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Impacts of Novel Protein Foods on Sustainable Food Production and Consumption: Lifestyle Change and Environmental Policy

XUEQIN ZHU[1,2,*], LIA VAN WESENBEECK[3] and
EKKO C. VAN IERLAND[4]
[1]*Department of Spatial Economics, Free University Amsterdam, De Boelelaan 1105, 1081 HV, Amsterdam, The Netherlands;* [2]*CPB Netherlands Bureau for Economic Policy Analysis, P.O. Box 80510 Van Stolkweg 14, 2508 GM, The Hague, The Netherlands;* [3]*Centre for World Food Studies, Free University Amsterdam, Amsterdam, The Netherlands;* [4]*Environmental Economics and Natural Resources Group, Wageningen University, Wageningen, The Netherlands;* **Author for correspondence (e-mail: xzhu@feweb.vu.nl)*

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Abstract. We analyse the impacts of a change in consumers' preference for Novel Protein Foods (NPFs), i.e. a lifestyle change with respect to meat consumption, and the impacts of environmental policies e.g. tradable emission permits for greenhouse gases (GHGs) or an EU ammonia (NH_3) emission bound per hectare. For our analysis we use a global applied general equilibrium (AGE) model that includes consumers' lifestyle change, different production systems, emissions from agricultural sectors, and an emission permits system. Our study leads to the following conclusions. Firstly, more consumption of NPFs assists in reducing global agricultural emissions of methane (CH_4), nitrous oxides (N_2O) and NH_3. However, because of international trade, emission reduction does not necessarily occur in the regions where more NPFs are consumed. Secondly, through lifestyle change of the 'rich', the emission reduction is not substantial because more 'intermediate' consumers will increase their meat consumption. Finally, for the same environmental target the production structure changes towards less intensive technologies and more grazing under environmental policy than under lifestyle change.

Key words: applied general equilibrium models, emissions, lifestyles, meat, Novel Protein Foods

JEL classifications: C68, D12, D58, Q17, Q33

Abbreviations: AGE – applied general equilibrium; EU – European Union; GHGs – greenhouse gases; NPFs – Novel Protein Foods

1. Introduction

The term 'sustainable production and consumption' was used in 'the earth summit's Rio declaration on Environment and Development' in 1992. This document concludes that the major causes of continued deterioration of the global environment are the unsustainable patterns of consumption and production particularly in the industrialised countries. It states that achieving sustainable development, including sustainable consumption and production will require both efficiency in production processes and changes in consumption patterns. The concept of sustainable food production and consumption is therefore related not only to the food availability but also to the sustainability of the environment, where production and consumption take place.

Food production and consumption impose considerable pressures on the environment due to resource use and emissions. Rising affluence, particularly in the developing countries, means that more people can afford the high-value protein that livestock products offer. Population growth and affluence increased the demand for the proteins, especially for animal proteins (CAST 1999; Delgado et al. 1999; de Haan and van Veen 2001). Many studies (e.g. Baggerman and Hamstra 1995; Goodland 1997; Carlsson-Kanyama 1998; Seidl 2000; White 2000; Kramer 2000; Smil 2002) show that an animal-origin diet causes a greater environmental pressure than a crop-origin diet, because the conversion of plant proteins to animal proteins is rather inefficient compared to direct human consumption of plant proteins. Therefore changing protein production technology and enhancing plant protein consumption seems to be one of the options for reducing environmental pressures from environmental point of view.

On the consumer side, some consumers are changing their attitudes towards food consumption due to animal diseases, and turning more to meat substitutes (MAF 1997; Miele 2001; Jin and Koo 2003). That is, the consumers' lifestyle concerning meat consumption is changing.

The Dutch multidisciplinary research programme PROFETAS[1] was launched to assist in analysing future problems related to food production and consumption. Specifically, it studies the prospect of replacing meat in the Western diet with the so-called NPFs.[2] Environmental life-cycle assessment of protein foods shows that NPFs are environmentally more friendly than pork (Zhu and Van Ierland 2004). Hence replacing animal protein food with NPFs seems to be a good option for reducing emissions caused by animal protein production and consumption. Another possible option to reduce emissions from food production and consumption is to implement environmental policy. The main environmental problem associated with meat production depends on the production system used (intensive production versus mixed farming and grass-based systems). Therefore, the introduction of incentive-based tradable emission permits for GHGs and emission restrictions for acidifying compounds should subsequently influence the way meat is produced, inducing a shift away from intensive production to mixed farming and grazing systems.

In this paper, we analyse the impacts of a change in consumers' preference for NPFs and the impacts of environmental policies on the sustainability of food production and consumption. The former impacts are not straightforward. For example, even if the EU consumers accept NPFs, pork production in the EU might not be reduced due to the high demand in developing countries, especially China. If so, the environmental problems caused by animal production in the EU will remain. The latter impacts on production structure are not obvious because of international trade. As a result, we expect changes in economic variables including production, consumption and international trade and environmental variables (i.e. emissions of CH_4, N_2O and NH_3), accompanying the introduction of NPFs and environmental policies.

The main contribution of this paper is to address questions related to achieving less environmental emissions concerning meat consumption. We use a global applied general equilibrium (AGE) model. There are three main reasons for choosing this approach. Firstly, there are strong international links between various regions of the world, especially the international trade of feed and meat. Secondly, two important issues are raised with respect to sustainable food production and consumption: the environmental pressure resulting from higher demand for animal protein foods and the changing consumer attitudes towards food consumption. Thirdly, the shift of production technologies (among intensive production, mixed farming and grass-based systems) in response to the tradable emission permits has a strong global character, because the scope for such a shift depends on the availability of grazing areas and residual feed (crop and household wastes) in different parts of the world. Therefore, our AGE model includes lifestyle change of consumers in meat consumption related to income level, different production systems, emissions and incentive-based emission permits. Using such a model we aim to obtain insights into the contribution of NPFs and environmental policies to sustainable food consumption and production.

The paper is organised as follows. Section 2 is a general discussion on the theoretical framework and different lifestyles of meat consumption. Section 3 contains the implementation of these lifestyles, the selection of environmental pollutants and the implementation of emission permits as well as local emission bounds in an applied model. Section 4 provides the information including the economic data and the environmental data. In Section 5, we formulate scenarios of lifestyle change and emission permits, present parameters for each scenario, and discuss the model results. Section 6 presents the main conclusions.

2. Theoretical Framework

AGE models have become a standard tool for the analysis of environmental issues and the determination of optimal policies to reduce environmental pressure (Copeland and Taylor 2003). For our analysis, we rely on a stylised AGE model which focuses on describing agricultural production, consumption, and trade (GEMAT,[3] see Appendix A for the model equations). In this paper, we have added the environmental aspects related to our study into the model including emissions and environmental policy instruments. Here we briefly describe the main characteristics of the model and the adjustments for analysing the impacts of changing consumption patterns, especially with respect to protein foods, and the environmental emissions related to proteins.

The model covers two time periods (1999/2000 and 2020), in which agents are assumed to make fully informed decisions on consumption and production. The representation of the future includes exogenous trends on population growth, technical progress, and yield increases. In terms of geographical coverage, the model distinguishes four regions (i.e. low-income countries, middle income countries, the EU-15 and other high-income countries). The model includes 14 agricultural sectors[4] and three industrial sectors (i.e. NPFs, industrial products and industrial services). In addition, the model considers different land types. In utility functions we distinguish between protein-related items (i.e. meat and NPFs), and other consumption items.

There are also two adjustments to the GEMAT model. *Firstly*, lifestyle change related to meat consumption is included in the model. Per capita demand for meat is not a concave function of per capita income; instead there are three different income-dependent lifestyles with respect to meat consumption (Keyzer et al. 2005). For low income, both consumption and income elasticity are low. Then, after income crosses a certain threshold $\underline{y}$, meat demand 'takes off' and rises rapidly with the increase of income. Finally, after income crosses another critical threshold $\overline{y}$, consumers become satiated with meat, and the income elasticity of meat demand is low again but at high levels of consumption (Figure 1). Accordingly, we label these different meat consumption patterns as 'poor', 'intermediate' and 'rich' lifestyles.

Secondly, the model distinguishes three possible production systems for livestock, namely grazing systems, mixed farming systems, and intensive livestock keeping, in terms of the classification by Seré et al. (1995) and de Haan et al. (1997). Whereas grazing systems rely predominantly on the availability of grazing area, crop residuals, and household wastes, intensive livestock keeping represents the opposite with an almost exclusive reliance on commercially bought feed (mainly cereals, root crops, and oilseed cakes). Mixed farming systems represent an interesting intermediate case, where livestock keeping and crop farming are integrated as much as possible, and additional feed is sometimes brought into the system. In our model, the choice for a particular production system is endogenous, depending on the availability and prices of grassland and residuals for feed to optimise the profits of producers.

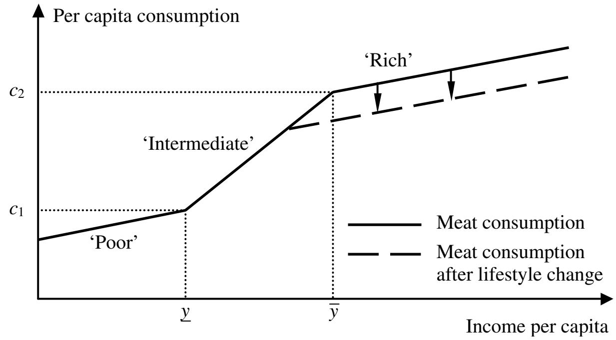

Figure 1. A stylised Engel curve for meat and lifestyle shift of 'rich' consumers.

In addition to considering economic output from agriculture, we also consider the environmental output in terms of emissions to the environment, which may lead to environmental problems.

3. Implementation

3.1. ECONOMIC ASPECTS

The stylised structure of our model includes a welfare program and a feedback program (see Ginsburgh and Keyzer 2002). A welfare program is a centralised representation of an economy, where the objective is to maximise the weighted sum of utilities of consumers in the economy, subject to constraints on resource and technology. In the feedback program, parameters of the welfare program are adjusted such that: (1) all individual budgets of the consumers hold (adjusting the welfare weights of the individuals in the objective), and (2) the percentage of consumers in a certain lifestyle is updated following the changes in average per capita income. An equilibrium of this system is then defined as a situation where a welfare optimum is found, all budgets hold, and the percentage of consumers within a region in a certain lifestyle is consistent with the average per capita income in that region.

3.1.1. *Lifestyles*

Regarding the representation of lifestyles, the best one of choosing one of the three lifestyles ('rich', 'intermediate' and 'poor') would be to use a migration[5] approach (see Keyzer 1995). For each individual consumer, this would imply formulating an optimisation program that reads,

$$\max_{m_l, x_l, n_l} \sum_l n_l u_l(x_l, m_l),$$

subject to

$$p\sum_{l}(n_l x_l + n_l m_l + n_l \hat{m}_l) = H,$$

$$n_l \bar{q}_{l-1} \leq n_l m_l + n_l \hat{m}_l,$$

$$n_l m_l + n_l \hat{m}_l \leq n_l \bar{q}_l,$$

$$\sum_{l} n_l = 1,$$

where the subscript l is used to represent the different lifestyles 1 (poor), 2 (intermediate), and 3 (rich), and (l–1) refers to the lifestyle of the income group just below lifestyle l. u_l (x_l, m_l) is the utility function associated with lifestyle l, which depends on the consumption of meat (m_l) and other consumption goods (x_l). $\hat{m}_l$ represents the committed consumption of meat for every lifestyle, $\bar{q}_l$ is the upper bound on meat consumption in every lifestyle, and H represents the given income of the consumer and p the given prices for meat and other consumption goods. n_l is the share of lifestyle l. Finally, the choice between different lifestyles is modelled as such that the share of n_l is summed to 1.

In the application, we use fixed lifestyle shares in the main program and update them in the feedback program. The general approach is to use the incomes and prices from the equilibrium solution of the welfare program to solve the migration problems. Seven hundred income classes are distinguished. For each of these classes, an individual optimisation is done to determine the share of consumers in this class that would migrate to a rich, poor, or intermediate lifestyle. Then, after multiplying these shares with the number of people in each income class and aggregating them over all income classes, we find the total number of people that follows a specific lifestyle. This share is then used in another round of iteration in the main welfare program.

The upper and lower bounds on meat consumption and the committed consumption for each lifestyle are set following Keyzer et al. (2005). Since the distribution of income depends on the level of the average income, it is clear that if no additional assumptions are made, the homogeneity of degree zero in prices is lost. To clarify, if all prices are multiplied by some factor A, incomes would rise with a factor A. This would lead to another income distribution with another pattern of lifestyles, and thus another consumer demand pattern. To overcome this problem, we first calibrate the model such that incomes are in the same range as the actual incomes on which the distributions are based, and then use the normalisation of prices used in this benchmark model as the base normalisation. For all other normalisation, corrections are made in the prices and income reported by the main program.

3.1.2. *Regional Specifications*

The model includes four regions: low-income region (denoted as Lowinc), middle income region (Midinc), the European Union (EU-15) and other high-income region (Highinc). In each region, there are region-specific production functions, utility functions, and committed meat consumption levels for each income level.

3.1.3. *Production Functions and Utility Functions*

For the functional forms of agricultural production, we use a nested production function with a CES technology at the highest level and a Leontief technology at the lowest level regarding the specific agricultural production characteristics. The Leontief technology captures upper bounds on yields or carcass weights. Furthermore, some important feed items, such as grain brans and oilcakes are represented as by-products of the production of other agricultural goods. The utility function is chosen as a CES function that allows substitution between different types of consumption goods.

3.2. ENVIRONMENTAL ASPECTS

In our study, we focus on the environmental emissions from the agricultural sector. Agricultural activities (including manure storage, soil fertilising and animal husbandry) are important sources of NH_3, CH_4 and N_2O emissions. NH_3 is an acidifying gas contributing to acidification, while CH_4 and N_2O are GHGs contributing to global warming. Other important greenhouse gas is carbon dioxide (CO_2) and acidifying gases are sulphur dioxide (SO_2) and nitrogen oxides (NO_x). The CO_2 emissions from agricultural processes are not covered in this study as agriculture itself is considered as both a source and a sink. For example, in the Netherlands the CO_2 emission from agriculture is only 4% of the total national CO_2 emissions in 1998 (CBS 1999). For the same reason, SO_2 and NO_x emissions are not considered because NO_x emissions from agriculture are only 2% of the total emission, and SO_2 from agriculture is negligible (CBS 1999). Therefore we only consider three pollutants: NH_3, CH_4 and N_2O.

For reasons of economic efficiency, we introduce economic incentive-based instruments for environmental management. There is a wide range of alternative instruments like taxes on emissions, subsidies for pollution abatement, or marketable permits for emissions of pollutants (Costanza et al. 1997). In terms of the effects of emissions, we consider two environmental policy instruments: tradable permits for GHGs (CH_4 and N_2O) and an emission bound for the regional pollutants (NH_3). For the two GHGs, it is the total emission volume that matters, irrespective of the location of the emissions, and therefore restrictions are set at a global level. Since the damage caused by the emissions of NH_3 is local, the relevant bound is its emission per unit of area in this model.[6]

4. The Data

In this section, we report the data used for calibrating the model and the emission factors used for calculating emissions of CH_4, N_2O and NH_3. The base year is 1999/2000. The economic data includes general regional characteristics, land use, labour working hours and expenditure shares. The environmental data includes the base year emissions of NH_3, CH_4 and N_2O, and the emission factors from animal farming and crop production.

4.1. ECONOMIC DATA

For the definition of the low income (Lowinc), middle income (Midinc), and high income (Highinc) regions, the classification of the World Bank (2001) was used in terms of income in 1998, with an additional breakdown of the high-income region into the EU-15 and other high-income region. Since an urban–rural distinction seems warranted for our purposes, the population is divided into these two groups, and migration tendencies are accounted for by including urban and rural population growth. Table I gives the important characteristics of the regions.

With respect to land use, three types of land are distinguished according to the FAO classification: grassland, cropland and cityland (FAOSTAT 2002). Grassland is defined as the element ‘permanent pasture’, while cropland is defined as ‘arable land and permanent crops land’. For cityland, there are no data in the FAOSTAT database, so we use assumed population densities for urban areas. For 1999, it is assumed that the average population density in cities in Lowinc equals 7 per ha; in Midinc 8 per ha; in other-Highinc 8.5 per ha, and in the EU 10 per ha (these figures are loosely based on World Bank (2001)). Then the total urban area consistent with these assumptions is labelled as “Cityland”. The difference between the sum of the three types of land, and the total land area per region, is assumed to be unsuitable for economic activity (e.g. rocks or inland waters). This area is not included in the model.

In the past, the reclamation of land was one of the ways in which agricultural production increased. As such, we apply exogenous trends for land use change, based on FAOSTAT data (FAOSTAT 2002) on land use for the period 1961–1999. Furthermore, we assume that through increased urbanisation the population density in urban areas will rise to 8/ha, 9/ha, 9/ha, and 10.5/ha, for the Lowinc, Midinc, Highinc, and the

Table I. Main characteristics of the regions

	Lowinc	Midinc	Highinc	EU
Population in millions (2000)[a]	3771.59	1234.55	487.42	375.51
Urban population in millions (2000)[a]	1257.72	851.60	380.29	295.87
Rural population in millions (2000)[a]	2513.88	382.94	107.12	79.64
Population in millions (2020)[a]	4825.18	1507.72	536.85	371.39
Urban population in millions (2020)[a]	2208.94	1146.09	443.94	308.74
Rural population in millions (2020)[a]	2616.25	361.63	92.91	62.66
Average yearly population growth	0.012	0.010	0.005	−0.001
Average yearly population growth urban	0.028	0.015	0.008	0.002
Average yearly population growth rural	0.002	−0.003	−0.007	−0.012
GDP in billions PPP US$ (1999)[b]	10676.71	7339.337	14285.53	8338.689
GDP per capita in PPP US$ (1999)[b]	2911.574	6187.908	28670.72	22209.37
GDP in billions PPP US$ (2020)[c]	28328.49	17587.8	23869.52	13933.01
GDP per capita in PPP US$ (2020)[c]	5870.973	11665.18	44462.42	37515.75

Sources: [a]FAOSTAT (2002); [b]World Bank (2001); [c]EIA (2001).

EU regions, respectively. There are also changes in grassland and cropland from 1999 to 2020. We assume that the area for grassland in Lowinc in 2020 is 1% larger than in 1999, and cropland 8%. For Midinc, grassland increases by 1% and cropland by 3%. In Highinc, the area of grassland in 2020 is 2% lower than in 1998, and the area for cropland remains constant. In the EU, there is a decrease of 1% for grassland and 0.5% for cropland. The land use overview is included in Table AI of Appendix A.

Available rural and urban labour is expressed in total working hours based on total workforce (aged 15–64), workforce share of total population, and urban and rural workforce numbers. We assume that in the EU and Highinc regions, 300 days can be worked yearly for 8 h a day. For Midinc, this is 280 days per year, 6 h a day, and for Lowinc, 260 days/year, 5 h a day. The difference in days/year and h/day between the regions reflects differences in, for example, the health status of the workers, and the differences in education. Because of increases in productivity, we assume 310 days/year and 8 h/day in 2020 in the EU and Highinc, 300 and 7 in Midinc, and 270 and 6 in Lowinc. The labour force and working hours are given in Appendix Table AII.

Production, consumption, and input use of all agricultural commodities in 1999 were taken from FAOSTAT (2002). For the estimation of meat production parameters by livestock system, we used the data in Seré et al. (1995) and de Haan et al. (1997), which were mapped to the regional aggregation in the model.

Table II. Expenditure shares of all consumption goods

Items	Lowinc	Midinc	Highinc	EU
Grains (cereals) [a]	0.132	0.058	0.021	0.021
Roots and tubers (potatoes)[b, c]	0.009	0.006	0.001	0.001
Pulses (beans, peas) [b]	0.005	0.003	0.001	0.001
Other agriculture (fruit and vegetables) [a]	0.108	0.061	0.026	0.026
Meat products [a)]	0.085	0.064	0.033	0.033
Vegetable oil (oil and fats) [a]	0.033	0.014	0.005	0.005
Other agriculture products (flour, beverages, juices etc.)	0.099	0.084	0.043	0.041
Industrial products [a]	0.33	0.42	0.49	0.49
Industrial services [a]	0.20	0.29	0.38	0.38
Novel Protein Foods [d]	0	0	0	0.002
Total	1.000	1.000	1.000	1.000

Source: [a]Regmi (2001), European Commission (2002); [b]Blisard (2001), and [c]Banse and Grings (2001), and [d]Aurelia (2002).

For consumption data for the EU-15 concerning food items, industrial services and industrial products, we used data from the European Commission (2002). Data for expenditure shares of other regions were taken from Regmi (2001), Blisard (2001), and Banse and Grings (2001) (see Table II).

4.2. ENVIRONMENTAL DATA

The environmental data reported in this section are useful for the calculation of NH_3, CH_4 and N_2O emissions from the agriculture sector. Therefore, the distribution of emissions in production of different products, emission factors from different sources (animals, plants), and emission factors from different manure management system are necessary.

NH_3 emissions come from both animal production and crop production. NH_3 emissions from animal production depend on the type of animals. The NH_3 emission from ruminants is 14.3 kg/animal, from pigs 6.39 kg/animal and from poultry 0.28 kg/animal (EEA 2002). The NH_3 emissions from arable agriculture (crop production) generally include the emissions from fertiliser application and from plants. The emission factor from N-fertiliser and from plants is 0.02 kg NH_3–N/ kg fertilisers applied (EEA 2002). The fertiliser use rate for plants (kg/ha per year) is based on IFA, IFDC and FAO (1999), which is given in Appendix Table AIII. By the land area use for plants and the emission factors, we can obtain the NH_3 emissions from crop agriculture.

N_2O emissions in agriculture are associated with animal production (manure management) and crop production (emissions from agricultural soils due to nitrification and denitrification). The N_2O emissions can be calculated in three parts: N_2O emissions from manure management, direct N_2O emissions from agricultural soils and indirect N_2O emissions due to agricultural activities (nitrogen use in agriculture). For calculating the N_2O emissions from manure management, regional information is obtained from IPCC (1997): nitrogen excretion from animals (see Appendix Table AIV), the animal waste management systems (Appendix Table AV) and emission factors for each system (Appendix Table AVI). The direct N_2O emissions come from agricultural soils due to the N-inputs e.g. synthetic fertilisers, animal excreta nitrogen used as fertiliser, biological nitrogen fixation, crop residue or sewage sludge. According to IPCC (1997), synthetic fertilisers are an important source of N_2O. The emission factor of the applied nitrogen fertilisers is 0.0125 kg N_2O/kg N-fertiliser (Brink, 2003). Through the fertiliser use and emission factor, the quantity of direct N_2O emissions can be obtained. The indirect N_2O emissions come from the pathways for synthetic fertiliser and manure input due to the volatilisation and subsequent atmospheric deposition of NH_3 and NO_x, as well as nitrogen leaching and runoff. The emission factors for deposition are 0.01 kg N_2O–N/kg (NH_3–N and NO_x–N) emitted, and for leaching and runoff are 0.025 kg N_2O–N/kg N leaching /runoff. As for the NO_x volatilisation, it is 0.1 kg nitrogen/kg synthetic fertiliser and 0.2 kg nitrogen/kg of nitrogen excreted by livestock. The leaching of nitrogen world-wide is 0.3 kg/kg of fertiliser or manure *N* (IPCC 1997).[7]

The major agricultural source of CH_4 emissions is animal husbandry, which contributes 96% of the total agriculture CH_4 emissions (EEA 2002). Thus we only consider the CH_4 from animal husbandry and omit CH_4 emissions from the production of other agricultural products in this study. CH_4 emissions from animal husbandry include the emissions in enteric fermentation and manure management. We use data from IPCC (1997) for CH_4 emission factors from both enteric fermentation (see Appendix Table AVII) and manure management (Appendix Table AVIII).

5. Scenario Formulation and Results

5.1. INTRODUCTION

As mentioned previously, there are two important ways towards more sustainable food consumption patterns for reducing emissions: one is a lifestyle change towards less meat and more NPFs, and the other is the implementation of environmental policy.

We first explore the possibility to reduce environmental emissions from meat production by changing consumer lifestyles with respect to meat consumption. If consumers change their behaviour, then the demand for animal products will change. Therefore, we study the effects of the lifestyle changes on production structure and emissions. More specifically, we want to show

how lifestyle changes, through different levels of NPFs replacement for meat (i.e. an increase of NPFs and a decrease of meat in the range of 0–30 kg per capita per year), influence the emissions.

In order to show the implications of different ways towards sustainability of food consumption and production, we carry out the following three scenario studies. We define a lifestyle change scenario as the *first* scenario (denoted as 'lifestyle'), in which 10 kg of NPFs per capita per year is consumed by the 'rich' consumers to replace the same quantity of meat.

The same level of emissions reduction from a lifestyle change in the first scenario may also be achieved by implementing environmental policy instruments. In the *second* scenario (denoted as 'permit Grand'), we introduce tradable emission permits for the two GHGs (CH_4 and N_2O), a policy that leads to a reduction of emissions by pricing the free environmental emissions. The permits are divided according to the 'grandfathering system', or that the permits are distributed according to the regional shares of emissions in base year 1999/2000.

Emissions of NH_3 cause local environmental problems like acidification, thus we need a local limit per unit of land to avoid high concentrations in some areas. The EU has introduced the Gothenburg protocol, where emission bounds of acidifying gases are 83% of the 1990 level. Since, in our simulations, we want to compare the impacts of lifestyle changes with those of environmental policies, we use the NH_3 emission level of the first scenario divided by the total area in the second scenario as the upper bound for the EU.

In the *third* scenario (denoted as 'permit Pop'), we distribute the initial emission permits according to population size for the same emission targets as in

Table III. Parameters under three scenarios

Scenarios	Contents
Scenario 1 ('lifestyle')	'Rich' consumers will replace meat by NPFs: 10 kg per year per capita; No environmental policy.
Scenario 2 ('permit Grand')	Emission permits of N_2O, CH_4 are the same as the emission levels under Scenario 1, division of permits is according to regional shares in base year 1999/2000, permits are tradable; Regional NH_3 emission permit for the EU is the same as the emission level under Scenario 1, permit is non-tradable, an upper bound of NH_3 emission per ha in the EU is imposed; No lifestyle change.
Scenario 3 ('permit Pop')	The same as Scenario 2 but division of permits is according to population size in each region.

Scenario 2, which should be more conducive to the development of developing countries. Table III describes the main characteristics of the three scenarios.

5.2. DISCUSSION OF RESULTS

The model was run for each scenario in GAMS software. In this section, we first report the model results for three scenarios. Then we compare the impacts of lifestyle change and environmental policy instruments on production structure. The comparison between Scenarios 2 and 3 can also show some implications of the environmental policy instruments.

5.2.1. *Impacts of Lifestyle Change*

We simulated the different levels of NPFs replacement for meat by 'rich' consumers in all regions. The switch of 'rich' consumers from meat to more NPFs will definitely influence the demand for meat, and will therefore have an impact on production structures and emissions. Accompanying the increased consumption of NPFs, meat demand will change because of substitution and income effects. The substitution of NPFs for meat, as a preference change, will decrease the meat demand. This substitution will also change the relative prices of meat and NPFs and thus the income of consumers will alter, resulting in an income effect. As an overall effect, the meat demand in the EU, other high-income, middle-income and low-income regions will decrease (see Figure 2). The extent of the change is greater in the EU and other high-income regions than the other two regions because there are more 'rich' consumers in the former than in the latter. We can observe from Figure 2 that after a certain level of NPF replacement by 'rich' consumers, the meat demand in the middle income region will exceed the meat demand in the EU and the other-high income region. This is because of the substantial substitution of NPFs for meat by more 'rich' consumers in the EU and the other-high income region. For a shift of 10 kg/capita per year of meat replacement with NPFs by 'rich' consumers, the per capita meat consumption in the EU will decrease by 8.6% (from 97.84 to 89.40 kg), and the world average meat consumption per capita will decrease by 4.9% (from 85.7 to 81.5 kg).

A change of meat demand affects the production level of meat. For example, if worldwide 'rich' consumers consume 10 kg NPFs per capita per year to replace meat, the total meat production in the EU will decrease by 3.9% (from 60.5 to 58.1 million mt) and global meat production will decrease by 25% (from 258.0 to 192.7 million mt).

A change of meat demand also affects the production structure of meat production, as there are three different livestock production systems. However, the effect is not profound. Although the share of grazing technology increases as the share of NPFs increases, this share remains very low and the

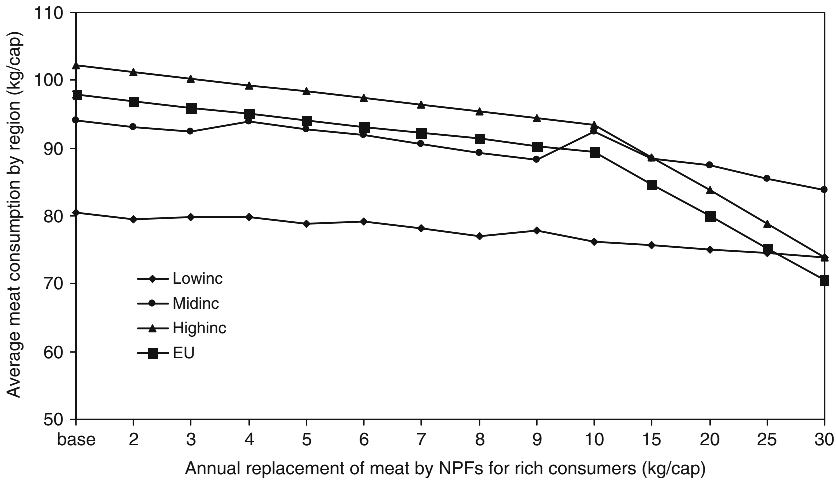

Figure 2. Development of average annual meat demand per capita in 2020 in response to an increasing replacement of meat by NPFs by 'rich' consumers.

largest share of production of meat still occurs in the intensive livestock production systems. This is because meat demand is still too high to be satisfied by more extensive livestock systems that require a larger amount of land.

Figure 3 shows the emission levels for different levels of NPFs. It shows that generally the higher the replacement of meat by NPFs, the lower the NH_3 emission. For the emissions of N_2O and CH_4, the same trend holds. The reason is obvious; emissions are lower for the production of peas (the primary product from which NPFs are made) than for meat. If 'rich' consumers eat 10 kg/capita per year NPFs to replace meat consumption, the global emission reduction will be 4% (from 76248 to 73239 million kg) for NH_3, 0.2% (from 16026 to 15997 million kg) for CH_4 and 3.7% (from 4294 to 4135 million kg) for N_2O. However, this emission reduction does not necessarily happen in the regions where more NPFs are consumed, rather it happens in the regions that switch to produce more NPFs and less animal products for their comparative advantages and possibility of international trade. For example, the agricultural emissions in the EU will be reduced by 2.9 % for N_2O and increased by 6 % for CH_4. There is no change in NH_3 emission in the EU. The emission reduction of NH_3 mainly occurs in the other high-income region because this region will produce fewer ruminants, and the emissions for NH_3 are higher in ruminants than in pork production.

Figure 3 also shows a fluctuating trend for NH_3 emissions. At low levels of NPFs, emission decreases first and then increases, though it is always lower than the 'business as usual'. This is because the NH_3 emission comes from both production of plant and animals. As we have discussed, the demand change will have an impact on the production structure. Around 8–10 kg of replacement by the 'rich', the emission reduction of NH_3 is not

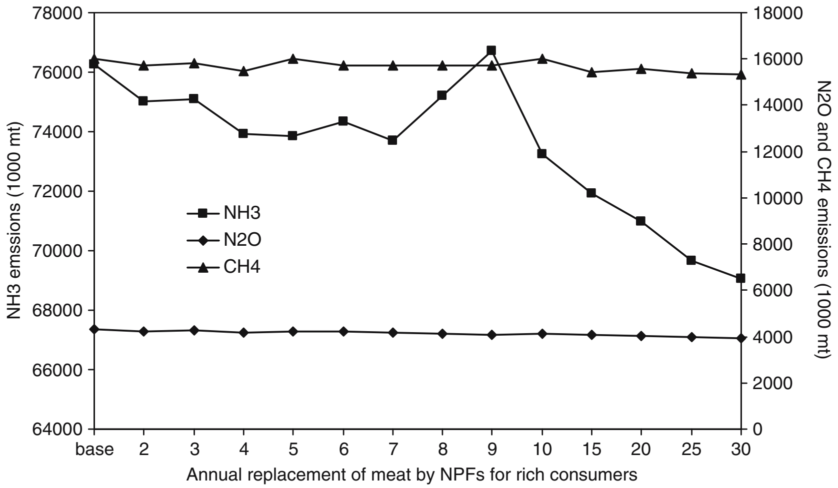

Figure 3. Development of emissions in 2020 under different replacement levels of meat by NPFs by 'rich' consumers.

obvious, because still increasing amount of meat is demanded by other categories of consumers. Of course, if a substantial replacement (more than 15 kg per capita per year) takes place for 'rich' consumers, the impacts are obvious again.

Despite the fact that the assumption of a 10 kg replacement of meat by NPFs may be heroic, the emission reduction of CH_4 and N_2O through lifestyle change is very limited for a lower level of replacement of meat by NPFs. This result can be explained by the assumption that only 'rich' people will switch to NPFs. Even in 2020, the share of people with the rich lifestyle in the total population is still low compared to that of the intermediate lifestyle. For example, in the low-income region with the highest population, 56% is still in the 'intermediate' lifestyle in 2020, and only 13% reaches the rich lifestyle income range. Therefore, the number of people with decreasing meat demand is relatively low, especially since the largest increase in meat demand stems from people in the 'intermediate' lifestyle category.

5.2.2. *Impacts of Emission Permits and Comparison Between Scenarios*

The results show that developing countries (i.e. low-income and middle-income regions) are relatively better off according to the utility levels in the scenario where permits are divided according to population size than in the grandfathering scenario. Although it would be interesting to compare welfare effects under different scenarios for the same emission targets for the GHGs, it is very difficult because the preferences have changed under Scenario 1. Therefore, we turn to the interpretation of the other variables of the different scenarios, such as the change of production structure and the distribution of emissions.

The tradable emission permits of CH_4 and N_2O, and emission bounds of NH_3 per ha, will redistribute the production patterns and thus have impacts on the distribution of emissions. Figure 4 gives the composition of world production structure in different scenarios. It shows that the production structure is changing towards more grazing system and less intensive production under environmental policy scenarios than the lifestyle change scenario, because emission bounds are imposed and it is more efficient to use a more extensive farm system.

Figure 5 shows emission distributions over different regions under different scenarios. The emissions are lower under three scenarios than under ‘business as usual’ because of the design of the scenarios. For GHGs, more emission will take place in the EU and middle-income regions under three scenarios because the EU will keep its meat production for export and the middle-income region will increase its meat consumption as well as production. The low-income and other high-income regions will import more meat from the EU and middle-income regions, thus the emissions are lower in low- and other high-income regions.

NH_3 emissions are lower in the lifestyle scenario than the ‘business as usual’. Since we imposed a per hectare emission bound (kg/ha) for the EU considering the real problem in the EU under Scenarios 2 and 3, emissions of NH_3 are reduced. This is achieved by a more extensive production system. Such a system reduces the NH_3 emissions in the EU though not the GHGs. This is because different emission coefficients apply to different animals. For example, the ratio of CH_4 emission coefficient for cattle and CH_4 emission coefficient for pigs is 32. The ratio of NH_3 emission coefficient of cattle and NH_3 emission coefficient for pigs is 2.3. That means that a pig emits more

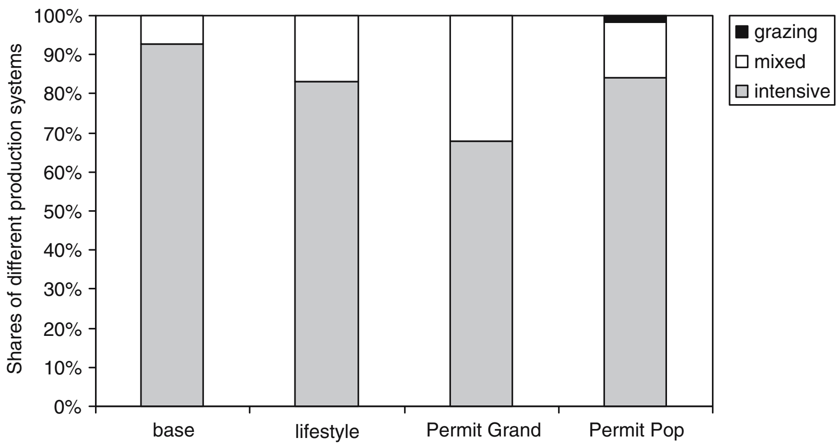

Figure 4. Structure of production systems in 2020 under different scenarios.

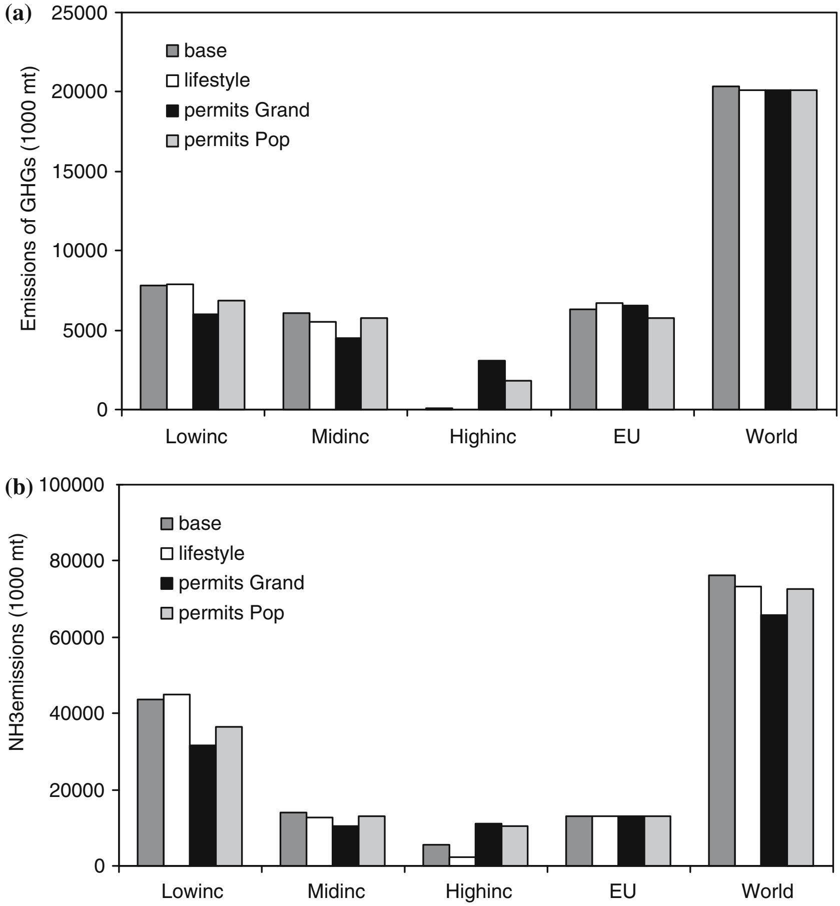

Figure 5. (a) GHG (CH_4 and N_2O) emissions 2020 for different scenarios; (b) NH_3 emissions 2020 for different scenarios.

NH_3 than CH_4 compared to cattle. Since the present cattle production is relatively extensive compared to pig production, much extensification will take place in pig production. Therefore, more NH_3 emissions can be reduced by a more extensive production system.

5.3. QUALIFICATION OF RESULTS

We have to emphasise that the results should be considered cautiously. Firstly, we have a stylised model, which means that a lot of simplifying assumptions have been made. For example, we have a very aggregate non-agricultural sector. Even for the agricultural sector we have limited information for production and consumption in various parts of the world. Secondly we have limited data on emissions for non-EU regions. From data sources like European Environmental Agency and IPCC, data on emissions are available only for a limited number of countries. Thirdly, lifestyle change is a complex phenomenon. Detailed information about how and to what extent it is changing is hard to find thus far. Therefore, in the model simulation we have to assume a range of changes in relevant parameters, for example in the committed level of meat consumption for 'rich' consumers.

6. Conclusions and Discussion

This paper has focused on studying the impacts of NPFs through lifestyle change of consumers and emission permits system through production structure change on sustainable food production and consumption. The following are our conclusions.

Firstly, lifestyle change towards more NPFs reduces global meat demand and thus meat production. This lifestyle change towards more NPFs reduces global agricultural emissions. If 'rich' consumers consume 10 kg NPFs per capita per year to replace meat, the global emission reduction for NH_3 will be 4%, for CH_4 0.2% and for N_2O 3.7%. But this emission reduction does not necessarily happen in the regions where more NPFs are consumed. It occurs in regions that switch to produce fewer ruminants based on their comparative advantages in the regime of free international trade. For example, the agricultural emissions in the EU will be reduced by 2.9% for N_2O and increased by 6% for CH_4. There is no change in NH_3 emission in the EU. It is the other high-income region that reduces the most NH_3 emissions.

Secondly, to achieve a similar emission reduction as that of a lifestyle change, we can also use environmental policy instruments. The study has investigated the impacts of environmental policy instruments that would achieve similar emission levels as a lifestyle change on the production structure. Lifestyle change leads to emission reduction through production reduction in meat sectors because less meat is demanded and production will increase in the NPFs sector, which impacts other related sectors such as feed and pulses. This change will make the production structure less intensive compared to our base case. Environmental policies reduce the emissions either through using a more extensive production system, or by production reduction in high emission sectors. However, the environmental emission reduction through a lifestyle change, which can be considered a culture-related issue, is limited because meat consumption is related to income. A cultural change may be more difficult to achieve than a policy change. Therefore, it may be difficult to make a substantial change in meat consumption using NPFs. The assumption of a 10 kg replacement of meat by NPFs per capita per year may be ambitious, and the emission reduction through lifestyle change is very limited for a lower level of replacement of meat by NPFs. It would be more effective to achieve *high* emission reduction by environmental policy than to induce a lifestyle change. For example a modest lifestyle change (10 kg NPFs per capita per year for rich consumers) is not sufficient to achieve an NH_3 emission target in the EU such as the target set by Gothenburg protocol. Then we have to rely on the local environmental policy in the EU to solve the local environmental problems caused by NH_3 emissions.

Thirdly, to achieve the same environmental emission reduction, environmental policy instruments are implemented through tradable emission permits for GHGs and an emission bound (kg/ha) in the EU for NH_3. With respect to the emission permits we have two different mechanisms to distribute the initial permits under a grandfathering scheme: based on historical emission share or population size. Since the policy targets are the same for these two measures of distributing permits, the impacts are on the welfare distribution. The results show that developing countries are relatively better off if the permits are divided according to population size than historical emission shares.

The important implication of this study is that NPFs offer future opportunities for sustainable food production and consumption pattern. If more NPFs replace meat, more emission reduction can be achieved. As such, promoting sustainable consumption patterns becomes important. However, as long as more poor consumers become richer, meat demand from these consumers continues to increase and therefore, substantial emission reduction is hard to achieve. Introducing a small amount of NPFs is only part of the measures to reduce environmental pressure. Our simulations also show that the group to be targeted should not only be the richest ones, but also low and middle incomes, in order to make the impacts substantial.

Concerning the methodology used in the paper, we have the following conclusions. Firstly, we have showed that the inclusion of a meat demand function for various income classes is possible and adds richness to the modelling of meat consumption. In our application, this is especially important because it allows us to include the lifestyle scenario. Secondly, the inclusion of emissions and policy instruments to reduce emissions into an AGE model is possible and relatively straightforward, and it enables us to calculate the impacts of changes in lifestyle and environmental policies and to ultimately compare the results.

Acknowledgements

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Appendix A

MODEL EQUATIONS

The model is written as a full format. The complete welfare program reads as:

$$\max \sum_r \sum_i \sum_l \alpha_{r,i} \left\{ \begin{array}{l} \delta^{1999}_{r,i,l} \left[\left(\sum_{nk1} (\beta_{r,i,l,nk1} x_{r,i,l,nk1})^{\rho_{r,i,l}} \right. \right. \\ \left. \left. \quad + \sum_{ckn1} (\beta_{r,i,l,ckn1} x_{r,i,l,ckn1})^{\hbar{\rho}_{r,i,l}} \right)^{\rho_{r,i,l}/\hbar{\rho}_{r,i,l}} \right]^{1/\rho_{r,i,l}} \\ \quad + \delta^{2020}_{r,i,l} \left[\left(\sum_{nk2} (\beta_{r,i,l,nk2} x_{r,i,l,nk2})^{\rho_{r,i,l}} \right. \right. \\ \left. \left. \quad + \sum_{ckn2} (\beta_{r,i,l,ckn2} x_{r,i,l,ckn2})^{\hbar{\rho}_{r,i,l}} \right)^{\rho_{r,i,l}/\hbar{\rho}_{r,i,l}} \right]^{1/\rho_{r,i,l}} \end{array} \right\}$$

$$- \sum_r \sum_{tg} (\tau_{r,tg} + \varsigma_{r,tg}) z_{r,tg}$$

subject to

$$\sum_g a_{k,r,j,g} \left(q_{r,j,g} - \bar{y}_{r,j,g} \right) + \sum_g \bar{a}_{k,r,j,g} \bar{y}_{r,j,g} = y^{-}_{k,r,j}$$

$$\sum_r z_{r,tg} \leq 0$$

$$\sum_i \sum_l \left(x_{r,i,l,tg} + \gamma_{r,i,l,tg} \right) + \sum_j y^{-}_{tg,r,j} \leq \sum_j \left(y^{+}_{r,j,tg} + \bar{y}_{r,j,tg} \right) + \sum_i \omega_{t,i,tg} + z_{r,tg}$$

$$\sum_i \sum_l \left(x_{r,i,l,sc} + \gamma_{r,i,l,sc} \right) + \sum_j y^{-}_{sc,r,j} \leq \sum_j \left(y^{+}_{r,j,sc} + \bar{y}_{r,j,sc} \right) + \sum_i \omega_{t,i,sc}$$

$$\sum_i \sum_l \left(x_{r,i,l,sf} + \gamma_{r,i,l,sf} \right) + \sum_j y^{-}_{sf,r,j} \leq \sum_i \omega_{t,i,sf}$$

$$y^{+}_{r,j,g} + \bar{y}^{+}_{r,j,g} = q_{r,j,g}$$

$$y^{+}_{r,j,\text{cakes}} \leq \sum_j \zeta_{\text{cakes},r,j,\text{fats}} y^{+}_{r,j,\text{fats}}$$

$$y^{+}_{r,j,\text{brans}} \leq \sum_{j} \zeta_{\text{brans},r,j,\text{grains}} y^{+}_{r,j,\text{grains}}$$

$$y^{+}_{r,j,\text{residu}} \leq \sum_{j} \zeta_{\text{residu},r,j,\text{grains}} y^{+}_{r,j,\text{grains}} + \sum_{j} \zeta_{\text{residu},r,j,\text{roots}} y^{+}_{r,j,\text{roots}}$$

$$+ \sum_{j} \zeta_{\text{residu},r,j,\text{oilcrops}} y^{+}_{r,j,\text{oilcrops}}$$

$$+ \sum_{j} \zeta_{\text{residu},r,j,\text{peas}} y^{+}_{r,j,\text{peas}} \sum_{j} \zeta_{\text{residu},r,j,\text{othagri}} y^{+}_{r,j,\text{othagri}}$$

$$\sum_{j} y^{+}_{r,j,\text{cityland}} \leq \breve{y}_{r,\text{cityland}}$$

$$\sum_{j} y^{+}_{r,j,\text{cropland}} \leq \breve{y}_{r,\text{cropland}}$$

$$\sum_{tg} \bar{p}_{tg} z_{r,tg} = 0$$

$$\sum_{l} \sum_{k} \bar{p}_{r,k} \left(x_{r,i,l,k} + \gamma_{r,i,l,k} \right)$$

$$= \sum_{k} \bar{p}_{r,k} \omega_{r,i,k} + \sum_{j} \pi_{r,i,j} \left(\sum_{g} \bar{p}_{r,g} \left[y^{+}_{r,j,g} + \bar{y}_{r,j,g} \right] - \sum_{k} \bar{p}_{r,k} y^{-}_{k,r,j} \right) + \theta_{r,i} T_r$$

where,

Parameters

$\bar{p}_{r,k}$ price used in individual budget constraints

$\bar{p}_{tg}$ world price used in balance of payments constraint

$a_{k,r,j,g}$ Input–output constants by producer, updated in feedback using Shephard's Lemma

$\alpha_{r,i}$ welfare weights of agents

$\beta_{r,i,l,k}$ LES parameters utility function

$\gamma_{r,i,l,k}$ committed consumption

$\breve{y}_{r,\text{cityland}}$ upper bound on cityland
$\delta^{1999}_{r,i,l}$, $\delta^{2020}_{r,i,l}$ weights for lifestyles 1999, and 2020
$\zeta_{k,r,j,k}$ joint output parameter
$\breve{y}_{r,\text{cropland}}$ upper bound on cropland use
$\pi_{r,i,j}$ share in profits by consumer and producer
$\omega_{i,k}$ endowments by consumer
$\rho_{r,i,l}$ elasticity of substitution in CES function consumers
$\breve{\rho}_{r,i,l}$ elasticity of substitution for protein goods
$\tau_{r,tg}$ tariffs on net imports of goods by region
$\varsigma_{r,tg}$ average transport costs by region
$\theta_{r,i}$ share in direct taxes by group and region
$\bar{y}_{r,j,g}$ setup production

Variables
$y^{+}_{r,j,g}$ output by good and producer
$y^{-}_{k,r,j}$ input by commodity and producer
$q_{r,j,g}$ activity level by producer and good
$x_{r,i,l,k}$ consumption by class and lifestyles
$z_{r,tg}$ net imports by region

Indices
1 year 1999
2 year 2020
r regions
i consumers
j producers
l lifestyles
k all commodities
ckn protein commodities
nk non-protein commmdities
g goods
sc non-tradable goods
tg tradable goods
f factors
sf non-tradable factors

SOME DATA

Table AI. Land use (1000 Ha)

	Lowinc	Midinc	Highinc	EU
Grassland (1998)	1,320,302	1,233,879	701,615	56,284
Grassland (2020)	1,333,505	1,246,218	687,583	55,721
Cropland (1998)	592,887	502,860	283,664	85,906
Cropland (2020)	640,318	517,946	283,664	85,476
Cityland (1998)	198,096	114,771	45,415	29,801
Cityland (2020)	276,117	127,344	49,327	29,404
Natureland (1998) not included in model	2,103,539	3,352,471	1,700,009	141,196
Natureland (2020) not included in model	1,964,884	3,312,473	1,710,129	142,586
Total land area (1998)	4,214,824	5,203,981	2,730,703	313,187
Total land area (2020)	4,214,824	5,203,981	2,730,703	313,187

Source: FAOSTAT (2002) and own projections.

Table AII. Urban and rural work force

	Lowinc	Midinc	Highinc	EU
Work force in millions (2000)	2,244	755	324	252
Work force as % of population (2000)	61.73	63.01	66.92	67.14
Urban work force in millions (2000)	722	502	253	200
Rural work force in millions (2000)	1,523	242	70	52
Urban work force in millions (2020)	1,364	722	297	207
Rural work force in millions (2020)	1,615	228	62	42
Total urban working hours in millions (2000)	938,957	843,388	607,854	479,392
Total rural working hours in millions (2000)	1,980,100	406,212	169,260	124,620
Total urban working hours in millions (2020)	2,208,997	1,516,417	736,770	514,094
Total rural working hours in millions (2020)	2,616,318	478,481	154,195	104,337

Source: World Bank (2001), and own projections.

Table AIII. Fertiliser use per crop per region (kg/ha year^{-1})

	EU	Highinc	Midinc	Lowinc
Grass	120	120	80	0
Grains	120	150	80	130
Roots & tubers	120	200	80	125
Oil crops	120	65	80	60
Other-agriculture	120	35	80	75
Pulses	0	0	0	0

Source: IFA, IFDC and FAO (1999).

Table AIV. Nitrogen excretion from animals (kg N/animal/year)

Regions	Type of animals		
	Ruminants	Pigs	Poultry
EU	70	20	0.6
High income	70	20	0.6
Middle income	50	16	0.6
Low income	40	16	0.6

Source: IPCC (1997).

Table AV. Animal waste management systems per region

Regions	Animal types	Percentage of manure production per animal waste management systems						
		Anaerobic lagoon	Liquid system	Daily spread	Soil storage & drylot	Pasture range & paddock	Used fuel	Other system
EU	Cattle	0	55	0	2	33	0	9
	Swine	0	77	0	23	0	0	0
	Poultry	0	13	0	1	2	0	84
Highinc	Cattle	0	1	0	14	84	0	1
	Swine	25	50	0	18	0	0	6
	Poultry	5	4	0	0	1	0	90
Midinc	Cattle	4	19.5	0	26	49.5	0	1
	Swine	0	18.5	1	25.5	13.5	0	42.5
	Poultry	0	28	0	0	1	0	71
Lowinc	Cattle	0	0	8.5	8.5	62.5	20	0
	Swine	0.5	22.5	0.5	73	0	3.5	0
	Poultry	0.5	1	0	0	62.5	0.5	35.5

Source: IPCC (1997).

Table AVI. Emission factors (kg N_2O–N/kg nitrogen excreted)

Animal waste management system	Emission factor
Anaerobic lagoons	0.001
Liquid systems	0.001
Daily spread	0.0
Solid storage and drylot	0.02
Pasture range and paddock	0.02
Used as fuel	0.0
Other system	0.005

Source: IPCC (1997).

Table AVII. CH_4 emission factors from enteric fermentation (kg CH_4/animal)

	Cattle	Swine	Poultry
EU	48	1.5	0
Highinc	47	1.5	0
Midinc	52.5	1.0	0
Lowinc	38	1.0	0

Source: IPCC (1997).

Table AVIII. CH_4 emission factors (Kg CH_4/animal/year) from manure management

Region	Animal type	Emission factors
EU	Cattle	20
	Swine	10
	Poultry	0.117
Highinc	Cattle	2
	Swine	14
	Poultry	0.117
Midinc	Cattle	7
	Swine	4
	Poultry	0.0675
Lowinc	Cattle	1.5
	Swine	4.5
	Poultry	0.023

Source: IPCC (1997).

Notes

1. Protein Foods, Environment, Technology And Society, see http://www.profetas.nl for details.

2. NPFs are modern plant-protein based food products, designed to have a desirable flavour and texture. Technically, NPFs can be made of peas, soybeans, other protein crops and even grass (Linnemann and Dijkstra 2000).
3. General Equilibrium Model of Agricultural Trade and production (van Wesenbeeck and Herok 2002). For more background information, see Folmer et al. (1995); Keyzer and Merbis (2000) and Keyzer et al. (2002).
4. These are: grass, grains, roots/tubers, oil crops, pulses, other agriculture, ruminants, monogastrics excluding pigs, pig meat, meat products, vegetable oil and fats, other agricultural products, oilseed cakes and grain brans.
5. The-term 'migration' here differs from the common use of people moving from one location to another. Instead, we take a broader meaning of individuals moving between lifestyle classes.
6. We have to acknowledge that the emission bounds for acidifying substances should be determined by the soil sensitivity, such as in the RAINS model (Alcamo et al. 1990). Therefore, the emission bounds should be more location-specific, which is not considered in this paper.
7. Indirect N_2O emission is thus calculated as: 0.01*(0.1*fertilizer use + 0.2*manure) + 0.025*0.3* (fertilizer use + manure).

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