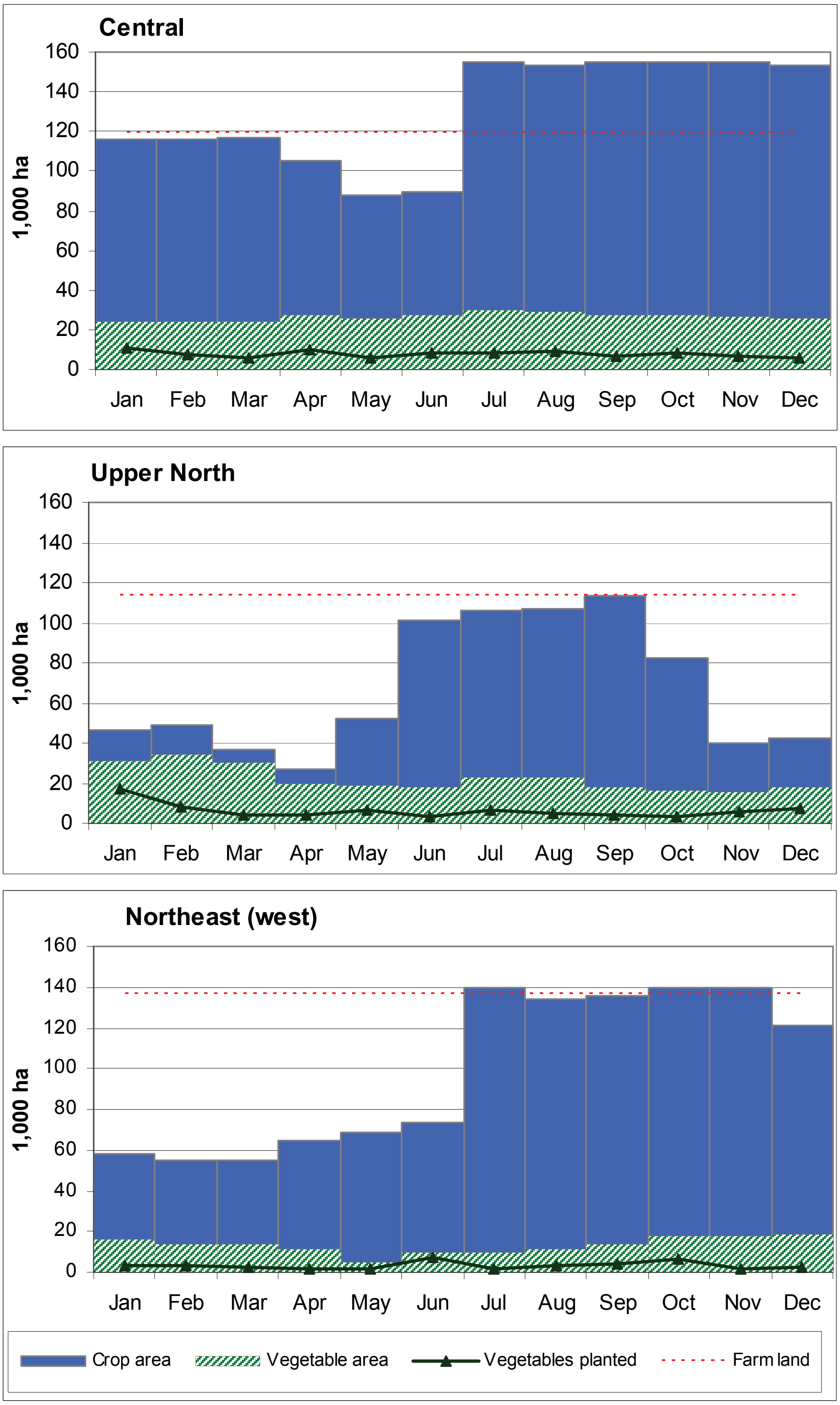

Figure 23: Seasonal land allocation in selected regions

During the cool and dry season, shallot and garlic planted in December and January can be grown with limited amounts of irrigation water and cover around a third of the planted area in vegetable farms, or up to 34,000 ha, until March. After the beginning of the rainy season in May and June, when paddy rice and glutinous rice have been planted, rice and field crop area exceeds vegetable area, which also decreases in absolute terms to around 20,000 ha and less between April and December. During this time only a fifth of the utilized area in vegetable farms is allocated to vegetable crops such as cabbage, hot chilli, ginger and an off-season crop of shallots. The seasonal pattern of land allocation in WNE vegetable farms shown in the bottom chart of Figure 23 is typical for all northeastern model regions, where only small areas are under irrigation and fewer specialized vegetable farms than in the central and northern regions exist. As a consequence, the land area of 137,000 ha in vegetable farms is fully utilized only during the wet season between July and November. In the dry season, less than half of the land is utilized – mostly by frugal crops such as cassava and sugar cane. Vegetables cover a significant share of around a fourth to a third of the cropped area only between January and April outside the main rice season. Vegetable area in absolute terms reaches a maximum of 18,000 ha in December and decreases down to its low of 4,700 ha in May when the dominant watermelon crop grown after rice has been harvested. Due to a lower water requirement compared to wet rice and higher value, vegetables are among the few crops economically viable within gravity irrigation schemes at low water levels during the dry season or outside where water is pumped from wells. During the rainy season, on the other hand, rice grown from July to November leaves vegetable area only a diminishing share leading to a pronounced seasonal fluctuation of vegetable production in the northeastern model regions.

Labour consists of a fixed endowment of family labour and an endogenously determined level of seasonal hired labour. Vegetable farms in CE have a comparatively large land to labour ratio of 1.42 hectares per family labour. As shown in the first chart of Figure 24, vegetable production alone uses between 71% and 116% of family labour, with the peaks between November and January. Total labour requirement varies between 82,000 and 165,000 person months and is covered by family labour only during July. At all other times, hired labour is important for covering labour peaks such as in November when high vegetable output and rice harvest coincide[55].

In UN a small average farm size leads to a low land/labour ratio of 0.83 hectare per family labour, which is reflected in an abundant family labour endowment. Also, the importance of exchange labour reported in the expert workshops (cf. chapter 4) corresponds to the abundant labour endowment and probably indicates slack labour. The resulting family labour capacity for vegetable and field crop production fluctuates between 140,000 person months during the cool season and a minimum of around 125,000 person months in July, which is due to the harvesting period for longan grown by some of the vegetable farmers. In contrast with the labour requirement of vegetables, field crops and rice use only a negligible amount of labour most of the time. From May to October, rice is grown on up to two thirds of the land in vegetable farms of the lowlands. This leads to strong peaks in labour requirement of the rice and field crop aggregate in June and October, the only period, in which labour is not mainly used in vegetable crops.

[55] The single peak during November might be overstated because rice and field crop technology is modelled in a less detailed manner, which might underestimate the flexibility of resource allocation to these crops.

In WNE a land to labour ratio of 1.75 hectares per family labour reflects a much larger farm size observed throughout the northeastern regions. Even though only a relatively small area is under irrigation and hence less intensively used, family labour is scarce most of the year in the vegetable farms of WNE and slack labour is observed only in the early rainy season before rice is planted in July and August. Most of the time, labour requirement of vegetable crops exceeds that of field crops and reaches up to 96% of all labour utilized in January. Hired labour is required in nine months of the year, with a peak during rice harvest in November.

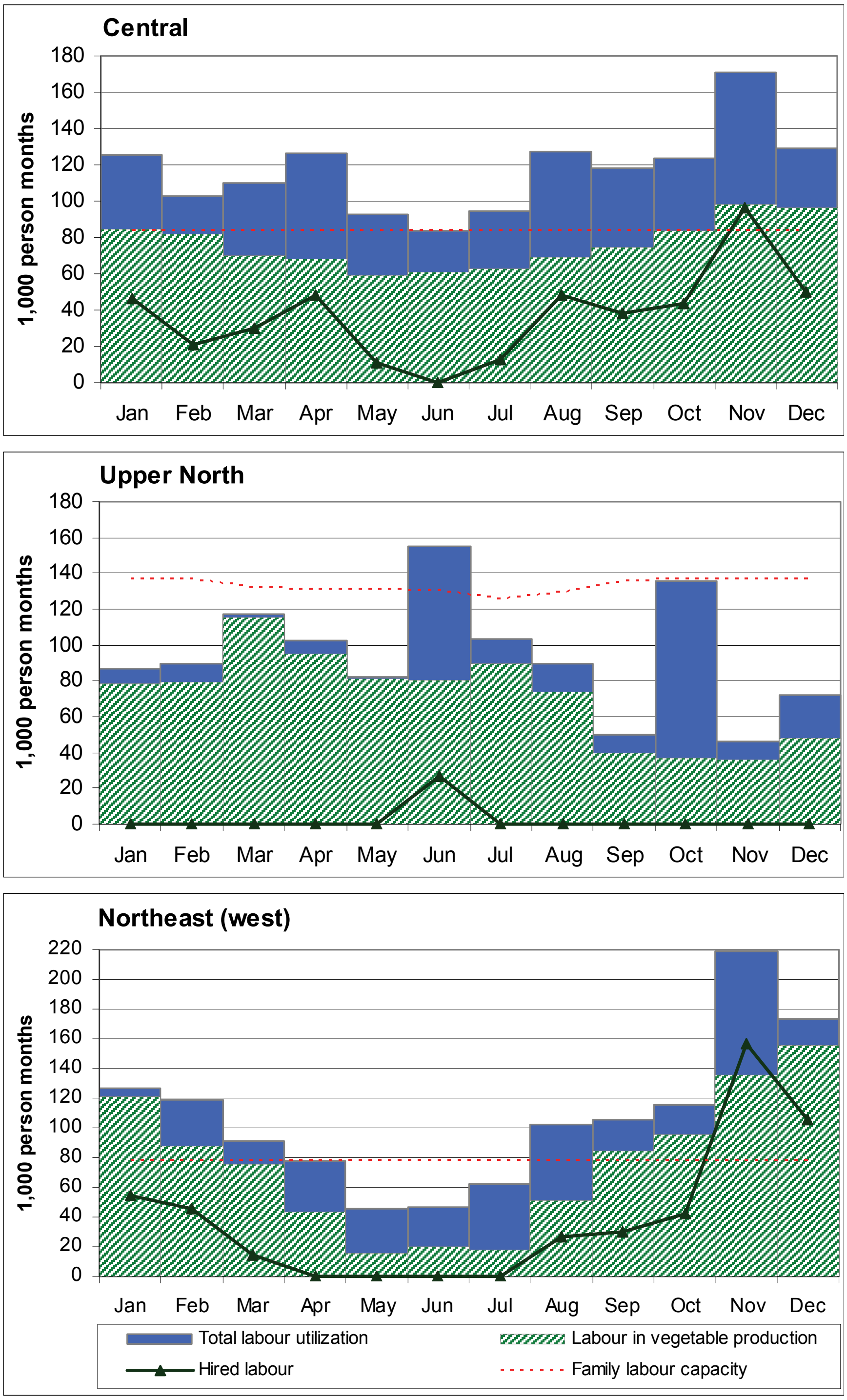

Figure 24: Seasonal labour allocation in selected regions.

The examples of regional land and labour utilization presented above are characteristic and are also found with some variation in the remaining model regions[56]. The resource utilization in LN follows the pattern of UN with a main rice crop in the rainy season and an off-season crop on a smaller area between November and February. Since farms are less specialized in vegetables, labour supply remains comparatively abundant in spite of a land/labour ratio of 1.44 hectares per person that is higher even than that of CE. The land use pattern of WNE is found throughout Northeastern Thailand, although with lower shares of vegetable area in ENE. BK and SO are similar in land use pattern to CE, though at a much smaller scale. As a consequence the lowest land/labour ratios at 0.63 and 0.65 hectares per family labour in BK and SO, respectively, labour is scarce only in certain months.

The general observation is that land allocation follows distinct seasonal patterns resulting from agro-ecological conditions and the availability of irrigation. In this respect, vegetable production has a smoothing effect on land and labour use, because even in the absence of public irrigation schemes, dry season production is possible. While land used for vegetables takes only a small share of the land endowment of the vegetable farms considered here, the employment effect is much more pronounced. The largest share of labour in all regions is consistently allocated to vegetable production.

5.1.3 Environmental indicators

Quantitative information on the environmental impact of the equilibrium production programme is determined by calculating aggregate indicators based on technical coefficients and activity levels of individual production activities. First, indicators of nitrogen application in vegetable production are compared to relevant benchmarks. Then the pesticide use in absolute and intensity terms is quantified. The direct effect of pesticides on applicators and farm workers is determined by the quantities of active ingredient applied, and the number of sprays calculated within the model separately for WHO acute toxicity classification[57]. Moreover, the environmental impact of pesticide use is determined on the basis of the environmental impact quotient (EIQ), which considers acute and chronic effects on farm workers, consumers and aquatic and terrestrial ecosystems as a comprehensive measure of pesticide side effects.

5.1.3.1 Nitrogen use

The external application of nitrogen in vegetable crops is accounted for by aggregating the nitrogen application rates of vegetable production activities as defined for the respective production systems. In order to provide a measure of intensity of nitrogen application with respect to area, the total supply of nitrogen is related to the area covered by vegetables in a calendar year. This approach implies that when year-round vegetable production systems prevail, nitrogen

[56] Reported in Figure 74 on p. 225 in the appendix

[57] See WHO (2005)

supply of subsequent crops is accumulated, whereas the nitrogen applied to a single crop is considered in seasonal vegetable production systems.

For producing approximately 3.6 million metric tons of vegetables, about 60,400 metric tons of nitrogen are applied either in the form of manures or mineral fertilizers. This corresponds to an average of 416 kg N ha^{-1} of vegetable land, a reasonable average value compared to case studies in the literature, which find an average intensity of e.g. 550 kg N ha^{-1} for an intensive production area in Southern Thailand (CHATUPOTE and PANAPITUKKUL, 2005) and ranges between 340 and 1280 kg N ha^{-1} for hot chilli and five consecutive crops of Chinese kale in one year (KAMNALRUT *et al.*, 2000, p. 85). As shown in Table 31, the level of regional nitrogen use generally varies with the respective supply share, but nitrogen use intensity is also highly variable. Low nitrogen intensity is observed in the northeastern regions, where seasonal vegetable production plays a role, and in the South. The highest intensity of nitrogen use prevails in CE as a result of substantial shares of asparagus and baby corn production, ranking first and third in terms of nitrogen requirement at 70kg N t^{-1} and 27.4 kg N t^{-1} respectively[58]. In addition, important crops such as Chinese kale are produced by more nitrogen-intensive technology compared to other regions. This higher intensity is in line with a long history of intensive vegetable production practices in the central region, which require higher levels of external inputs than under more balanced crop rotations and soil fertility enhancing practices. This applies by analogy to BK, where similar production conditions and – due to its closeness to the centre of demand – a high cropping intensity prevail. Here leafy vegetables like Chinese kale and Chinese mustard as well as hot chilli contribute to high nitrogen application rates. Although vegetable production in UN requires more nitrogen per metric ton of output (e.g. 57 kg N t^{-1} of garlic) than in Greater Bangkok, the intensity per land unit is lower as a result of the cropping system with successive vegetable and rice crops. In Bangkok on the other hand, specialized vegetable farms grow subsequent vegetable crops in the same plots, which lead to a higher annual nitrogen supply per unit of land.

Table 31: Regional nitrogen use and intensity in the baseline scenario

Region	Amount of nitrogen used (metric tons)	Nitrogen use intensity (kg N ha^{-1})	Nitrogen use per unit of output (kg N t^{-1})
BK	3,514	523	17.7
CE	18,243	607	21.6
LN	5,799	391	13.5
UN	15,715	454	19.5
WNE	5,552	305	14.6
ENE	4,511	262	13.3
UNE	4,123	300	12.7
SO	2,962	299	12.5
Total/average	60,420	416	17.0

[58] Technical coefficients are reported in Table 23 on p100.

Regions with low nitrogen intensity, such as ENE, UNE and SO are characterized by a large share of fruit vegetables in their portfolios (65%, 51% and 59%, respectively), which in general require less nitrogen than leafy vegetables. Watermelon presents an extreme example, which is on average produced with around 6 kg N per metric ton of output of the watery vegetable. This contributes to very low nitrogen use in relation to production and area in ENE and UNE, where 35% and 15% of total vegetable output consist of seasonal watermelon crops in rotation with rice and field crops analogous to the case of UN (see also Table 30 on p. 112).

5.1.3.2 Pesticide use

The absolute level of pesticide use in the baseline scenario is presented in Table 32. Over all WHO toxicity classes, a total of 1,512 metric tons of active ingredient is used for production of 3.6 million metric tons of vegetables. More than two thirds of this amount are considered "unlikely to present acute hazard in normal use" according to WHO classification (World Health Organization, 2005, p. 31). Another 94 metric tons (6%) belong to the slightly hazardous class III and about 216 metric tons (15%) of applied active substances are classified as moderately hazardous (II). A significant share of 9% of pesticides applied in vegetable production are categorized as highly hazardous (Ib) pesticides. A remainder of 16.6 metric tons (1%) belongs to the extremely hazardous group (Ia) and includes the active ingredients parathion-methyl and mevinphos, of which the latter has been banned in Thailand since May 2000 (DANIDA, 2006). Nevertheless, in two expert workshops, the use of mevinphos was still considered part of the typical production technology for brinjal and cauliflower. Parathion-methyl was used for growing cabbage, Chinese cabbage, cucumber and yard long bean in some locations at the time of the survey. It has been banned in Thailand since May 2004, but was still in use by vegetable farmers in Northern Thailand after the ban, as more recent surveys have shown (DANIDA, 2005b, a).

Table 32: Absolute pesticide use and environmental impact in the baseline scenario

Region	Active ingredient by WHO acute toxicity class (t)						Average sprays per week	Environmental impact[59]
	Ia	Ib	II	III	unclass.	total		
BK	0.1	17.2	4.2	4.4	53.1	79.0	1.25	2,980
CE	1.5	34.1	57.1	48.7	211.0	352.3	1.85	11,458
LN	4.4	10.3	24.3	6.2	132.0	177.2	1.91	5,958
UN	8.8	23.1	20.3	4.2	199.5	256.0	1.56	9,228
WNE	0.3	16.9	27.8	11.6	194.1	250.7	1.76	8,699
ENE	0.5	8.8	37.3	5.7	115.5	167.8	2.51	5,338
UNE	0.7	12.0	17.5	7.2	111.7	149.1	2.06	5,110
SO	0.3	6.8	27.2	6.1	56.0	96.3	2.34	2,959
Total	**16.5**	**129.1**	**215.8**	**94.2**	**1,072.7**	**1,528.4**		**51,729**

[59] Environmental impact quotient applied to all vegetable production according to equation (4.33), p. 84.

Because statistics on pesticide use in vegetable production are unavailable, only a crude comparison with anecdotal evidence is possible. A pesticide market study in 1994 found that 21% and 18% of the market volume of fungicides and insecticides was used in vegetable production, respectively. No details for other pesticide groups were given (JUNGBLUTH, 1997, p. 8). Application of the market value shares to the physical quantities imported in 2001[60], yields a total of about 2,600 metric tons used in vegetable production. Considering further the ratio of 72% of vegetable area covered by the model to total vegetable area, an absolute insecticide and fungicide use of 1,900 metric tons would be expected for the model farms. This crude approximation is likely to overestimate pesticide use in vegetables, however, as pesticides used in horticultural specialty crops are likely to be more expensive on average than those applied to the bulk of field crops because of tighter requirements of short waiting periods and smaller trade volumes. As other factors also might have changed the share of pesticides used in vegetables, the TVSM total of 1,528 metric tons of active ingredient remains plausible.

In terms of absolute quantities, by far the largest amount of active ingredients is not listed in the WHO acute toxicity classification or is considered as unlikely to be hazardous. Among these substances, sulphur widely used for its fungicidal effect, dominates. The average frequency of pesticide applications per week is lowest in BK, where the production of leafy vegetables such as Chinese kale and Chinese mustard, morning glory and lettuce dominate. On the one hand, these crops are characterized by a short cultivation period, in which the waiting period between the last pesticide application and harvest makes up a relevant part of the cultivation period. On the other hand, production technology of the typical Nonthaburi farm for Chinese kale and Chinese mustard involves only one spray as opposed to between two and seven sprays practised in other locations. Exposure of farm-workers to pesticides is thus lower than in other regions, although about a quarter of active substances applied is classified as highly hazardous. A slightly higher average spraying frequency is observed for the upper north, where ginger and shallot are produced with an average of only three sprays per crop, whereas production technology in the lowland areas of the North requires eight sprays, of which seven are from the least toxic group, however. Much higher spraying frequencies above two times per week on average prevail in ENE, UNE and SO. Fruit vegetables such as watermelon and hot chilli are major crops here and involve more frequent sprays. Moreover, production technology for chilli is more pesticide-intensive than e.g. for chilli production in the Northern lowland farms. In the Northeast, production of yard long beans involves about 10 sprays of class Ia and Ib pesticides, which results in a substantially higher exposure of farm workers in this crop to highly hazardous substances.

A focus on the total environmental impact (EI) as a weighted indicator for environmental and health risks from pesticide use reveals that BK and the SO carry the smallest burden when compared to the absolute impact computed for UN and CE region. On the other hand, these regions are much larger and the side effects are distributed over a greater area and therefore less concen-

[60] See Figure 12, p. 42.

trated than in BK especially, a fact that becomes apparent when the intensity of pesticide use with respect to vegetable area is explored (Table 33).

Table 33: Intensity of pesticide use per vegetable area and year

Region	Active ingredient applied to vegetables per year and unit of vegetable land (kg ha^{-1})						Average environmental impact per hectare
	Ia	Ib	II	III	unclass.	total	
BK	0.0	2.6	0.6	0.7	7.9	11.8	444
CE	0.0	1.1	1.9	1.6	7.0	11.7	381
LN	0.3	0.7	1.6	0.4	8.9	11.9	402
UN	0.3	0.7	0.6	0.1	5.8	7.4	267
WNE	0.0	0.9	1.5	0.6	10.7	13.8	478
ENE	0.0	0.5	2.2	0.3	6.7	9.8	310
UNE	0.0	0.9	1.3	0.5	8.1	10.8	371
SO	0.0	0.7	2.8	0.6	5.7	9.8	302
Average	0.1	0.9	1.5	0.6	7.4	10.5	356

According to model results, 10.5 kg of active ingredient per hectare of vegetable land are applied on national average. This includes all pesticides used in vegetable crops in one year on the land that is planted to vegetables at least once per year. The figure is lower than the weighted average of dated reports on insecticide intensities in vegetables, tomatoes, garlic, onion and chilli peppers, which reports 13.3 kg/ha of insecticide application (THAI-GERMAN PLANT PROTECTION PROGRAMME, 1993), but still in a plausible range. Among regions, pesticide use intensity differs substantially, with highest rates in the WNE, followed by CE and BK. The composite environmental impact with respect to vegetable area leads to a similar ranking and below average levels of impact per unit of land are observed in LN, ENE, SO and UN. This distribution is explained to a major extent by the share of seasonal vegetable production, which is comparatively high in UNE, ENE, and especially UN, where seasonal production of *Allium* species after the main rice crop is the prevailing production system.

The general picture highlights BK, CE and WNE as important producers and at the same time very intensive users of pesticides in terms of both quantity of active ingredient applied and environmental impact. Their common feature is that they are major year-round suppliers of vegetables for the capital city, whereas other regions have substantial shares of seasonal vegetable production in rotations with rice and field crops. In those areas, pesticide use intensity is lower as a direct consequence of fewer vegetable crops planted on a given piece of land and substantially lower intensities of external input use in rice and field crops.

5.1.3.3 Fuel requirement of transportation

The level of intra- and interregional transportation activities is endogenously determined by vegetable and month, and can be aggregated in a measure of total quantity times distance transported (tonne-kilometres). In total, roughly 1 billion tonne-kilometres are required to match wholesale market demand and farm gate supply in the baseline scenario, i.e. a metric ton of vegetables is transported about 293 km on average (Table 34). At the assumed transport rate of 7.5 l per 100 tonne-kilometres, a total of 78.3 million litres of diesel is required. When considering the transport distance for the supply from individual regions, one expects produce from BK to travel the shortest distance and supplies from UN to cover the longest distance, which is confirmed by model results. More surprisingly, the average transport distance of produce from the CE of 262 km is high compared to that of BK (60 km), even if the underlying within-region distance of 104 km for CE is considered, given that 65% of the produce remains within the region itself or the enclosed BK region. On the other hand, 15% of the produce goes to SO to supplement regional supplies there, involving an average transport distance of about 800 km.

As mentioned above, the large volumes of interregional transport are required to match seasonal demand and supply by supplementing temporary shortfalls in local supply with imports from other regions. The seasonal pattern of supply and demand is therefore an important determinant of the fossil fuel requirement of vegetable supply. The second crucial component is physical transport efficiency, i.e. the fuel requirement per tonne-kilometre, for which literature suggests there is still room for improvement (POLLUTION CONTROL DEPARTMENT, 2004, p. 26).

Table 34: Transport volume and fuel use by region

Region	Transport volume (1000 t km)	Average distance between origin and destination (km)	Fuel requirement (1000 l)
BK	11,498	58	866
CE	221,147	262	16,613
LN	143,416	334	10,762
UN	367,024	456	27,543
WNE	94,305	247	7,079
ENE	89,594	263	6,726
UNE	57,243	177	4,297
SO	59,723	252	4,484
Total	**1,043,949**	**293**	**78,370**

5.2 Effects of exogenous variables on supply response

5.2.1 Demand factors: Income and population growth

In order to simulate the supply response for conceivable scenarios of income and population growth, the current trends of demographic development and economic growth have been extrapolated for the year 2011, ten years from the baseline observation. According to the assumptions discussed in chapter 4, incomes will increase by about 60% in this period and population by 6.4%. As a result, domestic vegetable demand will grow by about 13% on a national average and between 7.5% and 22.4% in the regions (Table 35). If a linear instead of a semi-log functional form is assumed for the Engel curve, demand could even increase by 30% for leafy vegetables in the Central region. Except for considering different income elasticities for three vegetable groups, the structure of demand and its seasonal pattern are assumed to be constant. For assessing the effect of such changes in demand, the likely development scenario has been parameterized and supply response to gradual changes ranging from 50% to 200% of the predicted scenario is analysed in this section. For simplicity of presentation, in some cases only a comparison between baseline and the likely demand scenario in 2011 is presented.

Table 35: Expected growth in regional vegetable demand for a likely scenario in 2011

Region	Baseline demand (1000 t)	Likely change for 2011 (%)	Change in quantity (1000 t)
BK	637.9	12.8	81.9
CE	503.0	22.4	112.6
LN	316.6	15.1	47.7
UN	328.0	8.2	26.8
WNE	260.4	9.3	24.2
ENE	327.2	7.5	24.5
UNE	289.5	14.8	42.8
SO	345.0	9.8	33.9
Total domestic demand	3,007.6	13.1	394.3
Net exports	292.7	-	-
Total demand	**3,300.2**	**11.9**	**394.3**

Source: Author’s calculation based on assumptions in section 4.4, p. 102.

Regional distribution of vegetable production

The model adapts to increased demand by adjusting domestic supply – by allocating more land to vegetable crops or by increasing the share of more intensive cropping techniques. Furthermore, a reduction of transport distance and transport-related losses through shifting production closer to the centres of demand is possible. As discussed in chapter 4, land is not a binding constraint in the model because vegetable production uses only a minor share of total agricultural land and is very competitive in terms of returns to land and labour if compared to rice and field crops. In all model regions, there is still a large area planted to such crops so that either within farms or by renting additional land, vegetable area can be increased. As a consequence, the supply of vegetables increases in all regions as shown in Figure 25. The steepest increase takes place in CE as that has been the most important vegetable supplier in the baseline situation. However, the demand increase by 22%, which is the most pronounced among all regions, outpaces supply growth. As a consequence, net transports out of the region decrease (Figure 26). The second largest producing region, UN, has been a major net supplier to other regions before, and having one of the lowest growth rates of regional demand, becomes an even more important supplier for demand outside the region with additional transports to other regions of nearly 70,000 metric tons in the likely 2011 scenario. Moreover, production in WNE, and to a lesser extent in ENE, grows more than regional demand. For southern Thailand, a growth of supplies just ahead of a below-average demand growth is found. Not surprisingly, even the comparatively moderate increase of demand in the capital city and its vicinity cannot be matched by local supplies, which are predicted to grow by 10% when demand grows by 12.8%. However, as local supplies in absolute terms were far below local demand from the outset, additional supplies from other regions of more than 60,000 metric tons are required to satisfy forecasted 2011 demand levels (Figure 26). In UNE also, increasing supplies from other regions are required to satisfy a comparatively quickly rising demand.

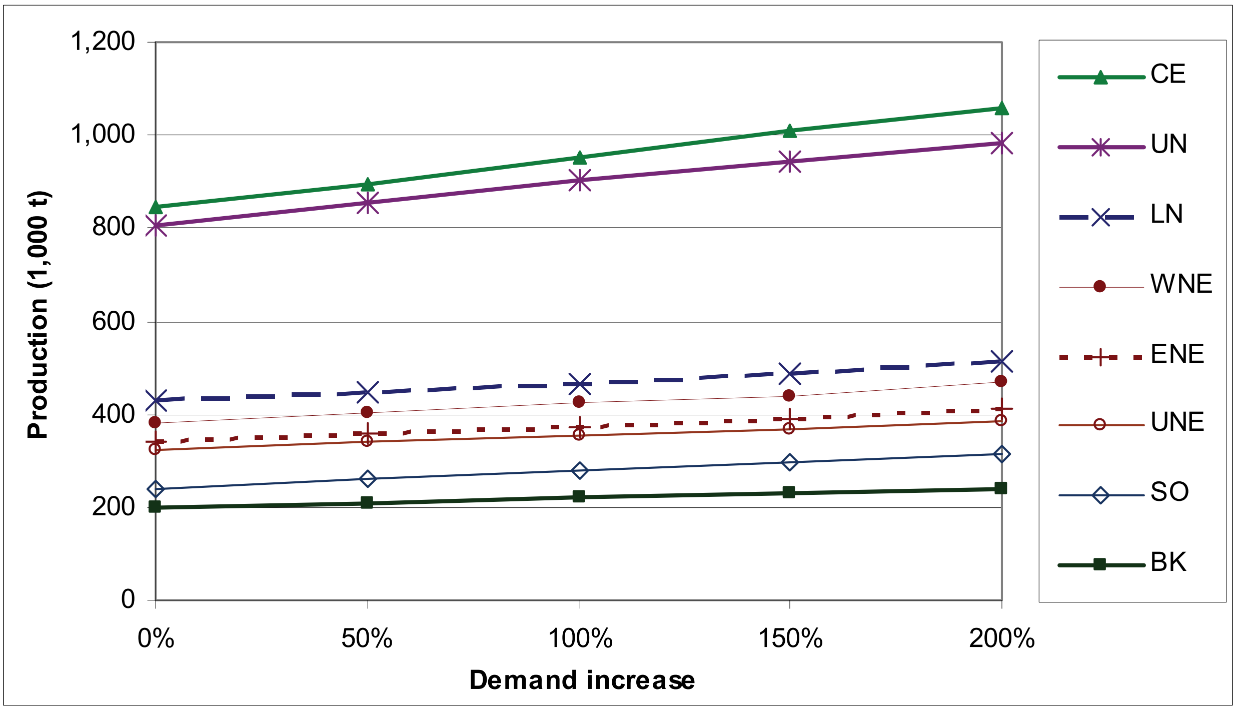

Figure 25: Vegetable supply by region as a function of growing demand[61]

[61] 100% refers to the demand level forecast for 2011.

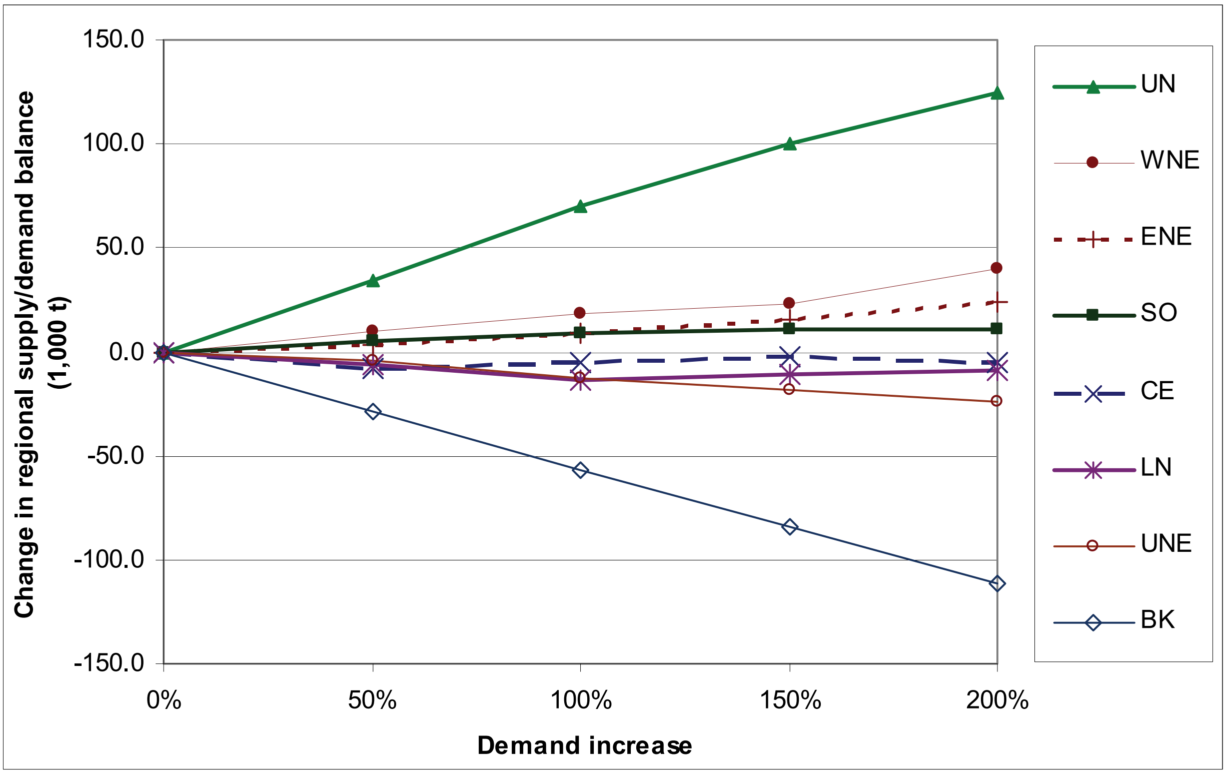

Figure 26: Change in regional supply/demand balance as a function of growing demand

The change in regional vegetable net-deficit or net-surplus shown in Figure 26 highlights the dependence of BK on additional imports when urban demand grows. Out of the additional demand of 82,000 t in the forecast 2011 scenario, about 20,000 metric tons are satisfied by increasing local supply. Also, to a lesser extent, UNE, LN and even the largest producer, CE, depend on additional supplies from other regions when demand increases. At the other end of the scale, the net surplus from UN increases more than the deficit in BK and therefore together with WNE and ENE covers increasing deficits in other regions. The change in vegetable flows for the demand scenario forecast for 2011 is shown graphically in Figure 27. It reveals that interregional transports increase notably for only a few combinations of regions. As expected, UN is an important supplier of additional 25,000 t and 22,000 t to CE and LN, respectively as well as about 15,000 t to BK. Additional supplies for the latter come from CE (+26,000 t) and SO (+12,000 t). Interestingly, the additional surplus from WNE (+12,000 t) and LN (+12,000 t) are directed only to CE. Transport of vegetables between CE and SO increases in both directions: by 14,000 metric tons from CE to SO and 16,000 metric tons vice versa in order to satisfy the seasonal demand patterns.

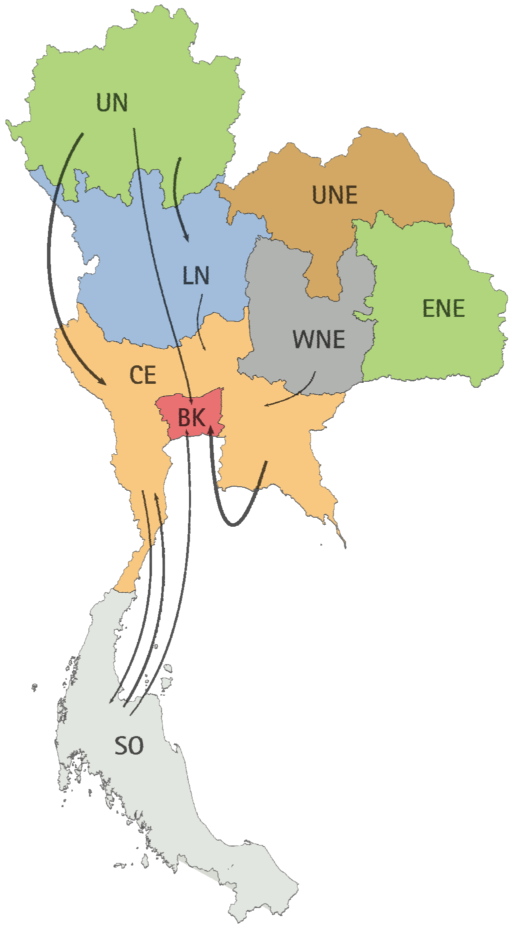

Figure 27: Change in vegetable flows for the demand forecast 2011[62]

Although the interregional trade volume increases, especially for the long distances between UN on the one hand and CE and BK on the other, the average transport distance increases only slightly from 293 km in the baseline scenario to 298 km. This minor change reflects the slight change in the regional supply shares as shown in Table 36. Even though demand grows at unequal rates, supply shares change by less at most 0.4 percentage points. Although regional demand grows less than national average, the supply share from SO increases the most, followed by CE. The contribution to national vegetable supply from LN and BK decreases even though demand grows faster than the average in these regions.

Table 36: Regional supply shares in the base and demand 2011 scenarios

Supply shares in %	BK	CE	LN	UN	WNE	ENE	UNE	SO
Baseline	5.6	23.7	12.1	22.6	10.7	9.6	9.1	6.7
2011 demand scenario	5.5	24.0	11.7	22.7	10.7	9.4	8.9	7.1

In summary, a pattern of regional supply reacting less to intra-regional than to national changes in demand emerges, and existing net-surplus/net-deficit roles of the respective regions become more pronounced when demand increases. In the analysed scenario of a more or less

[62] Arrow width is proportional to additional transport flows. The scale is identical to that of Figure 22a) on p. 111 and arrow widths represent 10-43 thousand metric tons.

proportional demand growth within regions and unchanged seasonal pattern, regional supply grows proportionally in general. Besides a rather constant pattern of supply shares from model regions when regional demand grows at different rates, the share of vegetables consumed within the same region of production as compared to total demand also remains nearly constant. This implies that, at least within the bounds of model specification, economies of scale are not observed with demand growth.

Marginal cost of vegetable supply

Whether vegetable supply growth is attained by intensification or allocation of more land to vegetable production, both mechanisms affect the marginal cost of production. Intensification involves higher levels of external inputs and unless planted area is extended in slack periods, allocating more land to vegetable production comes at the opportunity cost of foregone field crop production. Also, slack labour available in some periods in the baseline situation might be used up by additional production and require additional hired labour. Finally, average transportation distance has been shown to increase (slightly), which adds to increasing marginal costs of supply. As cost components, resource capacities differ across crops and regions, respectively, the effect on marginal cost of supply in the central market is expected to differ among crops. For selected crops, the effect of demand growth on the marginal supply cost at the BK wholesale level is shown in Figure 28. As regional markets are connected by unconstrained transportation activities, price differences are determined by the specific transportation cost. It is therefore sufficient to concentrate on changes in marginal cost in one regional market only.

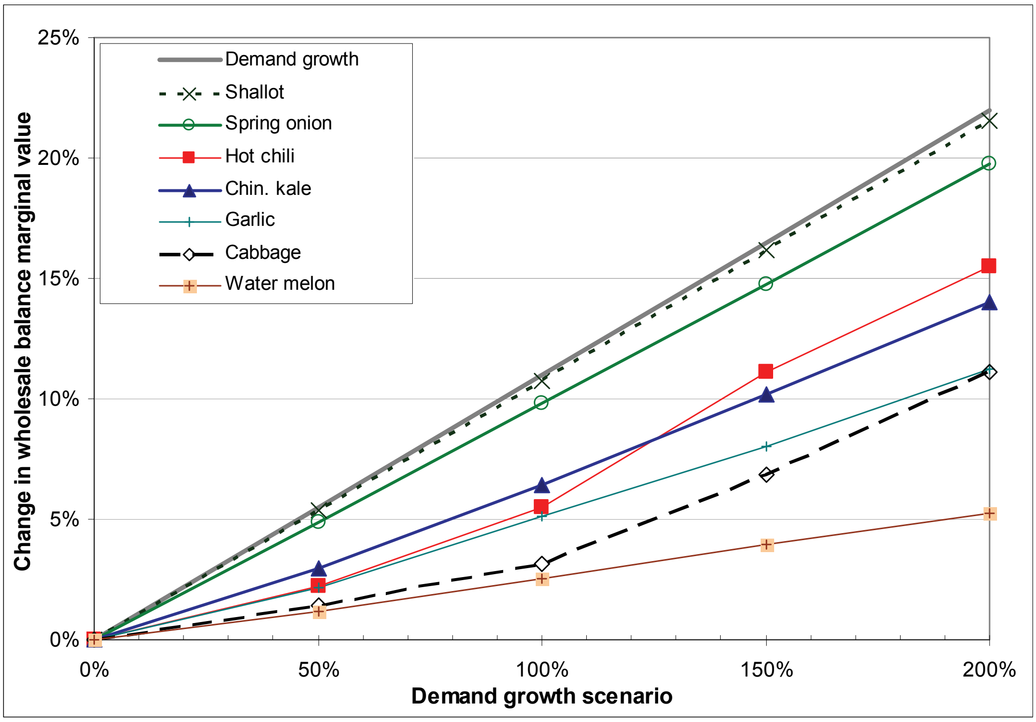

Figure 28: Change in average marginal supply cost at the BK wholesale level for demand scenarios

Over the simulated range, total demand grows by up to 22% compared to the baseline level. Marginal costs of supply also increase consistently, but less than those of total supply. Shallot and spring onion prices grow fastest with rates just below demand growth. Although a higher income elasticity of demand for leafy vegetables leads to a more than proportional growth in demanded quantities, the marginal cost of supply for Chinese kale grows more slowly and increases by 6.4% for the demand level predicted for 2011. Similarly linear developments result for wholesale prices of garlic and watermelon at 5% and 2.5%, respectively. The small price increases for these crops might be explained by the source of supplies from UN, UNE and ENE, where labour is less scarce than in BK and WNE, from where leafy vegetables such as spring onion and Chinese kale for consumption in BK originate.

Land and labour resource use

Under ceteris paribus conditions, additional demand is expected to be satisfied primarily by allocating more resources to vegetables. This can be observed by the average land area under vegetable crops over the year shown in Figure 29. As expected, changes in CE are most pronounced with an expansion of vegetable area by 7,000 ha (+27%[63]) when demand increases to the level forecast for 2011, followed by an increase of 3,300 ha (+15%) in UN and 1,300 ha (+20%) in SO. In all other regions, area grows by less than 820 ha or 11% of the baseline levels. Moreover, the rate of expansion in UN decreases beyond 100% and in CE beyond the 150% demand growth scenarios. The growth in total output of vegetables falls short of the area expansion with 13%, 12% and 18% in CE, UN and SO respectively. The large discrepancy in CE can be traced down to a shift towards land-intensive crops like asparagus and hot chilli, whose area is increased by 54% and 93%, respectively. Physical productivity in these crops is between 1.2 and 1.8 metric tons per hectare and month, whereas the average of all vegetable technologies considered in the model yield around 4.6 metric tons per hectare and month. Conversely, in WNE, where chilli area is reduced by about 9%, production grows by 11% along with an area expansion of just 2%. As a result, physical land declines from 31.9 to 28.4 t ha^{-1} in CE and increases from 29.6 to 32.2 t ha^{-1} in WNE. The seasonal pattern of land use is not affected by the demand scenarios considered here and is therefore presented only for selected regions in the appendix (cf. Figure 75 on p. 225).

[63] Figures in brackets are percent changes between demand 2011 (100%) and baseline scenarios.

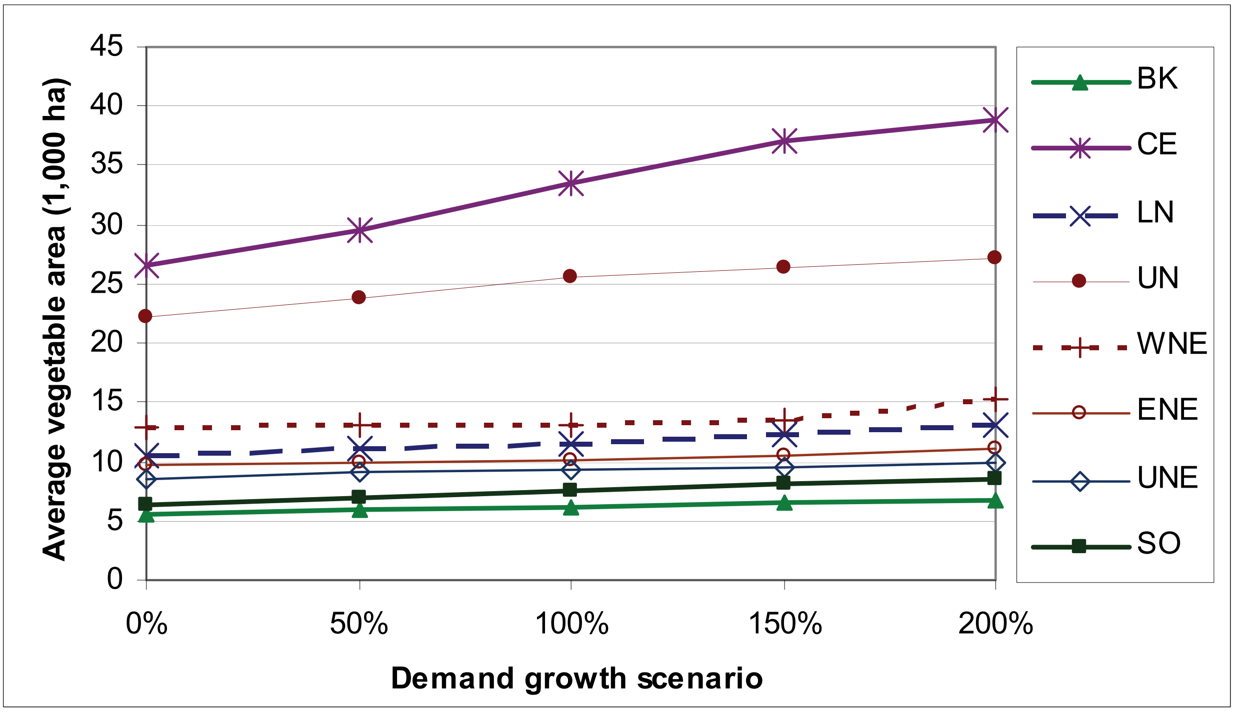

Figure 29: Average vegetable area under different demand scenarios

Along with an expansion of area planted to vegetables, a more or less proportionate increase of labour use in vegetable production is to be expected. Taking the labour use on vegetable farms over the year as the relevant indicator, a marked increase in CE by nearly 29,000 full-time labour equivalents or 38% is associated with the expected demand growth until 2011(Figure 30) and therefore even greater than the expansion of vegetable area. Again this rapid change is explained by the shift towards land- and labour intensive crops such as asparagus and hot chilli. Conversely, the labour use in WNE increases very moderately by 4% for the 2011 demand scenario. Only when demand increases further does labour use for vegetable production in this region increase more rapidly. Compared to vegetable land, labour use grows faster in all regions except for ENE and SO. In the latter, even a slight decrease is observed, whereas land area increases by 20%. An adaptation to growing demand is therefore associated with intensification in all regions except for ENE and SO.

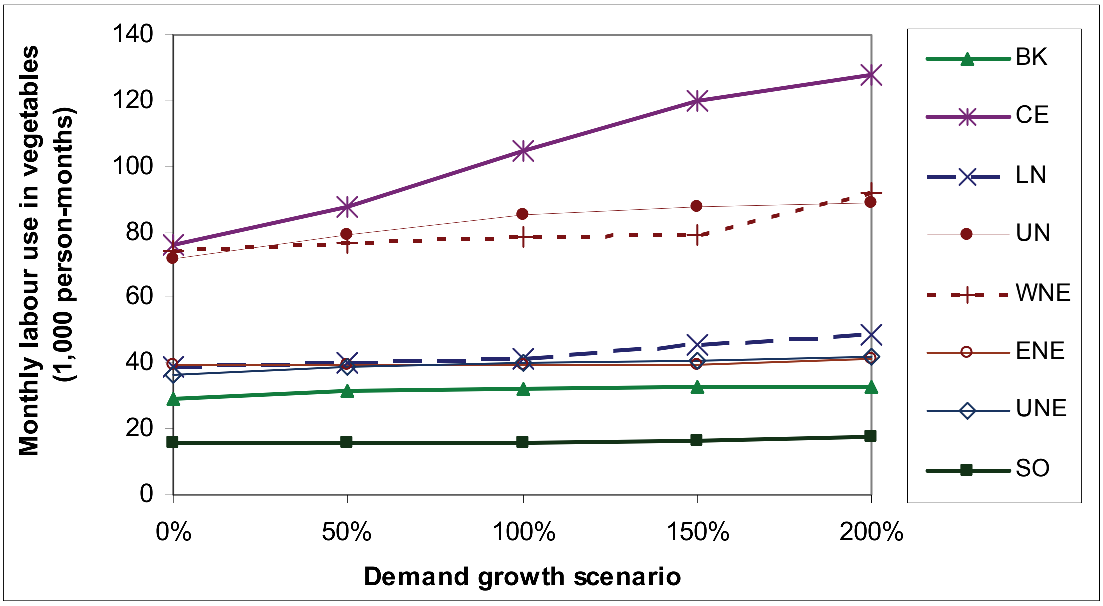

Figure 30: Average monthly labour use in vegetable farms by region under growing demand

The seasonal distribution of labour used in vegetable farms plotted for different demand scenarios shown Figure 31 and Figure 32 reveals that the pattern remains rather stable and labour use is shifted upwards in CE and UN for demand increases up to 150% of the predicted level in 2011. Beyond that point, labour needed on an additional chilli area of 1,850 ha during the dry season (December to April) in WNE leads to a strong increase in total labour requirement. In BK, labour use is levelled out by shifting some production from the late rainy season to the hot season, especially March and April, where in the baseline vegetable labour requirement was particularly low. Changes are most pronounced in the hot and large chilli crops, which make up significant shares in all regions.

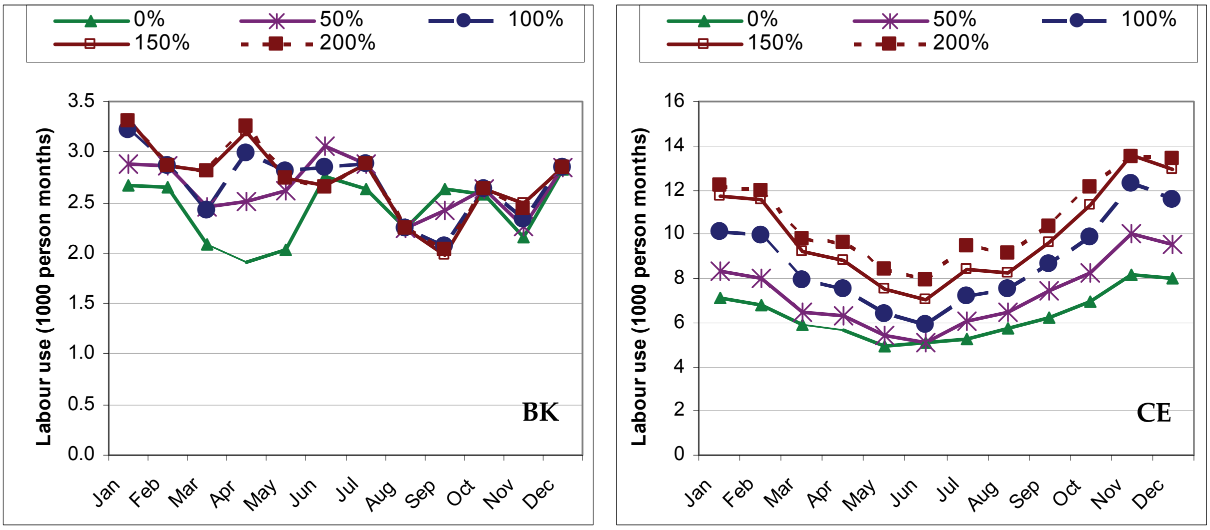

Figure 31: Seasonal labour use in vegetable crops for demand scenarios in BK and CE

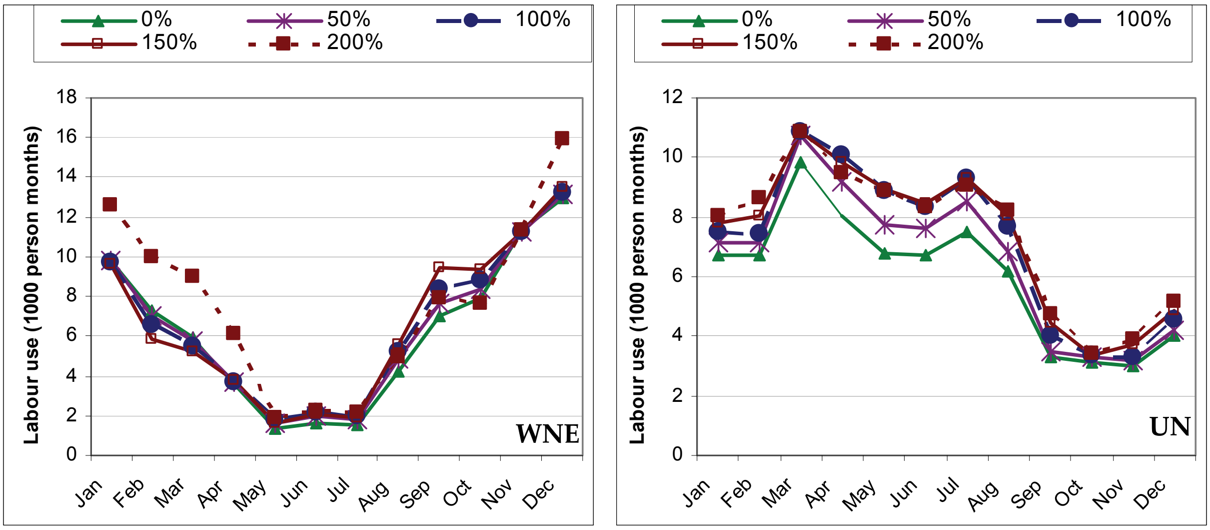

Figure 32: Seasonal labour use in vegetable crops for demand scenarios in WNE and UN

The implications of a demand growth by 13% on the national average over all crops for labour use in vegetable production as predicted by the TVSM are summarized in Table 37. In BK, LN, WNE, ENE and UNE, labour requirement grows less than proportionately or remains unchanged. In SO labour requirement goes down slightly in spite of an increase in planted area and output. At the other end of the scale LN, and especially CE, increase labour use in line with the largest increase in vegetable area and an additional intensification in terms of labour used per unit of vegetable area.

Table 37: Aggregate effect of demand growth on labour resource use in vegetable production

Unit: 1000 full-time labour equivalents

Region	Baseline		Likely 2011 demand		Change	
	Vegetable labour	Hired labour	Vegetable labour	Hired labour	Vegetable labour	Hired labour
BK	29.2	1.7	32.2	3.7	10%	117%
CE	75.8	37.1	104.8	69.2	38%	87%
LN	38.8	12.9	41.3	14.0	6%	9%
UN	71.9	2.3	85.3	4.2	19%	83%
WNE	74.5	133.3	78.3	133.3	5%	0%
ENE	39.3	3.7	39.3	3.9	0%	4%
UNE	36.3	5.7	40.3	7.1	11%	26%
SO	16.0	0.9	15.9	0.8	-1%	-13%

As farm labour resources are assumed constant in this analysis, any expansion beyond seasonal family labour resources requires additional hired labour. Accordingly, the expected growth of hired labour until 2011 is by about 2000 full-time labour units in BK, about 32,000 labourers in CE, 1,100 in LN, 1,900 in UN, about 1,300 in the UNE and a reduction by about 100 full-time labour units in SO. Although these are average figures and there is a sizeable seasonal variation in labour requirement, the scale of additional labour requirement especially in the central region suggests that in view of alternative labour opportunities, competition for permanent and seasonal hired labour might become problematic in the near future.

Use of external chemical inputs

The demand growth of about 12% in the likely 2011 scenario involves a growth in vegetable area by about 16% on the national level. A less than proportionate output growth with area response does not, however, mean that vegetable production becomes less intensive as can be seen in Figure 33, which shows changes in vegetable area, pesticide use in terms of environmental impact and number of sprays and transport activity over the baseline scenario. Nitrogen use perfectly matches the development of vegetable area, so that intensity remains unchanged. Although, as output grows more slowly than area and nitrogen use, this goes along with a diminishing efficiency of nitrogen application with respect to total output. However, that is also a result of a shift of output in favour of leafy vegetables, which generally require more nitrogen per unit of output.

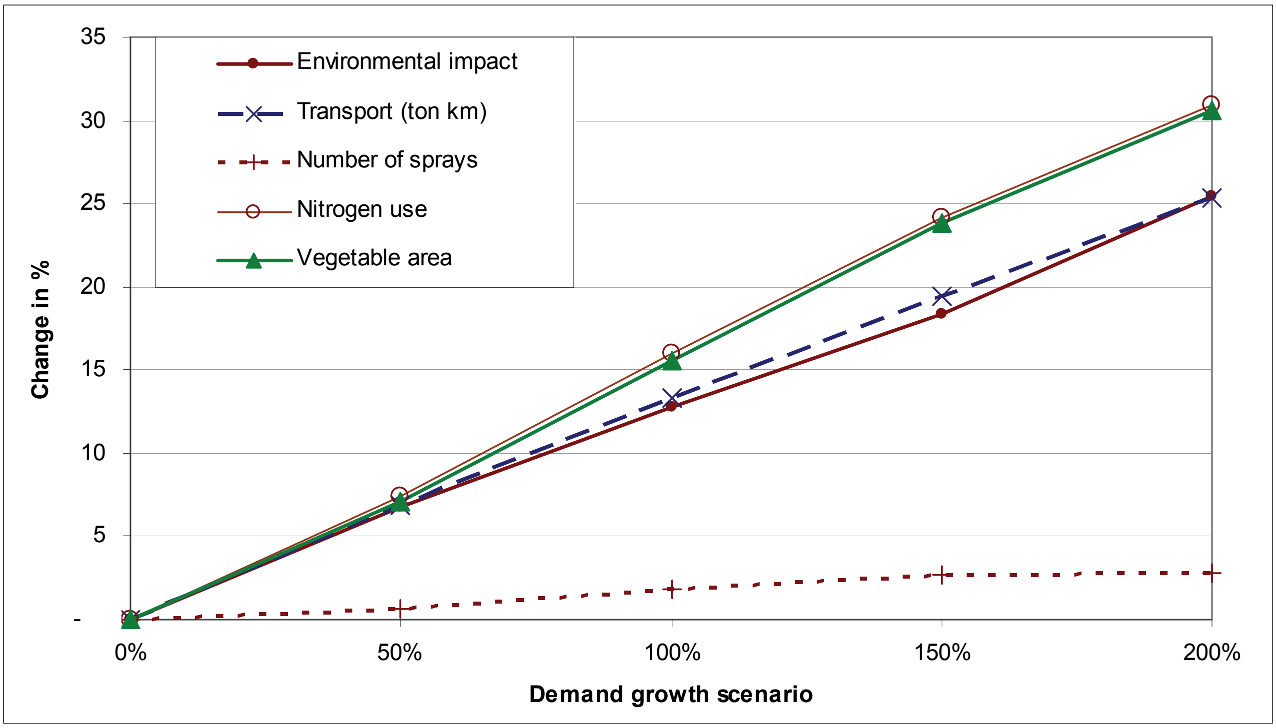

Figure 33: Change in vegetable area, total transport volume and input use indicators in different demand scenarios

The aggregate environmental impact and transport volume increase less than vegetable area but slightly more than demand. This implies that the efficiency of external input use does not increase with higher output levels. That observation is also supported by a growing average number of sprays per week in vegetable production. Although the change is comparatively small with 1.8% in the likely 2011 scenario, it is a clear indication of increasingly intensive technology, because all sprays are considered over the whole production period.

Moreover, the input use effects of growing domestic demand do not affect regions equally. In general, the absolute level of input use will increase with vegetable area and hence grows by 20%

and 17%, in CE and UN, respectively, whereas it hardly changes in BK[64] when demand grows as expected for 2011. Considering the intensity with respect to vegetable area reveals a more differentiated picture. The change in different indicators of pesticide intensity between the baseline and the likely 2011 scenario as presented in Table 38 reveals that the use of highly toxic pesticides and environmental impact in most regions decreases. But for the WNE, UN and UNE, pesticide intensity increases, at least for some toxicity classes and the environmental impact indicator. Two mechanisms explain the disparate development. One is the mere effect of using more land for vegetable production to meet peak demand. Additional land might be used for only a single vegetable crop per year and hence leads to a low intensity just by virtue of increasing the share of seasonal vegetable production. The extent of this effect is limited however, as e.g. in BK the share of seasonal vegetable area increases only from 16.1% to 18.0% and even decreases in CE. The second mechanism is a shift in portfolios among regions as mentioned previously. For instance, UN as virtually the only supplier of garlic and shallot as well as cabbage during the rainy season plants more of these crops, which all use class Ia and unclassified pesticides but not those of the intermediate toxicity classes.

Table 38: Percentage change in pesticide intensity between baseline and a demand increase as predicted for 2011 by region

	Active ingredient applied to vegetable area (% change)						Change in environmental impact per ha
Region	Ia	Ib	II	III	unclass.	total	
BK	-10.5	-0.7	2.3	-6.8	-4.3	-3.3	-3.4
CE	-7.1	1.1	-5.1	-6.8	-7.3	-6.1	-5.3
LN	-1.9	-2.0	-0.2	-8.8	-1.8	-1.8	-2.0
UN	0.5	-3.3	-1.7	-14.3	1.8	0.7	1.4
WNE	9.1	-8.6	4.2	11.1	13.7	11.0	11.8
ENE	-3.0	0.3	6.7	0.1	-4.3	-1.4	-3.9
UNE	-0.5	-1.1	2.2	-0.8	0.4	0.4	0.5
SO	-10.9	29.7	7.7	8.8	-5.9	1.4	-1.2
National average	-0.2	0.7	1.1	-0.4	-1.1	-0.6	-0.6

Turning to nitrogen fertilizer use, very similar results are observed (Figure 34). The absolute quantity of nitrogen applied to vegetable crops increases roughly proportionally with production, i.e. strongest in the Central and upper Northern regions, followed distantly by the lower North and the western part of the Northeast. For the likely 2011 demand level, a total of 70,000 t of nitrogen is predicted, which is 16% above the baseline level even though production increases by only 13%. This slight intensification is mainly caused by the shift towards leafy vegetables, which are grown with greater amounts of nitrogen per kg of produce.

The intensity of nitrogen use, however, exhibits a more complex pattern as the left panel of Figure 34 shows. While nitrogen intensity increases only slightly in the Central model region, it first goes down and then up in the greater Bangkok model region. This effect results from first

[64] See Figure 76 on p. 226 in the appendix.

increasing seasonal vegetable production and hence vegetable area. With further increasing demand, however, seasonal vegetable land is gradually used for year-round vegetable production. The trends in the upper and lower northern model regions are also slightly downward as a result of relative faster increase of the seasonal crops garlic and shallot. Only the southern region exhibits a continuously rising intensity that indicates an increasingly specialized and year-round vegetable production.

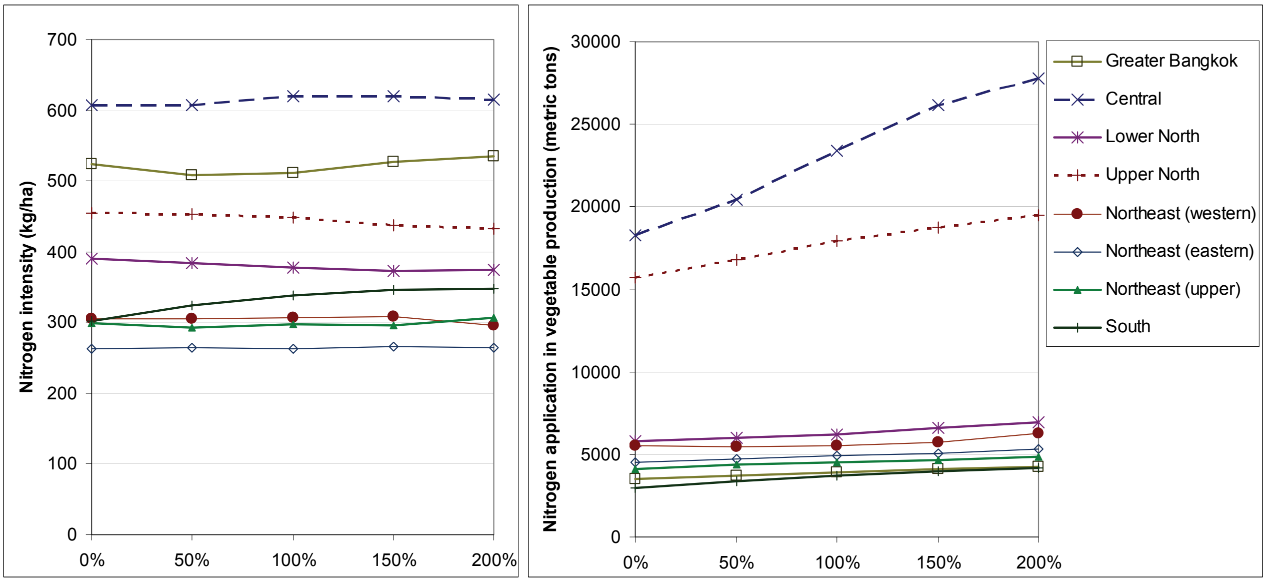

Figure 34: Nitrogen intensity and absolute quantities used in vegetable production by region under different demand growth scenarios

Allowing for the effects of a domestic demand growth by about 13%, we find that the intensity of input use in terms of active ingredient of pesticides or EIQ per hectare is slightly decreasing on the national average. However, declining intensities in BK and CE go along with higher use intensities in the WNE and UN. For nitrogen use, a rather constant per-hectare intensity of nitrogen application is observed, while physical productivity is slightly declining.

5.2.2 Supply side factors

5.2.2.1 Energy prices

As discussed in chapter 4, since the base year 2001 fuel prices have risen sharply and further increases are likely. Hence, in this section the effect of fuel price increases on the structure of supply is investigated. For this purpose fuel prices are varied over a range while all other exogenous variables are held constant. In order to explore the range where model results converge, model simulations for fuel prices from the baseline level of 12 THB/litre up to a 20-fold increase to 240 THB/litre are shown. Fuel prices affect transportation most significantly, but also to a lesser extent on-farm production costs through fuel used in soil preparation and pumping of irrigation water[65].

Regional distribution of vegetable production

In the baseline situation, fuel constitutes a share between 4% (lettuce) and 33.4% (garlic) of transportation cost to Bangkok wholesale markets, depending on vegetable crop and transportation distance. The share of fuel in the total cost of supply to BK wholesale markets ranges from 0.3% for spring onion to 13.7% for cabbage. Since the effect of transport costs differs among crops and distance, an increase in fuel price will change the competitiveness of production locations. This effect is shown clearly in Figure 35, where regional production is plotted as a function of increasing fuel prices. As expected, production from UN, which produces the biggest net surplus and is the most remote from BK, decreases fastest, though at a decreasing rate. The greatest supply reaction is observed for baby corn, cabbage and Chinese cabbage where a 1% increase in fuel costs leads to a reduction of supply from UN by 0.68%, 0.26% and 0.24%[66], respectively (Figure 36). The supply of other important crops from the upper North such as garlic, ginger and shallot remains largely unaffected by fuel price change and decreases only by -0.04%, -0.01% and less per 1% increase in fuel price (Figure 36). As demand remains fixed at baseline levels, the supply reaction from areas closer to the major markets determines this pattern. Although cabbage yields are highest in the cooler climate, modern varieties can be grown under lowland conditions, which explains the flexible reaction of the former group of crops and a hardly changing share of garlic, shallot and ginger, which are not commercially grown in tropical lowland conditions.

The gap is filled by additional supplies predominantly from CE, LN, WNE and BK. As above but with the opposite sign, supply response is most elastic in CE for cabbage (+0.90), Chinese cabbage (+0.37), cauliflower (+0.35), watermelon (+0.31) and tomato (+0.25) (Figure 36)[67]. The latter substitutes supplies from relatively remote ENE. However, as transport costs grow further,

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[65] Energy prices also affect fertilizer prices due to the high energy requirement in the production of nitrogen fertilizers. This effect of energy prices is not considered here, however.

[66] For characterizing the responsiveness of a variable y to changes in another variable x arc elasticities have been calculated according to $e = (y_1 - y_0) / y_0 \cdot x_0 / (x_1 - x_0)$, where indices 0 and 1 indicate the baseline values and the first step of parametric variation.

[67] For more details see figures on p. 227 in the appendix.

production starts to decrease again in LN (at 15fold prices) and WNE (around 20-fold price). In the former case, aggregate supply response is most affected by cabbage production, which doubles until the 15-fold fuel price is reached, before it starts to recede again. As supplies from UN continue to decrease (though at decreasing rates), fixed demand quantities are met by continuing growth in CE as lower yield levels are increasingly offset by relatively cheaper transport.

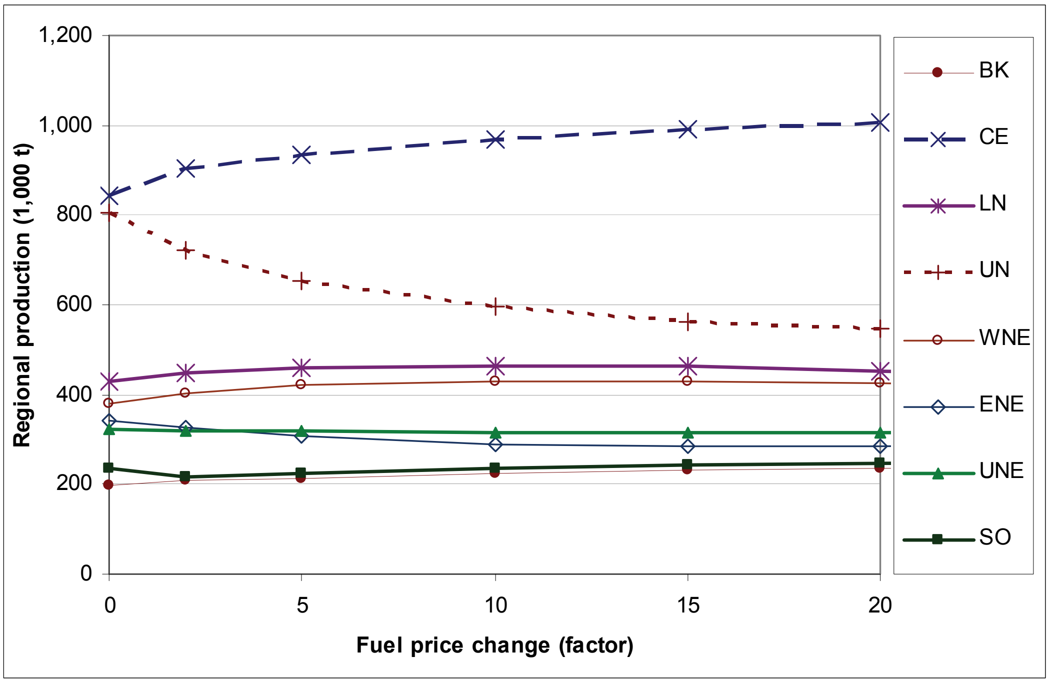

Figure 35: Effect of fuel price changes on regional production

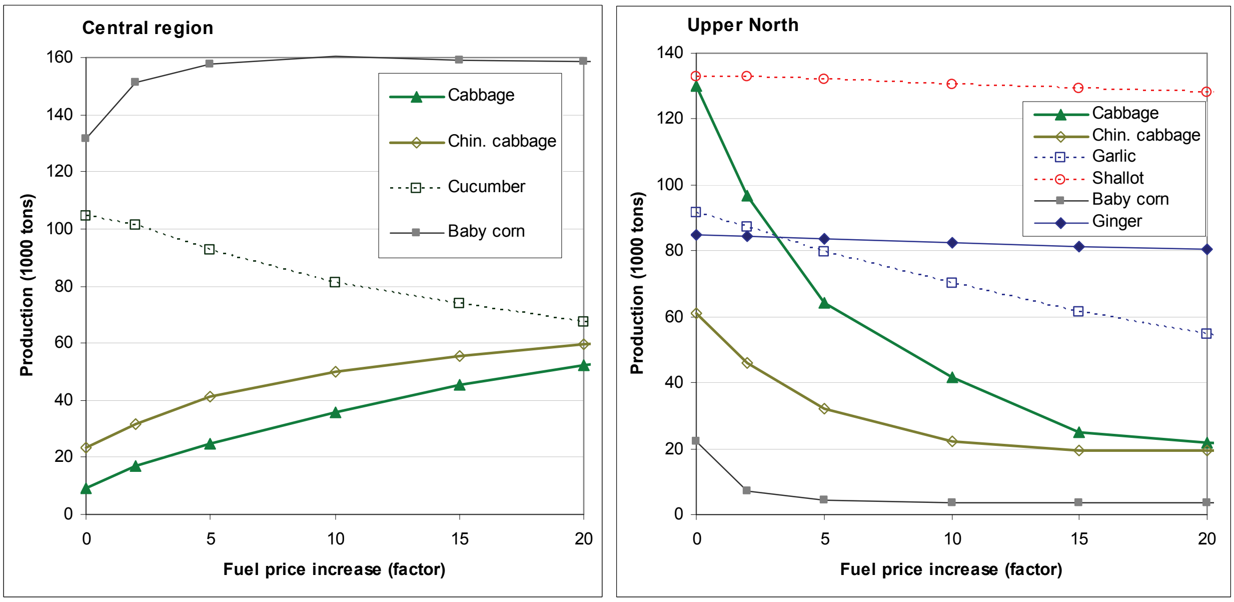

Figure 36: Effect of increasing fuel price on the production of selected vegetables in CE and UN

Marginal cost of vegetable supply

An increase in the price of fuel will ultimately lead to rising vegetable prices. The price increase can be partly compensated for by adjustments in the structure of supply because marginal costs of production differ across regions. Furthermore, the increase in vegetable prices will differ among the different types of vegetables due to the different relative importance of transportation cost. It can also be expected that the effect of fuel price increases will change with the level of increase, because adjustment possibilities of production regions will vary among crops.

Figure 37 illustrates the effect of a fuel price increase from 12 THB/litre in the baseline to 20-fold. It can be seen that doubling fuel prices lead to an increase in the wholesale price of cabbage of about 30%. As fuel price increases further, the marginal supply cost of cabbage continues to increase but at a decreasing rate, because cabbage production has been shifted from UN to CE and is therefore closer to the centre of demand and less sensitive to fuel prices. Also the marginal supply costs of baby corn, whose supply in UN is very elastic with respect to fuel prices (see above), and pumpkin, show comparatively strong increases of 20% and 18% when fuel prices double. On the other hand, the fuel price effect for hot chilli, cucumber and Chinese mustard is below 7%.

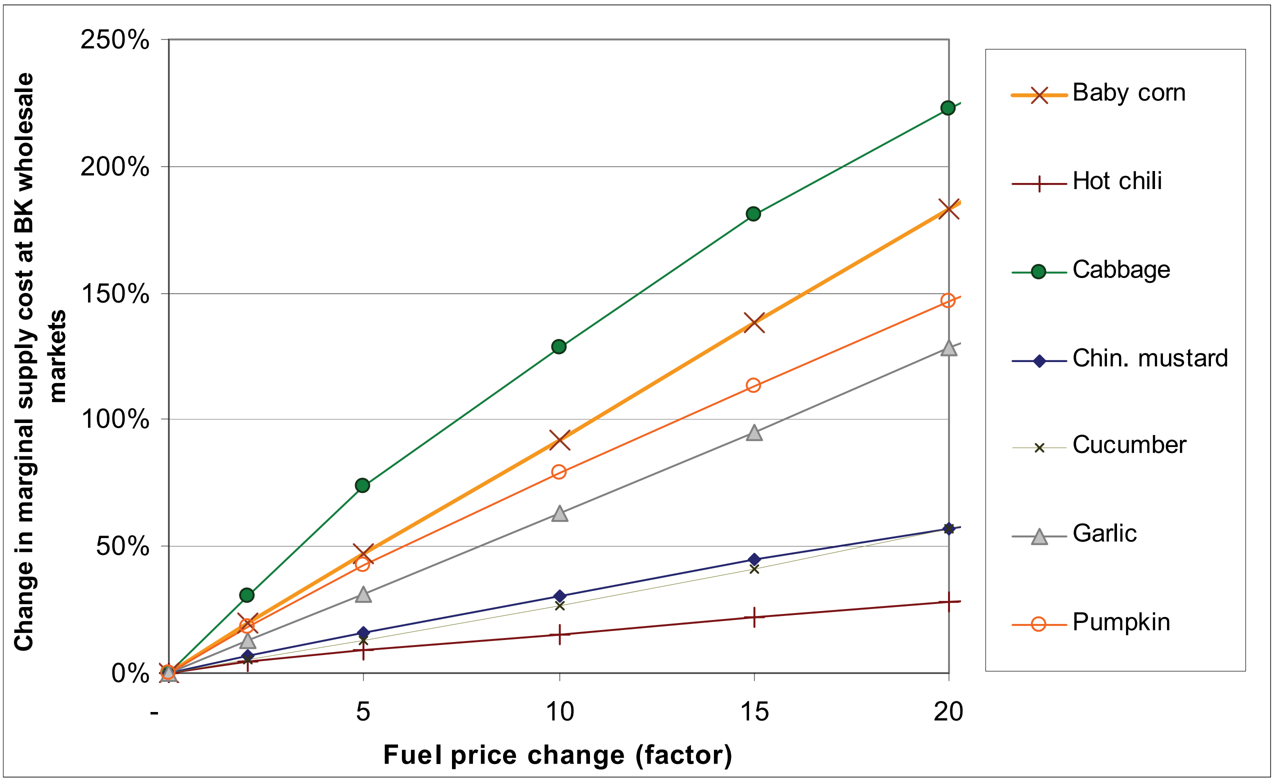

Figure 37: Relative change of selected vegetable wholesale prices at Bangkok wholesale markets as a function increasing fuel cost

For hot chilli, marginal costs of supply are least affected when transportation becomes more expensive, because transport cost represents only a minor share of total supply costs. Transportation costs are reduced by a further shift of production to BK and CE where marginal costs of production are low. The opposite is true for the marginal cost of supply of rather bulky crops such as (unpeeled) baby corn and pumpkin, which continue to rise when transport becomes more expensive. This is because the share of transport cost compared to variable production cost is higher and the opportunity cost of land and labour resources in regions close to the centre of demand increase with the expansion of vegetable area in these regions.

In general, the impact of the above mentioned regional shifts on the price at the Bangkok wholesale level is more pronounced and sustained over a greater range of fuel price variation for crops with a high average transport distance in the base scenario, and those for which transportation cost is high relative to marginal cost of production. The relative change in wholesale prices against the base scenario is small, however, compared to the extreme range of fuel prices considered here. For example, the average wholesale price for cabbage will double when the fuel price increases by a factor of 18, which is the most pronounced reaction as a result of a high share of transportation cost in total supply costs of this crop and a high average transport distance. The effect of a fuel price increase is less than proportional to the fuel cost share in total supply cost (13.7% for cabbage in the baseline scenario), since supplies from the upper North are increasingly substituted by supply from model regions closer to demand centres.

Land and labour resource use

As shown in the previous section, an increase in fuel prices implies increasing marginal cost of vegetable supply due to adjustments in production locations. These adjustments lead to changes in the use of resources, namely land and labour. Land use changes due to a shift in regional production volumes and patterns. Generally as shown above, the major shift in vegetable production is from UN to CE. The associated shift in vegetable land is observable in Figure 38. A fuel price increase to twice (10fold) the baseline value reduces vegetable land in UN by 7% (24%), whereas vegetable area in CE increases by 5% (17%). A consistently declining vegetable area is also observed in ENE. In most other regions, such as WNE, UNE and SO, vegetable area reacts strongly to small increases but remains nearly constant when fuel prices increase further. Except for minor increases in BK and LN, vegetable land expands only in CE.

Comparison of the reaction of output (Figure 35 on p. 136) and land use (Figure 38) shows that even where output increases (BK, WNE), vegetable area does not necessarily increase, because shifts in portfolios reduce seasonality of production and vegetable area. This effect also applies on the national level, where total production decreases by up to 1.5% in the extreme case of a 20-fold price increase as a consequence of reduction in transport volume and associated losses. Vegetable land decreases by 10% for this scenario because production in the specialized vegetable farms of BK and CE increases while seasonal vegetable production in UN, ENE and UNE decreases.

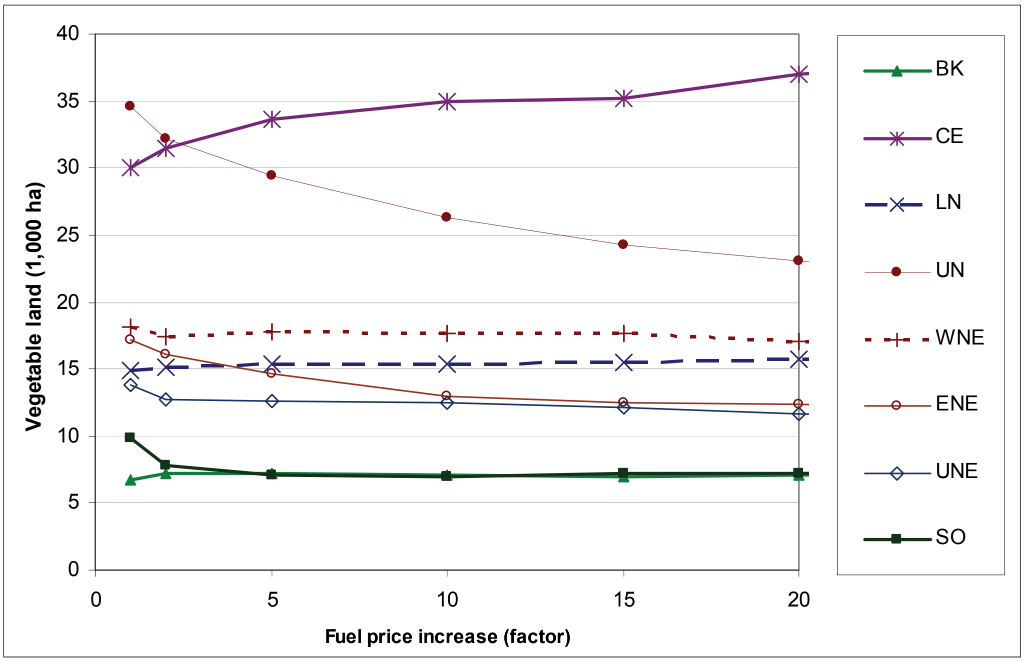

Figure 38: Development of regional vegetable area with increasing fuel prices

Analogous to land use, labour use is also expected to change with the shift of production from peripheral regions to locations closer to the centre of demand. Due to different labour intensity of among vegetable crops, changes in the portfolio will affect labour use and its seasonal distribution. The latter determines the utilization of family labour resources and the required amount of hired labour. The regional demand for hired labour as a function of fuel prices is shown in Figure 39. Due to the abundant family labour endowment of vegetable farms in the upper North, the diminishing production leads only to moderate decline in hired labour, but instead affects the utilization of family labour resources. Hired labour demand in the central region exhibits a particularly interesting shape. When fuel prices double, hired labour demand decreases in spite of a steep increase in land use and output as a result of the changes in the crop portfolio. The area planted to the rather bulky crops whose production is labour extensive relative to the crops in the baseline production plan of the Central region increases. In particular, cabbage, pumpkin and unpeeled baby corn require little labour per unit of output as compared to the fruit vegetables such as yard long bean, cucumber and hot chilli, whose area is decreased. As a consequence, hired labour that follows seasonal peaks of labour demand and is comparatively expensive in the central region, is reduced when transportation cost increases moderately. Only when fuel prices rise beyond the 15-fold initial value does vegetable farming in the central model region require more hired labour than in the baseline solution.

A slowly but steadily increasing labour demand is observed in BK and SO, where regional demand outstrips supply in the base situation. In the latter, increasing demand for hired labour over the whole range (and an initial drop of vegetable area) characterize a process of intensification, especially when considering the slight drop in physical output in the initial phase that results from a reduced production of the bulky fruit vegetables watermelon, pumpkin and cucumber in favour of higher value crops such as leafy vegetables and hot chilli. Finally, production, vegetable land and hired labour demand grow concomitantly but remain at low absolute levels compared to demand in the region. As the mixed portfolio implies only low seasonal variation of land and labour use, and production is very intensive in the original situation, more output is attained only by more or less proportionally increasing resource inputs.

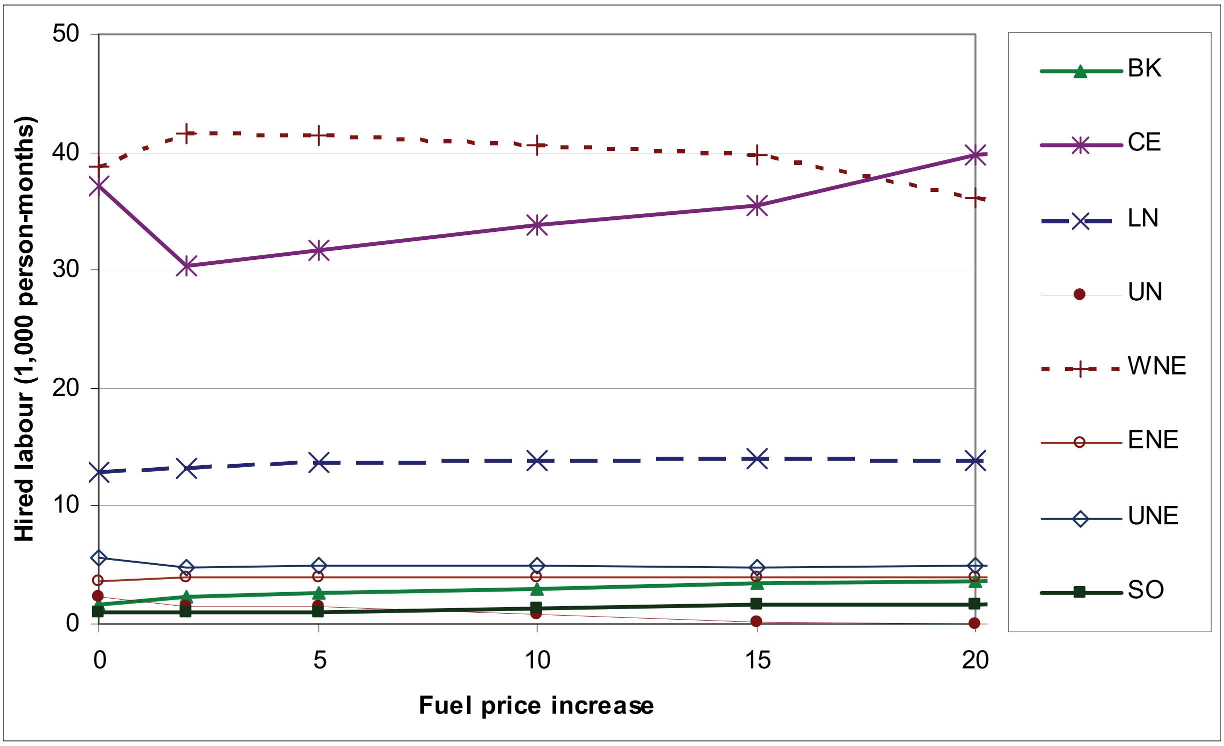

Figure 39: Development of regional hired labour demand under changing fuel prices

Environmental indicators

The effect of a price increase of one production factor is a reduction of its use in production through substitution by other factors. Moreover, it is expected that the elasticity of substitution decreases the more this substitution is advancing. This pattern is also reflected in fuel use shown along with other input use indicators in Figure 40[68]. Fuel use in vegetable supply reacts with an arc elasticity of -0.11 when fuel price doubles but decreasing elasticity as the price increases further. Moreover, the indicators for nitrogen use and environmental impact of pesticides decrease or stagnate for fuel price increases up to about 30-fold in line with loss reduction due to less transportation and resulting reduction of primary production. For further increasing transport costs, both environmental impact and to a lesser degree nitrogen use, increase again as production on less land in those areas close to the centre to demand intensifies. Hence, fuel is substituted (among others) by an increasing level of chemical inputs through a shift of production to CE and BK and the associated intensification.

[68] In order to demonstrate the non-monotonous response of nitrogen use and environmental impact of pesticide use, an extreme range up to a 100-fold fuel price increase is shown.

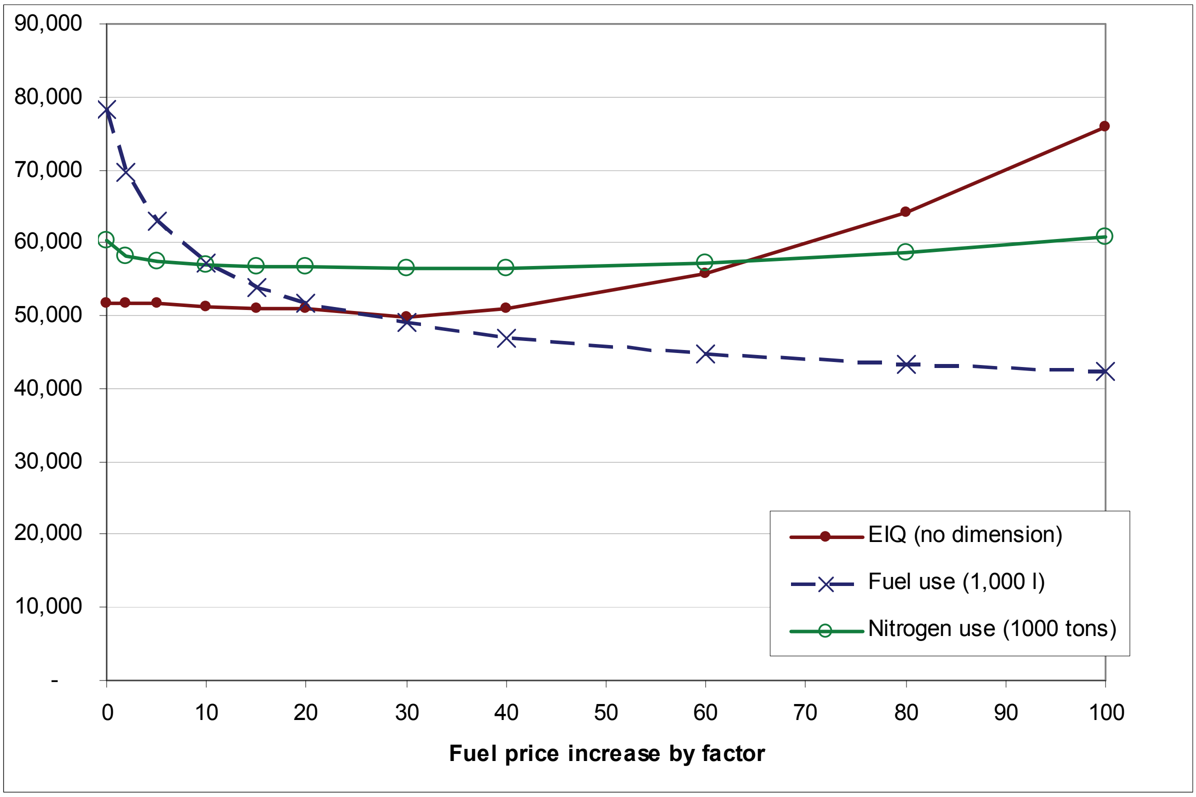

Figure 40: Aggregate environmental indicators as a function of increasing fuel prices

Summarizing the impact of fuel price increases, the following effects on vegetable production are observed: (1) Regional vegetable production is elastic with respect to fuel price near the baseline solution and initially shifts notably towards the centre of demand, though at decreasing rates. (2) In absolute terms, production and vegetable area are most affected in UN and CE regions. (3) In spite of increasing production, hired labour demand of central region vegetable farms recedes up to a fuel price of 24 THB/litre due to a shift in the portfolio towards less labour intensive crops before it rises again when vegetable supplies from CE continue to increase. As the general seasonal pattern of labour allocation in UN does not change for moderate fuel price increases, hired labour demand in the upper North decreases only to a small extent. (4) The elasticity of fuel use with respect to fuel price shows the expected negative sign but is rather low in absolute terms, reflecting the cost of shifting vegetable production to sites closer to the centres of demand.

5.2.2.2 Technical progress in transportation

The opposite effect to increasing fuel prices can be expected from technical progress in transportation that reduces technical loss through better-adapted technology. The scope for possible improvements ranges from introduction or extension of refrigerated transport, improved grading, cleaning and packaging at the farm level, better protection for bruises and wilting during transport and handling by plastic packaging of smaller portions and use of stackable boxes to more efficient organisation of the value chain in general to minimize the time span between harvest and consumption. The database on the potential of such improvements in the post-harvest chain is very small and the only indicative data for Thailand pertain to improvements in the long-distance transport of temperate vegetables from highland production sites to Bangkok. For head lettuce a reduction of losses from 70% in 1988 to 40-50% in 1999 could be attained (BOONYAKIAT, 1999). Therefore, a parametric analysis encompassing a range of loss reduction between 0 and 50% was conducted to ascertain the consequences of such improvement. It was further assumed that commodity-specific technical loss rates (cf. chapter 3) for individual vegetables are reduced proportionally and all other parameters including transportation and handling cost per unit remain constant.

Whereas the technical loss rate is the exogenous parameter varied in this simulation, total and average losses depend on the endogenously determined transport volume and distance by vegetables as well. A reduction of the technical loss rates c.p. implies lower unit cost of transportation, increases the competitiveness of peripheral production sites. It is therefore expected that transport volume will increase. The associated increase in average transport distance will lead to increasing average losses during transport and will therefore partially offset the technical improvement. The parametric analysis reveals that the average loss between farm gate and wholesale markets of about 5.8% in the baseline situation declines nearly proportionally with the changing loss coefficient (Figure 41). The gap between technical loss coefficient and average loss rate results from an increase in total transport volume. In absolute terms total transport increases from 1,041 to 1,063 million ton-kilometres (+1.8%) when transformation loss rates decrease by 50%. When demand quantities are fixed, reduced transport and handling losses translate into a decline of vegetable production that is required to meet the demand constraints. Both contribute to an increase in average transport distance from 293 km in the baseline to 308 km when losses are reduced by 50%. The share of production consumed within the region of origin declines only marginally by 1.3 percentage points from the baseline value of 43%.

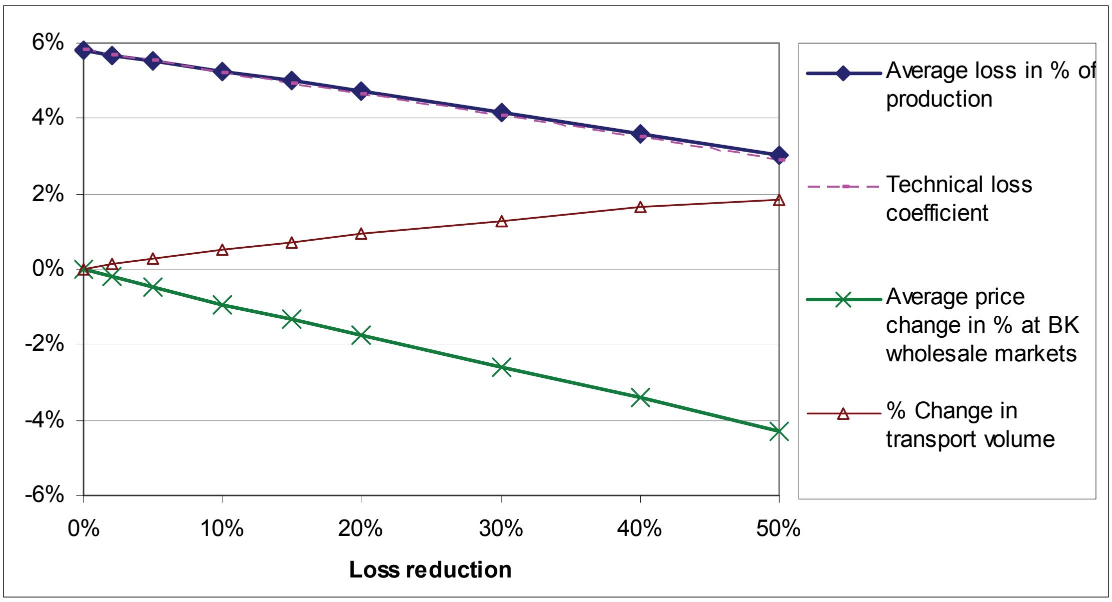

Figure 41: Average loss and price change as functions of reduced technical loss

Regional distribution of vegetable production

While output on the national scale shrinks by 103 thousand metric tons (2.9%) when efficiency of the chain increases through improved transportation, the regional contribution to total supply gradually shifts towards the more remote areas. As shown in Figure 42, total vegetable output from CE, BK and WNE and LN gradually declines by up to 7.6%, 6.0%, 5.3% and 4.5%, respectively, whereas that of the UN increases by up to 1.4% and even 6.3% in SO. Except for UNE and ENE, whose output declines (though more slowly than the national average) production gradually moves towards the more remote regions. The relative share of regional supply changes little with an increase by one percentage point from UN that compensates for a commensurate decline of the share supplied from CE at the extreme point of 50% loss reduction.

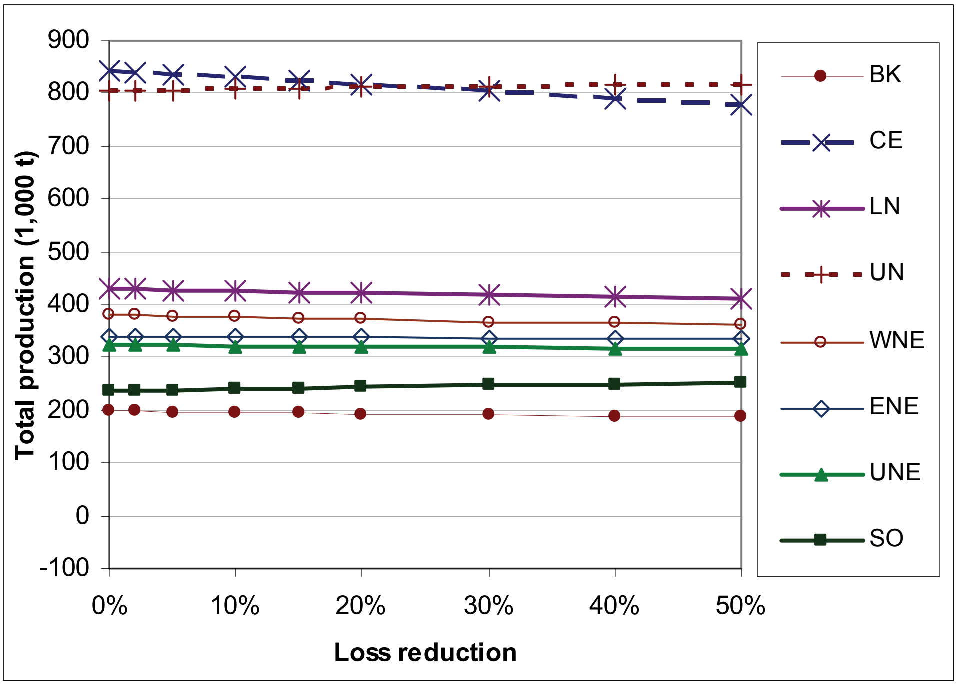

Figure 42: Regional production share as a function of a reduction of losses during transportation and handling by 0 to 50%

The crops affected most by these shifts in descending order are lettuce, cabbage, Chinese cabbage, cauliflower, hot and large chilli, whose production declines in CE and LN but increases in UN. Over the whole parameter range, production of cabbage declines in all provinces, though more rapidly in CE, SO and WNE, while a less pronounced absolute decline in the more remote model regions corresponds to a relative growth of the area under these crops.

Marginal cost of vegetable supply

Improvements in the technical efficiency of transportation are expected to reduce the marginal cost of supply. The amount of this reduction will depend on the extent of transport losses and the average transport distance, and therefore vary among different vegetables. The change in marginal cost of supply is plotted for selected crops at the BK wholesale levels in Figure 43. Loss reduction yields a (roughly) linear decline of the marginal supply cost for the sample crops. Such linear effect reflects the underlying technical relationship of a proportional cost reduction when technical loss rates decline. The slope depends primarily on the baseline loss rates, which differ between 1% and 3% for the handling loss and from 0.5% to 3% per 100 km transport distance for garlic and coriander/celery, respectively, on the one hand. On the other hand, the endogenous mean transport distance affects this relationship. The marginal cost of supply for spring onion is the most affected with an arc elasticity of -0.16 over the whole range, followed by tomato (-0.15, not shown) and cabbages, although for only the latter two crops, the mean loss rate in the baseline scenario was very high (9.9% and 8.6%, cf. Figure 66, p. 173). With improving transportation, spring onion production moves towards UN, where slack family labour is available. This effect over-compensates for the higher cost of transportation associated with an increase in average transport distance by 22% (cf. Figure 66, p. 173) and leads to marginal supply costs declining more rapidly than the technical loss coefficient. At the other end of the scale, marginal supply costs of garlic and hot chilli are least affected in line with their initially low loss rates of 4.2% and 5.1% respectively, and only minor shifts of production from CE to UN for hot chilli, whereas the locations of garlic production remain unaffected.

Although the extent to which the marginal cost of supply is lowered by reduced loss rates differs among crops, it is more than the change in average loss rates, which is about 2.8 percentage points in case of a 50% reduction (cf. Figure 41), whereas marginal costs of supply decline by between 3% and 8%.

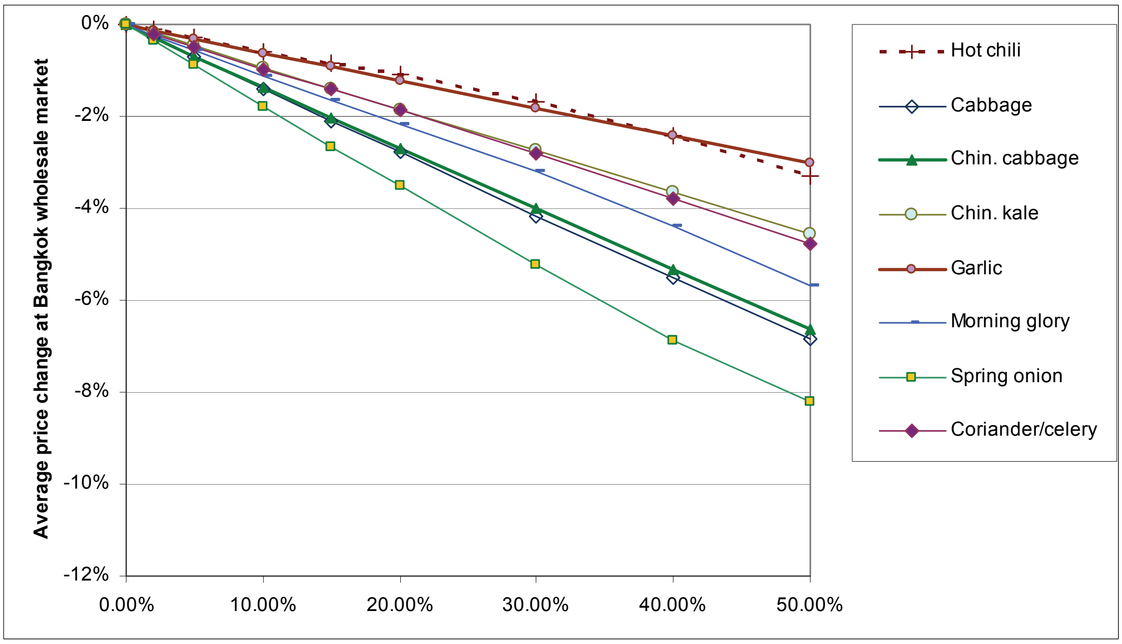

Figure 43: Change in marginal supply cost at BK wholesale level as a function of loss reduction

Land and labour resource use

As shown before for the case of increasing fuel prices, changing regional supply leads to changes in the use of land and labour resources. This applies analogously for a reduction in unit transportation cost. As the change in regional production shares is comparatively small over the parameter range discussed here, the effects on land and labour use are also small and therefore discussed only briefly[69]. Vegetable land declines the most by up to 13% and 7.6% in CE and BK, respectively. A shift from crops with low physical productivity per unit of land (such as hot chilli) to UN explains the less pronounced decrease of total output in CE by only 7.6% over the simulation interval. Land use increases by up to 2.9% in UN and even 3.7% in SO, whereas it remains largely constant in WNE, ENE and UNE.

The demand for hired labour generally changes according to total production and land use but is furthermore dependent on the seasonal labour requirements in production and labour availability. This is reflected in a much greater decline of hired labour in CE than that observed for output or land use (Figure 44). With the above mentioned northward shift of the land and labour intensive hot chilli production, labour required for vegetable production decreases by up to 35% and therefore significantly more than output and land. In UN, hired labour demand increases by up to 20%, but only from a very low baseline level.

The general observation is that as resources are set free by reducing transportation and handling losses, flexibility is utilized for smoothing resource use in general and that of labour in particular. A less variable land and labour resource use contributes to more than proportional reductions in marginal supply cost at the wholesale level because available labour resources are better utilized and less hired labour is required to cover labour peaks.

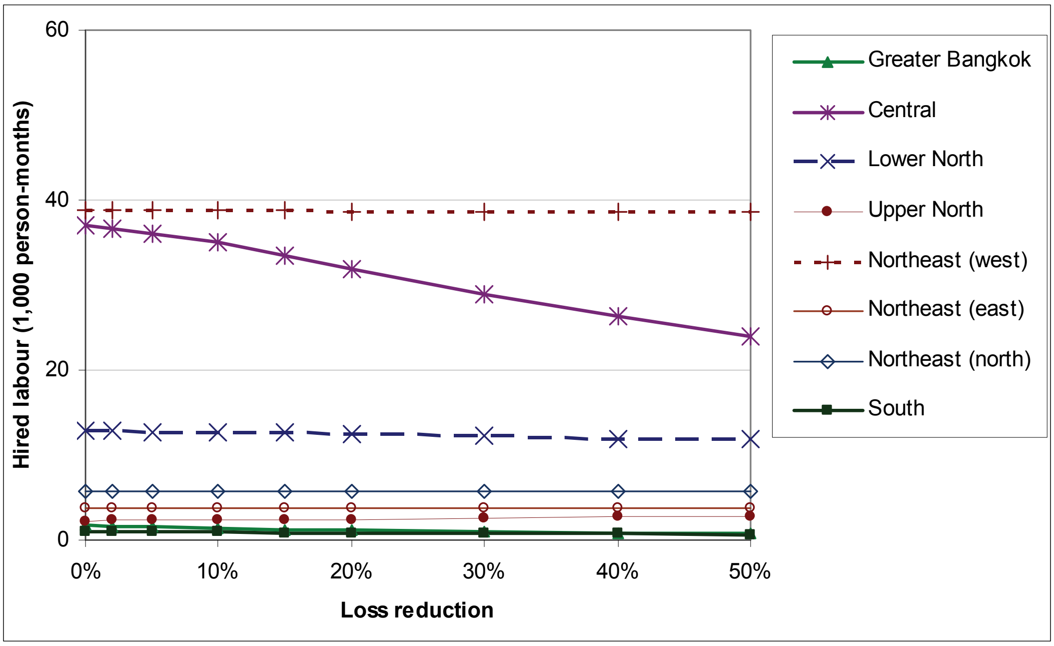

Figure 44: Hired labour demand as a function of loss reduction during transport and handling

[69] Regional land use is reported in Figure 80 on p. 228 in the appendix.

External input use

From an improvement in transport technology that reduces losses, an increasing transport volume and hence fuel use is expected, because the unit cost of transportation decreases. Moreover, a given demand can be satisfied by less production when losses along the chain are eliminated. This will also result in lower absolute levels of chemical inputs and the associated environmental impact. Together with production, the level of input use in the more peripheral regions will increase, and decrease in those sites closer to the centres of demand. Given different intensities in production systems, this might contribute to the reduction of input use in absolute terms and also in terms of intensity.

The simulation runs show the expected reaction to improved transformation efficiency (cf. Figure 81 on p. 229) for the national aggregate. Fuel consumption increases commensurately with transportation activity (+1.8%) whereas the quantities of pesticides applied in vegetable production and total environmental impact (EI) are reduced by up to 3.4% and 3.3% respectively and absolute nitrogen use decreases by 4.9%. Vis-à-vis a decline in total production by 2.9% in the case of a 50% reduction in losses, this implies a minor gain in average productivity of these inputs by shifts from production systems relying on higher intensities of chemical inputs toward less intensive ones.

At the regional level, the absolute quantities of agro-chemicals applied change mostly in line with total production as shown in the right hand panel of Figure 45 for the EI of pesticide use[70]. In CE and to a certain degree in BK and LN, the decline in environmental impact is greater than in total output production. This goes along with a substantial shift of hot and large chilli production from CE (-11%) towards UN, where less pesticide-intensive production technology is available in highland areas, thus contributing to a minor increase in pesticide intensity with respect to area. Moreover, the reduction in fruit vegetables such as cucumber, yard long bean and pumpkin, for which relatively pesticide intensive production technology prevails in the CE in favour of increased production in SO, contributes to a significant decline of environmental impact in the CE by up to 9.5%. In BK a 10% decline in EIQ goes along with 6% lower production – again mainly caused by a northward shift of hot chilli production.

The average EI per hectare of vegetable land is less sensitive to improved transportation efficiency but still reflects substitution among technologies and changing seasonal land use. In the CE the seasonal vegetable land decreases at double the rate of total production, due among other factors to a shift of baby corn production (-10%) to UN, leading to a slightly increasing intensity. On the other hand, slowly declining intensity in WNE and BK does not change the ranking of model regions according to EI intensity. Technology and crop portfolio in the WNE involve the highest EI per unit of vegetable land, while that of UN does not change even though production increases by 3% over the simulated range.

[70] Cf. Figure 82 on p. 229 in the appendix for nitrogen use.

The effects on regional nitrogen use and its intensity with respect to vegetable land are similar and are therefore not discussed here[70].

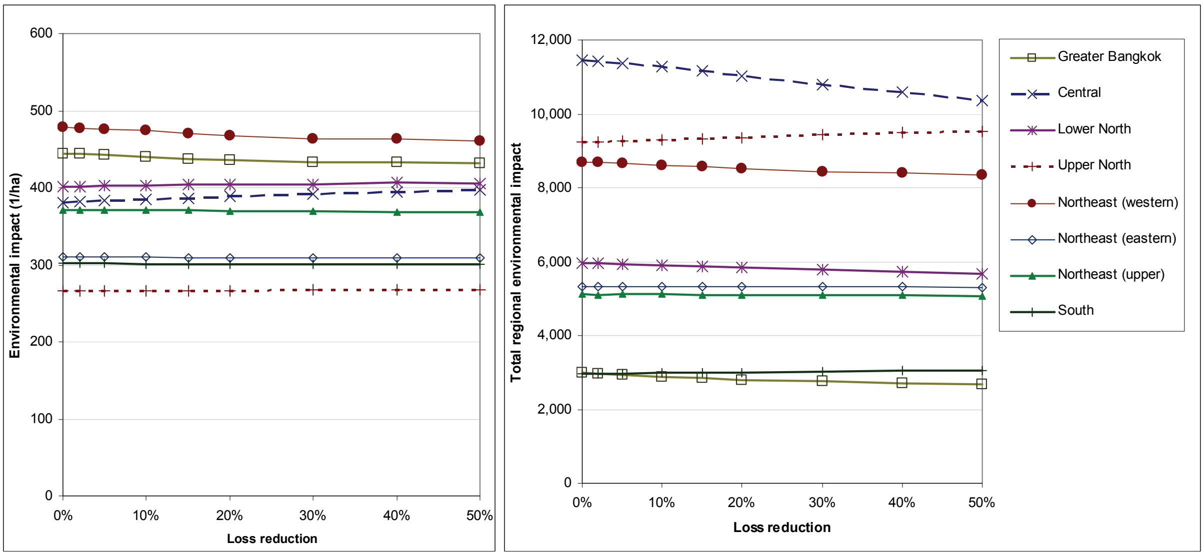

Figure 45: Regional environmental impact intensity and absolute EI as a function of loss reduction.

Summarizing the results of the simulation of a reduction in transport loss, a notable regional supply response is observed. The direction is a centrifugal movement from BK and the surrounding central model regions towards UN and SO. Decreasing losses lead to less than proportional lowering of marginal supply cost at Bangkok wholesale markets, because average transport distances increase. Contrarily, the environmental effects of vegetable production in terms of absolute nitrogen, environmental impact and absolute quantities of pesticides used in production decrease slightly more than proportionally. As resources become less utilized because efficiency along the chain improves, less intensive production technology becomes competitive and attains a greater share. Moreover, the fact that input use can be reduced by adapting regional portfolios reveals the potential for environmental policy measures that take into account the spatial structure of vegetable production. Within the bounds of existing production technology, a reduction of pesticide and nitrogen use by 3.4% and 4% respectively is feasible but associated with an increasing transport activity of 1.8%. Concerning the distribution of environmental burden, the above simulations show that the most affected regions such as BK, CE and WNE benefit most from improved transportation by both a reduction in total external inputs applied and a less concentrated distribution of vegetable production within the country.

5.2.2.3 Yield growth

After simulating the effect of technical progress in transportation, the consequences of technical progress in vegetable production will be discussed. A major contribution to technical progress in agriculture has been plant genetic improvements, often in connection with adapted external inputs, which have enabled farmers to increase their productivity with respect to land.

Vegetable yields in Southeast Asia have increased on average by about 1.6 % per annum in the past 20 years (WEINBERGER and LUMPKIN, 2005). In the absence of more specific information, the effect of yield growth in vegetable production is analysed for a range of homogeneous yield growth in all vegetables at rates between 0.2% and 4.0% per annum over a ten-year period, which corresponds to yield increases between 5.1% and 48% compared to the baseline. Further, it is assumed that improved varieties also increase harvesting efficiency by higher homogeneity of crops and yield, so that harvesting labour is therefore assumed to grow by 85% of yield increase. As the intensity of external input use in general is very high in the baseline technology, the application of external inputs per unit of land is assumed to increase at only half the rate of yield growth. Again a parametric analysis is used to quantify the effects of these trends on the vegetable sector.

Regional distribution of vegetable production

Under c.p. conditions and thereby a given quantitative demand, the immediate effect of yield improvements is a reduction in the area planted to vegetables. Although yield levels are assumed to grow proportionally for all vegetables and homogeneously in all production systems, it is expected that a reduction in land allocated to vegetable production (and to a lesser extent of labour) will also involve a shift of vegetable production towards the centres of demand, because with a given resource endowment more can be produced where transportation is cheap.

The simulation reveals that the effect of yield growth on regional supply is rather small. Even for yields augmented by 50% compared to the baseline, the largest response is observed for SO (+9%) and WNE (+3%). Conversely, production declines by 6% in ENE and by 3% to 4% each in LN, UN and UNE. The supply shares from the respective regions are hardly affected and change by at most 0.7 percentage points (cf. Figure 83 on p. 230).

The minuscule impact of yield growth on regional production shares results from the characteristics of this type of technical progress. Yield improvements are land-saving and therefore primarily concern a factor that is not considered a constraint to vegetable production.

Marginal cost of vegetable supply

In contrast to the regional shares, the marginal cost of vegetable supply at the Bangkok wholesale level changes notably with yield growth when demand is held constant. Most affected are spring onion, garlic and cabbage, whose marginal supply costs drop by nearly 8%, and about 5% when land productivity grows by 10%, whereas morning glory and brinjal prices are least affected and drop by only 2% (Figure 46). In the baseline situation the former group of crops is transported to a major degree from more remote regions, for garlic and shallot predominantly from UN. When demand is fixed, productivity gains irrespective in which crops allow for an increasing share of production close to the centres of demand and the share of crops transported over long distances decreases, which c.p. leads to lower marginal costs of supply. On the other hand, marginal costs of supply for crops grown close to the centres of demand such as morning glory or those with high labour intensity such as brinjal, are less affected by increasing land productivity.

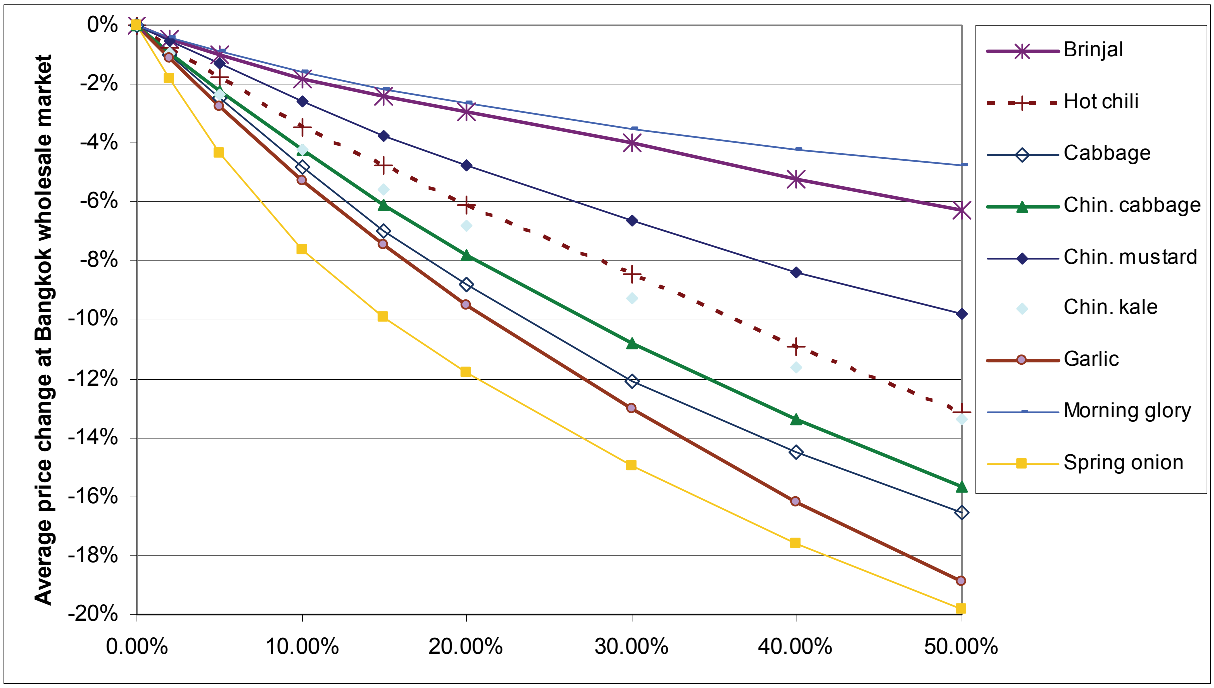

Figure 46: Change of marginal supply cost of selected vegetables at Bangkok wholesale markets as a function of yield growth.

Land and labour resource use

Obviously, higher land productivity leads to less area used for vegetable production when production caters only for a given demand. But regional vegetable area changes non-homogeneously when yields increase as shown in Figure 47. Vegetable area in UN decreases most rapidly in absolute terms with an initial arc elasticity below -1. The relative decrease is even stronger in SO and ENE. On the other hand, vegetable land in CE increases up to a yield growth of 5% before it starts to decrease slowly.

Due to the minor effect of yield growth on labour productivity implicit to the assumptions for this scenario, the demand for hired labour is expected to change to only a minor extent. The simulation reveals that this applies to BK, SO, ENE and UNE. The originally low demand for hired labour in UN diminishes to zero when vegetable area falls by about 7% as a consequence of a country-wide yield increase. It also decreases notably in WNE due to a shift away from labour-intensive crops, especially chilli, which is increasingly grown closer to the centre of demand in CE. There, a growing demand for hired labour is observed. According to the simulation results, a 10% growth in yields, which is a very likely scenario over a horizon of 10 years, will result in an additional demand for 4,100 full time labour units, while in the adjacent western part of the Northeast labour demand would drop by about 4,200 units.

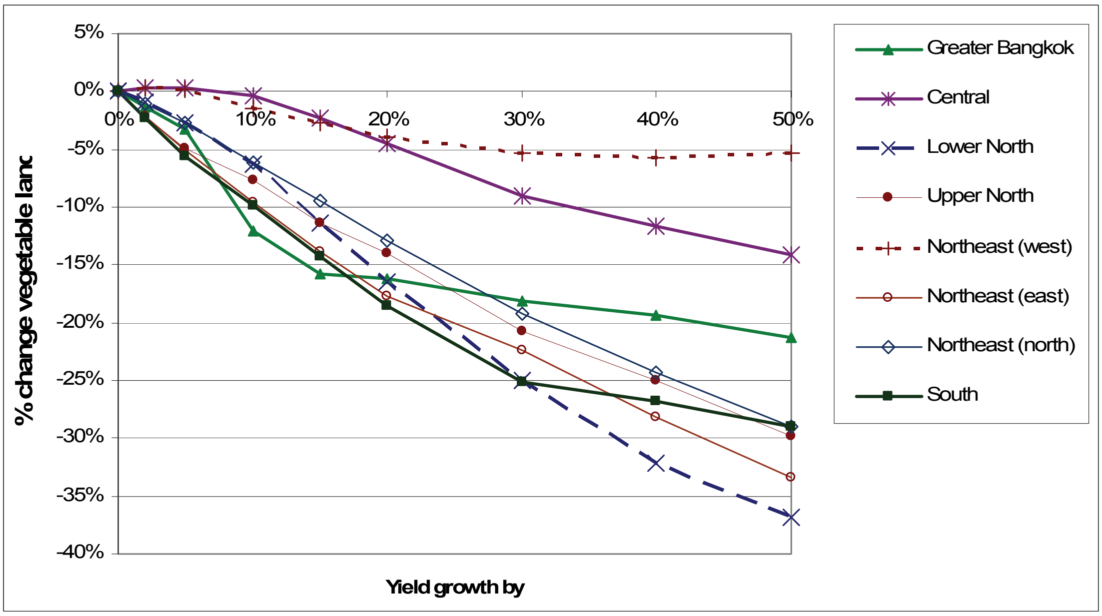

Figure 47: Change of regional vegetable land as a function of yield growth

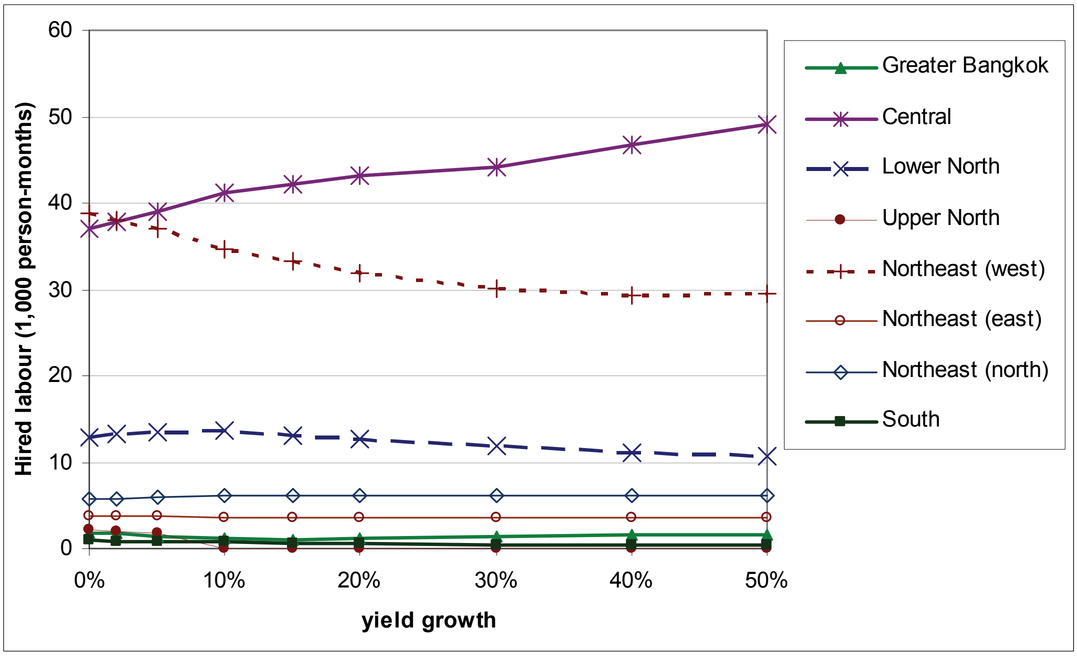

Figure 48: Regional demand for hired labour as a function of yield growth.

Such a disproportionate development of land and labour utilization originates from changes in the vegetable portfolio of regions. When capacity for increasing production in the Central region or Greater Bangkok becomes available through increasing yields and efficiency of labour use, those crops with a high relative share of transportation cost or high loss rates are grown to an increasing extent in areas close to the centres of demand.

External input use

The aggregate use of external inputs in the present parametric analysis depends to a large extent directly on the characteristics of technical progress in the assumptions. Under the assumption of sub-proportional growth of fertilizer and pesticide use, a similar relative decrease in the quantities applied to the crops should be expected.

The total environmental impact of vegetable production decreasing with an elasticity of around -0.5 is consistent with the underlying technical relationship (cf. Figure 84 on p. 230). In contrast to this, global nitrogen use in vegetable production remains closely around the baseline level of 60 million metric tons over the whole parametric range, which can be explained only by an increasing share of nitrogen-intensive technology. Moreover, given a decreasing vegetable land area, a more or less constant nitrogen use level means that nitrogen intensity with respect to vegetable area increases. The magnitude of this intensity effect differs between regions. As Figure 49 reveals, the high nitrogen intensity of CE vegetable production in the baseline grows up to a level of 732 kg/ha.

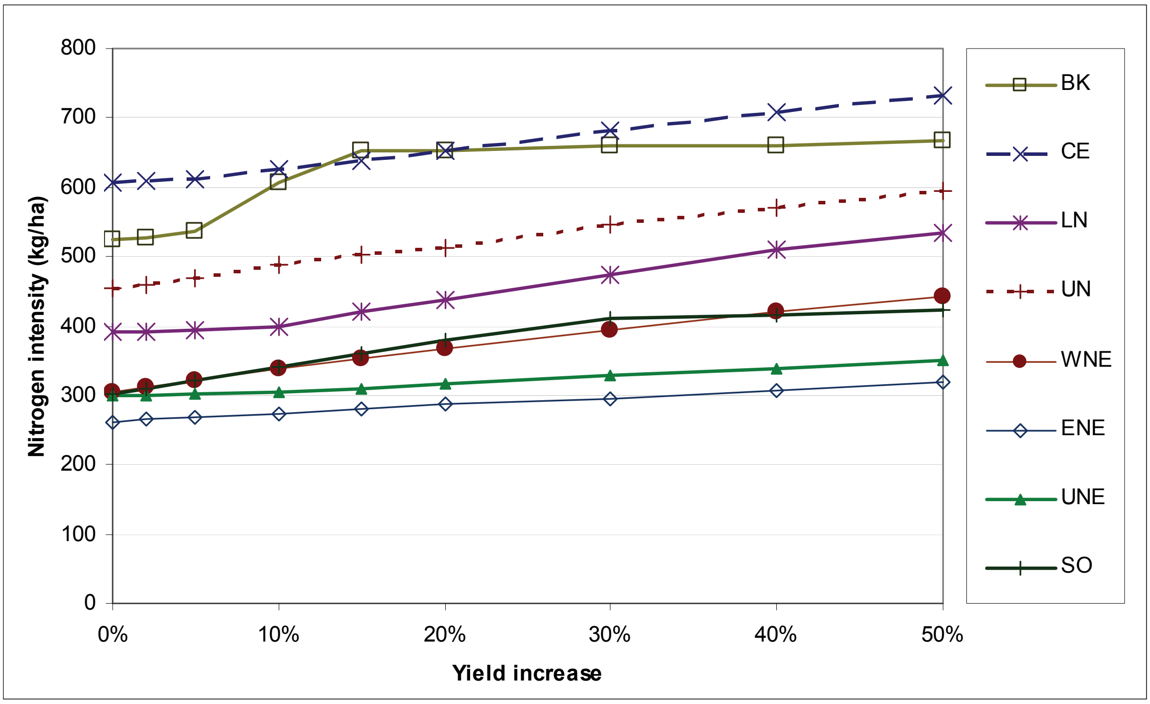

Figure 49: Regional nitrogen intensity and absolute quantities applied as a function of yield growth.

Intensity increases more in UN, where in line with a declining seasonal vegetable area (mostly planted to garlic and shallot) the land area planted at least once per year to vegetables shrinks comparatively rapidly at about -7% when yields increase by 10%, whereas nitrogen use and total output decline much more slowly (-0.5% and -0.8%, respectively for a yield increase of 10%). By analogy, the steep reaction of fertilizer intensity in the Greater Bangkok region in the range between 5% and 15% growth in yields can also be traced to a sudden drop in vegetable land in this interval, which in turn is a result of a reduced area planted to hot chilli in July and September, whereas the area planted at other times of the year increases.

When interpreting the results on the use of external inputs, it should be taken into account that the optimum level of external input use is not endogenously optimised but determined by the linear combination from a set of fixed Leontieff-type production technologies. In reality, farmers might adapt the level of chemical inputs to expectations of yield. As the respective marginal benefits of fertilizer and pesticide application might increase with yield levels, an even more rapid intensification could result. It is therefore likely that a growing physical land productivity will continue to contribute to an increasingly intensive use of chemical inputs.

5.3 Impact of selected policies on vegetable production

After an analysis of the effects of exogenous variables that change with demographic and economic development and technical progress, the focus is turned to those factors that can be purposively manipulated in order to bring about a desired effect on the vegetable sector. Such interventions are justified in the presence of market imperfections such as external effects commonly associated with high levels of external input use. The discussion in chapter 3 has identified the issue of adverse health and environmental effects from intensive vegetable production as a very obvious example of market failure, where policy intervention can contribute to welfare improvement. While an analysis of the welfare effect of policy interventions is beyond the scope of this study and that of a partial model, it is well suited to forecasting the supply side response to conceivable policy measures and the likely outcomes of various indicators. For this purpose, three different policy options are considered in sequence: (1) setting a fixed pesticide reduction target in the range between 0 and 30% of the baseline value, (2) levying a tax on pesticides that depends on the environmental impact associated with their use and (3) a zoning strategy that excludes intensive vegetable production from the inner area of the Greater Bangkok model region in order to effectively reduce the external effects concentrated in the smallest model region with the highest population density.

5.3.1 Implementation of a fixed pesticide reduction target

With a rising awareness of the risk of intensive pesticide use and over-use in vegetable production among consumers, retailers and policy makers on the one hand, and limited apparent success of past policies on the reduction of negative externalities from vegetable production on the other hand, the likelihood of regulatory intervention increases. Past policies of supporting diffusion of modern and less harmful technology and improving market transparency by certification of environmentally friendly products have failed to improve the negative externalities of pesticide overuse in vegetables on a national scale. For this reason, a more consistent enforcement of existing regulation or new instruments such as definition of pesticide use quotas or environmental impact quotas might be considered. While the theoretical foundation for fixing a quota at a certain absolute level is weak, the present practices are hardly acceptable considering the adverse human health and environmental effects. Against this backdrop, the model is utilized to predict how the sub-sector is likely to respond to a policy that defines reduction targets compared to the baseline use level. The definition of the reduction target takes advantage of the environmental impact quotient (EIQ) to combine in a single indicator the acute and chronic effects on applicators, farm workers, and consumers, as well as on aquatic and terrestrial ecosystems. In a parametric analysis the national reduction target for the environmental impact (EI) of pesticide use in vegetables is varied between 2% and 30% of the baseline level. Higher reduction targets cannot be attained unless a change in adoption of environmentally friendly technology is assumed. In the sense of a c.p. analysis, a parametric analysis excluding such adoption is presented before reporting a similar set of indicators for selected non-zero adoption rates for environmentally friendly production technology that already exists for several crops.

5.3.1.1 Regional distribution of vegetable production

It is expected that tightening EI quotas are first met by a reduction in the share of production activities characterized by high pesticide use and associated EI in favour of less pesticide intensive technologies. Depending on the regional availability of these technologies (cf. Table 23 on p. 100), a national quota might have different effects on the EI indicator and production in the various regions as cost-minimal adjustments will be preferred.

The simulation shows that regional vegetable output is hardly affected up to a global reduction target of 5% for the environmental impact of pesticides (Figure 50). In the interval between 5% and 20% reduction, production in LN is reduced by up to 33 thousand metric tons or 8%, while in UN and UNE increases of up to 21 thousand metric tons (2.6%) and 11 thousand metric tons (3.3%) respectively, are observed. Beyond a 20% reduction target, however, the supply response of UN is reversed: output declines by up to 14% below the baseline level. On the other hand, marked increases of the output from WNE and UNE by up to 18% and 10% respectively are observed.

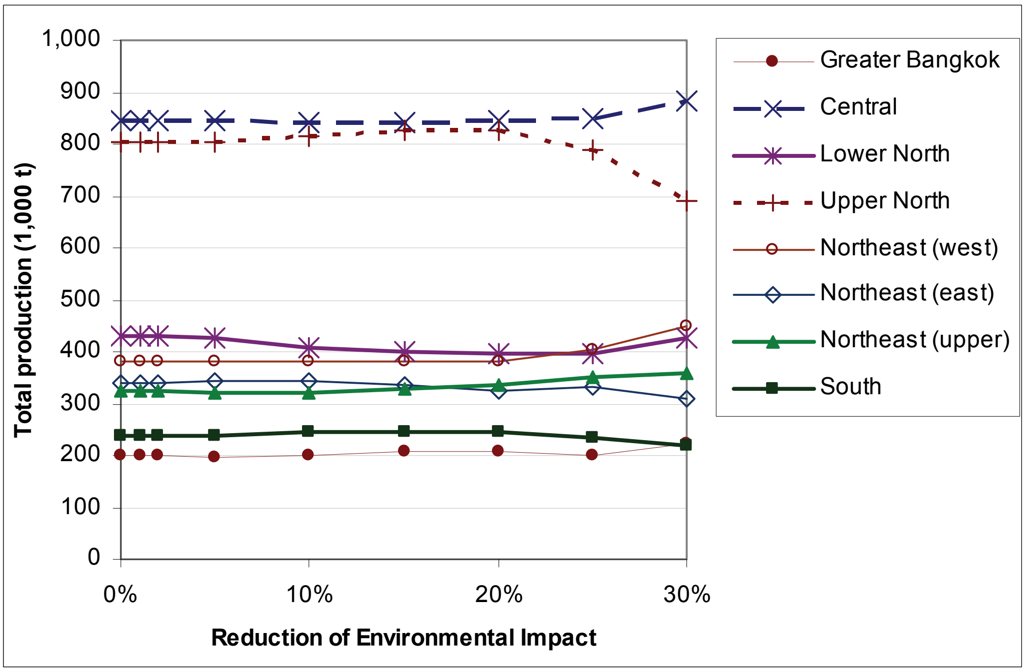

Figure 50: Regional vegetable output as a function of global environmental impact reduction targets.

Such non-monotonic supply response suggests that separate processes take place at different paces and affect the outcome to different extents. Before turning to a closer analysis of this change, associated the pesticide use trend will be considered. As shown in Figure 51, the use of unclassified pesticides in particular, declining from initially 1,100 to 750 metric tons follows the reduction target very closely, whereas the quantity of WHO class I used even increases up to a reduction target of 10% and that of class II pesticides up to a 20% reduction target. Obviously the cutback of environmental impact at lower reduction targets involves the substitution of less acutely toxic active ingredients by those of higher acute toxicity but lower environmental impact. Examples of such cases are technologies for yard long bean, spring onion and hot chilli production (cf. Table 23 on p. 100). Beyond a reduction target of 20% the quantity of pesticides applied declines for all toxicity classes and so does the level of transportation activity.

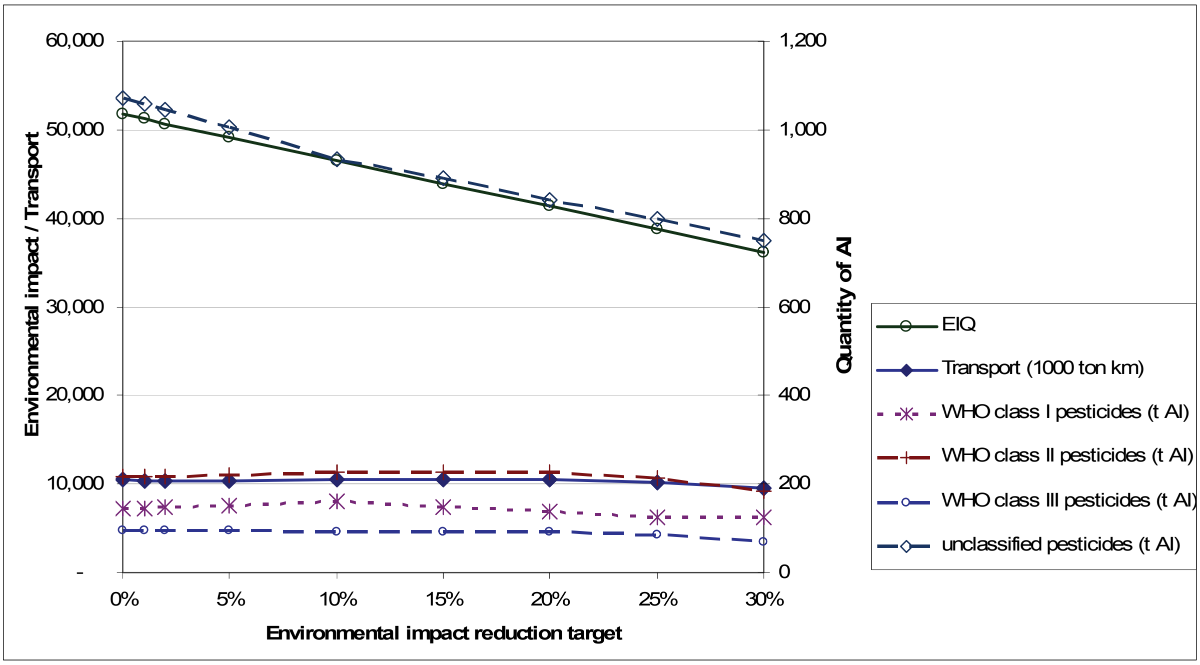

Figure 51: Pesticide use by WHO Hazard class for EIQ reduction scenarios under existing production technology

Starting from very different levels of environmental impact, model regions also benefit disparately from a global reduction target. The right hand panel of Figure 52 shows that CE continues to bear the largest share of environmental effects and benefits least from a reduction by at most 8%. In WNE, where the intensity of EI with respect to vegetable land is highest in the baseline, reduction lags behind the global target until it reaches 30%, where regional reduction also attains 33% in spite of increasing regional output (Table 39). In a similar way, increasing production in SO contributes to a less than commensurate reduction, but starting here from a low absolute level and intensity. In all other regions EI declines faster than the average: by up to 49% in BK, which was the second most intensive user in the baseline, and in a similar range in UN and UNE.

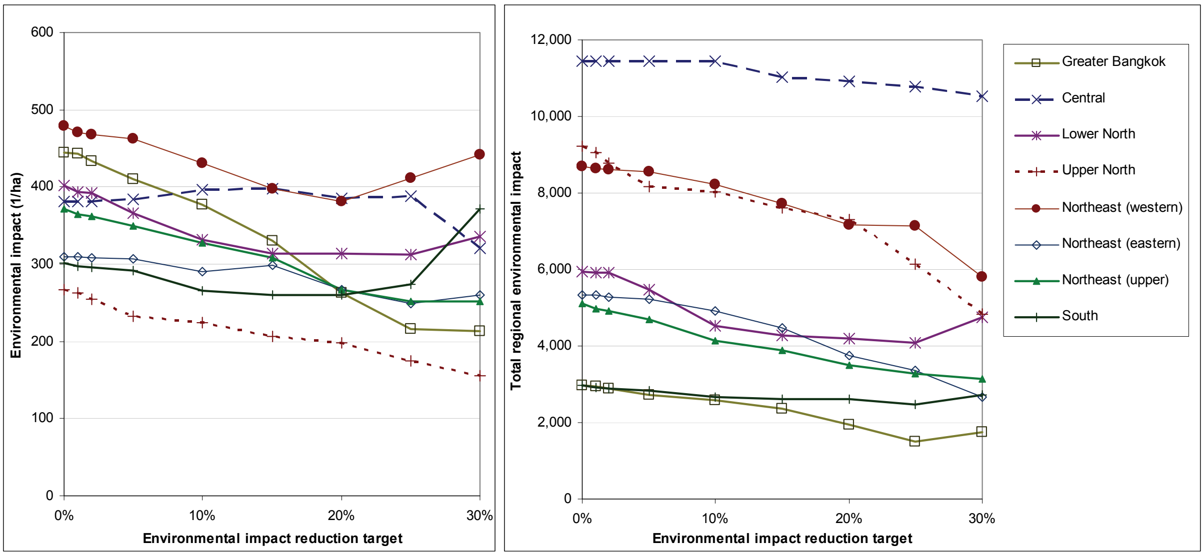

Figure 52: Regional environmental impact per hectare of vegetable land and absolute environmental impact as a function of global reduction targets

But even where output declines the most in absolute terms, i.e. in UN (-14.2%) and ENE (-9.4%), the much larger reduction of environmental impact in these regions (Table 39) cannot be explained by a mere reduction of planted area, even though beyond a 20% reduction target a gradual decline of transport activity by up to 9% (cf. Figure 51) indicates a relative shift away from the more distant production regions towards the centres of demand. Declining transport activity also entails decreasing losses and further reduction of production. However, on the country level, the average loss rate decreases only by about 5%.

Table 39: Changes in regional total environmental impact of vegetable production under global reduction scenarios in percent of the baseline value

Environmental impact reduction target	Bangkok	Central	North		Northeast			South
			lower	upper	western	eastern	upper	
5	-8.5	0.0	-8.1	-11.5	-1.6	-2.3	-8.0	-3.8
10	-12.9	-0.2	-24.1	-13.0	-5.4	-7.7	-18.8	-9.9
15	-21.0	-3.7	-28.4	-17.4	-11.3	-16.2	-23.9	-11.5
20	-34.3	-4.7	-29.6	-21.0	-17.6	-29.7	-31.7	-12.0
25	-49.4	-5.9	-31.3	-33.4	-17.9	-36.9	-35.9	-16.0
30	-41.1	-8.1	-20.3	-47.5	-33.4	-49.9	-38.3	-8.2

In order to identify the mechanism by which the environmental impact reduction is attained, the available production technology and changes in crop composition need to be considered. For the former, the indicators contained in Table 23 (p. 100) are useful. The variation within the indicator EIQ per metric ton of output represents the potential for substituting technologies with high EI by those with lower environmental impact within the set of technologies existing in the vegetable sector. On the other hand, for many crops only a single technology is available, which limits the scope for adaptation with respect to a pesticide reduction target and becomes manifest in the adjustment of regional portfolios.

Figure 53 depicts the output of selected crops as a function of a tightening pesticide reduction target in two regions, namely CE (chart a) and ENE (chart b). Up to a reduction in EI of about 20%, the composition of the regional crop portfolio changes only gradually. In the Central region the share of baby corn in the portfolio decreases slowly in favour of approximately commensurate increases in watermelon, chilli and Chinese kale (Figure 53 a).

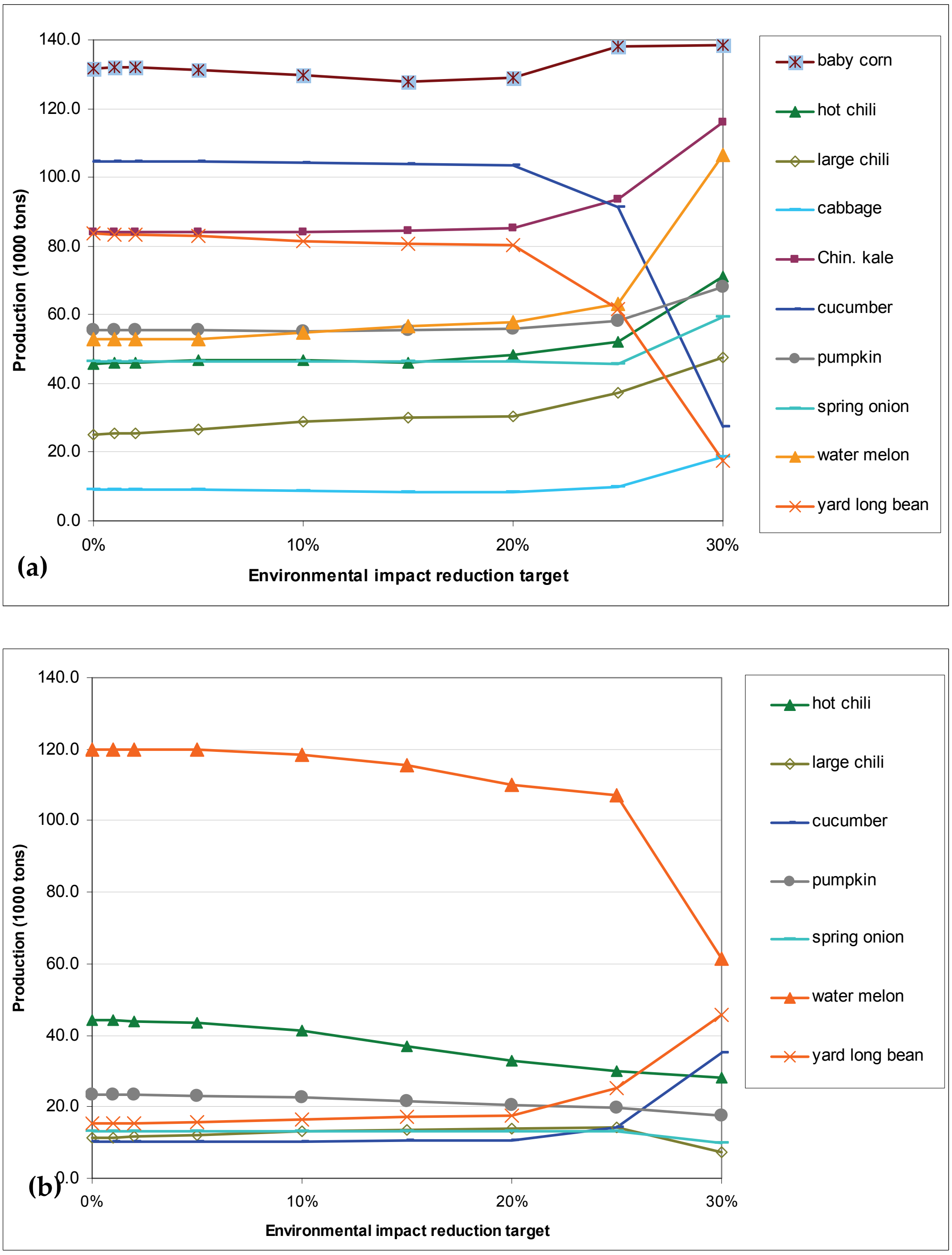

Figure 53: Regional production of selected crops under different environmental impact constraints (a) in CE and (b) in ENE

The reverse reaction is observed in ENE (Figure 53 b): watermelon production slowly decreases in favour of an increasing supply of yard long bean and large chilli. The EI of vegetable production is affected by this shift through two mechanisms. On the one hand, moving the centre of gravity of production of pesticide-intensive crops towards the sink reduces losses during transport and handling in these crops, which in turn means that demand can be satisfied by lower primary supply and hence at a lower level of EI. An instance for this case is the shift of watermelon production, which is based on a single technology throughout all regions. On the other hand, pesticide-intensive production activities can be replaced by less harmful technological alternatives that might be associated with higher marginal cost of supply. Yard long bean and cucumber represent examples for this case, because intensive year-round production technology prevailing in BK and CE (cf. Table 23, p. 100) contrasts with (in terms of external inputs) extensive off-season production technology in WNE, ENE and UNE. Therefore, yard long bean and cucumber production rapidly decline in CE and gain importance in the northeastern model regions. Analogous developments in other model regions contribute to meeting national demand.

Marginal cost of vegetable supply

Given the technology and resources available for vegetable production, the baseline solution represents the least cost combination of activity levels sufficient to satisfy demand constraints. Any deviation will ultimately lead to an increase in the marginal cost of vegetable supply. Thus the realization of an EI reduction target is also associated with higher marginal costs of supply in general. The extent to which individual crops are affected will depend, however, on the available alternative technologies, which substitute higher levels of land, labour or less harmful pesticides for those with higher environmental impact quotient and thereby increase the marginal cost of supply[71]. Moreover, different regional availability of such technologies might involve increasing transport volumes with the associated cost.

Simulation runs of reduction targets up to 5% reveal that the change in marginal supply cost at the Bangkok wholesale level as shown in Table 40 is rather minor, with the exception of large chilli, which is grown by a single technology characterized by the highest per metric ton environmental impact. Its marginal supply cost increases by 7.5% as production moves from UNE and LN towards the CE, where it utilizes scarce labour instead of slack family labour as before and thus becomes more expensive (cf. also Figure 55). This adaptation process continues with more restrictive global reduction targets and the marginal supply cost of large chilli increases fastest and reaches a 57-fold maximum in a 30% reduction scenario. This extreme point is associated with a massive decline of production in UN (-47%) and northeastern regions (-39%) and a commensurate increase of output in CE (+90%) and BK (+123%). The concomitant reduction of transport brings down the average loss rate in this crop from 5.7% to 3.0% and thereby contributes to reduction of environmental impact (EI) through a cutback of primary production.

[71] Examples from Table 23 on p. 100are: (a) Chinese mustard: more expensive but less harmful pesticides, (b) hot chilli: lower EI and lower yield levels, (c) cucumber: lower EI but higher labour requirement.

Table 40: Percent change in marginal cost of supply at the BK wholesale level for EI reduction targets

Crop	Environmental impact reduction target in percent			
	5	10	20	30
Asparagus	0.4	1.5	3.8	59
Baby corn	1.2	4.2	14.3	1,134
Brinjal	0.3	1.1	3.7	306
Hot chilli	1.6	4.1	13.9	789
Large chilli	7.5	26.4	86.2	5,723
Cabbage	1.0	2.5	8.1	687
Chin. cabbage	0.7	2.5	9.2	670
Cauliflower	0.6	2.5	9.6	773
Chin. mustard	1.2	4.4	12.0	157
Chin. kale	0.2	0.9	3.5	172
Coriander/celery	0.0	0.1	0.7	161
Chin. radish	0.5	2.2	7.1	476
Cucumber	2.7	10.1	35.9	2,229
Ginger	0.0	0.2	0.6	65
Garlic	0.3	1.3	4.5	407
Lettuce	0.4	-0.1	-0.2	45
Morning glory	0.0	-0.2	0.1	18
Pumpkin	0.7	2.5	10.2	746
Shallot	0.0	-0.1	-0.1	4
Spring onion	0.2	0.6	2.5	169
Tomato	0.6	2.2	6.9	369
Watermelon	1.8	7.4	23.4	1,338
Yard long bean	1.5	5.9	22.9	1,245

For cucumber and yard long bean substantial increases of marginal supply cost are also observed in spite of alternative technology that is characterized by drastically lower environmental effects, but higher variable cost. But as mentioned above, less intensive production practices are found only in the seasonal vegetable farms of the Northeast, and EI reduction targets beyond 20% are associated with substantial changes in the regional output shares – in this case a centrifugal move from BK and CE (-65% and -79%, respectively, at the bound of the interval) to WNE (+352%), UNE (+212%) and ENE (+196%). Such increase in average transport distance and associated transport losses is observed only for the 30% reduction target in yard long bean and cucumber as special cases. For other crops with substantial increases in marginal supply costs in the more extreme reduction scenarios such as watermelon, baby corn, cauliflower, cabbage and pumpkin, it is a substantial shift *towards* the centre of demand that contributes to appreciation by utilizing additional land and labour resources in BK, CE and SO (cf. Figure 53a). Finally, the supply costs for two groups of crops are hardly affected by a tightening EI constraint. Production of one group encompassing ginger, shallot and garlic, is generally restricted to a certain region (or two regions in the case of garlic) for climatic reasons. As a shift of production of these crops among regions is not provided for in the model, they are not affected by changing transport distance. The second group, that includes asparagus and lettuce, is affected only to a minor extent as their production takes place very close to the centres of demand and moving production cannot contribute to a reduction in losses.

Though technically feasible within the set of currently prevalent production practices, a reduction of environmental impact by 30% seems hardly realistic as it entails a very substantial rise in the marginal cost of supply for various vegetable crops at the BK wholesale level. Supply cost of more than half of all crops considered in the model are predicted to increase by a factor 3 or more in such a case. On the other hand, for a 20% reduction scenario price increases are rather moderate and below 20% for 18 of 23 crops considered in the model.

Alternatively, the cost implications of various reduction targets can be measured directly by the marginal value of the EIQ constraint[72]. As shown in column 2 for the assumption of zero adoption of advanced technology[73] in Table 41, the cost of saving an additional unit of environmental impact is highly non-linear with increasing reduction target. Initial reduction is comparatively simple and feasible by substituting highly pesticide intensive production technology by less intensive ones in only few crops. This is in line with a nearly unaffected regional pattern of vegetable production up to a 5% reduction target. Beyond this threshold, the cost of saving 1000 units of environmental impact first quadruples for a 5% step, then quadruples again between 10% and 20% reduction targets. The sudden rise of reduction cost to the 72-fold level at a 30% reduction target coincides with drastic changes to the regional pattern of vegetable production as shown in Figure 50 and Figure 53.

Table 41: Marginal cost per unit EI saved under increasing reduction targets and for alternative adoption rates of advanced production technology

(THB/1000 units of EIQ)

EI reduction	Adoption of environmental friendly technology (area share)				
	0%	10%	20%	30%	50%
1%	-2.36	-0.06	0.00	0.00	0.00
2%	-3.34	-2.92	-0.07	0.00	0.00
5%	-8.56	-9.68	-9.03	-6.35	-2.55
10%	-32.94	-29.48	-28.84	-27.72	-25.57
20%	-118.13	-113.51	-109.57	-98.97	-88.48
30%	-8,484.75	-3,017.11	-1,738.51	-1,154.64	-655.46

Obviously, a reduction of environmental impact beyond the substitution of existing production technology within a region by shifting production among regions is a comparatively costly approach. For example, the environmental impact of 72.5 units associated with the production of one kilogramme of large chilli would add 615 THB to the price per kg under a 30% reduction

[72] The marginal cost of the EI constraint is negative, as the objective function total variable cost is reduced by extending the permitted EI by one unit.

[73] These technologies have not been reported by regional expert workshops and hence are not part of the baseline solution of the model. See technologies designated by an asterisk in Table 23 (p. 100) for characteristics.

target, rendering such a target hardly acceptable. It is worth noting that this price premium roughly corresponds to the increase in marginal supply compared to the baseline scenario.

When adoption of less pesticide-intensive technology for just selected crops such as baby corn, hot chilli, Chinese cabbage and Chinese kale[73] is allowed for, a reduction of EI is less costly than if production was based on the prevailing technology alone. The difference is most pronounced in the extreme lower and upper range of reduction targets (Table 41). Assuming that a third of the area planted to the above mentioned crops was grown under less harmful production practices, the marginal supply cost of large chilli would increase by less than 90 THB per kg or 8-fold from the baseline value. Even though no alternative technology is included for large chilli production, the marginal supply cost of this crop is much less affected by a global reduction target. The utilization of available less EI-intensive technology in shares around 20% to 30% of the area planted contributes substantially to controlling the supply cost implications of an EI reduction target.

5.3.1.2 Utilization of farm land and labour

As regional land allocation is closely linked to changes in vegetable output as shown above, it will not be presented here (cf. Figure 85 and Figure 86 on p. 232). The effect of the observed production shifts on labour utilization is comparatively pronounced, however, and labour demand is discussed in some detail. Concerning the demand for hired labour (Figure 54) for small reduction targets up to 5%, a reduction of hired labour demand in all regions except for LN is observable. In WNE especially, hired labour demand declines by about a quarter for a 20% reduction and to less than half of its baseline value with more rigorous targets even though production of cucumber, yard long bean and watermelon expands in this region. But as their labour requirement is highest during the off-season, labour in these crops is covered by family labour most of the time. Vegetable farms in CE demand less hired labour for moderate reduction scenarios as in this area also, intensive production technology is replaced by relatively less labour- and external input intensive crops (hot chilli, Chinese mustard and Chinese kale, morning glory, spring onion[74]). Beyond a 25% reduction target, hired labour demand increases above the baseline level, however, when baby corn, hot and large chilli and other crop production increases during the cool and dry season. In BK, mostly due to switching from labour- and pesticide intensive to more extensive technology in hot chilli production, wet season labour requirement declines beyond the 20% reduction target. Similar developments, but at a greater scale, also reduce wet-season demand for labour in UN (cf. Figure 87 on p. 232). In addition, the absolute decline of cabbage production in the peripheral region contributes to a very substantial decline in labour requirement to around half the baseline levels for a 30% reduction in EI.

Given the pronounced effect on hired labour demand, the question arises how the return to family labour is affected. In the absence of a market equilibrium model, it is impossible to ascer-

[74] Cf. Table 23 (p.100).

tain whether and to what extent the cost increase is borne by consumers or producers. If, however, the assumption of constant wholesale prices that has been used to formulate a minimum farm income constraint in the model is maintained, the return to family labour can be used as an indicator for the impact of reduction policies on farm income.

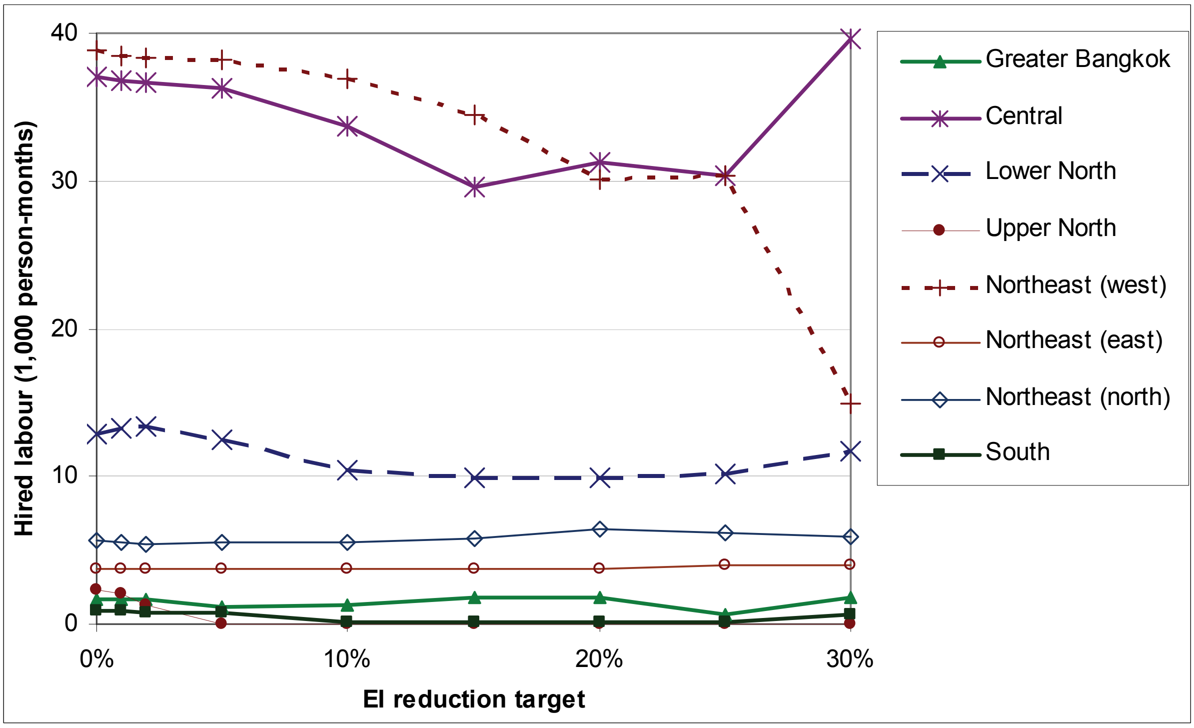

Figure 54: Regional hired labour demand of vegetable farms as a function of a global reduction target for the environmental impact of pesticide use

As shown in Figure 55, the return to family labour starts from very different levels, with returns in the CE around 420 THB/day close to the 2.5-fold level of the return to family labour in the eastern part of the Northeast at 170 THB/day, which is consistent with a high specialization and year-round production of vegetables in the former and mixed farms with off-season vegetable production in the latter. With slack family labour available throughout most of the year, return to family labour remains unaffected in ENE, even though aggregate physical output increases. In most other regions, return to family labour changes in parallel with output. In UNE and WNE, however, decreases over parts of the parameter range in spite of growing output are a consequence of an increasing share of – in terms of external inputs – less intensive technology, e.g. for cucumber and yard long bean. When comparing the course of regional environmental impact (Figure 52) and the course of return to family labour over the parameter interval, opposite trends are observed for most regions. Where environmental impact recedes at below average rates (SO, CE), the return to family labour increases, whereas on the other hand rapid declines in environmental impact are associated with a decreasing value of family labour (LN, UN, WNE, ENE). In the absence of a market model with elastic demand, the model results imply that a large share of adaptation cost is borne by *some* producers and this leads to an increasing regional disparity in farm incomes.

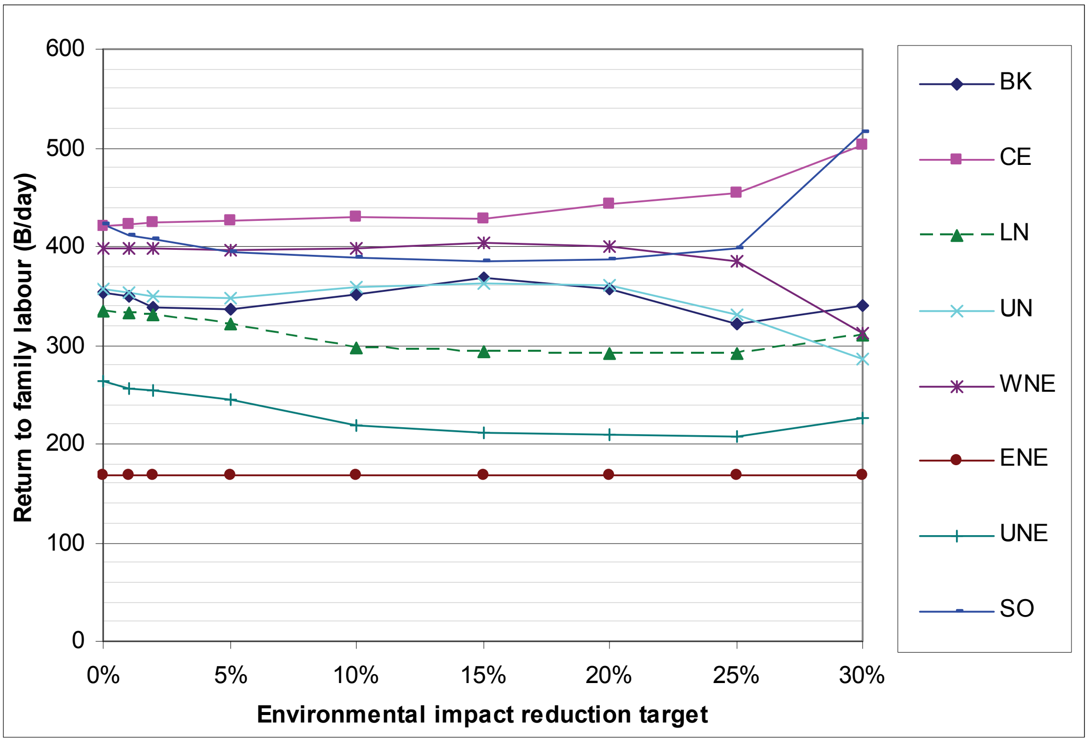

Figure 55: Return to family labour as a function of a global environmental impact reduction target.

A summary of the results of a parametric simulation of a global pesticide reduction target based on the environmental impact quotient as indicator has shown the possibilities and constraints of such a policy option in the framework of existing technology. While it is possible to reduce negative side effects by up to 30%, the cost of such a policy increases very rapidly when targets beyond a 20% reduction are set. Thus, the marginal supply cost for most vegetables increases by less than 5% up to a 10% EI reduction and by up to 15% for a 20% reduction. For a reduction scenario of 30% the marginal cost of supply for most crops increase more than twofold. The adoption of environmentally friendly technology for 30% of the area planted to just four out of 23 crops reduces this effect by a factor 7, but a 7 to 8-fold increase of marginal supply cost still remains (cf. Table 66, p. 231). The extreme rise in marginal supply cost in some vegetables can be used as an indicator of in which crops alternative technology could contribute most to a cost-saving implementation of pesticide reduction strategies. These are obviously large chilli, cucumber, yard long bean, watermelon and baby corn.

Although the model is well suited to assessing the effect of a policy on the regional aggregate use of pesticides, drawing conclusions for the residue limits on vegetables or the exposure of applicators and farm workers to hazardous substances is impossible as these depend on individual behaviour such as the timing of application and harvest, the actual (in contrast to the average) dose applied as well as protective clothing and safe handling practices. Nevertheless, a reduction in pesticide use implies on average a reduction of both consumer and occupational health risks and environmental hazards and is therefore still a valuable and suitable model scenario for an assessment of policies aiming at an improvement of the sector's performance with respect to health and environmental objectives.

5.3.2 Effect of pesticide taxation based on an environmental impact indicator

The results of the above simulations have shown that within the limits of existing technology by shifts among production activities and regions, a notable reduction of pesticide use in vegetable production is feasible. Implementing such a target requires either regulatory action or other incentives for individual decision makers to contribute to attaining such target. As an economic instrument, a Pigouvian tax can be used to internalize (a proportion of) the social costs of pesticide use that are external to pesticide users. Such a policy has already been implemented in some European countries and a province of Canada[75]. With regard to the cost of control, a tax is usually regarded to compare favourably to other policy options, as often existing tax mechanisms can be used and usually a much smaller number of players has to be monitored than compared to large populations of small-scale farms. On the other hand, the relevant information for determining the price premium required to bring demand for pesticides down to the desired level is often missing. Obviously this is a function of the elasticity of demand for pesticides, which likely varies widely among crops. Therefore tax rates based on the environmental impact of pesticides ranging from 10 to 500 THB/1000 units of EI have been analysed for their effect on the input use, regional distribution of production and marginal supply cost. The average price increase per application associated with a tariff of 10 THB/1000 units of EI is mapped as a cumulative distribution for those active ingredients that are used in the crop production activities of the model in Figure 56 and reveals a wide spectrum of price premiums from 1% for the insecticide abamectin to 385% for sulfur used as a fungicide. While the former is more recently developed, specifically targeted and therefore less harmful but on the other hand more expensive active ingredient (EIQ 67.4, 120 THB/application), the latter is a rather cheap but harmful input that is applied in comparatively large quantities (EIQ 14,380, 39 THB/application), and therefore receives the highest price increase from the proposed tariff.

The relative change of environmental impact brought about by an increasing tax rate on environmental impact is shown in Figure 57 and exhibits the expected decreasing marginal effect with increasing tax rates. The regional distribution of these effects is not discussed here but provided in the appendix (Figure 94, p. 238). A comparison of the tax rate and associated relative decrease of aggregate environmental impact to the marginal cost of an externally imposed restriction to environmental impact in the preceding section (Table 41) reveals a strong symmetry between the approaches. A tax of 10 THB/1000 units of EI leads to a decrease in EI by 5.5%, which is very close to the marginal value of 8.6 THB/1000 units EI at a 5% reduction target and so forth. The symmetry is a direct consequence of the duality of mathematical programming models

[75] According to an OECD database taxes or fees on pesticides/pesticide use are levied in Denmark, Finland, Norway, Sweden and the Canadian province of British Columbia (OECD, 2008).

and can be used in this context as an indicator for the level of taxation required to bring about the desired reduction in environmental impact.

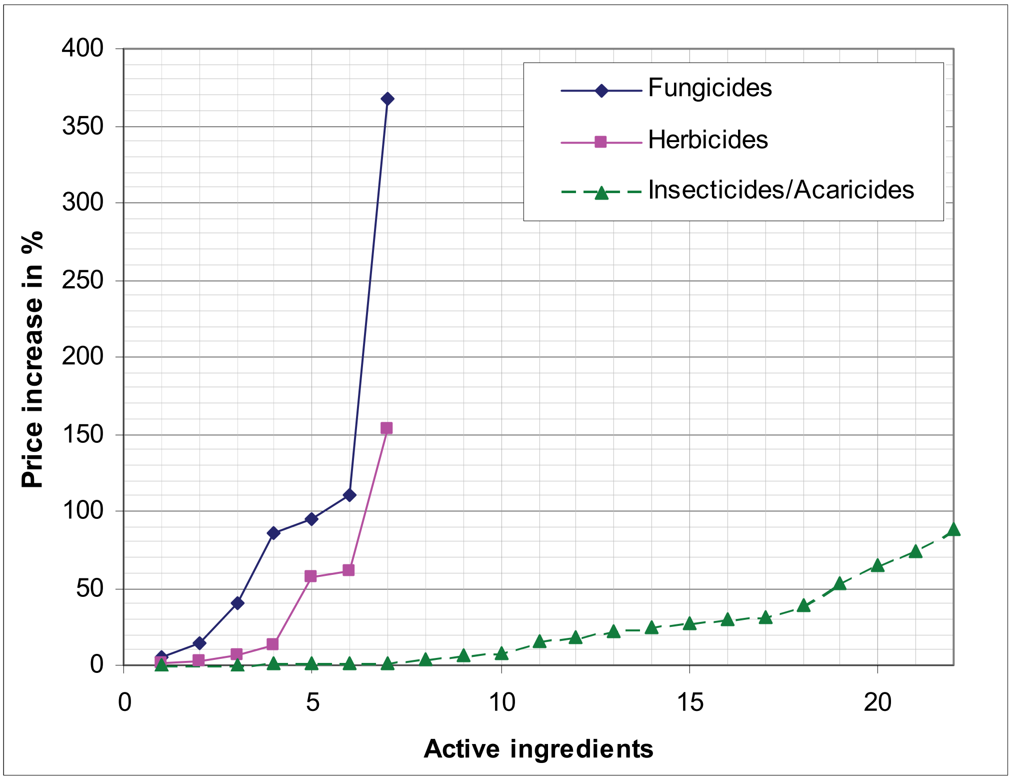

Figure 56: Average price increase per application for active ingredients used in vegetable production for a tax rate of 10 THB/1000 units of EIQ

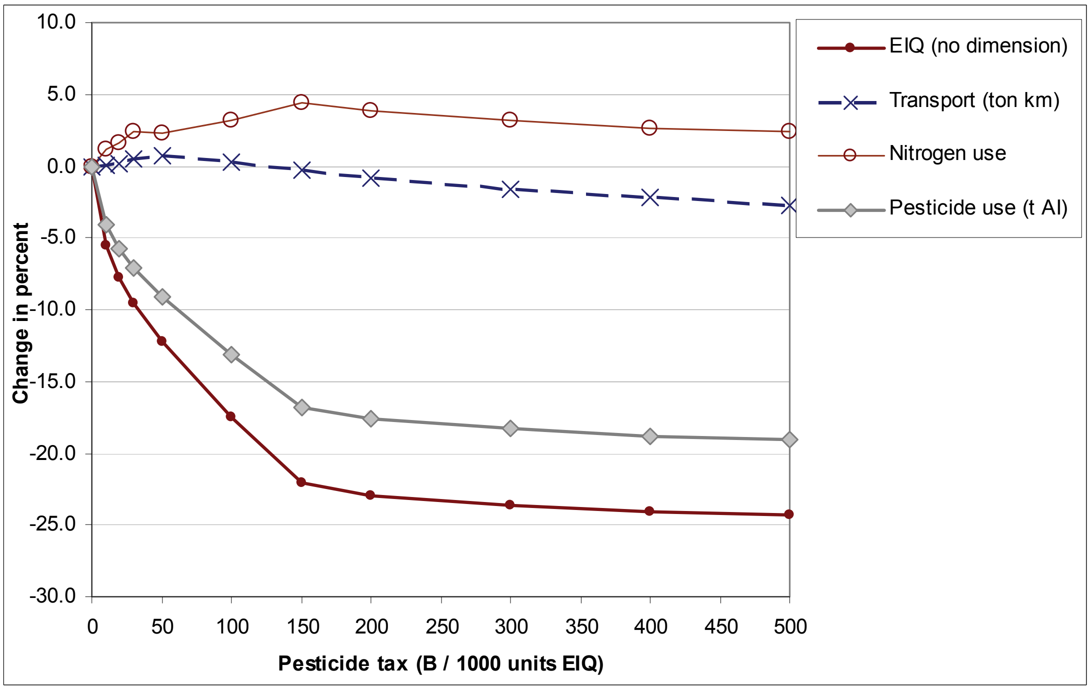

Figure 57: Change in environmental indicators in response to increasing tax tariff on pesticides

In order to illustrate the equivalence of the aggregate constraint to environmental impact and an indicator-based Pigouvian approach, just a few selected indicators are presented in the following. Considering first the distribution of vegetable production among regions with regard to Figure 58, the non-linear development of the marginal cost to linearly decreasing environmental impact constraints (Table 41, p. 159) has to be taken into account. The range shown in Figure 58 corresponds to an aggregate EI reduction by up to 22% at a tax rate of 150 THB/1000 units EI and an additional 2.3% over the remaining interval. Therefore an analogous course for regional production in both Figure 53, which shows regional production for a linearly tightening environmental impact constraint, and Figure 58 is found. They differ in terms of the X-axis scale, which in the latter is compressed for the first part, where marginal effects of increasing tax are still high, and stretched over a longer range where the marginal effect of a tax diminishes. The more pronounced changes of regional supply shares are not shown as the simulated parameter range does not reach the extreme marginal cost of a 30% reduction scenario that had been considered in the preceding section.

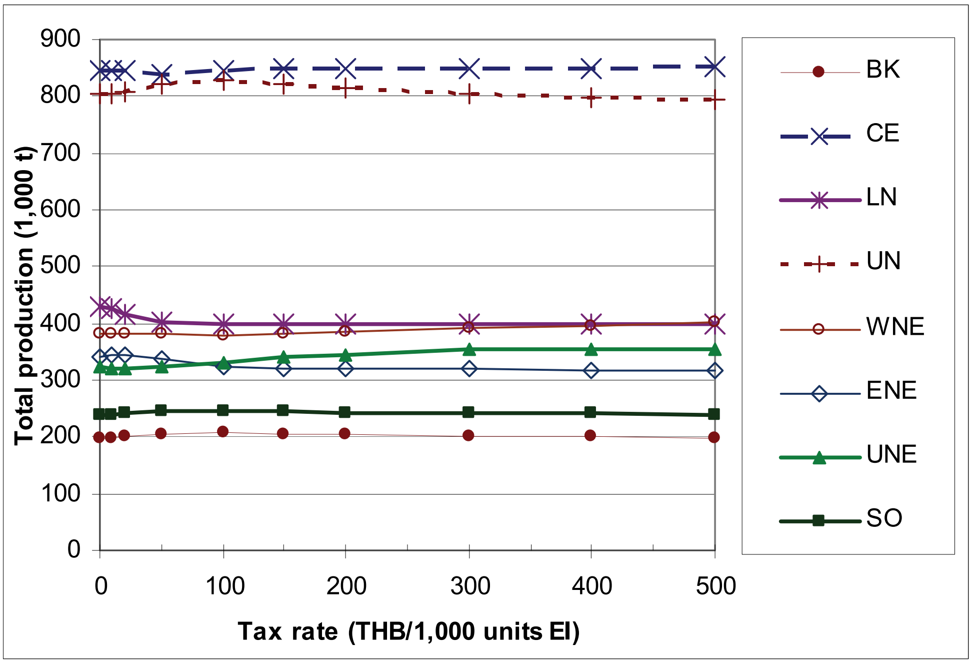

Figure 58: Regional production as a function of tax rates

In spite of a close correspondence between global reduction targets and a tax-based approach, the effects on farm incomes differ substantially as a comparison of Figure 59 and Figure 55 (p. 162) quickly reveals. For the tax-based reduction approach a very rapid initial drop of farm incomes is observed in UNE, LN and SO that changes to a gradual linear decrease as tax rates exceed 50 THB/1000 units EI, whereas the decline is more or less linear in other regions. For a tax rate of 150 THB/1000 units EI, which implies an aggregate reduction of EI by 22%, we find that the return to family labour decreases by between 30 THB/day (-8%) in UN and 108 THB /day (-26%) in SO. The strict downward direction and the size of income loss in the tax approach are, however, a result of product market representation in the model. As return to family labour is based on fixed market prices and a deduction of the additional cost linked to a pesticide tax, the resulting effect of such a policy is pre-determined by the implementation of the market model and is therefore valid only under strong assumptions. In the absence of better information on the elasticity of domestic vegetable demand in Thailand, the distributional effects of changes in technical, economic and policy parameters cannot be ascertained.

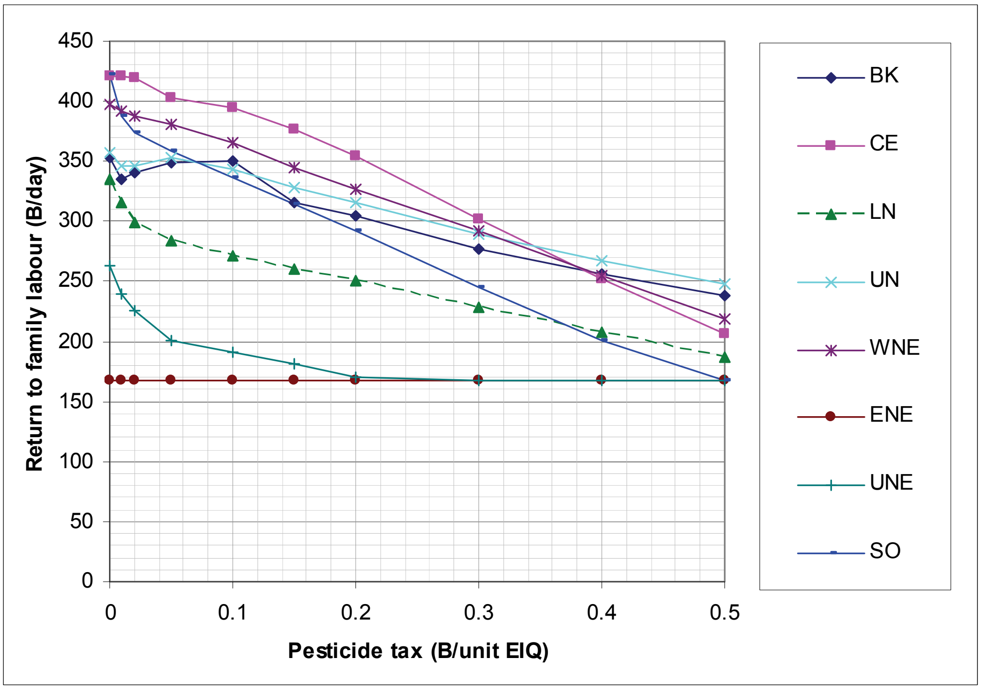

Figure 59: Return to family labour for different tax rates based on the EI of pesticides

Notwithstanding these limitations, the simulation results for the economic instrument of a pesticide tax based on a compound indicator show the demand reaction of vegetable producers for harmful pesticides. As a tax can be implemented only uniformly on all pesticides marketed for agricultural purposes, the demand reaction of other sub-sectors would also have to be taken into account if a sound policy is to be designed. Moreover, a likely income effect of input taxation will vary widely for different types of crops such as rice and field crops, vegetables or fruits.

5.3.3 Effects of a zoning policy banning vegetable production from the peri-urban fringe

According to simulation results, the policy measures discussed above perform well in a specific range of reduction targets and are effective in reducing the heavy use of external inputs in vegetable production as far as pesticide use is concerned. But the success of such strategies hinges on their ease and consistency of implementation. Within the framework of this study, it is not possible to ascertain the feasibility of a fixed national reduction target or an indicator-based pesticide tax, but monitoring costs of the former are likely to be very high and the latter requires a consistent framework that would affect also field and fruit crops, for which different levels of intervention might be required. A third option that addresses more specifically the problems of the greater Bangkok region by a zoning strategy will be analysed in this section. About 18% of the national population lives in BK, rendering it the most densely inhabited area with 1,516 persons/km², more than twelve times the national average of 122 persons/km². In addition to the environmental footprint of such a population and industries[76], vegetable production imposes a high burden in terms of environmental impact and nitrogen supply with respect to the total land area of the region. Table 42 reveals that for both pesticide use – measured in terms of environmental impact – and external nitrogen supply in vegetable production – the intensity per square kilometre of land is more than two times higher than that of the second ranking regions and above three times the national average.

Table 42: Indicators of pesticide and nitrogen use with respect to size and population of the region

Model region	Area (1000 km²)	Population (1000)	EI (10^6)	EI (1000/ km²)	Nitrogen application (1000 t)	t/ km²
Greater Bangkok	7.683	11,651	2,980	387.87	3,514	457.39
Central	93.939	10,003	11,458	121.97	18,243	194.20
Lower North	78.385	5,673	5,958	76.01	5,799	73.98
Upper North	96.277	5,853	9,228	95.85	15,715	163.23
Northeast (western part)	49.048	6,247	8,699	177.35	5,552	113.19
Northeast (eastern part)	59.867	7,865	5,338	89.16	4,511	75.36
Northeast (northern part)	58.841	6,987	5,110	86.84	4,123	70.06
South	71.557	8,384	2,959	41.35	2,962	41.40
Total/Average	**515.597**	**62,662**	**51,729**	**100.33**	**60,420**	**117.18**

Against this backdrop a reduction of the side-effects of vegetable production is most urgent in BK. The simulation of national level policies such as a general reduction target or an indicator based pesticide tax has shown that these approaches do not lead to an improvement in BK. In response to such failure, policy makers might decide on more localized but restrictive policy options such as a ban of vegetable production partially or completely in the whole region. This section therefore presents the simulation results for a successive containment of the area used for vegetable production in the BK region by a zoning policy. For this purpose, it is assumed that vegetable production is effectively banned in an increasing radius around settlement areas. At the spatial resolution of the model, this corresponds to a decreasing area available for vegetable production in the region. The associated increase in mean transportation distance is negligible given the small size of the region[77]. Moreover, it is assumed that vegetable farmers can move out from the BK at a maximum rate proportional to the area excluded from vegetable production by the zoning policy and continue vegetable farming in any other of the model regions. Their destinations are determined endogenously within the model.

[76] In 2006, about 44% of GDP from industries was generated in Greater Bangkok (NESDB, 2007).

[77] The coextensive circle of the Greater Bangkok region has a 50 km radius.

5.3.3.1 Regional distribution of production

As an immediate consequence of restrictions on land use for vegetable production in BK, an accordingly declining supply from the region and additional supplies from other regions close to BK are to be expected. Such an outward shift will be associated with additional transport costs and additional labour use in regions where vegetable production expands. As land becomes increasingly scarce, production in BK will be intensified on the remaining area in order to reduce the declining regional supply.

The total vegetable output by region shown in Figure 60 is in line with the diminishing vegetable land in BK and a compensating growth of output in all other regions, but primarily CE. In the case of a complete ban of vegetable production in BK, supplies from CE increase by 13.4%, followed by 7.6% in SO and 6.3% in WNE. However, this uneven growth does not significantly change the relative regional contribution to total supply. Obviously, the supply share of Greater Bangkok diminishes to zero whereas that of the Central region increases by 3.1 percentage points. The shares of other regions grow by less than 1 percentage point.

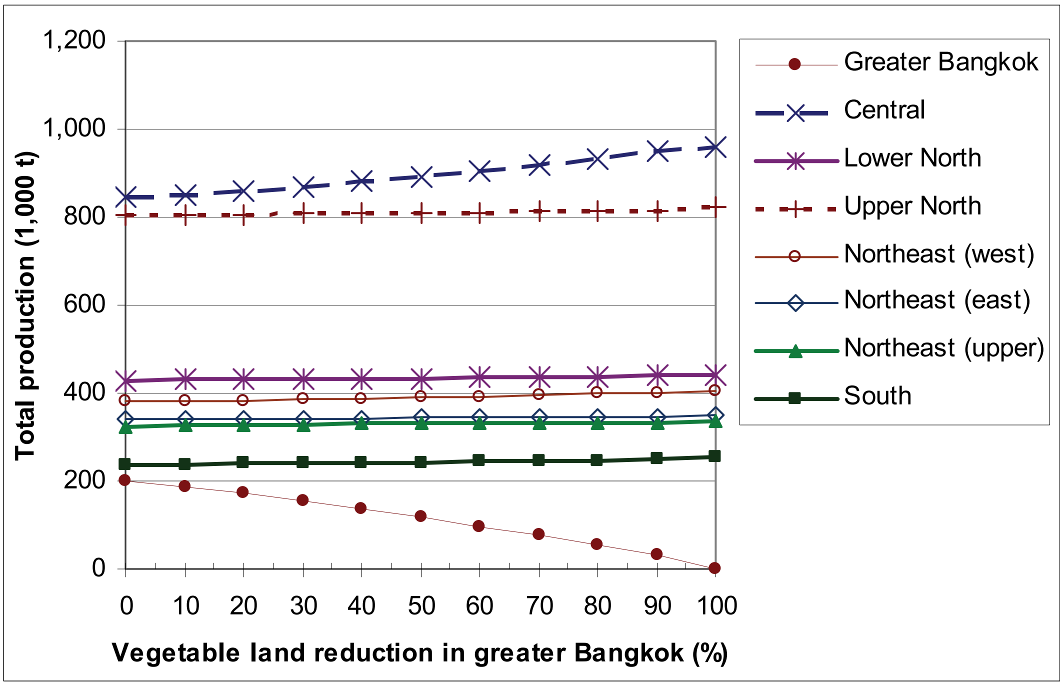

Figure 60: Regional production as a function of decreasing vegetable land

A closer examination reveals that output does not decline linearly but rather with an initial arc elasticity of just 0.56, which means that a 10% reduction in available area leads to just 5.6% lower output from the region, an effect that is attained by a relative shift among crops in the vegetable portfolio as visualised for the most important crops in Figure 61. While the area covered by crops such as baby corn, coriander/celery and hot chilli decreases faster than total vegetable area, other crops such as the leafy vegetables spring onion, morning glory, Chinese mustard and Chinese kale react after a considerable delay. The latter group is characterized by high physical land productivity (4.4-8 t/ha/month[78]) whereas the former is less productive with respect to land (1.8-2.7 t/ha/month) that becomes increasingly scarce under the zoning regime.

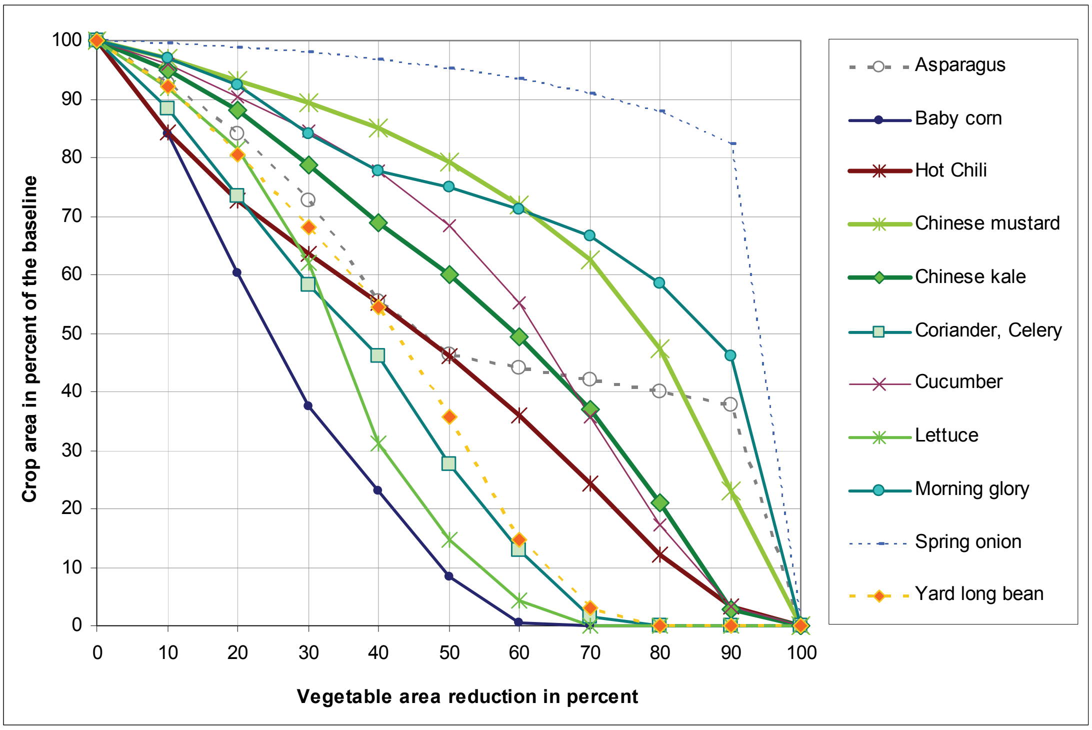

Figure 61: Change in planted area of the main crops in BK as a function of decreasing vegetable land

Given an abundant family labour endowment in the region in the baseline situation, such shift from land- to more labour intensive crops continues over the simulation range as the land/labour ratio remains unchanged when out-migration from BK is assumed to be limited to the same rate as vegetable land area is reduced[79].

5.3.3.2 Marginal cost of vegetable supply

The increasing scarcity of a production factor in BK that is linked to a zoning policy will contribute to increasing marginal costs of vegetable supply, because supplies must be produced on less land with higher levels of labour and external inputs, or must be substituted by additional production in other regions. At the same time it is assumed that skilled labour becomes available in other regions through migration of vegetable farmers, proportional to the land withdrawn from production. Such an increase in the endowment with the scarce human capital factor will contribute to a reduction in marginal cost of supply.

The different rates by which individual crop areas are adjusted to tightening restrictions on vegetable land in Greater Bangkok is also reflected in the course of marginal supply cost at the

[78] For detailed indicators of crop technology pls. refer to Table 23 (p. 100).

[79] Without such restriction, 63% of farm population would migrate to the Central region even in the absence of any zoning policy and a different reallocation of vegetable land is obtained. This scenario is not considered here.

regional wholesale level (Figure 62). Lettuce represents a special case, for which 56% of supplies come from BK in the baseline (cf. Table 30) and its area planted diminishes to zero when zoning reduces vegetable land by 70%. Two-thirds of regional production are then substituted by supplies from CE, where scarce family labour contributes to cost increases. The similarly rapid shift of baby corn production towards CE is not associated with increasing marginal cost as the crop is relatively labour extensive and – more importantly – baby corn output in CE grows by only 5% compared to the baseline. Adjustment costs for such minor change are low compared to the case of lettuce, whose production increases to the 114-fold of initially very low production.

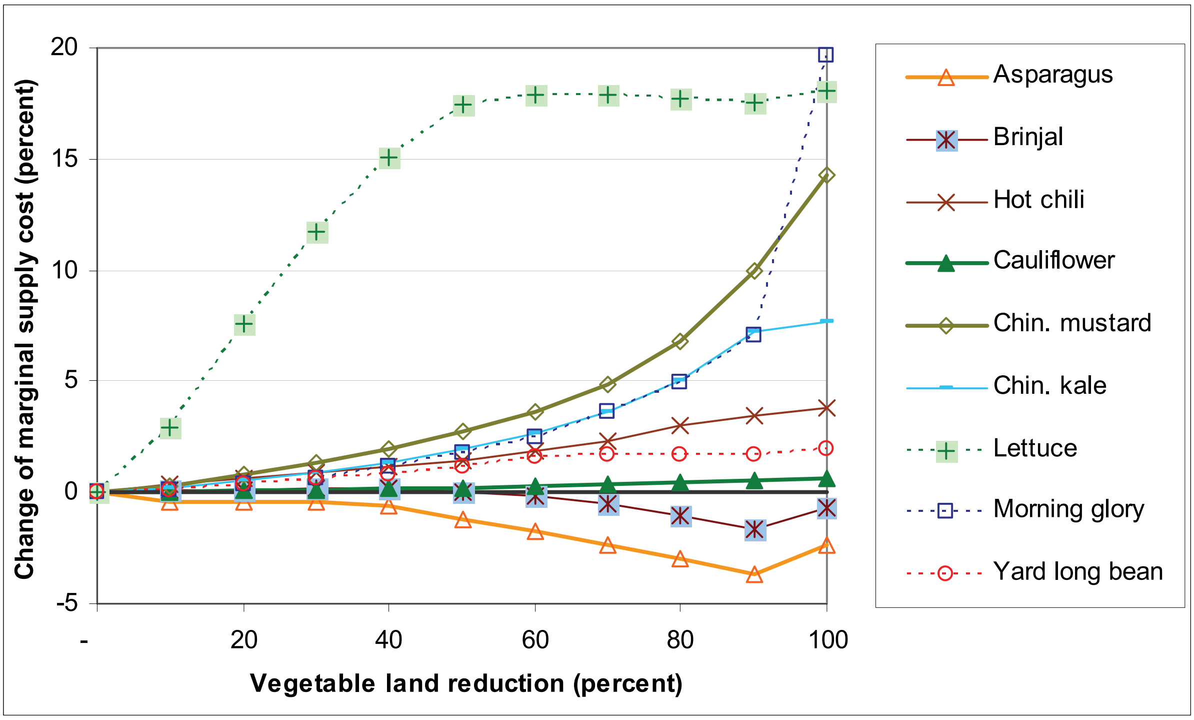

Figure 62: Change in marginal cost of supply of selected crops as a function of reduction of vegetable land in BK

For other crops the marginal supply cost reacts with very low initial (<0.03) but increasing elasticities to restrictions on land use. A decrease for even asparagus and brinjal is observed, whose production in the central region grows by 5% and 8%, respectively. As mean transportation distance hardly increases (+4 km in both crops), the increased availability of family labour contributes to a cost degression by up to -3.7%. Altogether marginal supply cost increases only moderately, as for 19 out of 24 crops an increase below 4% or even a decrease is predicted even under an extreme scenario of complete exclusion of vegetable production from BK. Given similar agro-ecological conditions, the closeness of BK and CE regions and a transfer of family labour between the regions, the prediction of a moderate effect on marginal supply cost is very plausible.

5.3.3.3 Land and labour resource use

Assuming a strict enforcement of the zoning policy, vegetable land in BK has to decrease according to the tightening restriction on land. The expectation that land use will increase especially in CE to compensate for the decreasing supplies from BK, due to the proximity and similarity of production systems, is confirmed by the simulation results (cf. Figure 90 on p. 234) and therefore not discussed in more detail.

A closer inspection of labour allocation is warranted because the scenario involves assumptions on the mobility of family labour. As mentioned above, migration of vegetable farmers from Greater Bangkok is limited to a share proportional to the reduction of vegetable land. As the destination of migrants is endogenously determined based on the objective function of minimization of total variable supply cost, the best utilization of labour resources is attained where labour is scarcest. In the baseline, labour is scarce in CE most of the year and the amount of hired labour is greatest (cf. Figure 23 on p. 114) so that for the underlying assumptions this region will receive most of migrating farmers.

The simulation finds that family labour migrates exclusively to CE (cf. Figure 63a). Under a complete ban, the family labour endowment of 38,000 person-equivalents is hence transferred completely to the Central region and contributes to a reduction of hired labour in most seasons and explains a reduction in average marginal supply cost of some labour intensive crops.

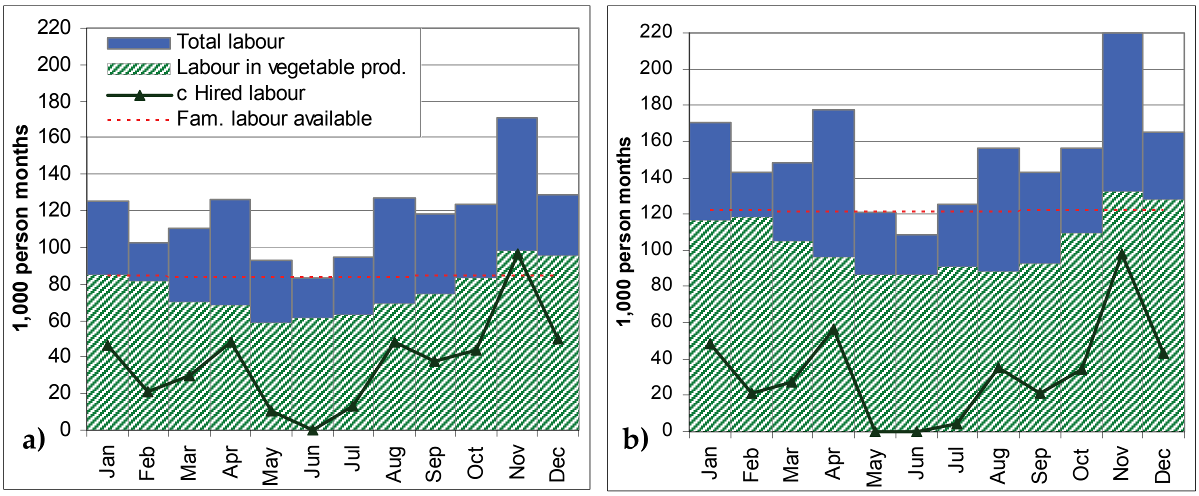

Figure 63: Labour resources and allocation in CE a) in the baseline and b) when vegetable production is banned from BK region

5.3.3.4 Indicators of external input use

Whether zoning can contribute to a reduction in aggregate input use is not clear *a priori.* A ban on the most intensive production systems in BK is expected to contribute to a reduction of overall input use. On the other hand, increasing supplies from other regions will lead to increasing input use there depending on the intensity of the prevailing production systems. As by far the largest part of additional supply comes from CE, where production is similarly intensive as in BK, a major reduction in terms of absolute use is deemed unlikely. The environmental burden will, however, be distributed over a larger area than in the baseline as the concentration of production in BK is dissolved.

Turning to the simulation results, a mixed effect of a zoning policy on the use of external input use is found. On the one hand aggregate EI decreases marginally by up to 1% when a ban of vegetable production is in effect for 90% of BK. On the other hand, nitrogen use and transportation increase faster by up to 5% and 3.5%, respectively. The latter is a natural consequence of decreasing production in locations close to the market and entails an increase of annual fuel consumption by up to 2.7 million litres and slightly higher average transportation loss.

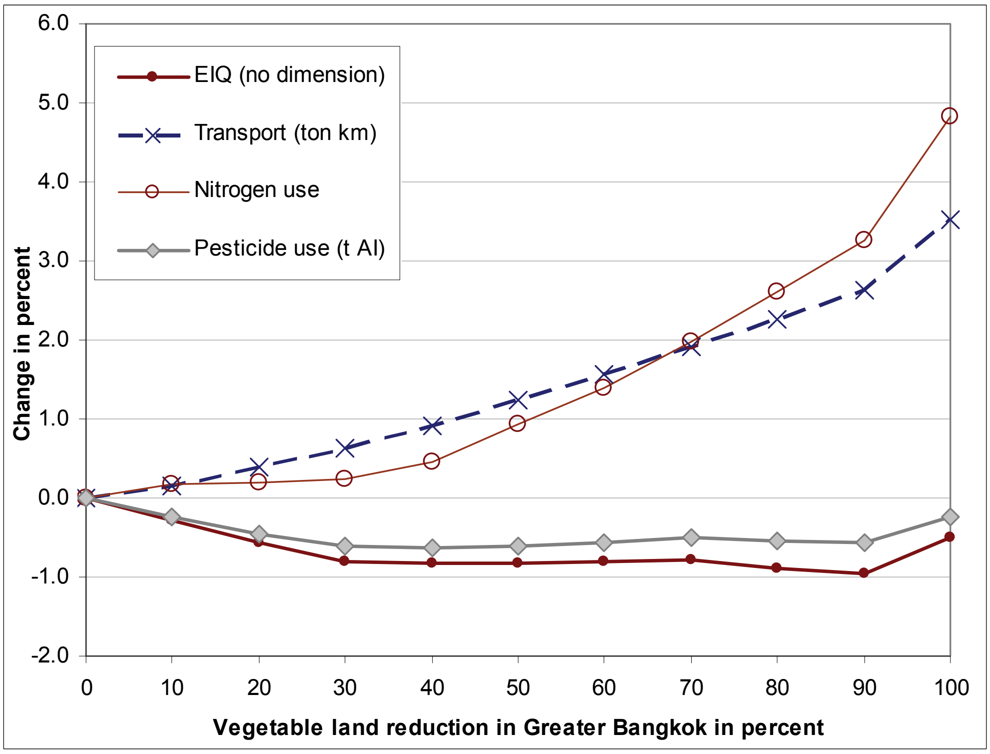

Figure 64: Aggregate change of external input use indicators as a function of reduction of vegetable land in BK

More relevant with respect to the supposed policy objective of a specific improvement of externalities in BK is the regional outcome shown in Figure 65 and Figure 66. First of all, the absolute decline in vegetable area leads to a continuous decline of both EI and nitrogen supply in BK (b). Only a closer inspection of the intensity with respect to vegetable land reveals that an increase up to a 60% area reduction precedes an accelerating decline of EI per unit of land for more restrictive zoning scenarios, while per hectare nitrogen supply increases up to a peak of 750 kg/ha. Such a development is a logical consequence of a mere restriction on land: as scarcity of land increases on the one hand, crops and technologies with higher partial productivity (see above) become more profitable, whereas intensity of factor use with respect to this factor increases where substitution is feasible on the other hand. Although each technology in the programming model in itself represents a Leontieff-type of technology with fixed factor proportions, the existence of alternative technologies and production sites implies substitutional production conditions that become apparent when the scarcity of single factors is changed.

As a consequence of such substitution among production sites, the effects on other regions are mixed. While absolute EI in CE increases with production, the intensity per unit of vegetable land declines over the whole parameter range; less intensive technology shifts to CE, whereas the high intensity in WNE is aggravated by the shifts induced by a zoning policy in BK.

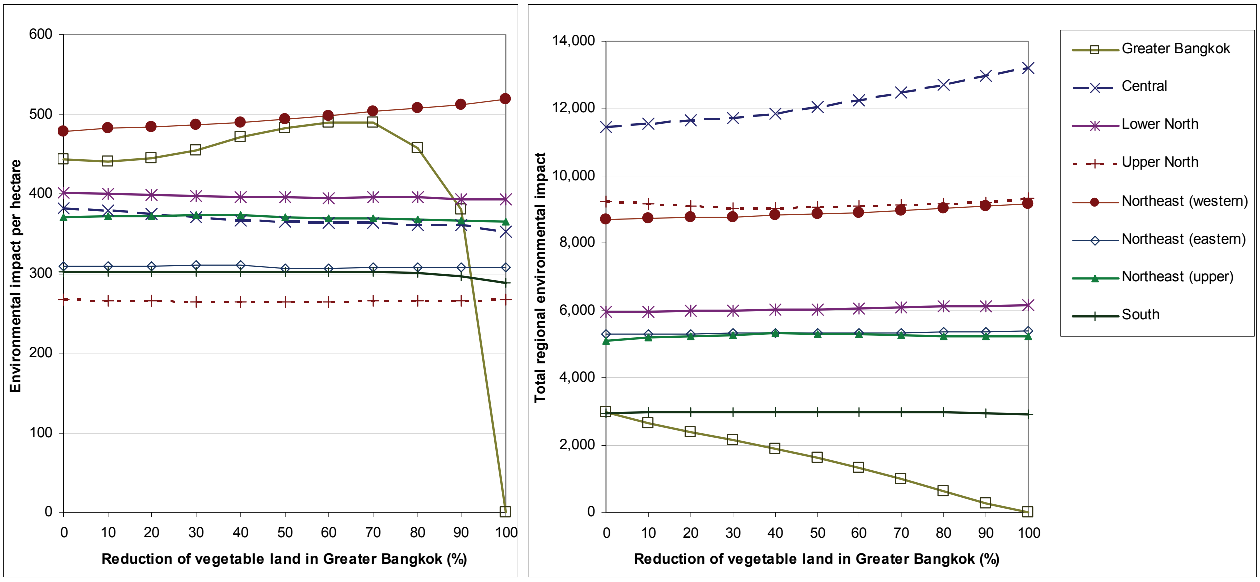

Figure 65: Regional EI intensity (a) and absolute EI (b) as a function of reduction of vegetable land in BK

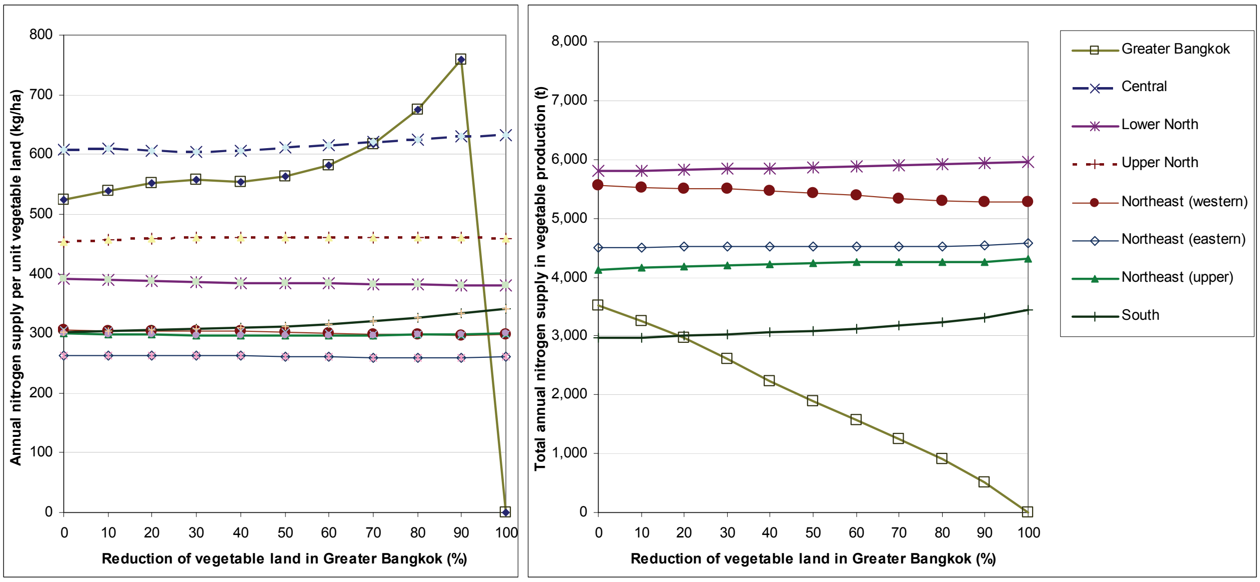

Figure 66: Regional nitrogen intensity (a) and absolute nitrogen use (b) as a function of reduction of vegetable land in BK

Summarizing the effects of a zoning policy that limits vegetable land in BK, it is worth noting that environmental improvements bound to a decreasing absolute level of production in BK first lead to increased intensity on remaining vegetable land. On the national scale, pesticide use in terms of active ingredient and EI is reduced only to a minor extent. Localized improvements in BK are offset by further increases in already high intensity levels in WNE and moreover increase transportation activity and nitrogen use within the sector. While trading off a reduction of pollution in the urban agglomeration of Bangkok and vicinity against increased transportation volume and pollution in other areas is beyond the scope of this study, the results presented here show that a zoning policy offers only a limited contribution to the problem of high input intensity existing on the national scale. It comes at the cost of aggravating high input levels in other areas, additional marginal supply costs and other costs involved in the political and social process of migration of vegetable farmers involved in this strategy, but exogenous to the model.

5.4 A scenario for 2011

So far this chapter has dealt with results of parametric simulations for individual variables. While this type of partial analysis provides insights concerning the magnitude of the impact each variable exerts on model outcome, the combined effect of changes in more than one variable depends on the interaction of the various effects and is therefore evaluated for a likely scenario for the year 2011, 10 years from the base year. The likely values for the parameters shown in Table 43 have been identified in chapter 4 and are presented here with their expected effects on the absolute consumption of external inputs and average transport distance as indicators for the shift of production locations towards or away from the Greater Bangkok model region.

Table 43: Exogenous variables for the scenario 2011

	2001	Average change rate 2001-2006	Applied Average annual change rate	2011	Expected effect on environ-mental burden	average transport distance
Population	62,774,538		0.62%	66,763,981	+	+
Per capita income (THB/month)	3,913	4.1%	4%	5,792	+	+
Fuel price (THB/l)	12.1	12%	12% - 2007, then 5%	29.0	-	-
Agricultural wage THB/month	2,284	4%	4%	3,381	+	-
Technical progress a) production	n.a.	n.a.	1.5% yield increase	1.16	-	-
b) transportation	n.a.	n.a.	-2% fuel consumption -1% loss reduction		-	+
c) adoption of environmentally friendly technology	n.a.	n.a.	1% of farms are new adopters		-	+
Vegetable farmer mobility	n.a.	n.a.	-1% for Bangkok Metropolis -1% vegetable area loss	1.1	-	+

Source: Own calculation (cf. section 4.4, p. 102)

Results for this scenario are presented in analogy to the parametric analyses above for simulation runs in 10% steps for all parameters to the likely 2011 values in order to provide information on a possible adjustment path over time. In other places, the indicator values for the baseline and forecast 2011 scenarios are compared directly or by reporting the relative changes.

5.4.1 Regional distribution of vegetable production

In line with a demand growth of about 12% on average (cf. Table 35, p.123) total production grows in all regions, and rates are rather similar, ranging from 9% in BK to 12% in the WNE (Figure 67), which leaves the contribution of regions to total national vegetable supply in principle unchanged (Table 44). In spite of a rather constant aggregate pattern, net surplus and deficits among regions change. Whereas demand growth is strongest in both absolute and relative terms in CE (+22% or +113,000 metric tons), regional supply grows by only 80,000 metric tons. For BK, the major 'sink', demand is expected to grow by 82,000 metric tons, whereas additional production is forecast at only 18,000 metric tons. In SO 7,000 metric tons of additional demand have to be matched by increased imports from other regions ,even though demand increases only moderately by about 10%.

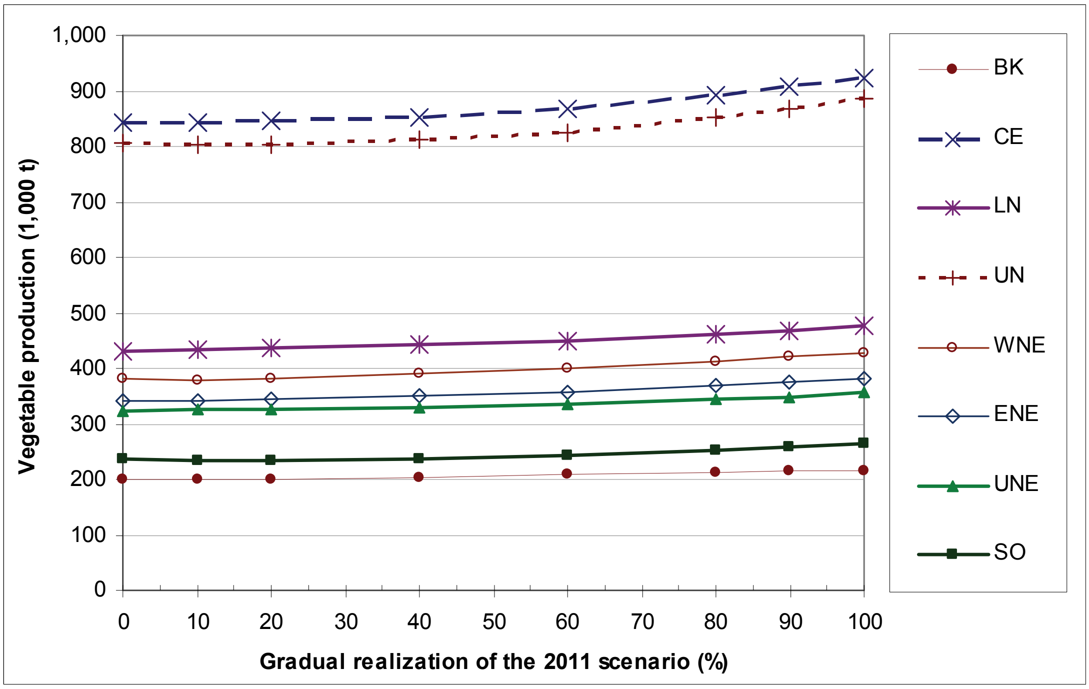

Figure 67: Regional vegetable supply response to a gradual realization of the 2011 scenario

In spite of these scissor-like developments of demand and supply in several regions, the share of regional demand that is consumed within the region remains stable (comp. Table 44 and Table 29 on p. 110). An increasing share of regional production consumed within the region is found especially for CE, SO and UNE. This contributes to a less than proportional growth of transportation activity (+8%) and a decrease in average transport distance from 293 to 287 km.

Differing from the response to demand growth alone (cf. section 5.2.1), regional supply responds more flexibly as technical progress in both production and transport increases flexibility of resource allocation. Even in BK, where land available for vegetable production declines by 10%, a substantial growth of output of 9% is attained through technical progress and intensification. The developments on a more detailed crop level can be analysed in terms of the change of regional supply share by crop. The regional "market shares" change by less than 7% throughout[80]. Only for the crops reported in Table 45 are notable shifts observed: production of baby corn and Chinese radish further concentrates in CE in line with high physical labour productivity in these crops (5 man-days/t) and increasing wages, which particularly affect CE, where hired labour is required throughout all seasons. Furthermore, a concentration of hot chilli production in WNE and tomato in UN is observed. Hot chilli is very labour intensive and production technology in the northeastern model regions is more productive in terms of labour (cf. Table 23) and hence becomes more competitive as wage rates increase. The opposite development of an increasingly even distribution of supply in the forecast scenario is found for brinjal, cabbage and Chinese cabbage and spring onion.

Table 44: Regional supply and demand in the likely 2011 scenario

	Production at farm gate level (1000 t)	Share (%)	Demand at the wholesale level (1000 t)	Share (%)	Share of regional supply consumed within the region (%)
Greater Bangkok	216	5.5	718	19.1	94.5
Central	924	23.5	615	16.4	27.9
Lower North	478	12.1	352	9.3	26.5
Upper North	886	22.2	364	9.7	36.5
Northeast (west)	428	10.9	379	10.1	26.6
Northeast (east)	381	9.6	355	9.4	55.8
Northeast (upper)	356	9.0	332	8.8	69.0
South	264	6.7	284	7.6	81.6
Net exports			293	7.8	
Seed stock[81]			72	1.9	
Total/Average	3 932		3,763	100	43.5

Given a homogeneous yield growth that under constant resource endowments provides the flexibility of adapting production to regional demand, such a trend should be expected, especially when unit cost of transportation and hired labour increase. The latter plays an important role in CE, where the ratio of hired to total labour is highest.

Table 45: Change in supply shares by crop between baseline and 2011 scenarios

Unit: Percentage points

	BK	CE	LN	UN	WNE	ENE	UNE	SO
Baby corn	-0.4	5.2	-0.4	-4.8	0.1		0.2	
Brinjal	0.1	-5.2	1.6	0.6	0.2	0.4	1.3	1.0
Hot chilli	-0.7	-1.6	-0.6	0.8	1.2		0.6	0.2
Cabbage		0.6	2.7	-3.4	0.2		-0.3	0.2
Chinese cabbage	0.2	3.7	-0.4	-4.6	0.8			0.3
Coriander, celery	0.2	-2.1	0.5	1.1	-0.3	-0.2	0.5	0.2
Chinese radish	0.4	1.2	-2.3		0.1	0.3	0.4	
Spring onion	-0.3	-2.4		6.4	-1.7	-0.7	-1.1	-0.1
Tomato	-0.3	-1.2	-0.0	5.0	-1.1	-0.7	-1.8	

[80] The data for all crops are provided in Table 68 on p. 236

[81] Ginger, garlic, shallot 'seed' used in vegetable production.

5.4.2 Marginal cost of vegetable supply

The combined effects of a growing demand, increasing cost of labour and energy contribute to higher marginal costs of supply. The reverse influence from technical progress leading to productivity growth in production and transportation is weaker, so that an increase in marginal supply cost is to be expected. The extent to which individual regions or crops are affected depends on numerous factors, among which average transport distance, labour intensity and seasonal labour scarcity play a role.

In line with these expectations, the simulation shows that an adjustment of regional activity levels cannot fully compensate for the cost increases implied by many of the parameter changes assumed for the 2011 scenario. The aggregate effect of these changes after adaptation of production technology and production location is reflected in the change of marginal supply cost at the wholesale level. The relative change in wholesale prices predicted for the 2011 scenario at the regional wholesale market level is listed in Table 46 and varies between -1% and +31%. The variation in average price changes weighted by demand quantities among regions is moderate and ranges from around 8.8% in northeastern model regions and 10.4% in BK.

Table 46: Percent change in marginal supply costs between baseline and forecast 2011 scenarios

	BK	CE	LN	UN	WNE	ENE	UNE	SO
Asparagus	15.5	15.5	15.2	14.5	15.2	14.8	14.8	14.3
Baby corn	11.0	11.0	11.0	7.4	13.4	16.3	15.0	18.1
Brinjal	28.7	28.7	29.8	31.1	28.6	28.3	26.5	30.6
Hot chilli	22.6	22.5	22.1	22.1	22.0	22.3	22.1	22.5
Large chilli	18.2	18.8	17.3	16.0	16.6	16.7	16.7	21.0
Cabbage	18.5	18.5	13.6	7.6	16.3	17.6	16.4	25.1
Chin. cabbage	8.3	8.3	4.0	-0.6	5.5	5.8	5.4	13.6
Cauliflower	15.1	15.1	11.7	8.0	13.0	12.1	12.4	19.8
Chin. mustard	11.5	11.5	12.0	11.1	11.6	12.1	11.8	9.7
Chin. kale	10.1	10.1	9.4	10.2	10.0	10.8	10.4	11.7
Coriander/celery	12.7	12.7	12.4	12.3	12.0	12.1	11.2	14.8
Chin. radish	6.3	6.3	3.0	8.2	8.0	10.6	9.5	14.9
Cucumber	9.4	9.4	10.4	12.7	11.3	13.0	12.6	10.8
Ginger	1.5	1.5	1.3	1.2	1.4	1.5	1.3	1.9
Garlic	6.4	6.4	3.4	0.6	6.7	6.8	7.0	12.4
Lettuce	11.5	12.6	15.4	17.2	12.9	14.3	10.7	19.1
Morning glory	15.3	15.6	15.5	14.7	15.3	14.9	14.8	14.9
Pumpkin	11.2	11.2	10.8	9.9	10.7	10.7	10.6	9.1
Shallot	3.9	3.9	3.9	3.8	4.0	3.8	3.9	4.1
Spring onion	1.0	1.0	1.2	1.2	1.7	1.2	2.1	1.1
Tomato	5.3	5.3	4.5	3.5	4.9	4.9	4.9	7.5
Watermelon	5.8	5.8	3.1	4.9	2.4	-0.9	0.7	5.7
Yard long bean	14.8	14.8	15.9	16.7	14.8	14.0	14.5	14.4
Weighted average	**10.4**	**9.9**	**10.0**	**10.0**	**8.8**	**8.7**	**8.8**	**10.0**

In spite of an average marginal cost increase of 10% in the region, SO experiences the most rapid increase in 13 out of 23 vegetable crops. This is particularly the case for crops whose demand is mostly covered by supplies from outside the region and hence sensitive to increasing transportation cost, such as garlic, tomato and Chinese radish with no local supplies and cabbage, cauliflower, and ginger with less than 25% local supplies. On the other hand, crops with a major share of production within the region are generally less affected as the cases of yard long bean, pumpkin, and cucumber suggest. Decreasing marginal wholesale supply costs are even predicted for Chinese cabbage in UN, where production declines by 5% and for watermelon in ENE and UNE. On the other hand, crops whose marginal supply cost increases significantly throughout the regions are brinjal, hot and large chilli, cabbage, cauliflower, morning glory and yard long bean. These crops either have high average transport distances (e.g. cabbage: 527 km, cauliflower 390 km, large and hot chilli: 293 km and 273 km, respectively) or use comparatively high amounts of labour per metric ton of output (e.g. large and hot chilli, 29 and 40-88 md/t) or both like asparagus (316 km, 116 md/t) and are therefore strongly affected by rising labour cost and in the case of the latter even more as supply is generally limited to the central region.

By and large an average increase of about 10% in marginal wholesale supply cost is rather moderate vis-à-vis substantial cost increases in several input factors such as hired labour (+48%), fuel (+140%) and additional constraints such as declining vegetable land in BK.

5.4.3 Utilization of farm land and labour

With respect to land utilization contrary effects of the parameter changes are also expected. Whereas demand growth (12%) will cause an increase in land allocated to vegetables, the higher land productivity through yields growing by about 16% will more than offset this effect, and aggregate vegetable land is expected to decrease.

Resulting from a more rapid yield increase than average demand growth, the land used for vegetables at least once per year on the national level decreases by 5.6% (Table 47). A uniformly downward trend is predicted for all regions except for the UN, which retains its maximum vegetable area of 34 600 hectares due to its distinctive seasonal peak from shallot and especially garlic production, which is bound to the region for its agro-ecological conditions (cf. also Table 45). The biggest relative reduction of vegetable area by 14% in SO is caused by a cut of the land use peak in April where especially fruit vegetables such as yard long bean, watermelon, pumpkin and cucumber area is reduced (see Figure 91 on p. 234). A roughly commensurate increase in July (due to an increase in hot chilli area) leads to an average vegetable area only about 2% below the baseline situation and a reduced seasonal variation of vegetable land use. The second largest reduction in BK reflects the declining vegetable area in the region, is consistent over all seasons (Figure 91) and implies a 12% decrease in average vegetable land. In UNE and WNE, on the other hand, a 10% drop of vegetable area occurs in the main seasons — January and February in UNE and October to January in WNE — contributing to a reduced variation in seasonal land use in vegetable farms. In both cases the area planted to hot and large chilli is reduced in favour of production in other regions (cf. Table 45).

While the area planted to vegetables declines in all regions and by 6.6% on average, the land utilized in vegetable farms for all non-permanent crops, i.e. rice and field crop production, remains rather stable and on average shows a decline by only 0.3%. Where farms are more specialized, i.e. in Greater Bangkok and the South, the change in the range of 1% of total land area reveals that such a decline in vegetable land has very little impact on the aggregate land use.

Table 47: Vegetable land in the baseline and 2011 scenarios

	Vegetable land (1000 ha)			Change in area planted (%)	Change in total land use (%)
	Baseline	2011	Change (%)		
Bangkok Metropolis	6.7	6.0	-11.3	-12.0	-1.3
Central	30.0	28.8	-4.2	-12.1	-0.5
Lower North	14.8	14.3	-3.6	-2.6	0.3
Upper North	34.6	34.6	0.0	-4.8	0.0
Northeast (west)	18.7	16.7	-10.3	-4.4	-0.7
Northeast (east)	18.3	17.3	-5.3	-6.1	-0.1
Northeast (upper)	14.8	13.4	-9.6	-3.4	-0.1
South	9.8	8.4	-14.0	-1.9	-1.2
Total	147.8	139.5	-5.6	-6.6	-0.3

The outcome of the 2011 forecast scenario with respect to labour utilization hinges crucially on the impact of yield increase on labour requirement. The 2011 scenario is based on the assumption that 90% of all labour requirement during harvesting months is for harvesting and this labour increases by 85% of the yield increase, because harvesting efficiency is expected to rise when the crop is more uniform and more harvestable produce per land unit is available.

The simulation results reveal that this increase in harvest labour productivity translates into a reduction of labour requirement in vegetable production by 9,300 full time equivalents or 2.6% of the labour force in vegetable production of the baseline. Together with the above mentioned reduction of seasonal fluctuation, this goes along with an even larger reduction in *hired labour* by about 15,000 person equivalents. Related is a more consistent utilization of fixed farm labour resources and as a consequence an increased return to family labour in most regions even in the presence of rising input costs (Table 49).

On the level of individual regions, first of all the endogenous movement of 2,900 family labourers from Greater Bangkok exclusively to the Central model region has to be mentioned. Accordingly, the endogenous migration activity is realised up to the assumed limit of 10.5% of initial farm population and the marginal value of this constraint is -89.5 THB/md. Accordingly, the shift of an additional man-day (md) of family labour from the Greater Bangkok to the Central model region contributes to a reduction of production cost by about 90 THB. As out-migration and decline of labour requirement proceed at similar rates, demand for hired labour in greater Bangkok remains stable. The opposite extreme is true for hired labour demand in the Central region, which declines by 13,700 full-time equivalents. Total labour requirement for vegetable crops declines by nearly 10,000 full-time equivalents through efficiency gains combined with a reduced area under labour-intensive crops such as asparagus, hot and large chilli. Together with an in-migration of family labour from greater Bangkok by 2 900 persons and reduced seasonal peaks, these developments release 13 700 full-time equivalents of hired labour. Moreover, the few regions with increasing labour requirement should be highlighted: in the western and upper sub-regions more labour is used for vegetable production as the labour-intensive crops grow proportionally or more rapidly than in other regions. Consistently with the seasonal profile of resource use, nearly half of this increase is covered also by hired labour in the western sub-region.

Table 48: Labour utilization in vegetable production

Unit: 1000 person equivalents

Region	Total labour use in vegetable production			Absolute change in hired labour
	Baseline	2011	Change	
BK	29	26	-2.9	-0.2
CE	76	66	-9.9	-13.7
LN	39	38	-0.7	-1.0
UN	72	73	1.1	-0.8
WNE	75	77	2.8	1.2
ENE	39	38	-0.9	0.0
UNE	36	38	1.8	-0.2
SO	16	16	-0.4	-0.6
Total	**382**	**372**	**-9.3**	**-15.3**

Although in a cost-minimization context the return to family labour can be calculated only as a surrogate indicator based on a fixed set of farm gate prices, a brief consideration is considered worthwhile to complement the above discussion. Generally (with the exception of BK) production schedules are adapted to reduce the amount of slack family labour and thereby increase the return to family labour as shown in Table 49. Considering the absolute levels of the return to family labour, the highest return is attained in WNE, which should then be the expected destination of vegetable growers migrating from BK.

Table 49: Return to family labour (THB/manday) assuming constant farm gate prices

Region	Baseline	2011	% change
BK	353	353	-
CE	421	440	4.4
LN	335	393	17.6
UN	358	389	8.7
WNE	398	487	22.3
ENE	168	172	2.7
UNE	263	288	9.6
SO	424	475	12.2

The fact that the endogenously determined migration goes exclusively to the CE is not a contradiction, because cost minimization is the objective in the model. In that case the return to family labour is not considered, but instead the total variable supply cost. On the one hand, family labour is scarce most of the year in CE (cf. p. 116) and wages for hired labour are higher than in other regions. On the other hand, the closeness to the centre of demand provides advantages to production there. Supply costs are then minimized by migration to the region with highest hired labour cost.

Finally, note that the difference in returns to family labour in greater Bangkok and Central regions in the 2011 scenario is 87 THB/manday and hence very close to the marginal value of the migration constraint of 89.5 THB/manday mentioned above. It results from this correspondence: as the return to family labour is calculated by deducting the cost of hired labour (together with other variable costs) from revenue, saving a unit of hired labour by extending the migration constraint has just the value of family labour in the destination region less the return the unit of family labour could have earned in the original destination. The ex-post calculation of return to family labour based on fixed farm gate prices corresponds quite well to results obtained from a cost minimization model.

5.4.4 Selected environmental indicators

The aggregate effect of the forecast 2011 scenario on input use of vegetable production is surprisingly small. As shown in Figure 68, an increased level of transportation inevitably associated with higher demand is required for the likely 2011 scenario, even though for a partial realization even a constant level of transportation is feasible. Notwithstanding increasing transportation, an absolutely declining level of fuel requirement is attained by a more rapid technical progress in transportation. A similarly balanced land productivity and demand growth leads to initially slightly lower levels of environmental impact of pesticide use and absolute quantities of nitrogen application, but finally rather stable absolute levels in these indicators.

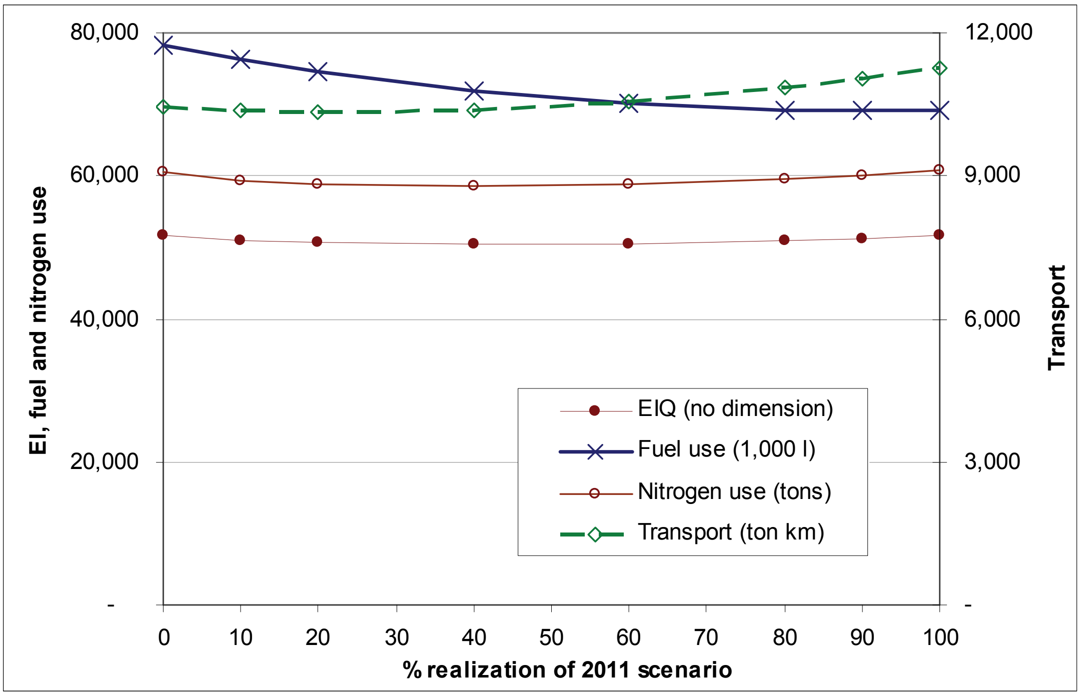

Figure 68: Aggregate environmental indicators in response to a gradual realization of the 2011 scenario

Pesticide use

Even though the environmental impact remains constant, the absolute level of pesticide use in the 2011 scenario rises – though rather moderately by 1% to 9% for different toxicity classes (Table 50) with the highest rate in the most toxic WHO class Ia in UN. This is a result of additional garlic production for which only a single production technology, using acutely hazardous pesticides, is considered in the model. On the other hand, the use of less toxic pesticides is reduced by 20% even in the same region. The aggregate effect is thus better captured by the environmental impact quotient that combines the effects of pesticide use on human health and aquatic and terrestrial ecosystems. Based on this indicator the 2011 scenario leads to the most significant reduction of the environmental impact (EI) by about 10% in BK – roughly proportional to the change in vegetable area. A decline in EI is also detected for UN, SO, CE and ENE. However, a comparison to the development of planted area (Table 47) reveals that most of this reduction is less than proportional to the decline in vegetable area, which implies rising intensity of external input use on vegetable land.

Table 50: Pesticide use indicators by region for the 2011 scenario

Region	Quantity of active ingredient applied by WHO toxicity class (t)					Avg. sprays per week	Environmental impact[82]
	Ia	Ib	II	III	unclass.		
BK	0.1	17.8	4.5	4.4	45.2	1.4	2,688 (-9.8)
CE	1.4	34.0	56.0	47.6	205.1	2.0	11,126 (-2.9)
LN	4.6	10.4	25.7	6.3	139.8	2.1	6,235 (+4.7)
UN	10.1	24.1	23.6	3.4	224.1	1.8	9,943 (+7.7)
WNE	0.3	15.6	28.0	11.9	194.9	1.8	8,751 (+0.5)
ENE	0.5	9.3	41.0	5.9	115.3	2.8	5,269 (-0.5)
UNE	0.7	12.5	17.7	7.4	105.5	2.0	4,881 (-4.8)
SO	0.3	8.7	27.5	6.1	52.6	2.5	2,867 (-3.2)
National total[82]	18.0 (+8.8)	132 (+2.7)	224 (+3.7)	93.0 (-1.4)	1,083 (+0.9)		51,760 (+0.1)

This is reflected in the intensity of pesticide use reported in Table 51, which in comparison to the baseline (Table 33) increases in all regions. In particular, vegetable cropping in the South and the western sub-region of the Northeast and the northern regions becomes more intensive in terms of pesticide use. This is in line with a strong growth of supply from the western part of the Northeast (+18%) as at the same time seasonality of vegetable production is reduced (Figure 91) and labour intensity increases. Thus the region's very high intensity worsens and is in addition clustered in the western part of this region as discussed below (Figure 70). Supply growth by 7% in the South lags behind the increase in pesticide intensity — as a combined result of less vegetable land (higher yields, more year-round production) and shifts within the portfolio in favour of more pesticide-intensive crops. The latter also applies to the northern model regions, where vegetable land remains stable but the output share of pesticide intensive crops such as cabbage

[82] Figures in brackets refer to the percentage change compared to the baseline scenario.

in LN and spring onion, tomato and watermelon increases. Intensities in UN remain lowest among all regions as most of vegetable area continues to be characterized by seasonal production after rice.

Table 51: Intensity of pesticide use in the forecast 2011 scenario

Region	Active ingredient applied to vegetable area (kg ha^{-1})						Environmental impact[82] (1 ha^{-1})
	Ia	Ib	II	III	unclassified	total	
BK	0.02	2.98	0.76	0.74	7.60	12.10	451 (+1.7)
CE	0.05	1.18	1.95	1.65	7.13	11.96	387 (+1.4)
LN	0.32	0.72	1.80	0.44	9.78	13.05	436 (+8.6)
UN	0.29	0.69	0.68	0.10	6.47	8.24	287 (+7.7)
WNE	0.02	0.93	1.67	0.71	11.64	14.97	523 (+9.3)
ENE	0.03	0.54	2.37	0.34	6.66	9.94	304 (-1.9)
UNE	0.05	0.93	1.32	0.55	7.87	10.72	364 (-2.0)
SO	0.03	1.03	3.27	0.72	6.24	11.29	340 (+12.7)
National total[82]	0.13 (+15.2)	0.95 (+8.8)	1.61 (+9.8)	0.67 (+4.4)	7.76 (+6.9)	11.11 (+7.4)	371 (+6.0)

Note: Figures in brackets refer to the percentage change compared to the baseline scenario.

Nitrogen use

The external supply of nitrogen in vegetable production increases by less than one percent on the national level as a result of the assumption of less than proportionate adaptation of nitrogen supply when yields increase. This is expressed in a consistently increasing nitrogen efficiency as indicated in reduced nitrogen requirement per metric ton of output (Table 52). As at the same time vegetable land declines, intensity grows moderately by 4.7% to an average of 436 kg N per hectare. Regional indicators are affected in different direction as shifts in regional portfolios modulate the global trends. Thus the highly nitrogen-intensive vegetable production systems in greater Bangkok undergo further intensification as land available for vegetable production is reduced and the remaining land is used more efficiently, which under rather stable absolute use levels increases intensity.

Table 52: Regional nitrogen use and intensity in the forecast 2011 scenario

	Nitrogen supply		Nitrogen use intensity
	metric tons	kg N t^{-1} of output	kg N ha^{-1} of vegetable area
Greater Bangkok	3,535 (+0.6)	16 (-7.7)	594 (+11.1)
Central	17,020 (-6.7)	18 (-14.8)	591 (-5.8)
Lower North	6,085 (+5.0)	13 (-5.7)	425 (+10.2)
Upper North	16,568 (+5.4)	19 (-4.2)	479 (+3.0)
Northeast (west)	5,408 (-2.8)	13 (-13.3)	323 (+7.5)
Northeast (east)	4,717 (+4.6)	12 (-6.5)	272 (+9.2)
Northeast (upper)	4,197 (+1.3)	12 (-7.9)	313 (+11.0)
South	3,292 (+11.1)	12 (-0.1)	391 (+25.0)
National total/average	**60,822 (+0.6)**	**15 (-8.9)**	**436 (+4.7)**

An absolute decrease in the Central region is attained by both a relative shift in the portfolio by above average growth in less intensive crops (large chilli, cauliflower, Chinese radish, pumpkin and watermelon) and less than proportionate growth in intensive crops (asparagus and baby corn) and by adoption of new technology for part of Chinese kale and Chinese cabbage production, which requires significantly less nitrogen per metric ton of output. The lower and upper northern regions experience an absolute increase and rising intensity as their production of tomato, garlic and shallot expands and savings from alternative technology adoption are low relative to the portfolio share of Chinese cabbage and Chinese kale. The change in absolute quantities is rather small in Northeastern Thailand but the initially low intensity increases in all subregions as land area declines by between 5 and 10%. The growth of southern supplies is matched by a commensurate growth of nitrogen use, which leads to a nearly constant nitrogen efficiency. Accordingly, the intensity with respect to vegetable land increases most rapidly by 25% but still remains below average. Such a substantial increase can be traced to a shift in the regional portfolio in which the prevailing fruit vegetables like cucumber (+4%), watermelon (+4%), yard long bean (+8%), hot chilli (+16%) grow relatively less than the leafy vegetable types like Chinese kale (+27%), Chinese mustard (+26%), Chin. cabbage (+23%) and morning glory (+17%). Hence the shifts in portfolios exert a strong influence on absolute nitrogen use and also intensity according to the variation of specific intensity among crops and production technology, a fact that has also bearing on the sub-regional level, which will be discussed next.

5.4.5 Sub-regional implications of the forecast 2011 scenario

The preceding discussion has widely emphasised the regional disparities in terms of both level and trends of vegetable output and input use. A geographical representation is therefore well suited to summarize and visualise the main findings. The spatial aggregation of model results on a regional level is highly aggregated for this purpose, whereas statistical baseline information available at the resolution of districts shows a clear clustering of vegetable production within the eight model regions (cf. Figure 8, p. 35). In order to accommodate both levels of information in a single map, an overlay technique is used to allocate regional characteristics to the district level proportional to the share of single crop activity levels. On the downside, this approach is incapable of capturing new production locations in regions that possibly gain importance, e.g. by inmigration from BK or the diffusion of knowledge from existing vegetable producers, because the sub-regional pattern is merely based on historical data. Nevertheless, the visual presentation supports the impression of the clustered nature of vegetable production and its effects and is therefore considered useful for the purpose of this research.

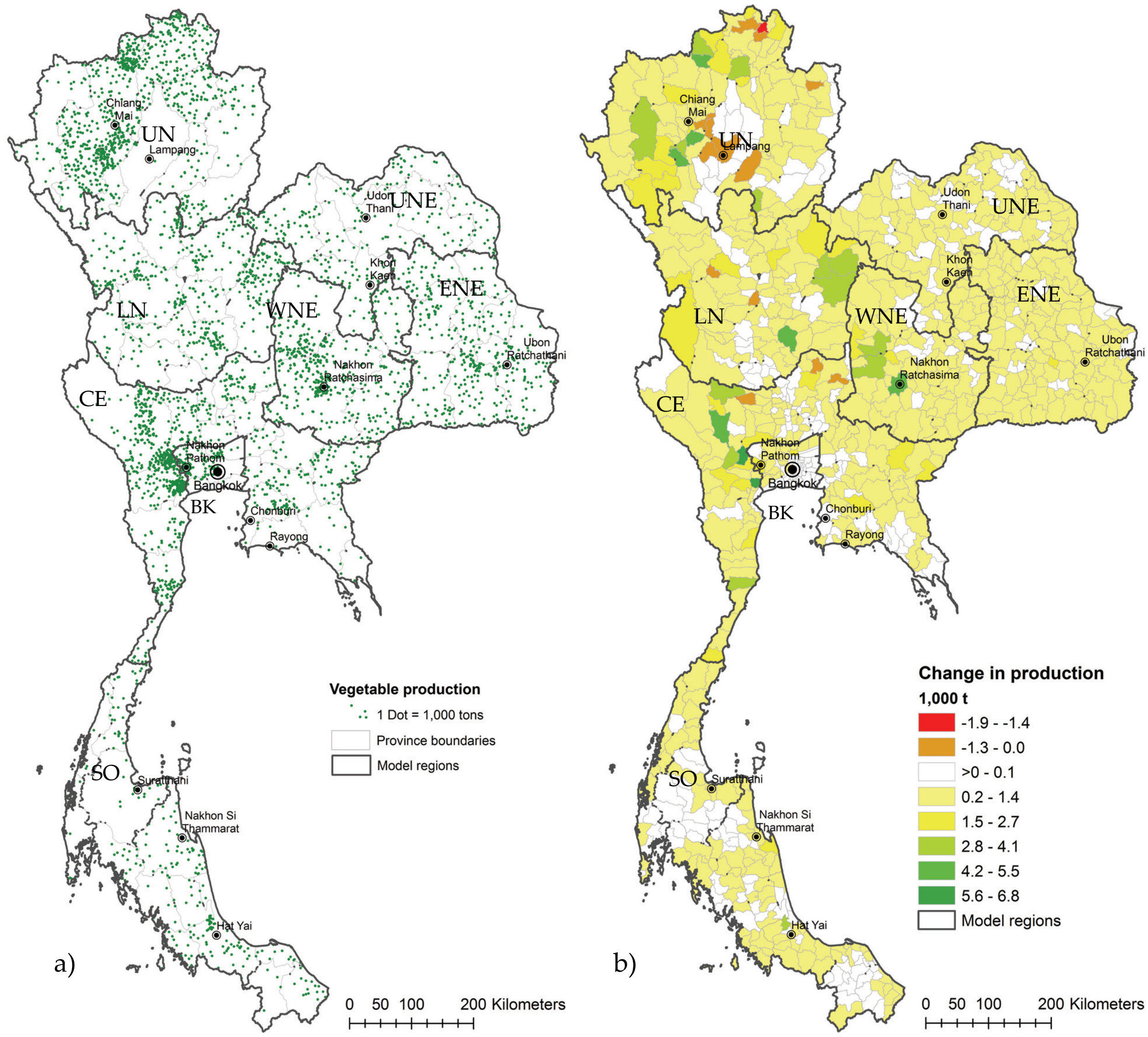

Figure 69: Distribution of vegetable production in the 2011 scenario and change compared to the baseline

The sub-regional distribution of vegetable production in the likely 2011 scenario is shown in panel (a) of Figure 69 with one dot representing an annual output of 1000 metric tons of vegetable production. Thus the total output and the 'density' of vegetable production are visualised simultaneously. In close correspondence with the map in Figure 8 (p. 35), production sites are well dispersed over the country, with highly concentrated vegetable production areas north of Bangkok (Pathum Thani province), west to BK (Ratchaburi and Kanchanaburi provinces), in Northeastern Thailand around Nakhon Ratchasima city and on the border between Nakhon Ratchasima and Chaiyaphum provinces, north and South of Chiang Mai city (Chiang Mai and Lamphun provinces) and finally north of Hat Yai city. However, as the absolute change against the baseline is comparatively small, the differences are explicitly shown by colour shades in panel (b). Most districts reflect the general positive trend of output and exhibit an increase between 200 and 1,400 metric tons annually. In BK, such growth is expected especially to the north of the capital (Pathum Thani province) and to the west (Nakhon Pathom) and further west in the central model region (Ratchaburi, Kanchanaburi provinces). Generally, the proportional allocation of changes based on historical production data will lead to a coincidence of districts with high growth of vegetable output and high initial levels. Deviating downward trends are expected for two districts in Lopburi province and one in Suphanburi province, because local production is dominated by hot chilli, which is the single crop with a declining production in CE (cf. Table 67, p. 235). A similarly divergent pattern applies also to the lower north, where the reduction in baby corn production leads to a downward total output trend in two districts of Kamphaeng Phet province, whose vegetable supply is by and large limited to baby corn. On the other hand, to the western border of the region the major production sites in Phetchabun province exhibit significant growth of output by 2,800-3,900 metric tons per year. An additional 5,000 metric tons is expected from a district specialized in watermelon production in Nakhon Sawan province. In the UN region, seven districts with falling output stand out due to a major share of baby corn in their portfolios, which is the only crop whose production decreases in UN. Significant increases coincide again with major production locations in Lamphun province (south of Chiang Mai town), Mae Jaem district in the west and the northern districts Chaiprakan and Fang. Throughout all northeastern model regions a consistent increase is expected. Supply growth above 2,800 metric tons per year is expected in four districts of Nakhon Ratchasima province. In the case of the provincial capital district this goes along with a very high concentration of leafy vegetable production (spring onion, Chinese kale and Chinese mustard, Chinese cabbage), whereas three districts to the northwest specialize in hot chilli production, which increases by 20% in this region from a high initial level of 120,000 metric tons (cf. Table 67, p. 235). Although on a regional level output grows least by only 7% in SO, it is rather homogeneous and non-negative in all districts with strongest growth in existing concentrations north of Hat Yai and close to Nakhon Si Thammarat, where leafy vegetables are grown.

The concentration of vegetable production and also its expected growth as described above, becomes even more acute when its repercussions on the environmental effects of production practices are considered. Results of the 2011 scenario are therefore presented in terms of environmental impact of pesticide use in Figure 70 and nitrogen intensity in Figure 77. For the former a separate map for the intensity with respect to vegetable area and an absolute quantity per district are shown concurrently as the former better characterizes production technology and reflects the exposition of persons involved in field operations, but fails to capture the significance of vegetable production and thereby the absolute level within the district. The absolute level of environmental impact, on the other hand, reflects the relevance of both the level of vegetable production as such and its concomitant environmental effects.

The intensity of environmental impact of pesticide use shown in panel (a) of Figure 70 exhibits a wide variation between 9 and 3,300 units of environmental impact per hectare, whereas regional averages are in the range from 304 to 523 and its distribution is heavily skewed to the right. A comparatively intensive core encompassing large parts of LN and adjacent parts of UNE and WNE is surrounded by a generally less intensive "green" periphery in UN and large parts of the Northeast. Central and Southern Thailand in general reflect moderate average intensities and less variation among districts. When the absolute level of EI shown in panel (b) of Figure 70 is considered, a few 'hot spots' (cf. Figure 69a) emerge as heavy users of pesticides, whereas the overlap of high intensity and high absolute use levels is rather limited. More relevant is a closer examination of districts where high absolute levels and high intensities coincide. For districts where intensity is beyond 600 units of EI/ha and the absolute levels beyond 150,000 units in the upper North, production of large chilli dominates with an extremely high EI intensity per hectare (cf. Table 23 on p. 100). Districts with high absolute EI levels but moderate intensities (e.g. north and south-west of Chiang Mai town) stand out due to high concentrations of vegetable production, especially seasonal garlic and shallot production, which are associated with lower pesticide intensity as only one vegetable crop per year is grown on a given piece of land. In LN, high intensity and absolute levels coincide only in Tak provincial capital district, where 17% of regional production of large chilli is concentrated. It also plays an important role in districts with high intensities, whereas the high absolute levels observed on the western border of LN in Phetchabun province are associated with the production of brinjal, cabbage, cauliflower and ginger, as well as hot and large chilli. The latter crops also cause the only 'hot spots' in Loei province in the west of UNE. Moreover, only the districts surrounding the cities (Khon Kaen and Udon Thani) show a significant level of environmental impact due to above average production. The eastern sub-region is also characterized by low to moderate levels of environmental impact, with single exceptions where large chilli production plays a role, and again close to Ubon Ratchathani city.

Besides a similar concentration around Nakhon Ratchasima, city the western sub-region differs from the other Northeastern sub-regions in terms of its average environmental impact intensity and an absolute level that ranks second (cf. Table 51), especially for its substantial hot chilli production of 120,000 metric tons, which is concentrated in the northwest of Nakhon Ratchasima province and adjacent southwest of Chaiyaphum province. Combined with substantial production of large chilli and watermelon, which are grown under highly intensive pesticide use, this area is rendered one of the heaviest users of pesticides.

In spite of being the largest vegetable producer and with a prevailing year-round vegetable production pattern with multiple crops per year, CE is only a moderately intensive user of pesticides, and the intensity is also relatively homogeneous[83]. Absolute levels of environmental impact above 100,000 units are common to the west and northwest of Bangkok with highest levels at the border to BK in the provinces of Ratchaburi and Kanchanaburi. Here, completely different sets of crops play a role. Fruit vegetables (cucumber, yard long bean and baby corn) in Damnoen Saduak[84] and Tha Maka districts on the one hand and asparagus in Prachuab Khiri Khan province on the peninsular part of the region on the other hand. In other places, production of leafy vegetables (Chinese kale, Chinese cabbage) contributes the major share to above average produc-

[83] Isolated spots of high intensity in Lopburi and Ayutthaya province are less relevant in terms of absolute quantities.

[84] Damnoen Saduak district has a long history of intensive vegetable production introduced by Chinese immigrants.

tion. In the southern model region, variation is even less around low to moderate intensities as production is also comparatively small and less concentrated.

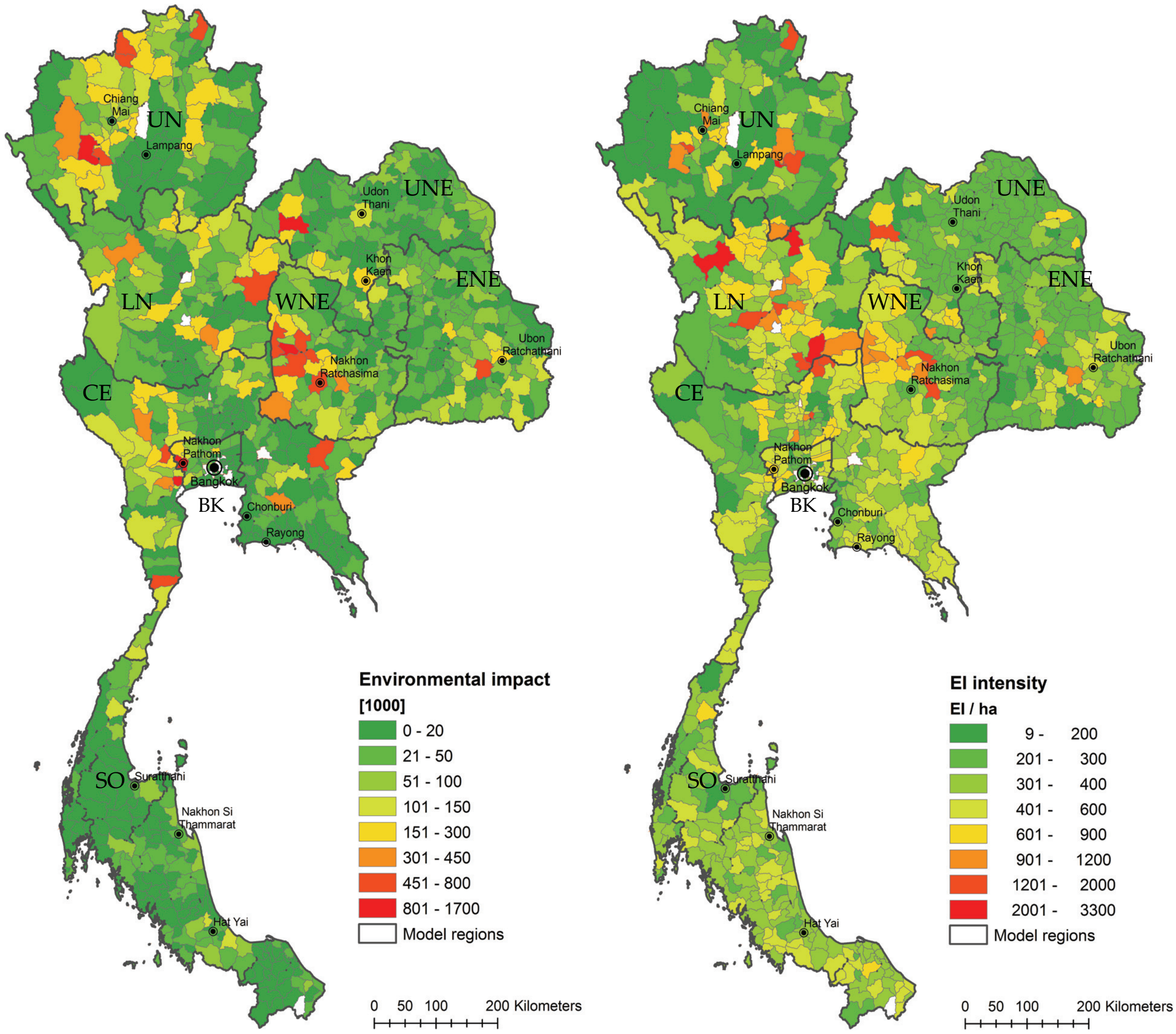

Figure 70: Absolute environmental impact of pesticide use and intensity per unit of vegetable land by district in the 2011 scenario

Although covering a smaller range, intensity of external nitrogen supply per unit of vegetable land (Figure 71) varies widely and shows little correlation with pesticide use except for a likewise generally low intensity of fertilizer use in all Northeastern regions that reflects the seasonal land use for vegetable production after rice and field crops in this area. According to the specific nitrogen intensity for production technologies (Table 23), especially asparagus, tomato with a long cultivation period and to a lesser extent some technologies for baby corn, shallot and cucumber are crops that drive intensity of nitrogen fertilizer. Accordingly, high nitrogen intensity in UN is linked to tomato and cabbage production in highland areas in the western part of the region (Om Khoi and Hot districts, Chiang Mai province, Mueang and Khunyuam districts, Mae Hong Son province). In the lowlands (especially south of Chiang Mai town and Lamphun province) it is the co-existence of seasonal shallot and garlic production with year-round production of spring onion and baby corn in some cases that drives nitrogen intensity.

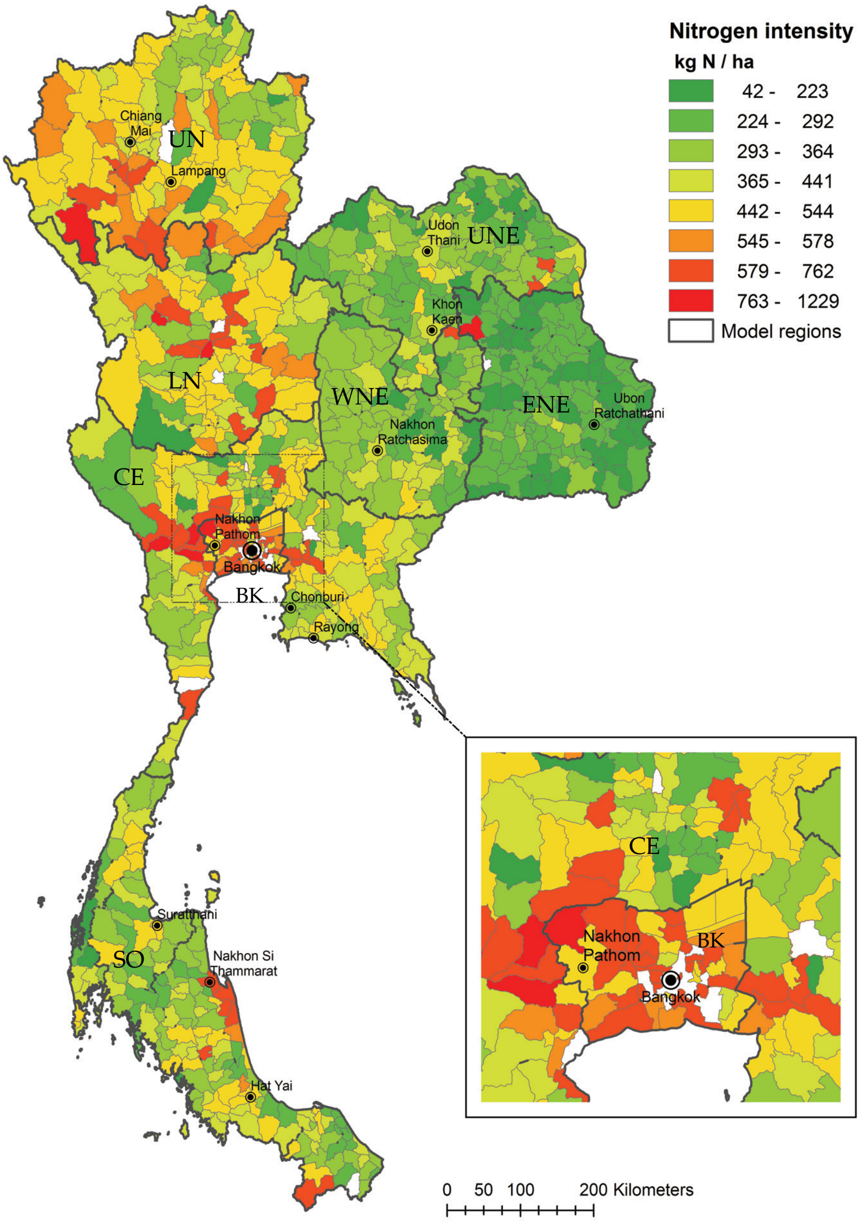

Figure 71: Intensity of nitrogen supply per unit of vegetable land by district in the 2011 scenario

LN has intensive patches northwest of the regional centre in lowland areas of Kamphaeng Phet and Pichit where baby corn causes high intensities. To the north of the regional centre, a concentration of year-round intensive vegetable production characterized by leafy vegetables (Chinese kale, spring onion, Chinese mustard, morning glory etc.) in two districts around Phitsanulok town drives nitrogen intensity. In CE, nitrogen intensity is among the highest on average and together with vegetable production is concentrated within and particularly to the west of BK. Closer to Bangkok city, farms grow a mixture of vegetables in a dense rotation involving leafy vegetables in particular. Multiple cropping of short duration crops contributes to a high supply of nitrogen in these production systems. Further west, especially in Kanchanaburi, province the large share of baby adds to high nitrogen intensity. Finally, in the southern model region, high nitrogen intensity is associated with multiple crops in farms characterized by year-round production for demand in nearby cities.

Summarizing the above discussion, the heterogeneity of input use intensity and level shown in the maps can been traced back to two phenomena: a) a substantial variation in specific intensity among production technologies and b) the degree of multiple vegetable cropping on a given piece of land as determined by the production system. It can further be observed that nitrogen intensity appears to vary less within the region and more among regions, whereas pesticide intensity is distributed in the opposite way. This is related to the distribution of crops and of both indicators among production technologies. While nitrogen use is more homogeneous, EI varies between 0 and 72,000 units per metric ton of produce among crops and technologies. As a consequence, the additive effect of multiple cropping affects nitrogen intensity relatively more than the prevalence of a specific crop does with respect to pesticide use. Thus higher nitrogen intensity is generally associated with year-round production systems (BK, CE and around large cities in other regions). Intensive pesticide use, on the other hand, is more closely linked to production of specific crops as the extreme example of some of the northern lowland production technologies and large chilli in particular illustrate. Such insight is helpful in guiding policies addressing the negative side-effects of intensive vegetable production.

6 Summary and conclusions

This study was undertaken with the objectives (a) to identify the relevance of different factors in determining the spatial structure of vegetable production in an emerging economy, (b) to prospect the likely development of the sector in the medium-term future and (c) to assess the relationship between changing production locations and production technology and (d) to assess the potential of selected policy options for reducing the environmental externalities of vegetable production in the light of high prevalence of over- and misuse of external inputs in intensive vegetable production. This chapter commences with a summary interpretation of the results established by the model, firstly, with respect to the structure of the vegetable sector and, secondly, its dynamics with respect to the effect of exogenous demographic, economic, technical and policy factors. The influences of the respective factors are evaluated as a preparatory step for further conclusions and policy recommendations. The chapter concludes with a delineation of possible model extensions and areas for further research.

6.1 Summary

Beyond a reproduction of historical production statistics by the Thai Vegetable Supply Model (TVSM), the baseline solution provides information not available from statistics and extrapolation with respect to (a) the level and seasonal fluctuation of resource use, in particular land and labour, (b) the level and seasonal pattern of transport activity and (c) the aggregate indicators of the environmental side-effects of vegetable production, which will be reviewed in sequence.

As a result of multiple cropping and seasonal fluctuations, the official production statistics[85] and agricultural census data are unsuited for an assessment of land use for vegetable production. Thus the model developed in this study has established that information, including both planted area and total area under vegetables. The seasonal peak of land use for vegetable production over all regions amounts to 148,000 hectares or 0.93% of total arable land in Thailand. As reported in Figure 23 (p. 111), even in vegetable producing farms only a fraction of total farm land is used for vegetable production and the share reaches 52% in the South, about 30% in the upper North and 27% in greater Bangkok, just below 20% in the central region and less than 17% in the remaining model regions. Conversely, labour resources in vegetable farms are used primarily for vegetable production, with averages between 53% in the lower North and 83% in the South. During peak periods, vegetable production uses up to 80% of total labour in vegetable farms of the central region, 87% in the lower north and above 96% in all other regions (cf. Figure 24, p. 116).

[85] Although DoAE production statistics (DoAE, 2001) are collected on a monthly basis and could therefore provide seasonal land use estimates, a closer inspection reveals substantial inconsistencies among total area under a given vegetable crop, newly planted area and area harvested as procedures for data collection differ regionally and over time. For this reason only production data are referred to throughout this study.

The high labour intensity of vegetable production compared to field crops is the major constraint to an expansion of vegetable production and explains the limited use of farm land for that purpose. The prevailing production systems shape the seasonal pattern of resource use and vegetable output. Accordingly, regional vegetable production fluctuates within a year to different extents. The lowest coefficient of variation is observed in the central (7%) and greater Bangkok (10%) regions, where specialized intensive vegetable farms prevail. A much more pronounced seasonality is observed in the upper North (28%) where seasonal producers in lowland areas and specialized year-round highland vegetable farms coexist. Further, seasonality is pronounced in the southern (30%) and the Northeastern regions (31-44%), where vegetables are produced on farms with usually higher land endowment growing rice and field crops as the main crops and vegetables only during the off-season. These fluctuations and the high perishability of the vegetable crop require interregional transport of vegetables to match supply and demand.

The level and direction of seasonal transport activity as contained in the baseline solution of the model reflects this interconnected structure of supply and demand among the different regions. Out of 64 possible combinations of surplus and deficit regions, transport flows greater than 1000 metric tons are realised in 55. On aggregate more than half of vegetable production is consumed outside the region of origin. An average transport distance of 293 km for a production of 3.6 million metric tons involves 1.05 billion ton-kilometres of transport activity for the vegetables considered in the model. An extrapolation to all vegetables reported in production statistics, assuming that the 15% of vegetable output not considered in the model corresponds to an analogous production and transport pattern, yields 1.21 billion ton-kilometres. At a fuel efficiency of 7.5 l/100 ton-kilometres, vegetable transport uses 90 million litres of diesel corresponding to about 0.61% of national diesel consumption[86] and associated CO_2 emissions of 245 thousand metric tons annually for the baseline situation. A comparison of the economic relevance of vegetable production on the basis of GDP contribution shows that depending on the assumption on the exact share of vegetable production in the GDP aggregate[87], fuel consumption for vegetable transport is roughly of the same order of magnitude as GDP contribution from the vegetable production.

It was found that the statistical information on input use, and in particular fertilizer and pesticides, is based on annual sales or import figures pertaining to the agricultural sector as a whole. Thus, the aggregate input use level and intensity in vegetable production provide a valuable complement to the existing evidence from case studies in different regions, especially as intensities are much higher in vegetable production than in field crops[88]. The nitrogen (N) use in production of model vegetables of about 60,000 metric tons (Table 31, p. 118) amounts to about 6% of national nitrogen fertilizer consumption, and is used on less than 1% of arable land. Accord-

[86] Total diesel sales in 2001 were 15.2 billion litres (Energy Policy and Planning Office, 2008)

[87] GDP from vegetable production is reported together with horticultural specialties and nursery products. In constant 1988 prices, this aggregate has share declining from 0.70% in 2001 to 0.64% in preliminary 2006 data (NESDB, 2007).

[88] FAOSTAT reports a national fertilizer consumption of 1.019 million metric tons of nitrogen in 2002, which corresponds to intensities of 64 kg N ha^{-1} of arable land or 96 kg N ha^{-1} of rice land.

ingly the national average intensity of 416 kg N ha^{-1} on vegetable land is a multiple of average nitrogen supply on agricultural land — partly due to multiple cropping and reflecting high physical land productivity and consistent with higher nitrogen removal associated with produce and crop residues. On the other hand, the average figure also includes areas planted to vegetables only once per year and therefore implies an even higher intensity in areas with year-round production. This is also reflected in the regional disparity of intensity, which is most extreme in the central region; above 600 kg/ha where land is mostly used for vegetable production all year round.

Concerning pesticides, the vegetable sector uses 1,528 metric tons (cf. Table 32 p. 119), which out of a total import of 39,380 metric tons of active ingredient corresponds to a share of 3.9% vis-à-vis a land use of less than 1%. The average pesticide use per hectare in vegetable production then amounts to more than four times the sectoral average. While these figures support anecdotal evidence on high pesticide intensity in vegetable production, and are consistent with a high incidence of produce exceeding maximum residue limits, the aggregate quantities do not allow for a more differentiated conclusion on the final effect on human health or the environment. The environmental impact quotient that has been considered and aggregated for production technologies in the model is in principle available but aggregate data for comparison are lacking. It can be used, however, for a comparison of regional intensities and levels. The initially hypothesized difference in external input intensity between the long-history production sites in the periphery of the capital city is reflected only partially in the indicators of regional aggregates. Nitrogen intensity, for instance, is highest in the central region, followed by greater Bangkok and the upper North, whereas all other regions have far less intensive production systems (Table 33, p. 121). But the quantity of pesticides used per hectare is consistently close to 11.8 kg ha^{-1} in greater Bangkok, Central and Lower North model regions. Intensity in terms of active ingredient and environmental impact is lowest in the upper North followed by the South and the eastern and northern sub-regions of the Northeast, which are clearly the most peripheral regions. This difference has been the central argument for supporting or accelerating the shift towards more remote production regions and thereby reducing total externalities of vegetable production. On the other hand, the extreme pesticide intensity in the western part of the Northeast that has been traced to a combination of concentrated production of hot chilli and watermelon, and particularly sub-standard production technology, and the sub-regional mapping of intensity indicators (cf. Figure 70, p. 189 and Figure 71, p. 190) reveals that regional differences are strongly influenced by the respective crop portfolios. Whether an outward shift of production leads to less intensity is then obviously a question of whether less harmful production practices prevail in the periphery.

In most scenario simulations, the regional distribution of supply proves to be very stable as substantiated by the overview of elasticity estimates found throughout the simulations. For most factors the absolute elasticity of regional supply is clearly less than unity. Of course, supply reacts to growing demand, with elasticities close to unity differing little among regions except for a stronger reaction in the South. Also, total transport activity increases more than demand, indicating that regional supply does not simply adapt proportionally to demand but the latter is satisfied by additional supplies from other regions. A similarly strong reaction is only observed for greater Bangkok under a zoning policy: as available land is reduced by 1%, vegetable output decreases by 0.56%. It is less than unity because of intensified land use, while the remainder of supply is contributed from elsewhere, especially from the Central region where supply reacts inversely and grows as vegetable land in greater Bangkok is reduced.

Fuel price increases and transport loss reduction directly affect the cost of transportation in a contrasting direction, but their effects are different, as loss reduction has a dual effect. It firstly reduces the cost of transportation and secondly reduces the required level of production. Therefore the reduction in the central region is doubled and in greater Bangkok tripled when transport losses decline more than supplies increase in response to a rising fuel price. On the other hand, supply in the upper North is more affected by increasing fuel prices than from a loss reduction, because reduced losses involve a relaxation of the resource use in all regions, which in turn counteracts the advantage gain for the remote regions.

The effect of exogenous factor variation on transport activity is generally in line with expectations (cf. Table 43, p. 175): increasing demand, improving transport efficiency and an exclusion of vegetable production from the urban fringe of Bangkok result in increasing average transport distance, i.e. they support production in more remote areas. Conversely, increasing fuel prices and a tightening constraint on the aggregate environmental impact from pesticide use lead to reduction in transport activity. While the latter effect is not consistent over the range of 0-30% reduction targets, reduction at higher levels is only attained by reducing transport activity, losses and absolute level of production.

In summary, most factors exert a centrifugal influence on production locations, although a very slight one. In line with rather constant resource endowments, regional shares change comparatively little. The very likely scenario of a substantial growth in (urban) demand with continuing economic development indicates that even though in the upper North labour resources in vegetable farms are less utilized during most seasons, supply for a growing demand would preferably come from the Central and the western of the Northeastern model regions. Obviously, transportation cost impedes a more balanced growth of supplies from all model regions.

The combination of likely developments in exogenous factors in the forecast 2011 scenario leads to a rather stable development as major changes such as growing demand and yield growth have opposite effects. Regional output will grow mostly proportionally, while labour and land use decline. Especially in the Central region, labour use is expected to decline by 10,000 full-time equivalents or 13% – all hired labour – while family labour is more effectively used. In greater Bangkok, the declining labour demand in vegetable production is matched by out-migration of about 10% of initial farmer population and hired labour demand reduces only a little. The assumed improvement of transport efficiency more than compensates for the increase in transport volume so that fuel requirement decreases by nearly 12%. Increasing yields and a less than proportionate increase in nitrogen and pesticide intensity contribute to stagnant nitrogen use and environmental impact in spite of higher production. As vegetable area declines, however, intensities increase by 5% and 6%, respectively, and this implies that intensification is likely to continue unabated unless effective measures to tackle the problem are implemented. In spite of a gradual adoption of less intensive production technologies in up to 10% of total area under selected crops, the average regional intensity increases even where it has been high at the outset. For instance in the western part of the Northeast, an increase by 9% is predicted from the highest level of 478 units per hectare in the baseline and a less notable increase by 2% for the second ranking greater Bangkok region, where nitrogen intensity increases further by 11%.

At the same time, marked increases in fuel price and agricultural real wages and growing input intensity add to an increasing marginal cost of vegetable supply at the wholesale level by about 10% from baseline values throughout the country. In spite of yield growth, labour intensive crops (brinjal, hot chilli, yard long bean) appreciate at above average rates, whereas rather extensive crops – especially root and bulb vegetables – experience far smaller price increases. The likely development until 2011 is therefore expected to lead to a 10% real increase in vegetable prices at the wholesale level, which may lead to lower per capita consumption of vegetables than predicted on the basis of income elasticities only.

Motivated by extensive reports of the negative side effects of intensive use and overuse of agrochemicals, three intervention strategies were selected for simulation of their effect on the vegetable sub-sector. While implementation of an externally imposed reduction target might suffer from severe problems, the scenario calculations have shown that up to 30% of the baseline environmental impact can be saved with production technology available in the field. Such a level of cutback comes at a substantial cost and involves more than a 10-fold increases in marginal wholesale supply costs of various vegetables (Table 40, p. 158), which is hardly an acceptable price. On the other hand, due to a strong non-linearity in costs a 20% reduction affects prices only moderately, by less than 15% in 18 out of 23, crops and moreover adoption of existing environmentally friendly technologies reduces these effects. It is interesting that for a global reduction target, more than proportional effects are observed for greater Bangkok, which is the second most intensive user of pesticides, and a sub-proportional reduction in the central region, a consequence of an "export" of intensive production from greater Bangkok to the Central region.

The introduction of a Pigouvian tax on pesticide use depending on their environmental impact might be more easily implemented, and proves to be effective in reducing the environmental impact by nearly 25% of the baseline value. Even a moderate tax of 0.15 THB per unit of EIQ[89] is expected to bring about a 22% reduction that leads to quickly declining intensities in all areas except for the Central region. Greater Bangkok in particular benefits from an intensity that is nearly halved by a tax rate of 0.15 THB per unit of EIQ. In contrast, the return to family labour is clearly affected if farm gate prices remain constant in spite of such tax, and decrease by 30 - 108

[89] Depending on the price and environmental impact quotient of the respective pesticide, the tariff of 0.15 THB per unit EI leads to a cost increase per application between 1 and 216 THB (1% - 552%).

THB/man-day (Figure 59 on p. 166). Nevertheless, the taxation solution is very effective in reducing the environmental impact.

Finally a zoning policy aiming at an exclusion of vegetable production from the urban fringe, where highest intensities of vegetable cropping and associated pollution affect a large population, has also been evaluated. Such a policy might be easier to implement than other options as zones can be delineated according to administrative units and monitoring compliance is feasible by inspection. At the spatial resolution available, i.e. the greater Bangkok model region, the total environmental impact and nitrogen use in vegetable production decrease. However, up to a reduction in vegetable land by 70%, the intensity of pesticide use actually increases before it goes down again. Such intensification is a cogent support of model validity, as production theory predicts that with increasing scarcity a given factor is substituted by others – in this case external inputs are substituted for the declining land. Moreover, as production moves to other regions so do the associated side effects. On aggregate, pesticide use in terms of environmental impact is hardly reduced (0.2%-0.9%) and nitrogen use increases by up to 5%. In essence, the strategy solves the problem in one region effectively at the cost of other regions because it is non-specific. A shift from a production concentrated in areas of high population density to more dispersed production sites further away from urban concentrations could, however, still reduce the effect per unit of land or water and in terms of population at risk.

6.2 Policy implications

From a policy perspective, the areas where market failures lead to social costs or risk of substantial social costs that are not reflected in the transactions among agents, are the focus. According to the discussion in chapter 4, these fall into two spheres: (a) the massive environmental side effects and health implications of intensive production systems and (b) a level of vegetable intake that is below dietary recommendations for a healthy life in a growing population. While the latter is also a matter of consumer preferences, seasonal price fluctuations and a general upward trend in prices have also been cited for explaining this phenomenon. Therefore, the effect of interventions on vegetable prices should be taken into account.

In literature on highly intensive vegetable production systems in the tropical lowland conditions around Bangkok it was hypothesized that conditions in more favourable climatic conditions of highland production areas contribute to a less intensive production technology, and a policy encouraging a migration of vegetable farmers to more remote and highland areas could lead to an improvement. According to model results, this is not an effective option, although aggregate intensity indicators vary significantly. Low average intensities are on the one hand associated with seasonal production, where only a single crop of vegetables is grown under high external input conditions and a subsequent rice or field crop under far less intensive conditions, which lead to a moderate average intensity. On the other hand, very marked differences in specific intensities of crops are less dependent on the production location. On the contrary, the aggregate intensity of a production location depends on the crops grown there (and technology). This fact is well illustrated by the variation of intensity within regions as shown in Figure 70 (p. 189) and Figure 71 (p. 190). Moreover, simulations of a global reduction target, as well as the pesticide tax, show that all regions more or less consistently enjoy a reduction in absolute level, its intensity or both. Therefore, evidence in support of the above mentioned hypothesis is very weak.

The results of a 2011 forecast scenario indicating a continued growth of external input use intensity call for an alternative approach that is more specifically targeted to the problem. The approach of excluding vegetable production from parts or the complete greater Bangkok region has proven ineffective as it builds on the weak link of location and external input intensity. Quite differently, the implementation of a global reduction target of up to 30% was feasible given existing production technology and had positive effects in most regions. The associated increase in marginal supply cost could be limited effectively by a more rapid adoption of environmentally friendly technology. On the downside, this approach requires cooperative behaviour that is unlikely to be achievable, because such it would be very difficult to monitor.

The difficulty is avoided by a taxation approach, for which a variant with a tax rate proportional to potential hazard as expressed by the environmental impact quotient (EIQ) has been analysed. While for a price-based tax, POAPONGSAKORN *et. al.* (1998) mention the low demand elasticity of pesticides and the political infeasibility of the required rate of price increase as main obstacles to an otherwise desirable Pigouvian solution, the EIQ-based tax considered here can reduce the environmental impact by 20%. Such a policy would further benefit from a renewed effort of disseminating more environmentally friendly production technologies, as their adoption will enable farmers to maintain their incomes by relying less on hazardous inputs.

6.3 Further research needs

The discussion above has shown that even in a scarce data environment, a mathematical programming model on the sub-sector level can be created from a limited set of secondary and primary data and is suited for an assessment of the contribution of exogenous factors on supply response and related indicators. Moreover, it has been successfully used for simulating and evaluating the effect of explicit technological change and selected policy interventions. The selection of parameters and scenarios analysed was based on the objectives of the research and the expected contribution to a better understanding of the vegetable sector's response to exogenous factors, and as a matter of course leaves ample room for further analyses with regard to other questions and emerging policy options.

By the very nature of a partial model, the approach is, however, not capable of explaining the mobility of farmers, which depends on economic incentives and socio-economic characteristics of individuals. Similarly, the returns to competing land uses remain exogenous and cannot be assessed for their contribution to farmer mobility. An extension in this direction is conceivable but would include a more comprehensive model of agriculture and other land use options, as well as a more detailed spatial resolution to take into account the loss of land due to industrial and housing development at the urban fringe, and is deemed rather difficult to achieve.

There are two major areas where further research is warranted. On the demand side, the lack of sufficiently detailed elasticity estimates of vegetable demand has limited the model specification to a cost minimization problem subject to minimum supply constraints. Firstly, establishing a set of own-price and cross-price elasticity estimates for individual vegetable crops would allow for a more realistic representation of demand in a model that maximizes the sum of consumer and producer surplus. This approach would also permit an attribution of welfare implications to consumers and producers, thereby enhancing the value for policy advice. Secondly, further differentiation of the vegetable market by product and process quality assurance schemes ("safe" or "hygienic" products, organic labels) introduced by governmental and non-governmental organisations could better represent the complex value chain for vegetables. Both demand and marketing channels differ for such products, with likely different cost structures. The growing market share and specific analyses will therefore require more detailed representation in the model.

Finally, on the supply side an inclusion of more alternative production technologies like organic production is useful for assessing their specific competitiveness in the respective environments and to more accurately assess the differences between private and social optima. A comprehensive representation of well established technology and more recently developed systems proven feasible in a commercial farming context contributes to a suitable description of the sector and an accurate representation of policy outcomes. This might therefore be more convincing to policy makers and allow them to turn knowledge on strategies for reducing external effects into actual policy.

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8 Appendix

8.1 Appendix to chapter 3

Table 53: Recent vegetable production statistics of the DoAE in comparison to FAOSTAT

1,000 metric tons	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
FAOStat	3,148	3,176	3,348	3,257	3,231	n. a.
DoAE	5,577	4,482	5,285	1,821	2,800	3,569

Sources: FAO (2008c as of 8 July 2008) and DoAE (2008 as of 10 July 2008)

Table 54: Fruit and vegetable wholesale markets in Thailand 2003

Location	Name of the market
North	
Phetchabun, A. Lomsak	Raan Santisuk
Chiang Mai	Mueang Mai[1]
Northeast	
Nakhon Ratchasima	Aranyayont Ltd
Nakhon Ratchasima	Suranakhorn Mueang Mai Ltd.
Kalasin	Kalasinnakhorn Ltd.
Kalasin	HJK Chaisiwathat
Central	
Pathum Thani	Don Mueang Phattana Ltd. (Talad Si Mum Mueang Daan Nuea)
Pathum Thani	Thai Agro-Exchange Ltd. (Talad Thai)
Bangkok	Pak Khlong Talad (Ongkarn Talad)[2]
Samut Sakhon	Garden City Holding Ltd.
Ratchaburi	Agro Commerce Group Ltd.
Nakhon Pathom	HJK Talad Pathom Mongkhon
Rayong	Saharayong Garn Talad Ltd.
South	
Nakhon Si Tammarat	Hua It
Phang Nga	HJK Khokkloygarnkaset

Source: Department of Internal Trade (2003)

[1] WIBOONPONGSE (2004), [2] FUKUI & ISVILANONDA (1999)

Table 55: Scientific and common names of commercially important vegetables in Thailand

Family	English common name	Thai common name	Scientific name
Alliaceae	Chinese chive	กุยช่าย	*Allium tuberosum* ROTTLER. ex SPRENGEL.
	Garlic	กระเทียม	*Allium sativum* L. var. *sativum*
	Chinese leek	กระเทียมต้น	*Allium odorosum* L.
	Onion	หอมหัวใหญ่	*Allium cepa* L. var. *cepa*
	Shallot	หอมแดง	*Allium cepa* L. var. *ascalonicum*
	Spring onion	ต้นหอม (หอมแบ่ง)	*Allium cepa* L. var. *ascalonicum*
Apiaceae	Carrot	แครอท	*Daucus carota* L.
	Coriander	ผักชี	*Coriandrum sativum* L.
Asteraceae	Lettuce	ผักกาดหอม	*Lactuca sativa* var. *crispa* L.
Brassicaceae	Broccoli	บร็อคโคลี	*Brassica oleracea* var. *italica*
	Cabbage	กะหล่ำปลี	*Brassica oleracea* var. *capitata*
	Cauliflower	กะหล่ำดอก	*Brassica oleracea* var. *botrytis*
	Chinese cabbage	ผักกาดขาวปลี	*Brassica campestris* var. *pekinensis*
	Chinese flowering mustard/chaisim	ผักกาดกวางตุ้ง	*Brassica campestris* var. *chinensis*
	Chinese kale	ผักคะน้า	*Brassica oleracea* L. var. *alboglabra* BAILEY
	Chinese radish	ผักกาดหัว	*Raphanus sativus*
	Mustard green	ผักกาดเขียวปลี	*Brassica juncea* var. *rugosa*
Convolvulaceae	Morning glory	ผักบุ้งจีน	*Ipomoea aquatica* FORSK.
	Water morning glory	ผักบุ้งน้ำ	*Ipomoea aquatica* FORSK.
Cucurbitaceae	Angled gourd	บวบ	*Luffa* spp.
	Cantaloup	แคนตาลูป	*Cucumis melo* L.
	Chin. bittergourd	มะระจีน	*Momordica charantia* L.
	Cucumber	แตงกวา	*Cucumis sativus* L.
	Pumpkin	ฟักทอง	*Cucurbita* spp.
	Watermelon	แตงโมเนื้อ	*Citrullus lanatus* (THUNB.) MATSUMURA & NAKAI var. *lanatus*
	Waxgourd	ฟักเขียว (แฟง)	*Benincasa hispida* (THUNB.) COGN.
Fabaceae	Yard long bean	ถั่วฝักยาว	*Vigna unguiculata* var. *sesquipedalis*
Liliaceae	Asparagus	หน่อไม้ฝรั่ง	*Asparagus officinalis* L.
Malvaceae	Okra	กระเจี๊ยบเขียว	*Abelmoschus esculentus* (L.) MOENCH.
	Roselle	กระเจี๊ยบแดง	*Abelmoschus esculentus* (L.) MOENCH.
Poaceae	Baby corn	ข้าวโพดอ่อน	*Zea mays* L.
	Sweet corn	ข้าวโพดหวาน	*Zea mays* L.
Solanaceae	Bell pepper	พริกยักษ์ (หวาน)	*Capsicum annuum* L. var. *grossum*
	Chilli 2-3 cm	พริกขี้หนูสวน	*Capsicum frutescens* L.
	Chilli 3-5 cm	พริกขี้หนูใหญ่	*Capsicum* spp.
	Chilli 5 - cm	พริกใหญ่	*Capsicum annuum* L.
	Plate brush eggpl.	มะเขือม่วง	*Solanum melongena*
	Snake egg-plant	มะเขือยาว	*Solanum melongena*
	Tomato, fresh	มะเขือเทศส่งตลาดสด	*Lycopersicon esculentum*
	Tomato, processing	มะเขือเทศส่งโรงงาน	*Lycopersicon esculentum*
Zingiberaceae	Ginger	ขิง	*Zingiber officinale* ROSC.

Sources: DoAE (2001), CHAIMONGKON (2005)

Table 56: Exports and imports for average 2006/2007

	Export			Import		Net export	
						Quantity: metric tons, value: 1000 THB	
	Quantity	**Value**	**Share %**	**Quantity**	**Value**	**Quantity**	**Value**
Dried chilli	2,778	301,811	1.3	37,686	851,326	-34,908	-549,516
Garlics, dried	429	11,911	0.1	26,873	251,345	-26,445	-239,434
Young corns in air-tight containers	71,415	1,712,118	7.6			71,415	1,712,118
Ginger gery and white	23,347	426,993	1.9			23,347	426,993
Other vegetable juice	114,672	3,279,495	14.6	6,033	298,309	108,640	2,981,187
Vegetables prepared or preserved	221,430	8,245,944	36.8	21,704	937,002	199,727	7,308,942
Vegetables, fresh or chilled	44,984	2,803,124	12.5	140,963	1,833,692	-95,979	969,432
Onions, shallots, garlics,leeks and other, fresh or chilled	71,452	678,138	3.0	16,445	45,575	55,007	632,563
Vegetables, chilled, frozen	40,962	1,926,183	8.6			40,962	1,926,183
Vegetables, dried, dehydrated	3,620	180,305	0.8	8,278	312,234	-4,659	-131,929
Tomatoes, prepared or preserved	2,202	59,845	0.3	7,465	175,933	-5,264	-116,088
Tomatoes, fresh or chilled	1,498	13,782	0.1			1,498	13,782
Potatoes, fresh	199	2,994	0.0	4,273	105,849	-4,074	-102,855
Vegetable seeds for planting	2,852	1,056,092	4.7	1,661	364,107	1,191	691,985
Other seeds for planting	494	194,314	0.9	4,475	71,996	-3,981	122,318
Bamboo-shoots in air-tight containers	21,126	526,917	2.3			21,126	526,917
Asparagus, prepared or preserved	18	589	0.0			18	589
Asparagus, fresh or chilled	14,016	904,600	4.0			14,016	904,600
Bamboo-shoots, fresh or chilled	1,121	42,646	0.2	323	23,259	799	19,387
Shallots, dried	212	4,386	0.0	74	1,107	139	3,279
Onions, dried	17	6,539	0.0	338	28,795	-321	-22,257
Mushrooms, dried	626	47,585	0.2	4,891	785,910	-4,266	-738,325
Other beans, dried			0.0	12,063	221,836	-12,063	-221,836
Peas			0.0	7,767	112,594	-7,767	-112,594
Total	**639,464**	**22,426,308**	**100.0**	**301,308**	**6,420,865**	**338,156**	**16,005,443**

Source: OAE (2008)

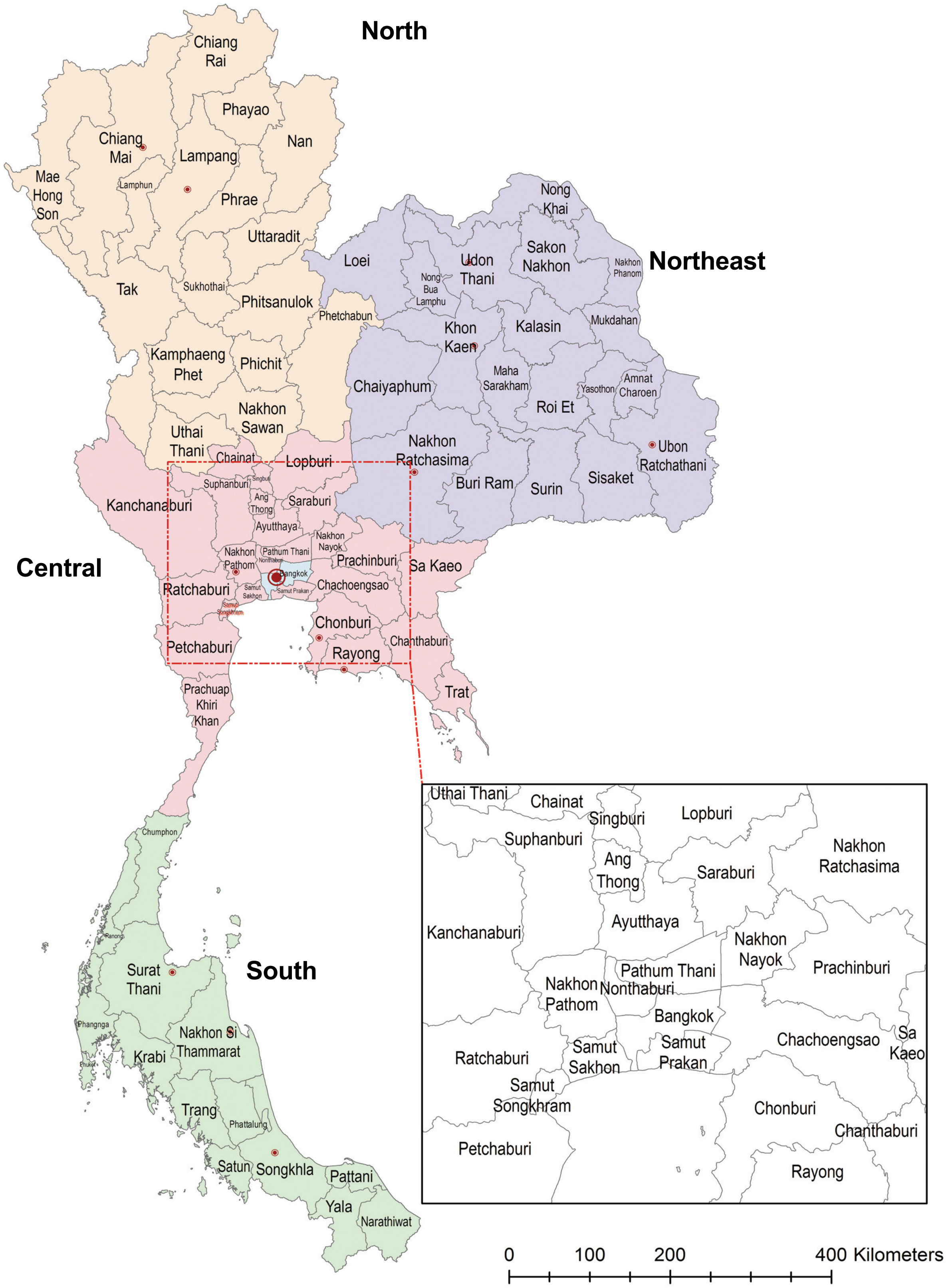


Figure 72: Thailand administrative units: Provinces and official regions

Source: Administrative units of Thailand (NSO, 2002)

8.2 Appendix to chapter 4

Table 57: Overview of vegetable farming survey 2001

Region	Central	Northeast	North
Number of interviews	29	10	9
Provinces	Bangkok, Nonthaburi, Nakhon Pathom, Kanchanaburi, Ratchaburi	Nakhon Ratchasima	Chiang Mai, Lamphun, Phitsanulok, Phetchabun
Crop budgets covered	26	10	9
Participants in DoA hygienic vegetable	1	-	-
IPM FFS alumni	2	-	2
Vegetable grower group	7	1	4

Source: Vegetable farm survey 2001

Table 58: Farm interviews conducted in 2001 by location

Province	District	Sub-district	No.	Crop budgets
Central				
Kanchanaburi	Mueang	Wang Dong	KB-07	Large Cucumber,
Kanchanaburi	Mueang	Wang Dong	KBXX	Yard long bean
Kanchanaburi	Phanom Thuan	Don Thapet	KB-03	Cantaloup
Kanchanaburi	Phanom Thuan	Don Thapet	KB-06	Watermelon
Kanchanaburi	Tha Maka	Tha Khram En	KB-05	Baby corn
Kanchanaburi	Tha Maka	U Lok Si Mun	KB-04	Chilli 2-3 cm
Kanchanaburi	Tha Muang	Wang Sala	KB-02	Chin. white cabbage
Kanchanaburi	Tha Muang	Wang Sala	KB-01	Onion
Bangkok	Taling Chan	Tawee Wattana	BKK15	Lettuce
	Taling Chan	Tawee Wattana	BK14	
Nakhon Pathom	Kamphaengsaen	Huaykhwang	NP12	Tomato, fresh
Nakhon Pathom	Kamphaengsaen	Tung Khwa	NP13	Morning glory
Nakhon Pathom	Mueang	Nong Ngu Lueam	NP10	Asparagus
Nakhon Pathom	Mueang	Nong Ngu Lueam	NP11	Yard long bean
Nakhon Pathom	Mueang	Nong Ngu Lueam	NN08	Chilli 2-3 cm
Nakhon Pathom	Mueang	Nong Ngu Lueam	NP09	Spring onion
Nonthaburi	Bang Bua Thong	Bang Bua Thong	NN01	Chinese chive
Nonthaburi	Bang Bua Thong	Phimonrat	NN-03	Chinese kale
Nonthaburi	Sai Noi	Kong Kwang	NN07	Yard long bean
Nonthaburi	Sai Noi	Sai Noi	NN05	Lettuce
Nonthaburi	Sai Noi	Sai Noi	NN06	Okra
Nonthaburi	Sai Noi	Sai Noi	NN04	Water morning glory
Ratchaburi	Damnoen Saduak	Tha Nat	RB-01	Chinese kale, Pak Choi, Chinese flowering mustard
Ratchaburi	Damnoen Saduak	Tha Nat	RB-02	Baby corn
Ratchaburi	Damnoen Saduak	Tha Nat	RB-03	Chilli 5 - cm, Cucumber
Ratchaburi	Damnoen Saduak	Tha Nat	RB-04	Yard long bean
Ratchaburi	Mueang	Ang Thong	RB-06	Snake egg-plant
Ratchaburi	Mueang	Ang Thong	RB-07	Chin. bittergourd
Ratchaburi	Mueang	Ang Thong	RB-05	Cucumber

Table 58 continued

Province	District	Sub-district	No.	Crop budgets
North-Eastern				
Nakhon Ratchasima	Chaloem Prakiat	Nong Yang	NR-05	Cucumber
Nakhon Ratchasima	Chaloem Prakiat	Nong Yang	NR-04	Yard long bean
Nakhon Ratchasima	Kham Thalee So	Kham Thalee So	NR-11	Spring onion
Nakhon Ratchasima	Kham Thalee So	Pong Daeng	NR-09	Spring onion
Nakhon Ratchasima	Kham Thalee So	Pong Daeng	NR-10	Chilli 2-3 cm
Nakhon Ratchasima	Mueang	Hua Thale	NR-02	Cauliflower
Nakhon Ratchasima	Mueang	Ban Ko	NR-01	Chin. kale, Pak Choi, Chin.fl. mustard
Nakhon Ratchasima	Pak Chong	Pak Chong	NR-07	Cucumber, Pumpkin
Nakhon Ratchasima	Pak Chong	Pak Chong	NR-08	Chin. white cabbage
Nakhon Ratchasima	Pak Chong	Paya Yen	NR-06	Tomato, fresh
Northern				
Chiang Mai	Mae Rim	Mae Sa Mai	CM-MS1	Chin. cabbage
Chiang Mai	Mae Rim	Mae Raem	CM-05	Chin. cabbage
Chiang Mai	Mae Taeng	Ban Pao	CM-06	Onion
Chiang Mai	San Sai	Nong Han	CM-XX2	Cauliflower
Chiang Mai	San Sai	Nong Han	CM-02	-
Chiang Mai	Saraphi	Don Kaeo	CM-01	Cauliflower
Lamphun	Mueang	Mueang Chi	CM-03	Garlic, Shallot
Lamphun	Mueang	Umong	CM-04	Chilli 2-3 cm

Source: Farm Survey 2001

Table 59: Representative points for model regions drawn

Region	Centroid	Demand Centroid	Production Centroid	Representative point
Upper North	54 km east of Chiang Mai	64 km east of Chiang Mai	35 km east of Chiang Mai	Chiang Mai town
Lower North	46 km east of Kamphaeng Phet	63 km south of Phitsanulok	54 km south of Phitsanulok	Midpoint of demand and production centroid on Highway 117
upper North-East	19 km southeast of Udon Thani	32 km southeast of Udon Thani	23 km south of Udon Thani	19 km southeast of Udon Thani, near Highway 2
western part of North-East	46 km north-east of Nakhon Ratchasima	48 km north-east of Nakhon Ratchasima	37 km north-east of Nakhon Ratchasima	53 km road distance north-east of Nakhon Ratchasima on Highway 2
Eastern part of North-East	47 km north of Si-saket	43 km north of Si-saket	40 km north of Si-saket	Centroid, 8 km from Highway 23 (Ubon Ratchathani – Yasothon)
Central	Bangkok, Northern City (Phahonyothin Road)	7 km north of Nakhon Pathom, 55 km east of centroid	14 km east of centroid	Bangkok city
Greater Bangkok	Nonthaburi city	7 km north-east of Bangkok city centre	28 km North-west of Bangkok city, Nonthaburi prov.	Bangkok city
South	44 km south-west of Nakhon Si Thammarat	74 km south of Nakhon Si Thammarat	57 km south of Nakhon Si Thammarat	Midpoint between demand and production centroids, 67 km south of Nakhon Si Thammarat

Source: Own presentation

Table 60: Participant list of 1st expert workshop, 19-20 November 2001, Nonthaburi

Name	Function	Duty station/home address
Mr. Satid Pibul	Extension	Bangkok
Mr. Piched Namtian	Extension	Nakhon Pathom
Mr. Saksid Shriwichai	Extension	Nonthaburi
Mrs. Somrid Authaichay	Extension	Nonthaburi
Mrs. Maneewan Deejongngam	Trader	Goods and Service Distribution Cooperative Office, Nonthaburi
Mr. Seree Mungmaeung	Extension	Centre for Biological Pest Control, Western Region
Miss. Saman Panpin	Farmer	Mueang district, Nonthaburi
Mr. Surachai Chudaung	Farmer	Mueang district, Nonthaburi
Mrs. Samai Linsomboon	Farmer	Mueang district, Nonthaburi
Mrs. Somkid Panchot	Farmer	Don Tum district, Nakhon Pathom
Mr. Sompong Prisrimaung	Farmer	Don Tum district, Nakhon Pathom
Mrs. Nhung Maungyu	Farmer	Don Tum district, Nakhon Pathom
Mr. Surachai Liboonchu	Trader	Mueang district, Nonthaburi

Table 61: Participant list of 2nd expert workshop, 22-23 November 2001, Kanchanaburi

Name	Function	Duty station/home address
Mr. Satid Pibul	Extension	Bangkok
Miss. Chanita Chokesap	Extension	Kanchanaburi, Tha Muang district
Miss. Oarathai Purakatekul	Extension	Kanchanaburi
Mr. Surapol Punakit	Extension	Kanchanaburi
Mr. Manoth Pulsupich	Extension	Ratchaburi, Ban Pong district
Mr. Woratash Janpayom	Extension	Centre for Biological Pest Control, Western Region
Mrs. Suwin Phueam	Farmer	Kanchanaburi, Tha Muang district
Mr. Som Khomkhol	Farmer	Kanchanaburi, Tha Muang district
Miss. Duangkhae Wangplathong	Farmer	Ratchaburi, Ban Pong district
Mrs. Po Dibun	Farmer	Ratchaburi, Ban Pong district
Mr. Wichai Sopa	Farmer	Ratchaburi, Ban Pong district
Mr. Jek Phuchaloay	Farmer	Ratchaburi, Ban Pong district

Table 62: Participant list of 3rd expert workshop, 29-30 November 2001, Nakhon Ratchasima

Name	Function	Duty station/home address
Mr. Satid Pibul	Extension	Bangkok
Mr. Charuk Nuankokesung	Extension	Nakhon Ratchasima Agricultural Extention Office
Mr. Surapol Punakit	Extension	Centre for Biological Pest Control, North-Eastern region
Mr. Suksamran Anjpru	Farmer	Mueang district, Nakhon Ratchasima
Mr. Chareon Chaimoungnoi	Farmer	Sung Noen district, Nakhon Ratchasima
Mrs. Subin Nakboa	Farmer	Chalerm Prakiat district, Nakhon Ratchasima
Mrs. Woraporn Phopan	Farmer	Chalerm Prakiat district, Nakhon Ratchasima
Mr. Mongkol Pummapan	Farmer	Pakthongchai district, Nakhon Ratchasima
Mrs. Pratip Pummapan	Farmer	Pakthongchai district, Nakhon Ratchasima
Mr. Surapol Noumkoksung	Farmer	Mueang district, Nakhon Ratchasima
Mr. Aungard	Farmer	Mueang district, Nakhon Ratchasima
Mr. Chatri Wongkaew	Farmer	Chakkarat district, Nakhon Ratchasima
Mr. Pad Chamnanmho	Farmer	Wang Nam Khiao district, Nakhon Ratchasima

Table 63: Participant list of 4th expert workshop, 3-4 December 2001, Chiang Mai

Name	Function	Duty station/home address
Mr. Satid Pibul	Extension	Bangkok
Mr. Somboon Plongcha	Extension	Lamphun
Mr. Satid Pibul	Extension	Chiang Mai
Mr. Wichai Shripongam	Extension	Centre for Biological Pest Control, Northern region
Mr. Narong Moonra	Farmer	Mueang district, Lamphun
Mr. Wibul Pirokash	Farmer	Mueang district, Lamphun
Mrs. Sangwan Bunpeng	Farmer	Sarapi district, Chiang Mai
Mr. Samai Bunbeng	Farmer	Sarapi district, Chiang Mai

Table 64: Participant list of 5th expert workshop, 6-7 December 2001, Chiang Mai

Name	Function	Duty station/home address
Mrs. Plissana Panpato	Extension	Mae Rim district, Chiang Mai
Mrs. Pimporn Manmachrihod	Extension	Sa Moeng district, Chiang Mai
Mrs. Walaiporn Kieadpapping	Extension	DoAE Northern Region
Mr. Sompong Aishara	Extension	Chiang Mai
Mrs.Pamita Kaewroungrai	Extension	Centre for Biological Pest Control, Northern region
Mr. Tom Laosaue	Farmer	Mae Rim district, Chiang Mai
Mrs. Baukaeng Chaiyathep	Farmer	Mae Rim district, Chiang Mai
Mrs. Srongfa Wongsaue	Farmer	Mae Rim district, Chiang Mai
Mrs. Buangpad Thinaruaeng	Farmer	Mae Rim district, Chiang Mai
Mr. Thong Ainta	Farmer	Sa Moeng district, Chiang Mai

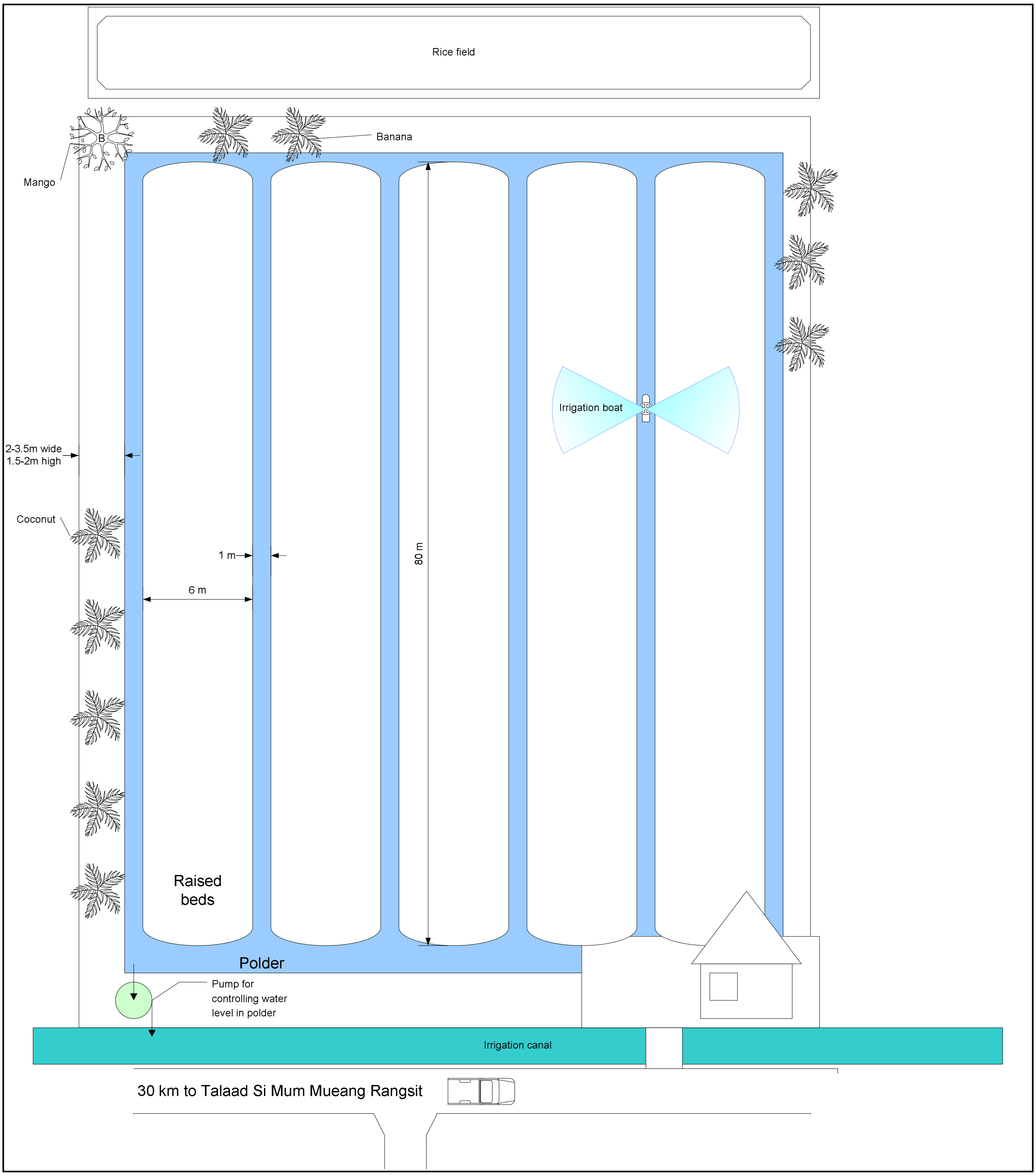
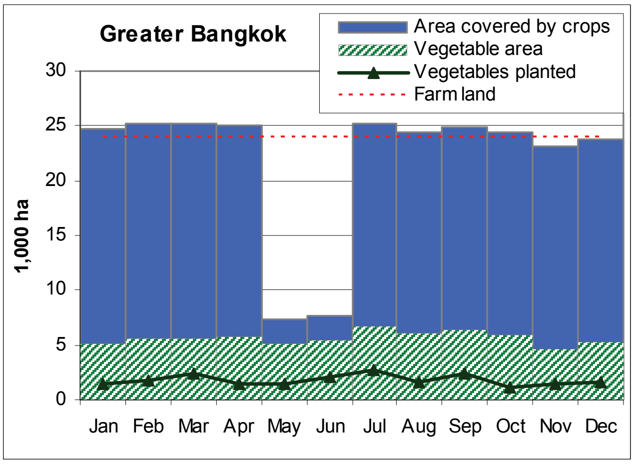


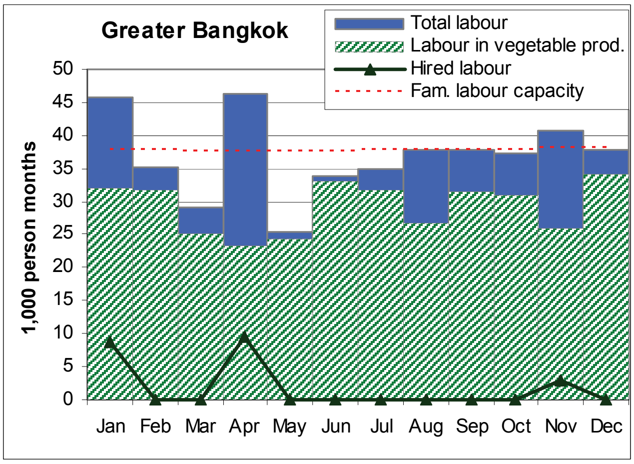
Figure 73: Sketch of a typical vegetable farm in Nonthaburi province

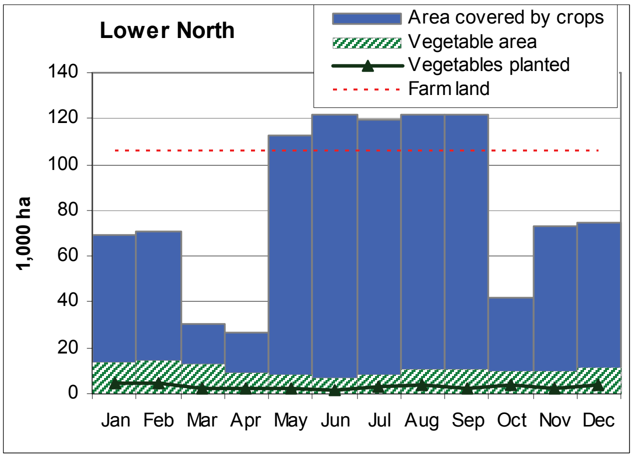
Source: Expert workshop

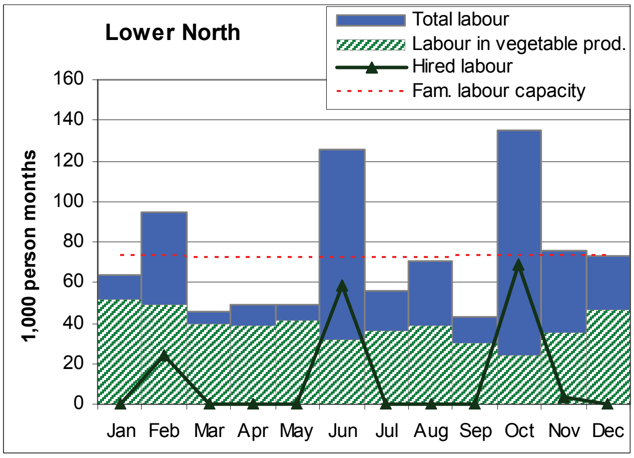
8.3 Appendix to chapter 5

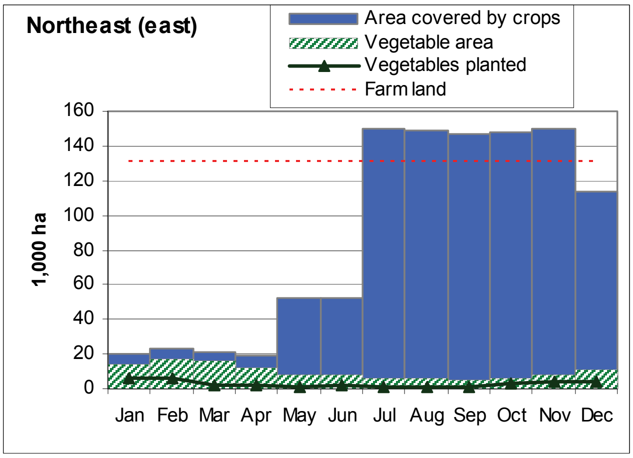
8.3.1 Baseline

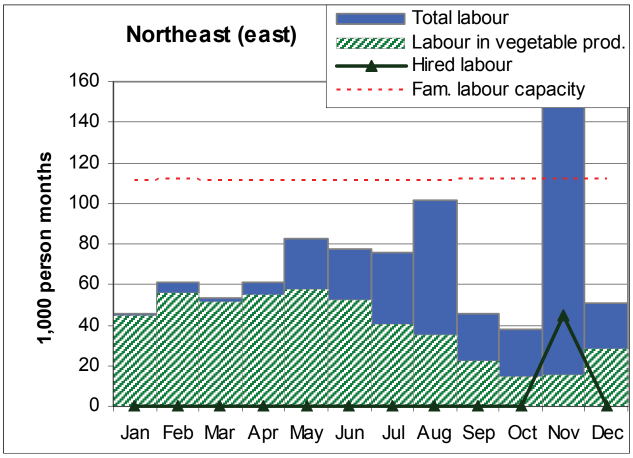












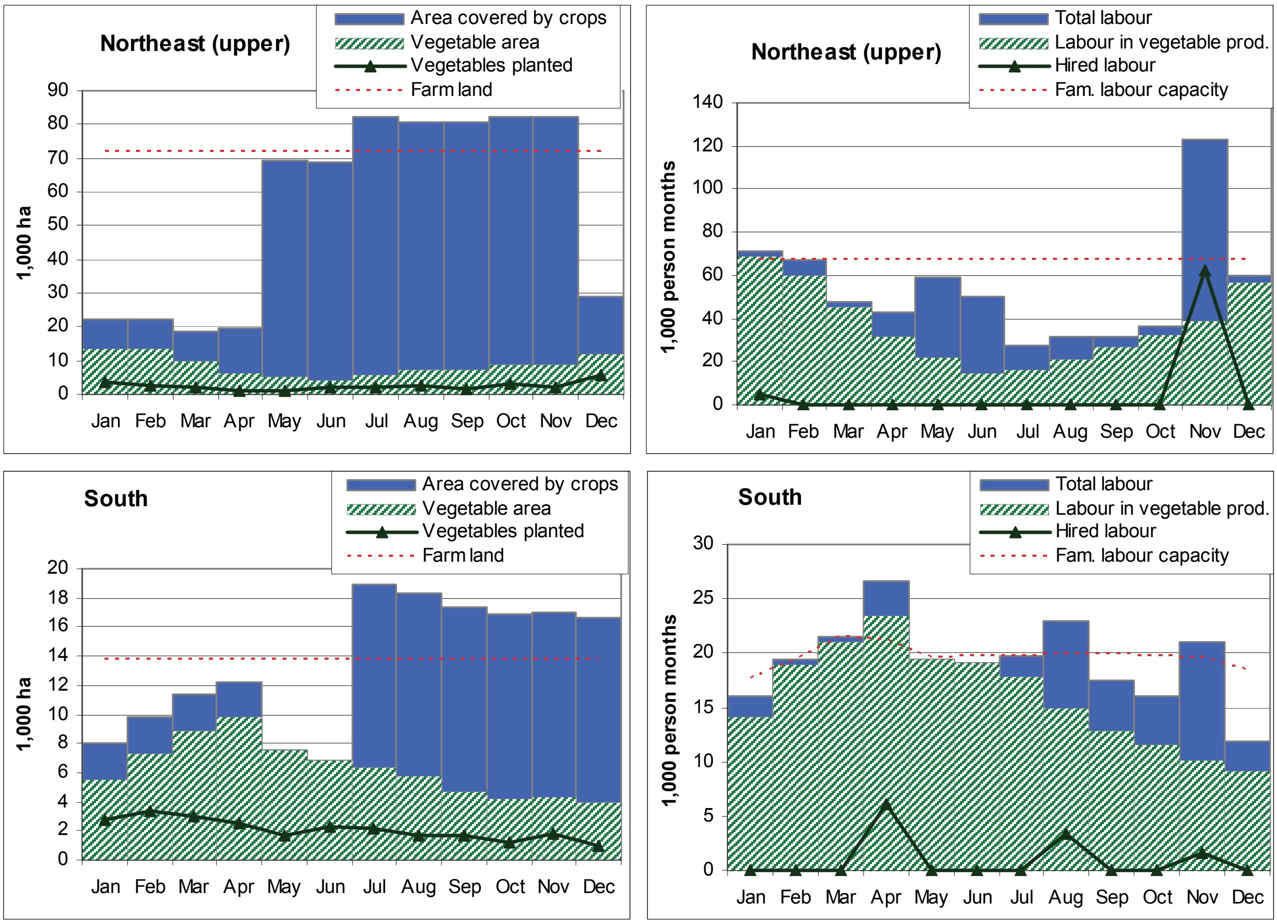


Figure 74: Seasonal resource allocation in the baseline scenario by model region

8.3.2 Demand growth

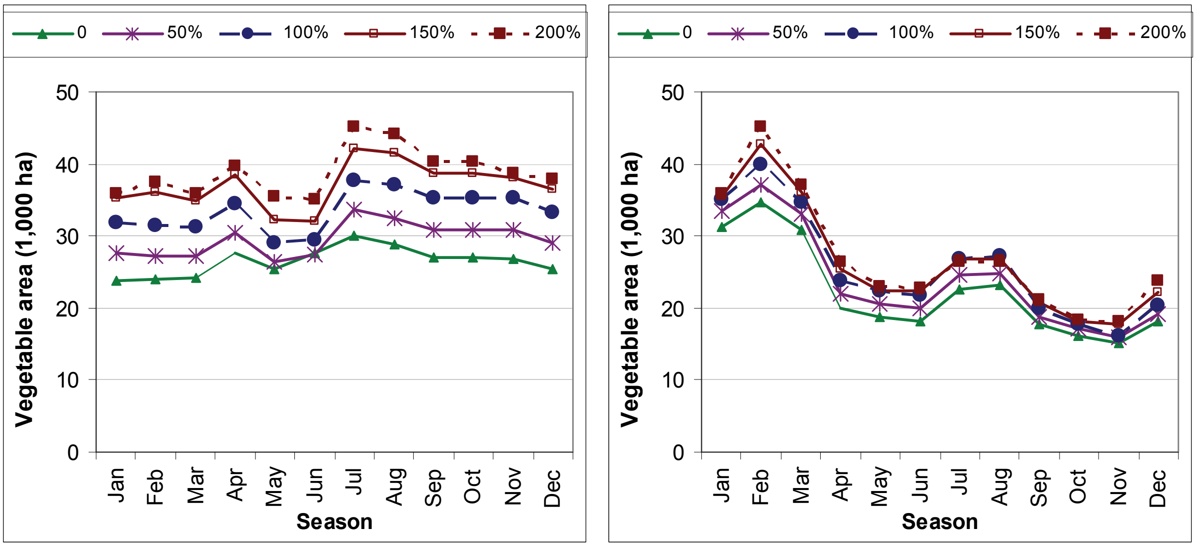


Figure 75: Seasonal land use by vegetable crops in CE (left) and UN (right) under different demand scenarios

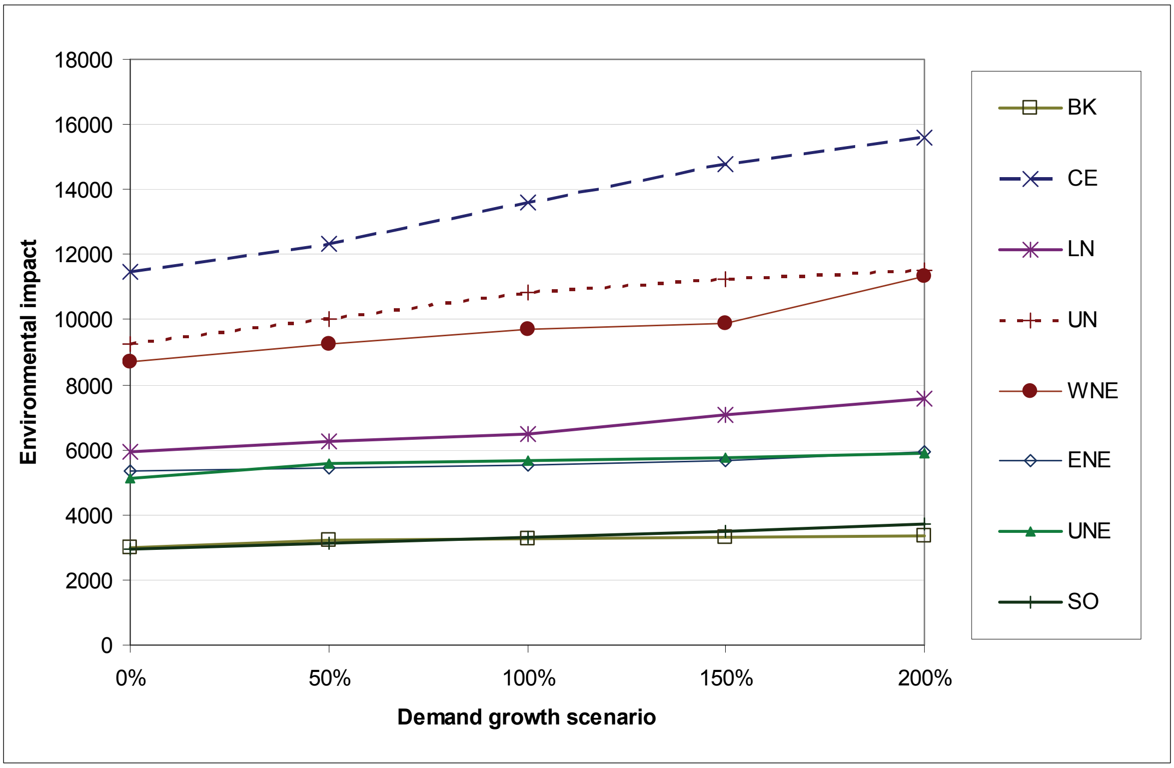


Figure 76: Regional environmental impact by region under different demand growth scenarios

8.3.3 Fuel price

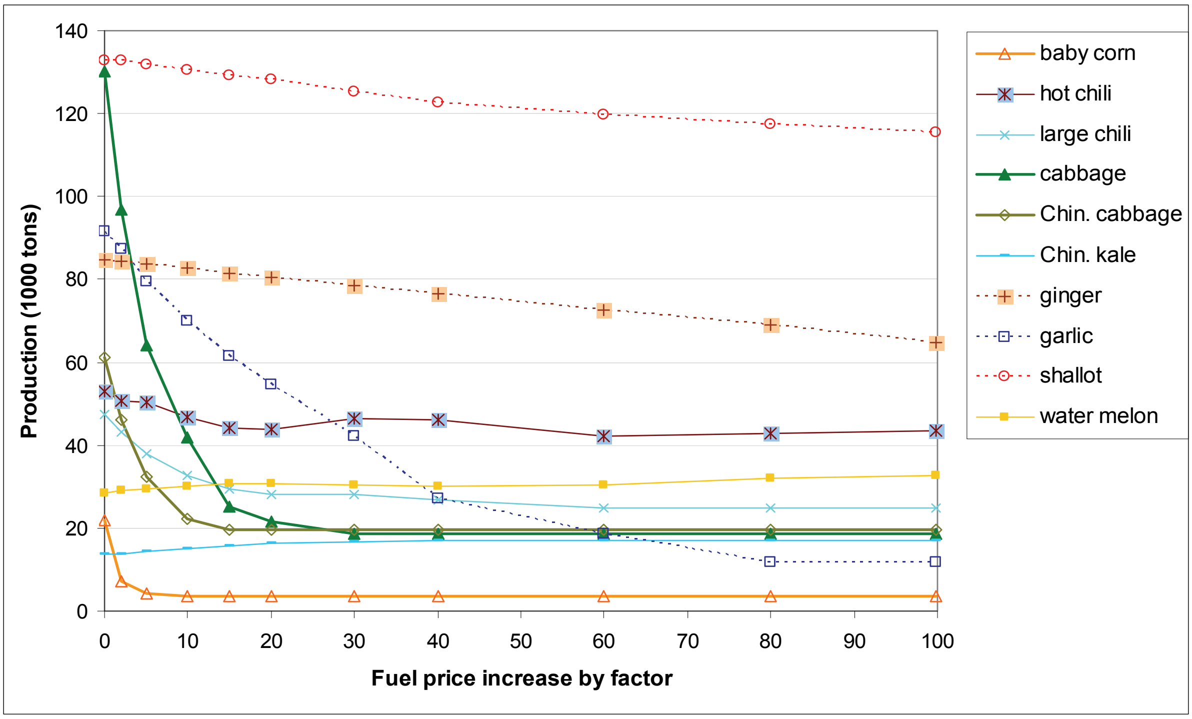


Figure 77: Production of selected crops in the UN as a function of fuel price increases

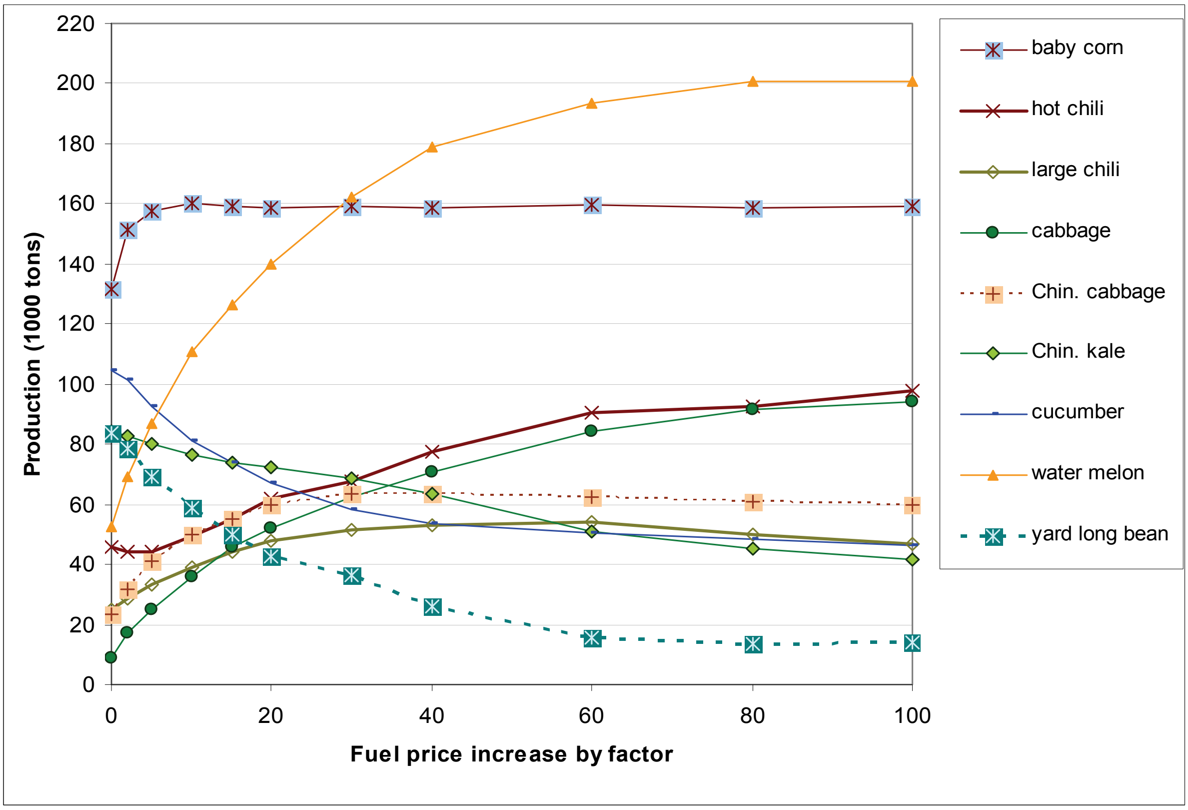


Figure 78: Production of selected crops in the CE as a function of fuel price increases

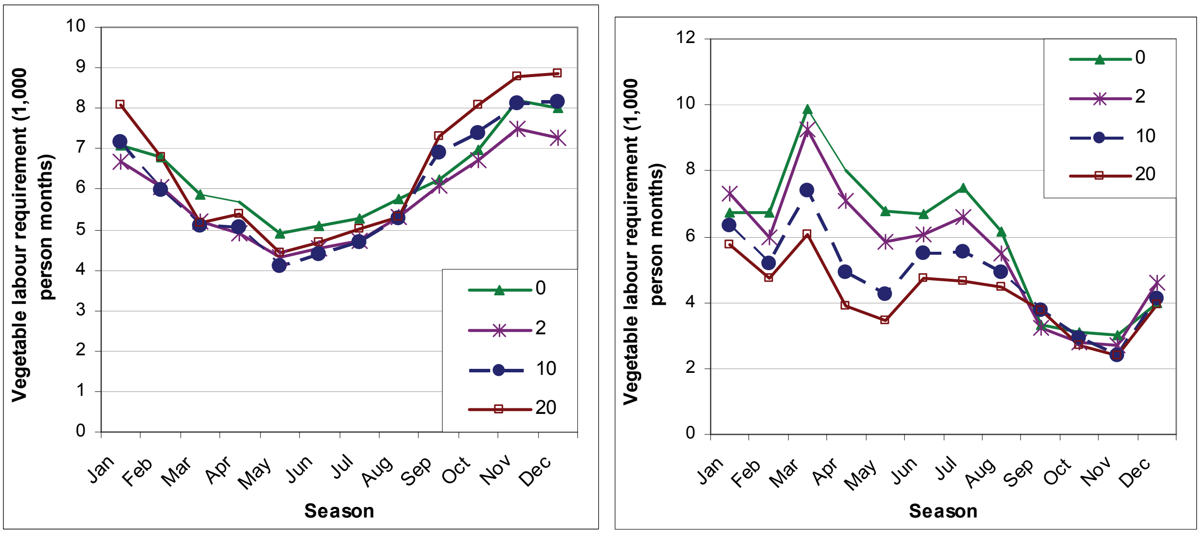


Figure 79: Seasonal labour use in vegetable production in CE and UN for selected fuel price scenarios

8.3.4 Reduced losses

Table 65: Change in average transport distance and average loss when technical loss coefficients are reduced by 50%.

	Original distance km	Change in transport distance %	Original loss %	Change in loss %
Asparagus	312	-1.8	7.2	-50.6
Baby corn	198	13.6	4.4	-46.3
Brinjal	204	2.3	5.6	-49.4
Hot chilli	248	3.7	5.1	-48.9
Large chilli	293	1.4	5.7	-49.5
Cabbage	525	1.5	9.9	-49.4
Chin. cabbage	330	6.4	8.6	-47.5
Cauliflower	384	2.8	7.3	-48.9
Chinese mustard	183	10.7	6.7	-47.1
Chinese kale	165	8.8	6.3	-47.7
Coriander/celery	200	8.3	8.5	-47.1
Chin. radish	281	0.3	6.2	-49.9
Cucumber	235	13.1	5.5	-45.8
Ginger	421	2.1	5.2	-49.3
Garlic	648	0.1	4.2	-50.0
Lettuce	228	3.3	5.9	-49.0
Morning glory	174	14.4	7.4	-45.7
Pumpkin	252	7.3	4.5	-48.0
Shallot	526	-0.9	3.6	-50.3
Spring onion	177	22.0	6.0	-43.6
Tomato	289	4.3	7.8	-48.4
Watermelon	293	3.0	4.9	-49.1
Yard long bean	198	17.0	5.0	-44.9

Source: TVSM simulation

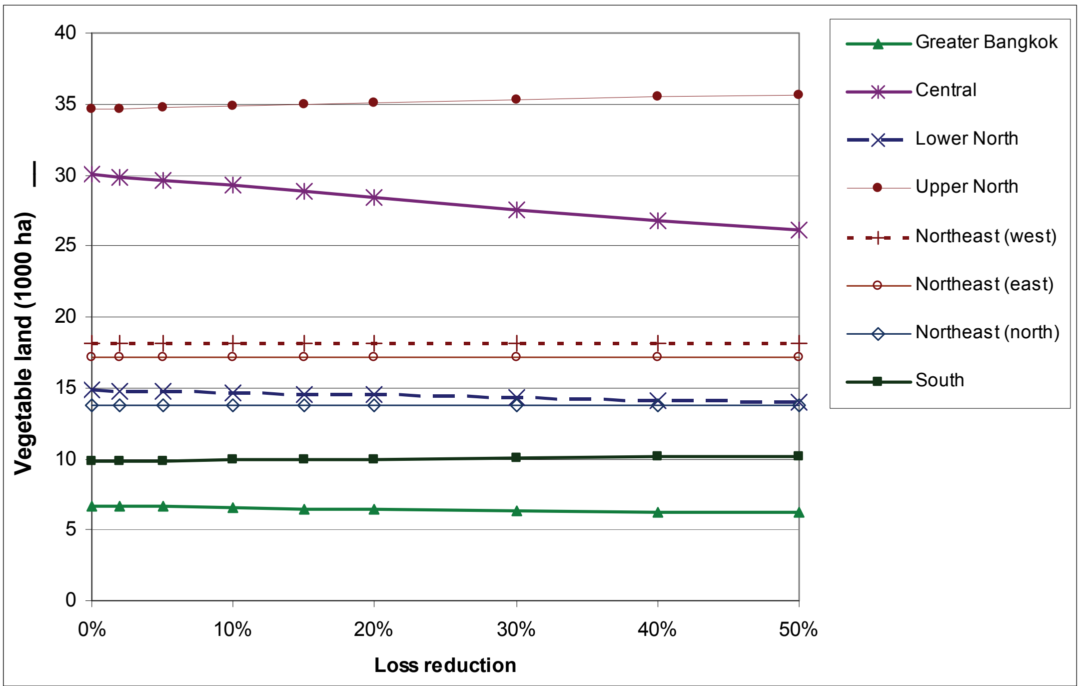


Figure 80: Vegetable land use as a function of loss reduction during transport and handling.

Source: TVSM simulation

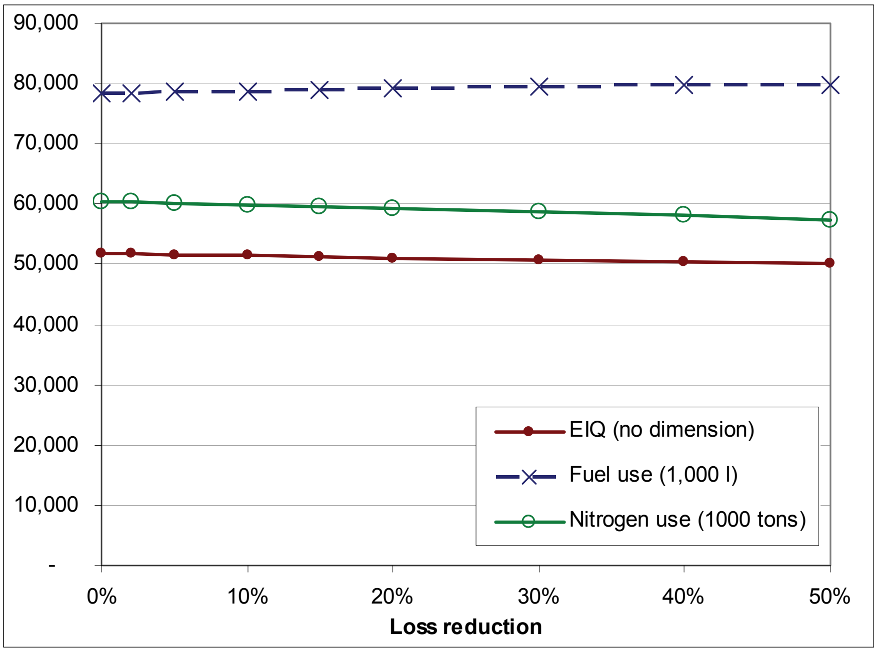


Figure 81: Aggregate indicators of external input use as a function of reduced transformation loss rates.

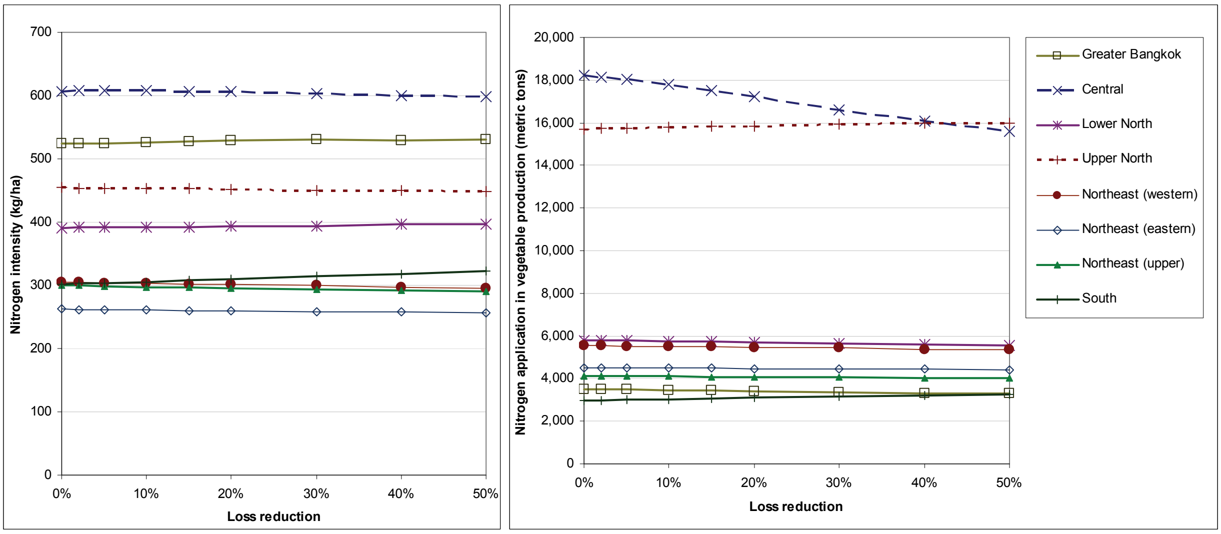


Figure 82: Regional nitrogen intensity and absolute quantities applied as a function of transport loss reduction.

8.3.5 Yield growth

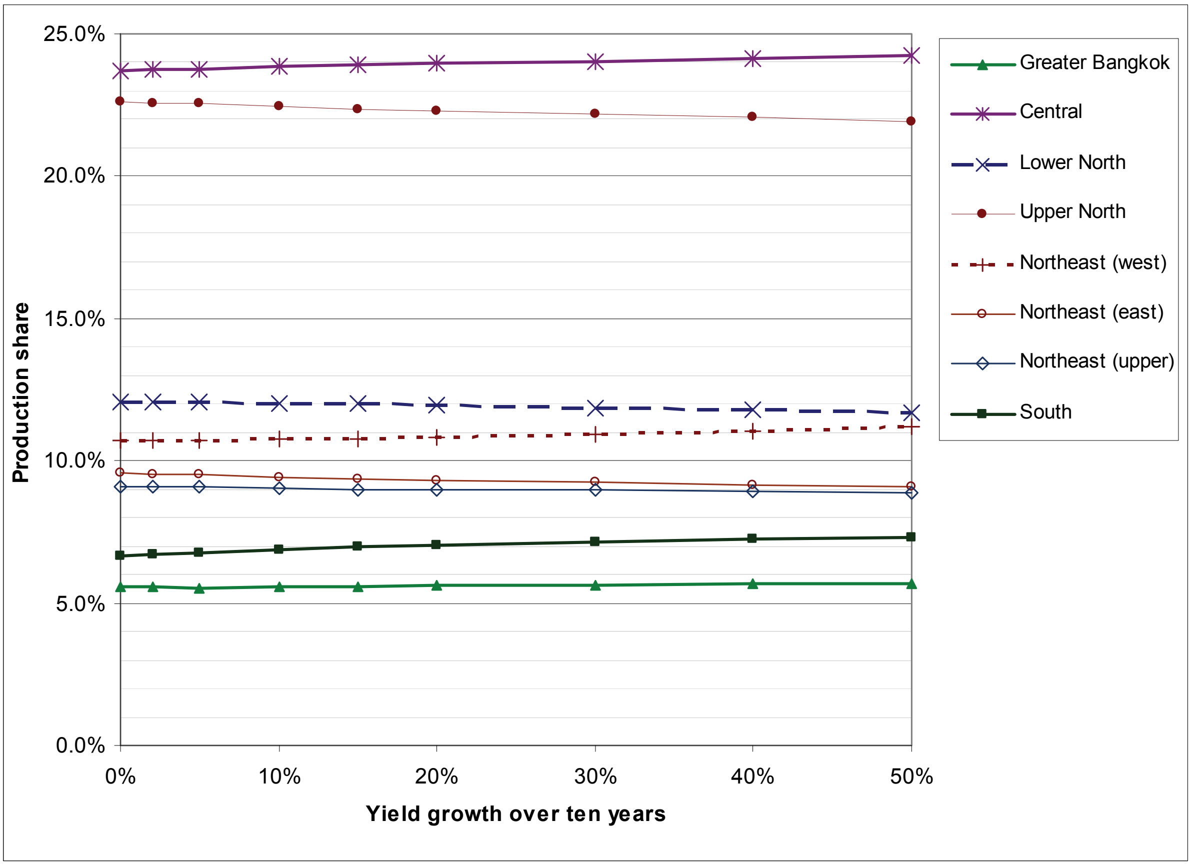


Figure 83: Regional supply shares as a function of yield growth

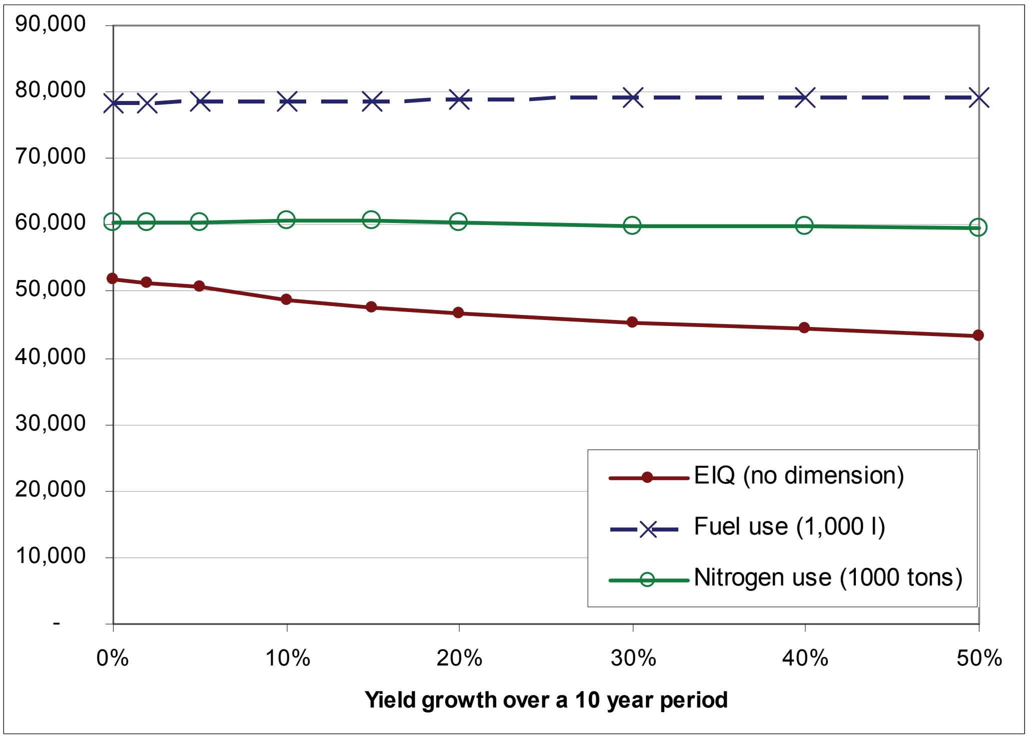


Figure 84: Aggregate indicators of external input use as a function of yield growth

8.3.6 EI Reduction

Table 66: Change in wholesale market price for different environmental impact reduction targets

Unit: %	Environmental impact reduction target in percent			
Crop	**5**	**10**	**20**	**30**
Asparagus	0.0	1.3	3.5	718
Baby corn	1.0	4.1	12.3	875
Brinjal	0.3	1.0	2.9	743
Hot chilli	-5.2	-2.7	3.8	774
Large chilli	5.8	23.3	72.2	798
Cabbage	0.8	3.4	7.6	812
Chin. cabbage	0.5	2.2	7.7	804
Cauliflower	0.6	2.3	7.8	819
Chin. mustard	0.9	3.8	11.0	756
Chin. kale	0.1	0.7	2.7	731
Coriander/celery	-0.2	0.0	0.6	719
Chin. radish	0.5	1.7	5.6	775
Cucumber	2.0	8.8	30.1	1,098
Ginger	0.1	0.2	0.5	710
Garlic	0.5	1.4	3.8	762
Lettuce	-0.2	-0.1	-1.0	698
Morning glory	-0.1	-0.1	-0.2	700
Pumpkin	0.5	2.2	8.6	818
Shallot	0.0	-0.1	-0.1	701
Spring onion	0.1	0.6	2.1	730
Tomato	0.5	2.1	6.3	766
Watermelon	2.0	6.7	19.6	930
Yard long bean	1.1	5.2	19.0	955

Source: TVSM scenario calculations.

Note: A 30% adoption of environmentally friendly technologies in baby corn, hot chilli, Chinese cabbage and Chinese kale production is assumed.

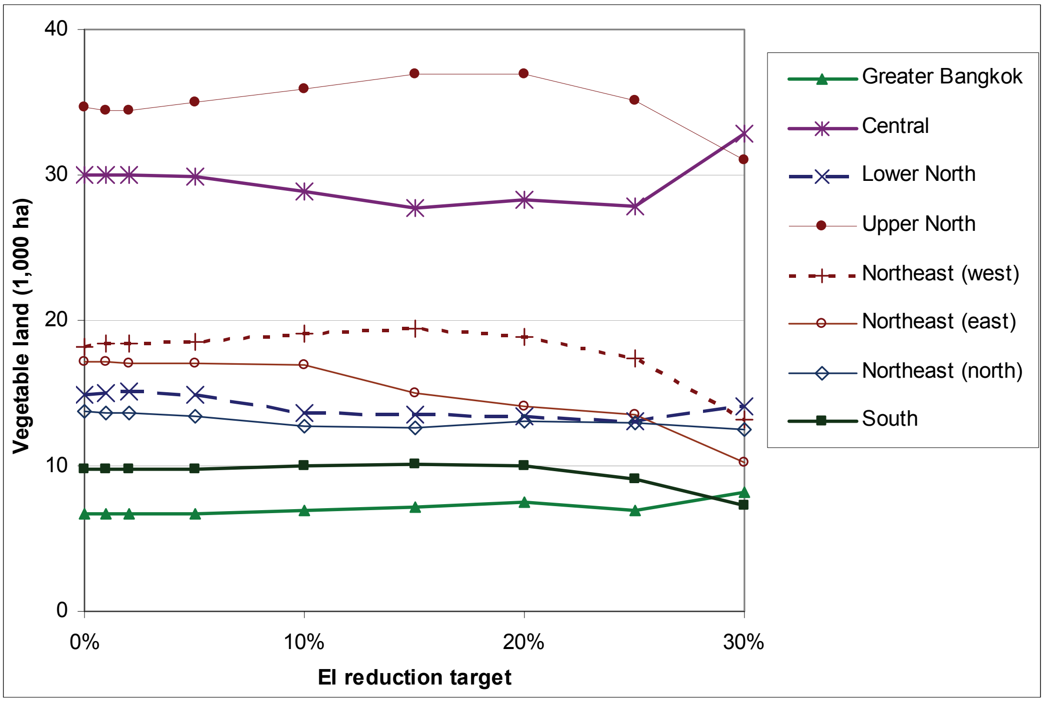
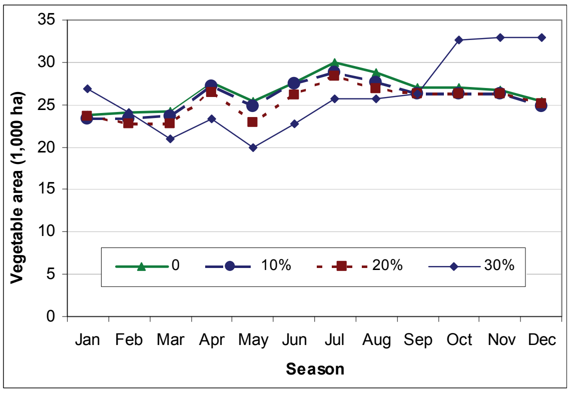


Figure 85: Regional land utilized for vegetable production as a function of the environmental impact reduction target



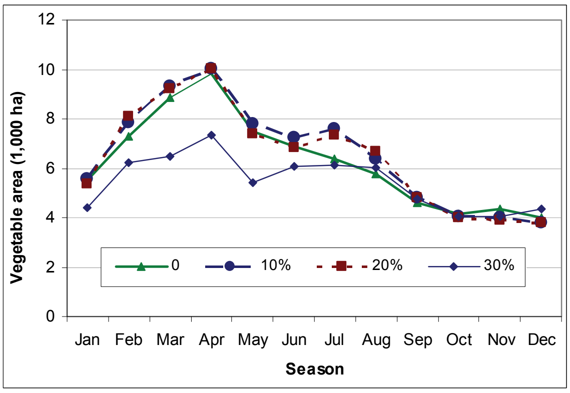
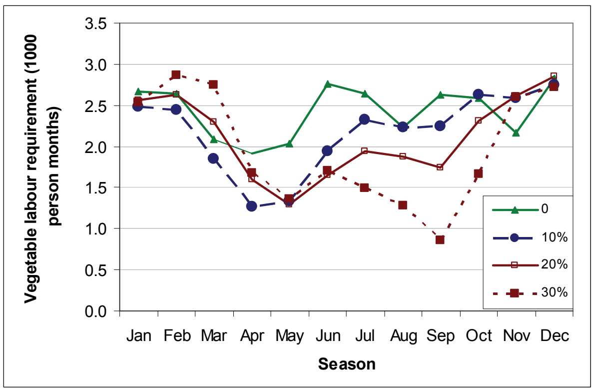


Figure 86: Seasonal land use for vegetable production in CE (left) and SO (right) for selected environmental impact reduction targets



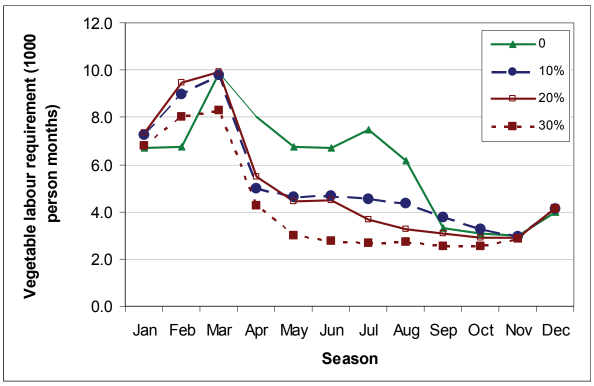


Figure 87: Seasonal labour use in vegetable production in BK (left) and UN (right) for tightening EI reduction targets

8.3.7 Pesticide tax

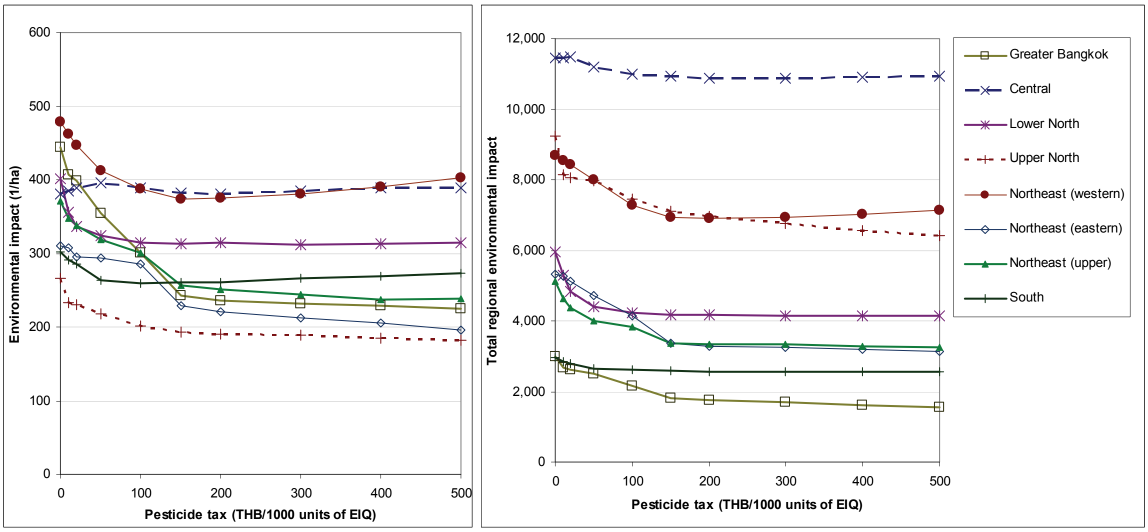


Figure 88: Regional environmental impact of pesticide use and intensity as a function of increasing pesticide tax

8.3.8 Zoning

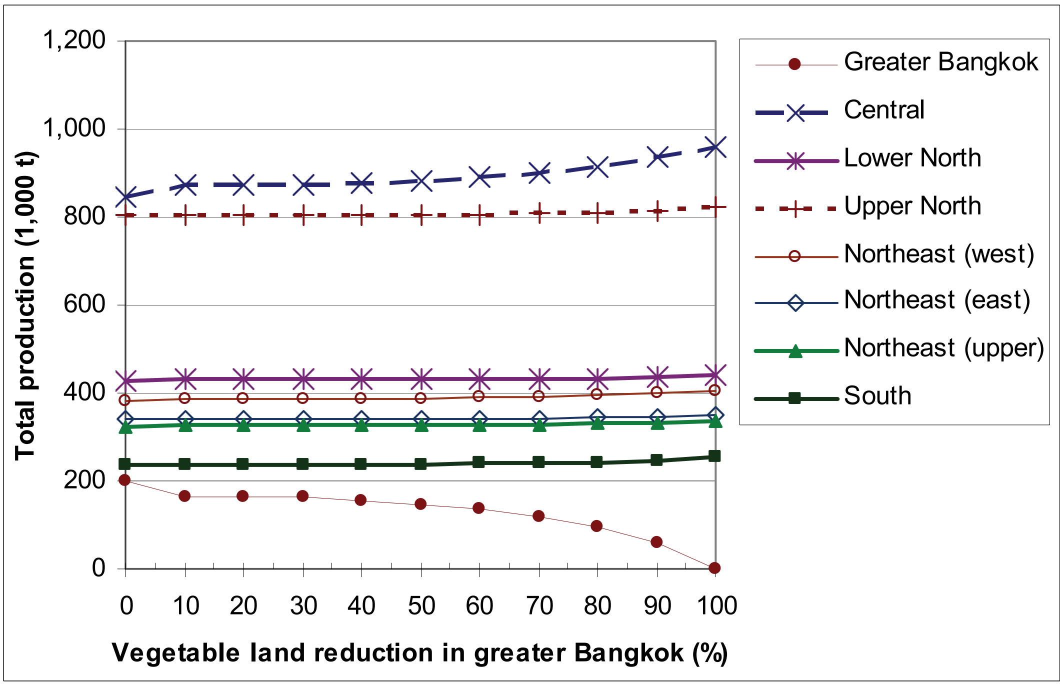


Figure 89: Total regional production as a function of decreasing vegetable land in BK due to a zoning policy.

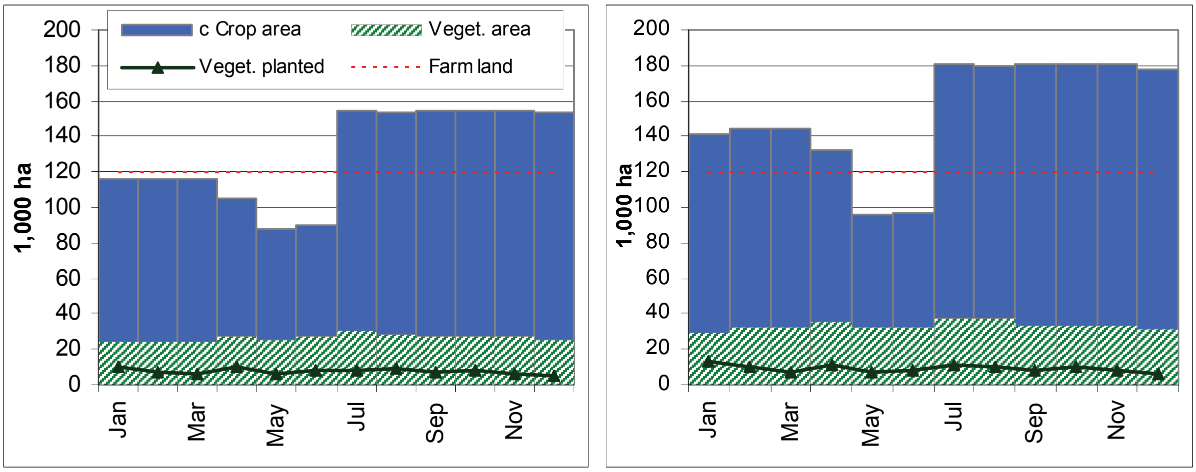


Figure 90: Land resources and land use in CE in the baseline (left) and under a zoning policy excluding vegetable production from BK (right)

Table 67: Production by crop aggregate and region in the forecast 2011 scenario and change compared to base scenario.

1000 t	Greater Bangkok	Central	North		Northeast			South	Total
			lower	upper	western	eastern	upper		
Asparagus	2 (+14%)	45 (+10%)			1 (+13%)	3 (+16%)			51 (+11%)
Baby corn	7 (-7%)	144 (+9%)	25 (-1%)	13 (-41%)	1 (+22%)		3 (+16%)		194 (+2%)
Brinjal	2 (+15%)	23 (-1%)	8 (+23%)	2 (+32%)	2 (+17%)	3 (+18%)	8 (+22%)	4 (+27%)	53 (+11%)
Hot chilli	50 (+4%)	43 (-5%)	55 (+6%)	63 (+19%)	140 (+17%)	49 (+12%)	58 (+18%)	22 (+16%)	480 (+12%)
Large chilli	2 (+14%)	28 (+12%)	24 (+19%)	58 (+22%)	24 (+7%)	12 (+7%)	10 (-8%)	3 (+32%)	161 (+14%)
Cabbage	1 (+18%)	12 (+28%)	47 (+29%)	137 (+6%)	5 (+21%)	5 (+10%)	21 (+8%)	2 (+51%)	229 (+12%)
Chinese cab-bage	3 (+23%)	32 (+38%)	33 (+7%)	59 (-4%)	18 (+20%)	14 (+10%)	14 (+9%)	6 (+23%)	178 (+10%)
Cauliflower	1 (+19%)	5 (+16%)	14 (+16%)	16 (+10%)	2 (+9%)	3 (+7%)	2 (+10%)	1 (+45%)	44 (+13%)
Chinese mus-tard	27 (+10%)	34 (+9%)	7 (+12%)	26 (+11%)	17 (+10%)	10 (+12%)	18 (+10%)	20 (+26%)	158 (+12%)
Chinese kale	40 (+11%)	97 (+15%)	36 (+10%)	15 (+12%)	24 (+10%)	8 (+11%)	15 (+11%)	20 (+27%)	255 (+13%)
Coriander and celery	8 (+13%)	21 (+5%)	8 (+17%)	7 (+24%)	9 (+9%)	5 (+9%)	7 (+18%)	2 (+24%)	67 (+11%)
Chinese radish	3 (+18%)	28 (+12%)	25 (+3%)		2 (+14%)	2 (+19%)	3 (+20%)		63 (+9%)
Cucumber	9 (+11%)	114 (+8%)	22 (+13%)	10 (+17%)	29 (+15%)	12 (+17%)	9 (+18%)	34 (+4%)	238 (+10%)
Ginger		3 (+3%)	39 (+4%)	88 (+4%)			36 (+5%)	3 (+5%)	170 (+4%)
Garlic			5 (-4%)	102 (+11%)	1 (-63%)	3 (+16%)	3 (+17%)		113 (+9%)
Lettuce	17 (+11%)			4 (+29%)		1 (+13%)	6 (+2%)	2 (+33%)	30 (+12%)
Morning glory	21 (+15%)	27 (+7%)	3 (+15%)	11 (+16%)	6 (+5%)	9 (+19%)	11 (+17%)	18 (+17%)	108 (+13%)
Pumpkin	1 (+7%)	63 (+14%)	8 (+19%)	39 (+3%)	10 (+17%)	26 (+11%)	16 (+9%)	23 (+10%)	186 (+11%)
Shallot			17 (+8%)	144 (+8%)	9 (+7%)	43 (+7%)	3 (+9%)		217 (+8%)
Spring onion	7 (+4%)	48 (+3%)	4 (+13%)	31 (+77%)	38 (+4%)	14 (+4%)	30 (+5%)	4 (+6%)	175 (+12%)
Tomato	3 (+4%)	8 (+2%)	2 (+9%)	15 (+30%)	6 (+1%)	4 (+2%)	10 (+%)		48 (+9%)
Watermelon		59 (+12%)	85 (+15%)	37 (+30%)	69 (+10%)	136 (+14%)	55 (+7%)	73 (+4%)	513 (+12%)
Yard long bean	13 (+9%)	89 (+7%)	10 (+15%)	10 (+18%)	13 (+20%)	18 (+20%)	20 (+22%)	28 (+8%)	203 (+11%)
Total	216 (+9%)	924 (+10%)	478 (+11%)	886 (+10%)	428 (+12%)	381 (+12%)	356 (+10%)	264 (+11%)	3,932 (+10%)
Normalized Her-findahl index	0.09	0.04	0.04	0.05	0.12	0.13	0.04	0.09	0.02

Table 68: Change in supply shares by crop between baseline and forecast 2011 scenarios

Percentage points	Greater Bangkok	Central	North		Northeast			South
			lower	upper	western	eastern	upper	
Asparagus	0.1	-0.5				0.3		
Baby corn	-0.4	5.2	-0.4	-4.8	0.1		0.2	
Brinjal	0.1	-5.2	1.6	0.6	0.2	0.4	1.3	1.0
Hot chilli	-0.7	-1.6	-0.6	0.8	1.2		0.6	0.2
Large chilli		-0.3	0.7	2.3	-1.0	-0.5	-1.5	0.2
Cabbage		0.6	2.7	-3.4	0.2		-0.3	0.2
Chinese cabbage	0.2	3.7	-0.4	-4.6	0.8			0.3
Cauliflower	0.1	0.3	0.7	-0.9	-0.2	-0.3	-0.2	0.5
Chinese mustard	-0.4	-0.5		-0.1	-0.2	-0.0	-0.2	1.4
Chinese kale	-0.4	0.6	-0.4	-0.1	-0.3	-0.1	-0.1	0.8
Coriander, celery	0.2	-2.1	0.5	1.1	-0.3	-0.2	0.5	0.2
Chinese radish	0.4	1.2	-2.3		0.1	0.3	0.4	
Cucumber		-0.7	0.2	0.3	0.5	0.3	0.2	-0.9
Ginger							0.1	
Garlic			-0.7	1.4	-1.0	0.1	0.1	
Lettuce	-0.4	-0.1	0.2	1.5	-0.2	0.0	-2.0	0.9
Morning glory	0.4	-1.5		0.2	-0.4	0.4	0.3	0.5
Pumpkin		1.2	0.3	-1.5	0.3	0.1	-0.2	-0.1
Shallot		-0.0		0.2		-0.2		
Spring onion	-0.3	-2.4		6.4	-1.7	-0.7	-1.1	-0.1
Tomato	-0.3	-1.2	-0.0	5.0	-1.1	-0.7	-1.8	
Watermelon		0.0	0.4	1.0	-0.2	0.4	-0.5	-1.1
Yard long bean	-0.1	-1.9	0.2	0.3	0.5	0.6	0.9	-0.4
Total	-0.1	-0.2	0.1	-0.1	0.2	0.1		

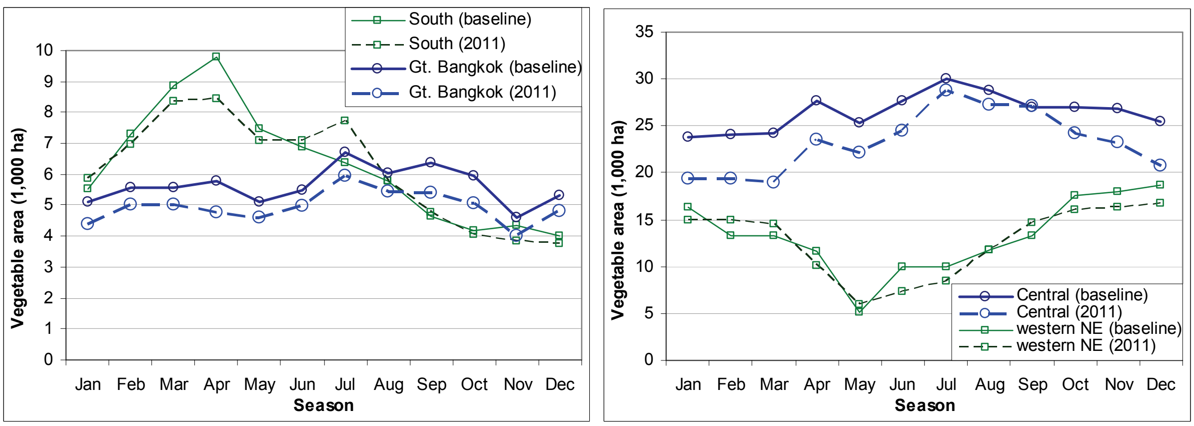


Figure 91: Seasonal land use for vegetable production in selected model regions in the baseline and 2011 forecast scenarios

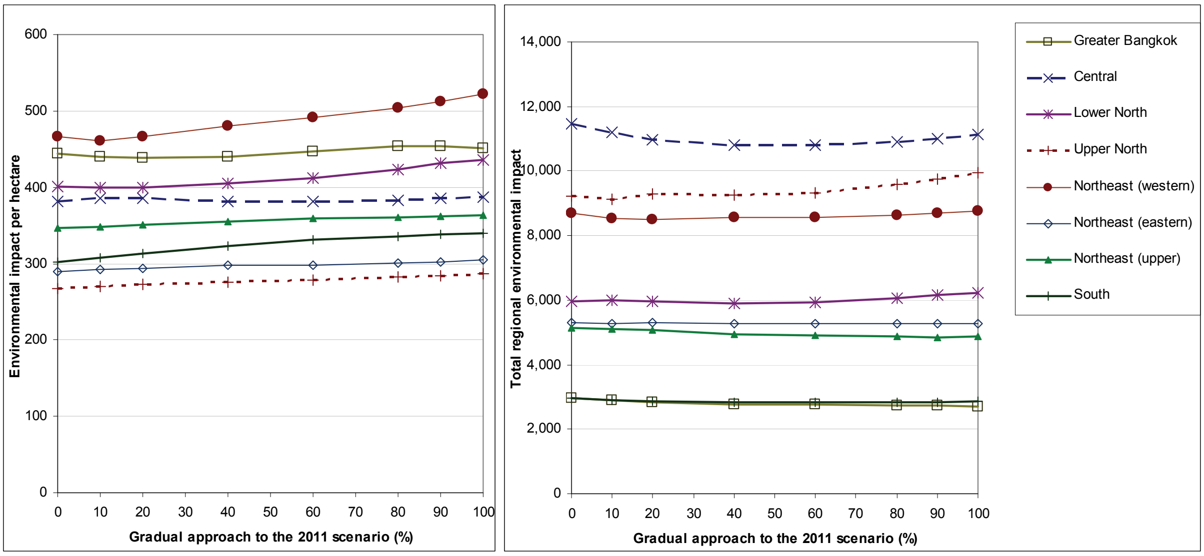


Figure 92: Development of regional intensity of pesticide use measured by the environmental impact indicator per hectare of vegetable land (a) and absolute level (b) by region under gradual realization of the 2011 scenario.

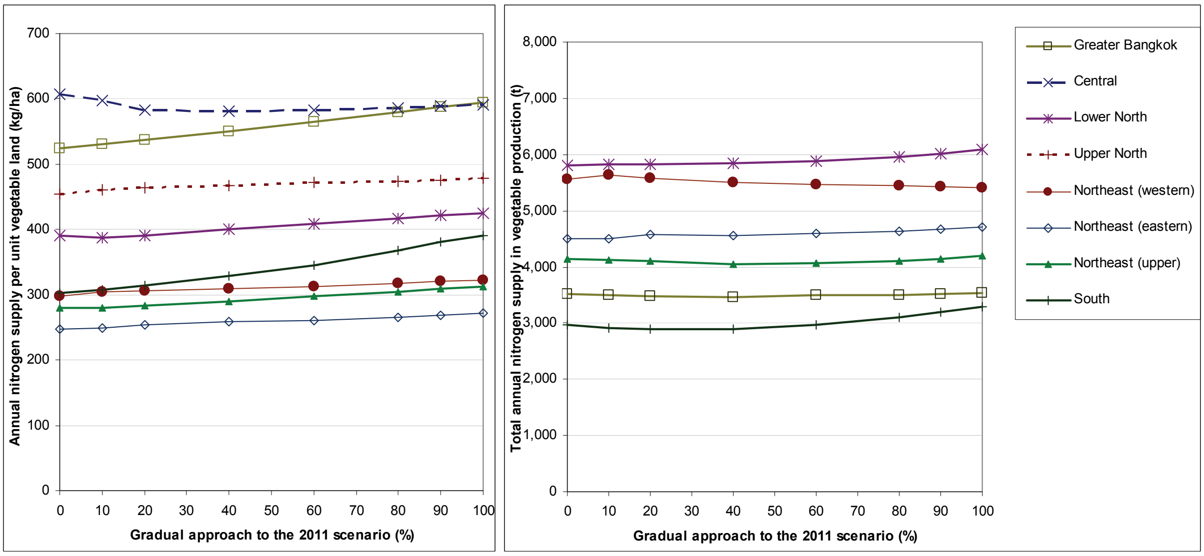


Figure 93: Development of regional intensity of external nitrogen supply in vegetable production per hectare of vegetable land (a) and absolute level (b) by region under gradual realization of the 2011 scenario.

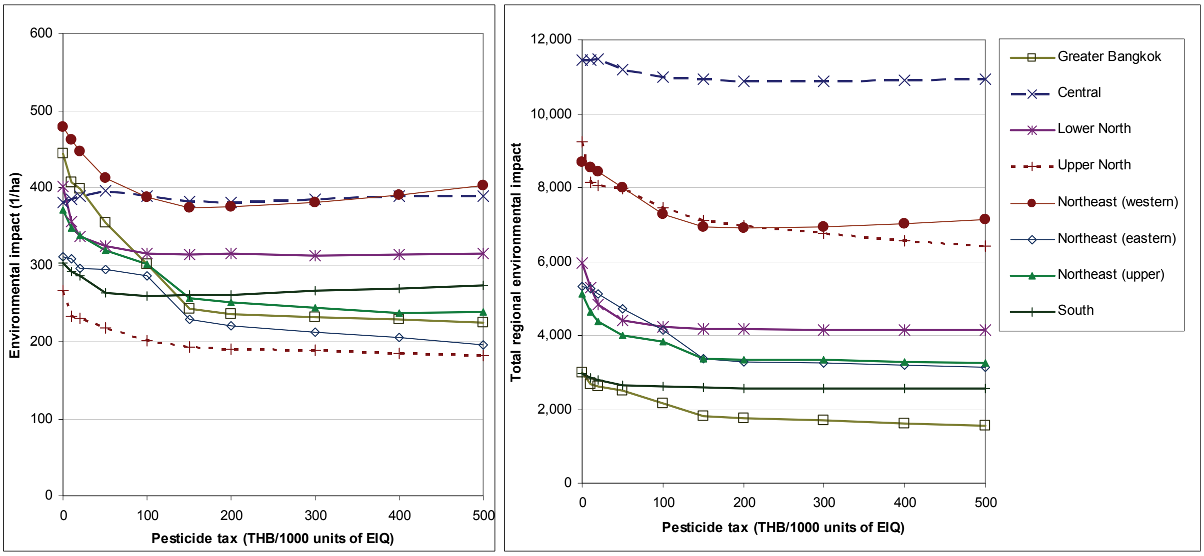


Figure 94: Regional environmental impact intensity and use level as a function of a pesticide tax based on environmental impact quotient